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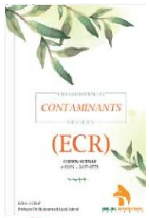

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RESEARCH ARTICLE

ASSESSING SHIELDING ADEQUACY OF SELECTED RADIOLOGICAL FACILITIES TO ASCERTAIN RADIATION SAFETY IN IBADAN METROPOLIS

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ABSTRACT

The use of ionizing radiation (X-ray) in diagnostic radiography could be hazardous and could cause somatic and genetic damages. Adherence to radiation safety and radiation protection practices could mitigate such risks. The aim of the study was to assess the shielding adequacy of selected radiological facilities to ascertain radiation in Ibadan Metropolis. Radiation survey meters was used to obtain the instantaneous dose rates (IDR) in the study area, the data were analysed and the estimated annual doses (D_{eff}) calculated and compared with the NCRP standard. Radiation dose rates of ranges (0.14 µSv/hr – 2.75 µSv/hr),(0.19 µSv/hr – 1.28 µSv/hr), (0.23 µSv/hr – 3.01 µSv/hr),(0.09µSv/hr – 0.19 µSv/hr),(0.27µSv/hr – 7.51 µSv/hr) (28µSv/hr - 99 µSv/hr), (46 - 99 µSv/hr - 18.45mSv/hr), (0.25 µSv/hr - 3.56mSv/hr), (11.9 µSv/hr - 45.2µSv/hr) and (27 µSv/hr - 42 µSv/hr) were respectively obtained in each of the ten radiological facilities considered. These Results showed that the level of radiation safety for the personnels was low and radiation safety guidelines were compromised. Application of shielding devices such as lead lining for protection was neglected completely in the first three centres and none of the facilities has personnel's dosimeters in use. Results further showed that the people living around the diagnostic centres were also at high risk because of their level of exposure to radiation from the diagnostic centres.

KEYWORDS

Ionizing radiation, radiological facilities, instantaneous dose rates, dosimeters.

1. INTRODUCTION

Exposure of the general public, patients, and radiation workers to ionizing radiation must be mitigated to minimize the risk of harmful biological effects. In 1954, the National Committee on the Radiation Protection (NCRP) proposed the principle that radiation protection should be kept "as low as reasonably achievable" ALARA concept (Holmberg et al., 2010; Boice et al., 2020). The concept is accepted by all regulatory agencies including International Commission on Radiological Protection (ICRP), the World Health Organization (WHO), and the European Commission. When human body is exposed to ionizing radiation, it damages living cells by ionizing atoms composing of the molecular structures, causing abnormalities in the functioning of the living cell and consequently health issues (IAEA, 2018). Despite the complex nature of human system, there is no organ that is immune to ionizing radiation or has ability to innately detect its presence to the extent that any organ that is damaged by ionizing radiation can never be repaired. This makes ionizing radiation more deleterious and stochastic (Hafizoglu, 2013; David et al., 2021).

In this regards, the most fundamental aim of radiation scientist is to ensure radiation protection and safety through scientific research and recommendation. To achieve this goal, effects of ionizing radiation emanating from different sources must be examined (Johnson et al., 2010). The radionuclides are found in varying amount in environmental substances such as rocks, soils, water and air (Ilugbo et al., 2018; Adebiyi et al., 2018; Alabi et al., 2019; Alemayehu et al., 2023; Adebo et al., 2023). The geological setting of an area dictates the spread and level of the radionuclides of the area (Bjarnason et al., 2020). However, the presence of radionuclides in various environmental matrices has prompted the International Atomic Energy Agency (IAEA) to advocate for measurement and monitoring of radiation in human environment (IAEA, 2002, 2018).

The presence of natural radionuclides in various environmental matrices has raised concerns and worries among radiation-scientists worldwide (Joseph, 2020). The concerns have prompted many authors to embark on broad assessment of ionizing radiation and its effects on human health and environment in the last few decades (Nkubli et al., 2017; Hrgovic et al., 2020). However, relevant agencies including United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), International Commission on Radiological Protection (ICRP), Environmental Protection Agency (EPA) and International Atomic Energy Agency (IAEA) have similarly embarked on the control and regulation of exposure of human and environment to natural ionizing radiation (Yonekure et al., 2019; Mohammed et al., 2020). With the understanding of fundamental principle of radiation protection, only patients who should get maximum benefits from ionizing radiation (justification), making sure that radiation dose as a result of medical exposure are only enough to achieve needed diagnoses (optimization) considering economic and societal factors and reducing time of exposure to source of radiation. Compliance to radiation protection practices help to mitigate risk from unplanned exposure (Eldeen, and Farouk, 2020; Fiagbedz et al., 2022).

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The exposures of personnel(s) who work in the facility and to the public due to inadequate shielding of the X-ray room or department allow scattered and leakage of ionizing radiations during medical imaging is to increase (Omojola et al., 2021; Qabandi, and Alshammary, 2022). Currently limited study has been conducted in these facilities to assess shielding adequacy hence there is need to survey and assess the level of leakage from the X-ray rooms (Willegaignon et al., 2023). It has been reported that the annual per capital effective dose has doubled worldwide over the past decade due to daily increase in diagnostics procedures. Due to detrimental side effects of x-ray, it has become every important to mitigate the radiation exposure to the patience and radiation workers taking ALARA (as low as reasonably achievable) concept into the consideration. Most radio-diagnostic-centers in Nigeria are not radiation safety compliant. In Ibadan, radio-diagnostic centers found in different areas, majorly in the urban settlement, fall into this category. Hence, the study to investigate the shielding adequacy, design layouts and personnel dosimetry of some selected diagnostics centers in Ibadan is needed.

2. Description of The Study Area

Three out of the general diagnostic centers involved in the study were purpose- built; the remaining seven were only converted to suit the purpose (Figure 1). Figures 1 show the sketched layouts of six out of the ten centres studied. Diagnostic Centre A has a room dimension of 5.0m x 4.0m with a minimum and maximum distance 100cm and 280cm from the x-ray tube to the nearest wall or protective barrier. A 2.23mm lead sheet bonded to plywood was used as the shielding material. Diagnostic Centre B has a room dimension of 8.0m x 5.0m with a minimum distance of 3.8m to the console area. This centre is purpose-built with a minimum wall thickness of 0.3m around the X-ray room. Diagnostic centre C has a room dimension of 4.0m x 3.2m. the walls of the X-ray room were made with ordinary hollow blocks thereby offering no protection for the workers and patients.

Diagnostic Centre D has two X-ray rooms with dimensions 3.3m x 3.8m and 3.0m x 3.8m. Diagnostic Centre E and F have room dimensions 3.5m x 3.4m and 4.0m x3.2m respectively. Both centres were purpose- built and a 2mm Pb were bonded with plywood on the wall of the rooms. Diagnostic Centre A has a room dimension of 5.0m x 4.0m with a minimum and maximum distance 100cm and 280cm from the x-ray tube to the nearest wall or protective barrier. A 2.23mm lead sheet bonded to plywood was used as the shielding material. Diagnostic Centre B has a room dimension of 8.0m x 5.0m with a minimum distance of 3.8m to the console area. This centre is purpose-built with a minimum wall thickness of 0.3m around the X-ray room. Diagnostic centre C has a room dimension of 4.0m x 3.2m. the walls of the X-ray room were made with ordinary hollow blocks thereby offering no protection for the workers and patients. Diagnostic Centre D has two X-ray rooms with dimensions 3.3m x 3.8m and 3.0m x 3.8m. Diagnostic Centre E and F have room dimensions 3.5m x 3.4m and 4.0m x3.2m respectively. Both centers were purpose- built and a 2mm Pb were bonded with plywood on the wall of the rooms (Figure 2).

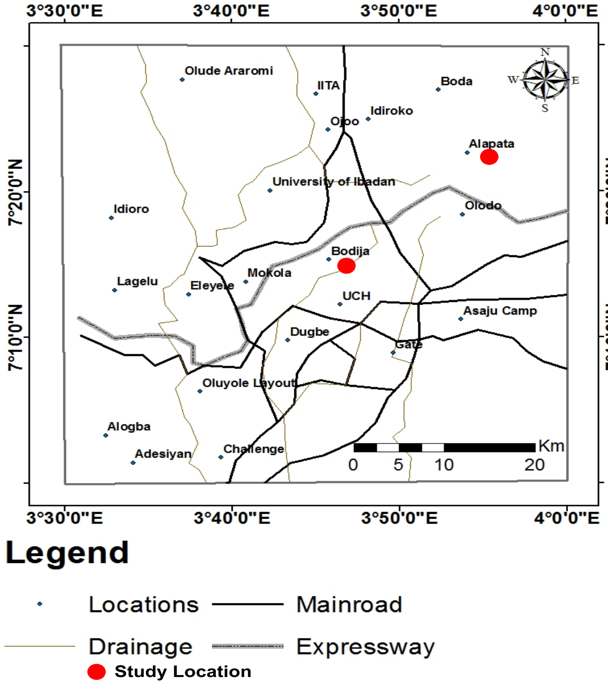

Figure 1: Map showing the Study Location

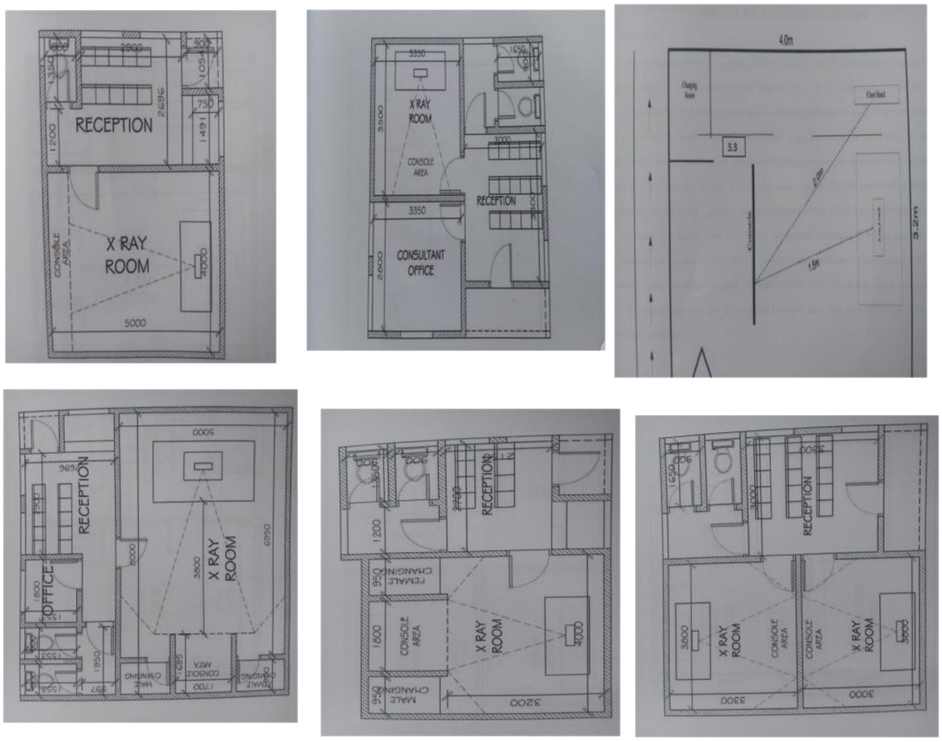

Figure 2: (a) Design layout of diagnostics center A (b) Design layout of diagnostics center B (c) Design layout of diagnostics center (d) Design layout of diagnostics center D (e) Design layout of diagnostics center E (f) Design layout of diagnostics center F

3. Materials Used for Data Collection

Three radiation survey meters, (two Rad TRACE) and one RADEYEG – 10 gamma survey Meter. (The two Rad Trace meter were relatively new, year 2020 and 2019 models). Measuring tape, dummy carton (used to represent a human), and recording materials.

3.1 Data Collection

Reading of dose rate per radiological facility is designed to be carried out in the available office and area within the facility and behind the facility. Different days were allocated for data collection to make sure all necessary areas and protocols are not jumped. The background dose rate was checked across all facility and all tube was wormed before the commencement of experimental survey.

3.2 Annual personnel dose estimation

The survey meter measures in micro Sievert ($\mu Sv/h$)*per hour*. An Excel Spreadsheet (2016 version) was used to calculate the annual dose a radiation worker is exposed to as well as the shielding accuracy

$$D(eff) = D(p).h.n.T \quad (1)$$

Where, D(eff) is the effective dose to a person in a single year, D(p) is the measured survey meter reading at a particular position, h is the number of hours an individual spend in the measured point. n is the number of days an individual work in a year and T is the occupancy factor. The occupancy factor is conservatively chosen to be one (1) for the purpose of this study.

The result of each procedure will be discussed form the scientific point of view and proper recommendations will be given based on the result obtained. Six of the 10 diagnostic facilities had their floor plans drafted in order to demonstrate their size and the relationship of adjacent structures (such as offices, reception area, toilets, x-ray archive etc.) In addition, the chest-stand, the x-ray machine, and the control panel were depicted in the schematic, and the distances between each of these components were measured. All of the diagnostic facility that are being looked into are privately held. In addition, the chest-stand, the x-ray machine, and the control panel were depicted in the schematic, and the distances between each of these components were measured. All of the diagnostic facilities that are being looked into are privately held. In addition, the chest-stand, the x-ray machine, and the control panel were depicted in the schematic, and the distances between each of these components were measured. All of the diagnostic facilities that are being looked into are privately owned.

4. Results

Radiological assessment was carried out on a total of 10 (A-J) diagnostic facilities, which four (4) are purposed built and six (6) are converted. Total of 98 workers were sighted in this diagnostic facilities. The results are presented in Table 1 to 10. From the tables, years of manufacture of equipment used in the various facility is indicated, year of installation, position where the readings were taking, model of the machine, working hours, were all noted. The annual effective dose (D_{eff}) to workers is also calculated. However, allowance can be made for the degree of occupancy of areas near the radiation room; in this way the barrier thickness can be adjusted to that actually required. For instance, a stair way is assumed to be occupied only one-sixteenth of the time by the person as compared to a controlled area. Therefore, the occupancy factor is one sixteenth, reducing the shield requirement by 4 half value layers of 4 HVL (HVL, the thickness of the shield required to reduce the initial beam intensity by half). For locations normally occupied by radiation workers, this factor is assumed to be 1. Radiation dose meter was dominantly used in all the centers to take reading at different locations. The readings are taken as the exposures are being made using a dummy to represent human and the distance from the tube to the object were all subjected to be 1.5 m with a measuring tape except diagnostic Centre I which was 1.01 m.

Table 1: Center A

Machine information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp & mAs**	**m**	**Location**	**IDR**	**WH/D**	**T**	**$D_{(eff)}$**
Allengers E7239X / Sept 2007 (2017)	125 - 40kVp & 500 -0.1mAs	80kVp/ 40mAs	1.5	Background	0.10	10 /6	1	0.006
				Console area	2.75	10/6	1	0.165
				X-Ray Door	1.05	10 /6	1	0.063
				Reception area	0.23	10 /6	1	0.0138
				Behind X-ray room	0.21	10 /6	1	0.0126
				Laboratory	0.14	10 /6	1	0.0084

Table 2: Center B

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	**$D_{(eff)}$**
300Ma Medical Diagnostic X-Ray Machine	120 -20kVp 300-50mAs	100KvP/50mAs	1.5	Background	0.10	10 /6	1	0.006
				Consol area	1.28	10 /6		0.0768
				X - Ray room Door	0.31	10 /6	1	0.0186
				Next room X-ray room (general LAB)	0.25	10 /6	1	0.015
				Reception Area	0.57	10 /6	1	0.0342
				Corridor	0.19	10 /6	1	0.0114

Table 3: Center C

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	**$D_{(eff)}$**
300Ma Medical Diagnostic X-Ray Machine (Oct.2012)	120 -20kVp 300 -50mAs	50KvP/0.5m As	1.5	Background	0.08	10 /6	1	0.0048
				Consol area	3.01	10/6	1	0.1806
				x-ray room door	1.06	10 /6	1	0.0636
				Reception area	0.23	10 /6	1	0.0138
				Laboratory	0.2	10 /6	1	0.012
				Managers Office	0.15	10 /6	1	0.009
				Outside back of the building	0.23	10 /6	1	0.0138

Table 4: CENTER D

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
Allengers High Voltage Double Tank manufactured Oct 2015.		60kvP/10mAs	1.5	Background	0.11	10 /6	1	0.0114
				Consol area	0.19	10 /6	1	0.0066
				Radiographs office	0.16	10 /6	1	0.0096
				X- Ray Door	0.12	10 /6	1	0.0072
				Rest room	0.09	10 /6	1	0.0054

Table 5: CENTER E

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
Siemens Somatom Sensation 16. 2005 09/2015	140-50 kVp 400-100mAs	120 KvP /90mAs		Background	0.09	10 /6	1	0.0054
				Consol area	7.51	10/6	1	0.4506
				CT door	13.5	10 /6	1	0.81
				Waiting area	5.75	10 /6	1	0.345
				Outside the building	0.18	10 /6	1	0.0108
				Front of CT rest Room door	0.27	10 /6	1	0.0162

Table 6: CENTER F

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
PX-20N/April 1990	50 – 80 kVp 2 – 20 mAs	80kVp, 20mAs	1.5	Background	0.11	10 /6	1	0.0066
				X-Ray Room Door	67.57	10 /6	1	4.05
				Office Opposite X-Ray room	0.11	10 /6	1	0.0066
				Corridor Opposite X- ray room	35.0	10 /6	1	2.1
				Reception area	0.13	10 /6	1	0.0078
				Laboratory Room	0.17	10 /6	1	0.0102
				X-ray room outside window	99	10 /6	1	5.94

Table 7: Center G

Machine Information				Data				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
AMX 4 Plus/July 2003 (March 2020 installation date)	125kVp 200mAs	120kVp 64mAs	1.5	Background	0.09	10 /6	1	0.006
				X-Ray room	17,580	10/6	1	1054.8
				X-Ray room console area	18,450	10 /6	1	1107
				X-Ray Room Door	86	10 /6	1	5.16
				Behind X-Ray room	41	10 /6	1	2.46
				X-ray back window	1500	10/6	1	90
				Window 2	1,360	10/6	1	81.6
				Building close to X-ray room	631	10 /6	1	37.86

Table 8: Center H								
Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
F100 Surgicare England August 2007, 2020	40 – 80 kVp 15 – 60 mAs	80 kVp 60 mAs	1.5	Background	0.10	10 /6	1	0.6
				Behind X-Ray Room Curtain	55.48	10/6	1	3.3288
				Reception Area	19.40	10 /6	1	1.164
				Walkway Opposite reception Area	19.40	10 /6	1	1.164
				Behind X-Ray Room window outside	3,560	10 /6	1	213.6
				Chief Nurses Officer Office next to X-Ray room reception	0.25	10 /6	1	0.015

Table 9: CENTER I								
Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
MARS 6R Allengers /July 2020, November 2016	40 -125 kVp 1- 200 mAs	120kVp 80 mAs	1.01	Background	0.09	10 /6	1	0.0054
				X –Ray Room consol area chest	12.7	10 /6	1	0.0054
				X-Ray Room Door	1.76	10 /6	1	0.003
				Laundry room next to X-ray room (table top)	0.09	10 /6	1	0.054
				Laundry room next to X-ray room (chest)	12.85	10 /6	1	1.185
				Reception area	1.11	10 /6	1	1.0488
				H/R Office area	1.10	10/6	1	2.34
				X-ray room window outside	45.2	10/6	1	2.52
				Floor above the X-ray room	0.08	10 /6	1	0.762

Table 10: CENTER J								
Machine Information				**Data**				
EQ/MD &(ID)	**Max/Min kVp & mAs**	**Used kVp /mAs**	**m**	**Location**	**IDR**	**WH/Day**	**T**	$D_{(eff)}$
SIEMENS Mobile ETT Plus Hp/ 2003 (2017 installation date	40 – 133 kVp 0.50 – 32 mAs	81 kVp 28 mAs	1.5	Background	0.15	10 /6	1	0.009
				Consol area (chest)	10.3	10/6		0.618
				X – Ray door (chest)	0.15	10 /6	1	0.009
				Outside the building	0.15	10 /6	1	0.009
				Behind X-Ray room (Chest)	0.16	10 /6	1	0.0096
				Consol area (table top)	42	10/6	1	2.52
				X-Ray room door (Table top)	13.7	10 /6	1	0.822
				Laboratory opposite X-ray room	0.33	10 /6	1	0.0198
				EGG/ECHO room	27.4	10 /6	1	1.644
				Reception area	0.16	10 /6	1	0.0096
				Waiting area	0.14	10 /6	1	0.0084

5. Discussion of Findings

The international Atomic Energy Agency (IAEA) recommended a dose-rate of not more than 2.5μSv/h at any accessible location to the public. Any location with dose rate more than 7.5μSv/h is considered a controlled area and access to such location must be restricted (IAEA, 2018). The survey meter readings as seen in Table 1 gives the dose rates measured at various units of Diagnostic Centre A, the investigated diagnostic center model of machine, year of purchase and year of manufacture. This table shows that the X-ray machines located in Diagnostic Centre was manufactured 16years ago (close to two decades), purchased 13 years ago while It has kVp rage of 125 - 40 and mAs of 500 – 0.1. 80kVp and 40mAs was used for the study. The distance of the X-ray tube to the dummy object is 1.5 m.

The building was purposed built which was clearly seen in the radiation dose rate data as presented in Figure 1. The receptionist's area, behind X-ray room door and the laboratory room were found to have satisfactory levels <0.5μSv/h of radiation dose rate as recommended by NCRP (NCRP, 2015). The radiation dose rates measured in the consol area and X-ray room door read 2.75μSv/h and 1.05μSv/h respectively. As clearly shown in Figure 1 the technician has an estimated annual dose (D_{eff}) of 0.165 mSv which is the highest in the facility but seen to be < 0.96mSv as recommended by National Council on Radiation Protection and Measurements (NCRP) Report 147 and International Commission on Radiological Protection (ICRP). The radiation dose rate of diagnostic facility A were found satisfactory and reads (0.14 – 2.75 μSv/hr).

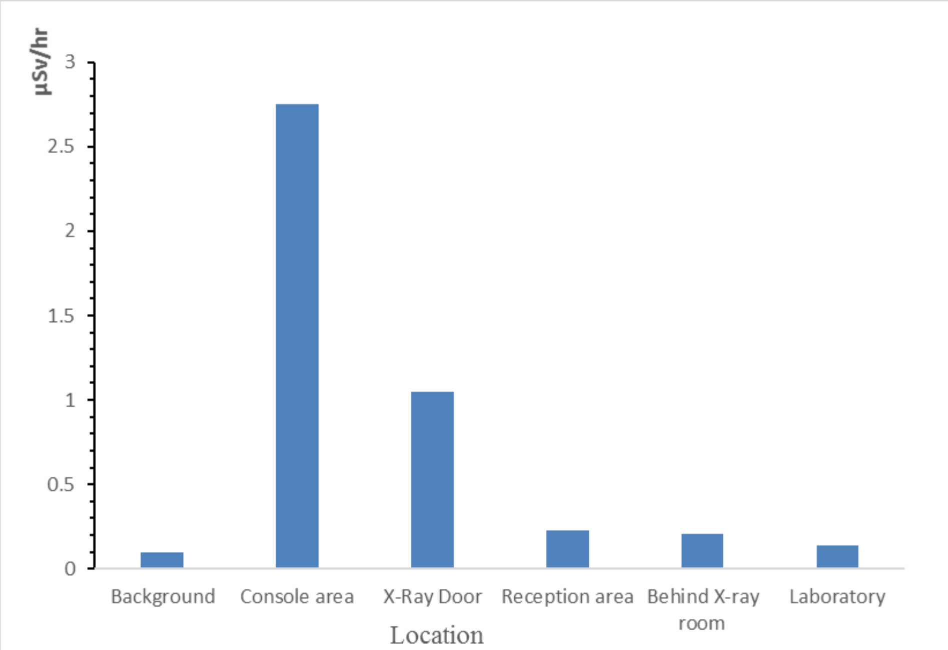

Figure 1: Radiological facility A Radiation Dose rate at different locations

The X-ray machine in diagnostic Centre B was manufactured about fifteen (15) years and purchased seven (7) years ago. The X-ray Machine model is 300Ma Medical Diagnostic X-Ray Machine and has a maximum kVp of 120 and 300 mAs. 100kVp and 50mAs was used for the study. The distance of the X-ray tube to the dummy object is 1.5 m. From Figure 2, the consol area which is a small caved out space inside the X-ray room, with a radiation dose rate of 1.28μSv/h has an estimated annual dose of 0.0768 mSv/week for the technician is < 0.96mSv/week as recommended by NCPR. However, the X-ray room door, general lab, reception area and corridor has dose rate (< 0.5μSv/hr) which is the satisfactory level. The radiation dose rate in facility B is (0.57 – 1.28μSv/hr). Facility B is purposed built facility and has a total of 18 staff that spends 10 hours daily.

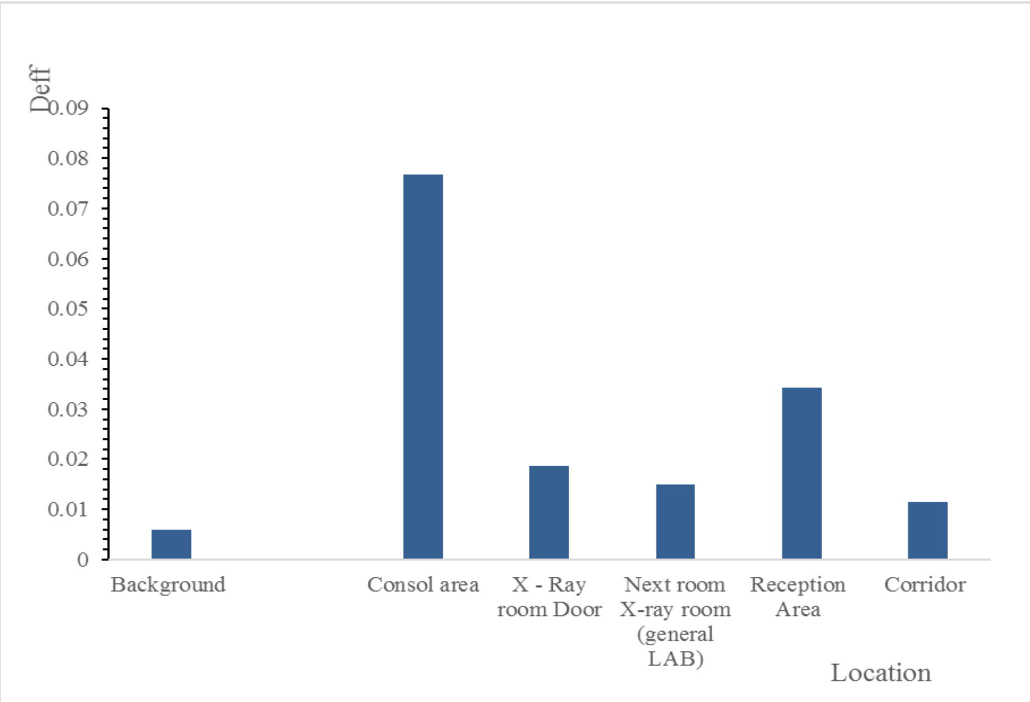

Figure 2: Annual effective dose at different locations in the study area B

The machine in Diagnostic Centre C is 300Ma Medical Diagnostic X-Ray Machine manufactured in October, 2012. 50kVp and 0.5mAs was used for the study while the machine has a maximum of 120kVp and 300 mAs. This diagnostic Facility is not a purposed built facility for diagnostic activities. The background radiation dose is within acceptable limit. The radiation dose rate is 0.08μSv/hr - 3.8mSv/hr (Figure 3). The technician takes procedures with his lead apron behind a small wood which he uses as console area. Diagnostic Centre C does not have any personal dosimetry service provider as recommended by the ICRP and NNRA. The estimated annual doses were calculated based on the dose rate at various locations in the Diagnostic Centre. The technician had the highest value in this center with an annual estimated dose of 0.1806mSv.

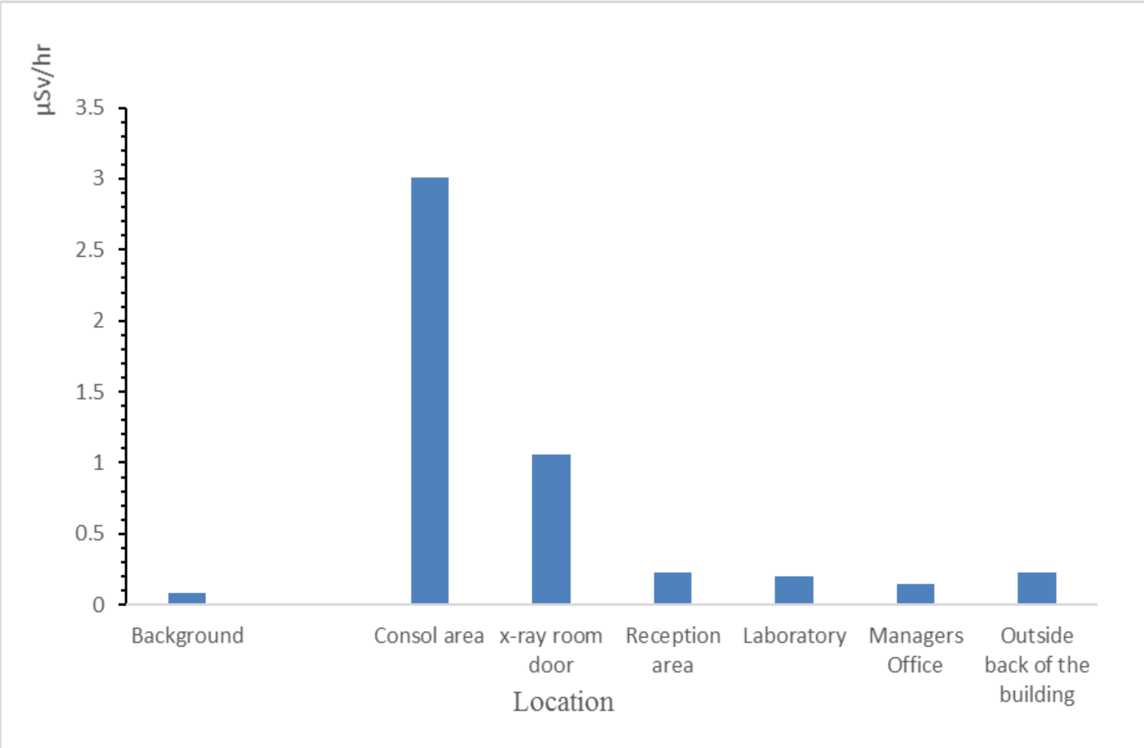

Figure 3: Dose rate at different locations in the study area C

Facility Diagnostic Centre D is one of the puposed built facility the study was carried out in, with a total of 23 staff.From Figure 4 as shown the radiation dose rate is (0.09μSv/hr - 0.19 μSv/hr) which is within the satisfactory level (<0.5μSv/hr) this means that the X-ray room is well shielded thereby the persons and public are in save based on my study. The effective dose is 0.0066 which is < 0.96 mSv/ week as recommended by NCRP. The machine model is Allengers High Voltage Double Tank manufactured October 2015.

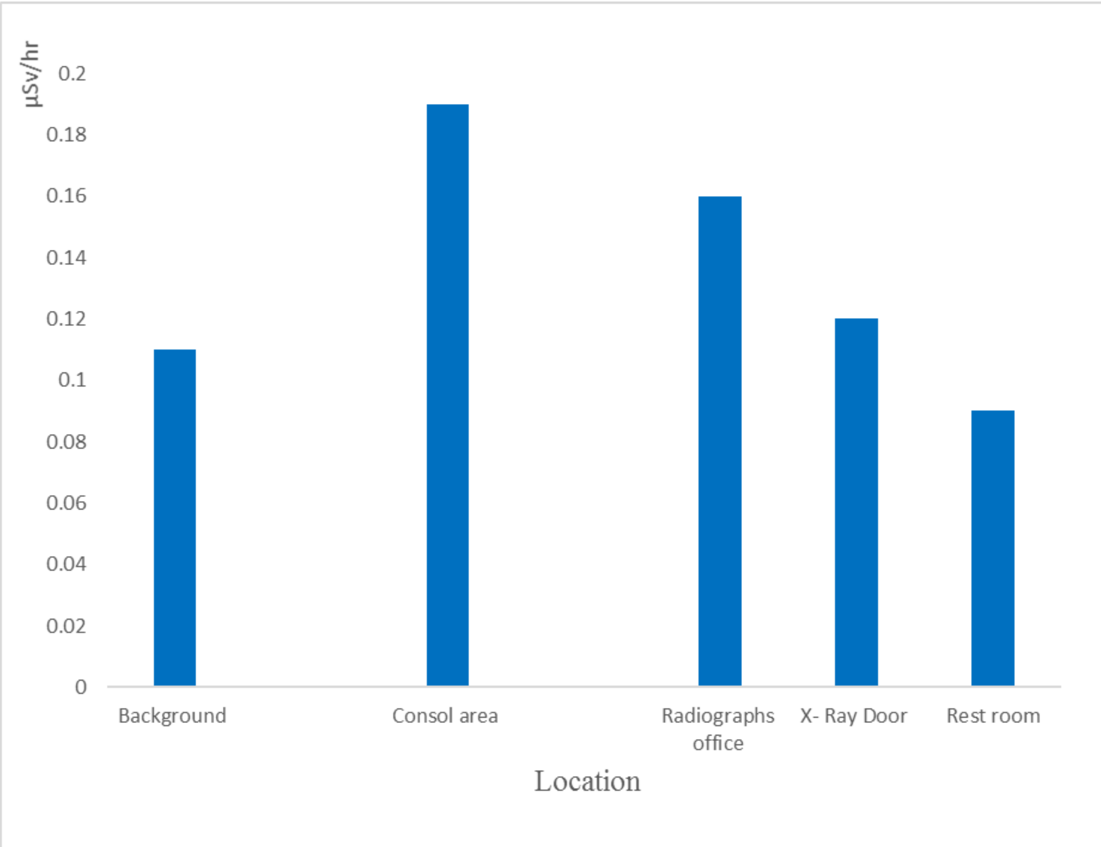

Figure 4: Dose rate at different locations in the study area D

Radiological Diagnostic Centre E as presented in Table 5, the wall of the CT room is shielded with lead sheets and the survey meter measurements showed very low dose rates. This is in compliance with regulatory standards. The estimated annual dose to workers as presented in Table 5 showed that the dose rates are within the recommended values. The highest estimated annual effective dose is 0.81mSv/week which is within the recommended dose limits for occupational radiation workers of 50mSv/a by International Commission on Radiological Protection (ICRP). From Figure 5, Diagnostic facility E, the background radiation dose is normal, the radiation dose rate in the facility is (0.27 µSv/hr – 7.51 µSv/hr). Machine use for the study in the particular facility is a computed tomography machine and no dummy object was use as the exposures were all done with real human but with different kVp and mAs as different procedures (Lumbosacral, Chest, Neck etc) were taking place. From figure 4.9 the CT door has the highest dose rate 13.5 µSv/h and the door is very close to the waiting area. This is hazardous to the public and personal who have activity to do within there. The public limit is 0.019mSv/week. The consol has a radiation dose rate of 7.51 µSv/h and estimated annual dose rate of 0.4506 mSv/h.

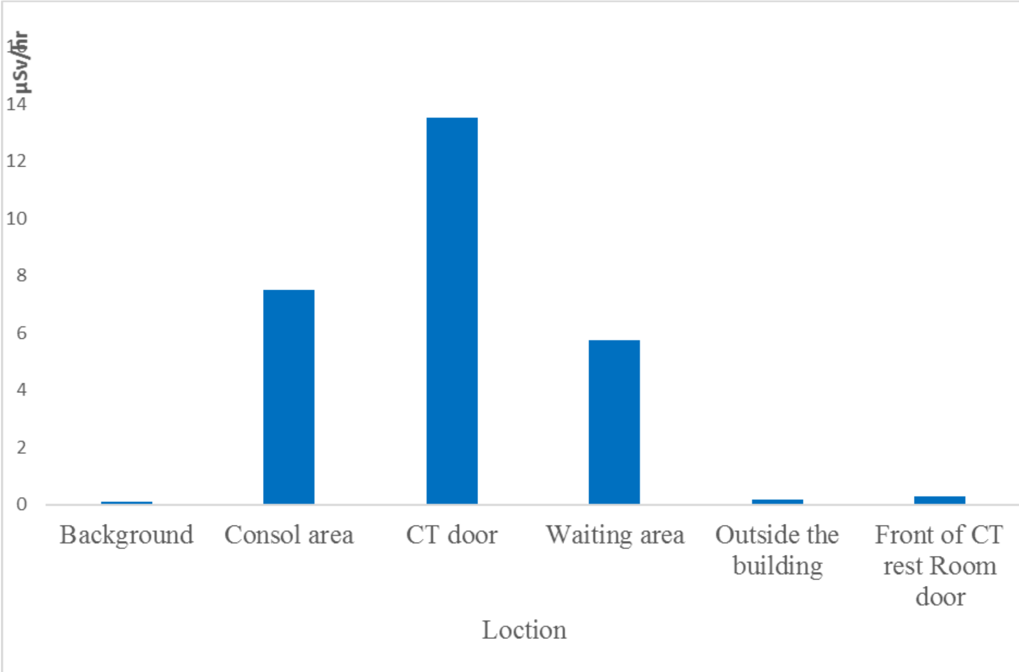

Figure 5: Dose rate at different locations in the study area E

The machine investigated in Diagnostic Centre F was manufactured about twenty years ago.

This center has eight (8) workers. The X-ray machine model is PX-20N and was manufactured April 1990, over thirty years ago. The kVp (80) and mAs (20) of the machine have been fixed constant for any type of exposure. Though, it ranged from 50to 80 kVp and 2-20 mAs respectively. The distance of the X-ray tube to the dummy object used is 1.5m. From the table, the estimated annual doses of technician 0.77mSv/h is slightly higher than that of the manager 0.5376mSv/h and the receptionist 0.6912mSv/h which are all within the recommended limit.

As well shown in Figure 6, the receptionist's area, general waiting area and the laboratory room were found to have satisfactory levels <0.5µSv/h of radiation. However, the radiation dose rates measured in the X-ray room door is 67.57µSv/h with D_{eff} of 4.05mSv/h where the technician stands when taking exposures and corridor opposite the X-ray room door 35µSv/h are very high there by personnel and public within the facility who will be present within this point while exposure is been taken will be at a very high risk. X-ray room outside window which is also very close to where people are living have a very high dose rates, this mean that everybody who stays in that particular building will always receiver a very high effective does rate of 5.94mSv/h each time exposure is taken even without going to radiological facility. The radiation dose rate of diagnostic facility F were found very high at this three point and reads (29 - 99 µSv/h).

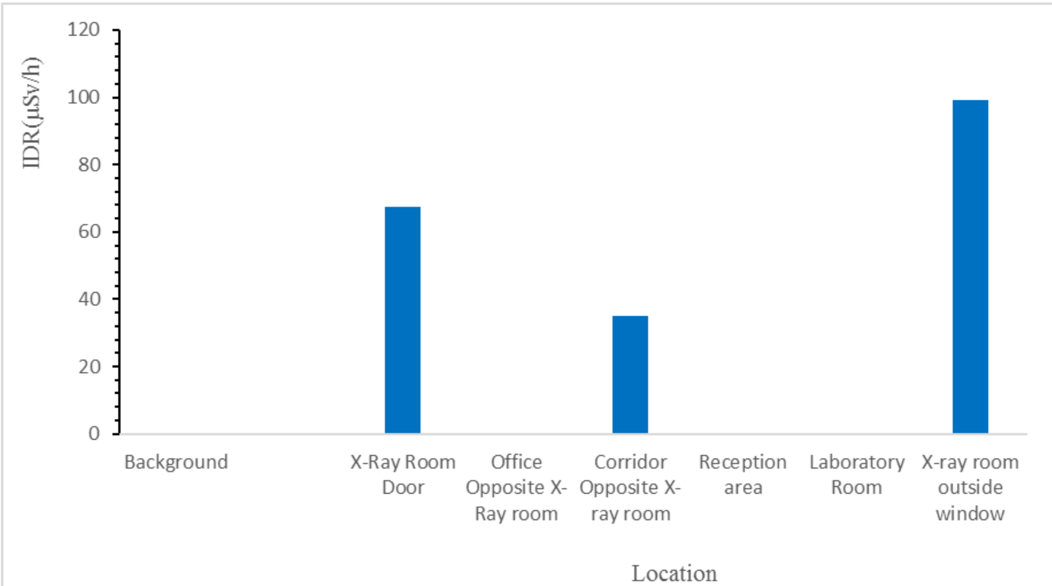

Figure 6: Radiological facility F Radiation Dose rate at different locations.

Diagnostic Centre G has the result is presented in Table 8. The facility has nine workers; it is very clear that there is a danger. The technician stays in the same room were the X-ray machine is while taking exposure without any standing barrier (consol). The background dose rate is normal but while espousing, every other location measured was very high. Where the technician stands with only his lead apron reads 18.45mSv/h (18,450μSv/h), X-ray room door (86μSv/hr) and the outside window (1.36mSv/hr) which very hazardous to X-ray technicians and the public living very close to the X-ray window as was sighted. The radiation dose rates in this facility G is (46μSv/hr – 18.45mSv/hr) with D_{eff} (2.46mSv/h - 1054.8mSv/h) which more than the NCRP recommended dose of 0.96mSv/h The X-ray machine model is AMX 4Plus and was manufactured July2003 (Figure 7). Have a maximum kVp of 125 and maximum mAs 200. 120 KVP and 64mAs was used during this assessment. The distance of the X-ray tube to the dummy object is 1.5m.

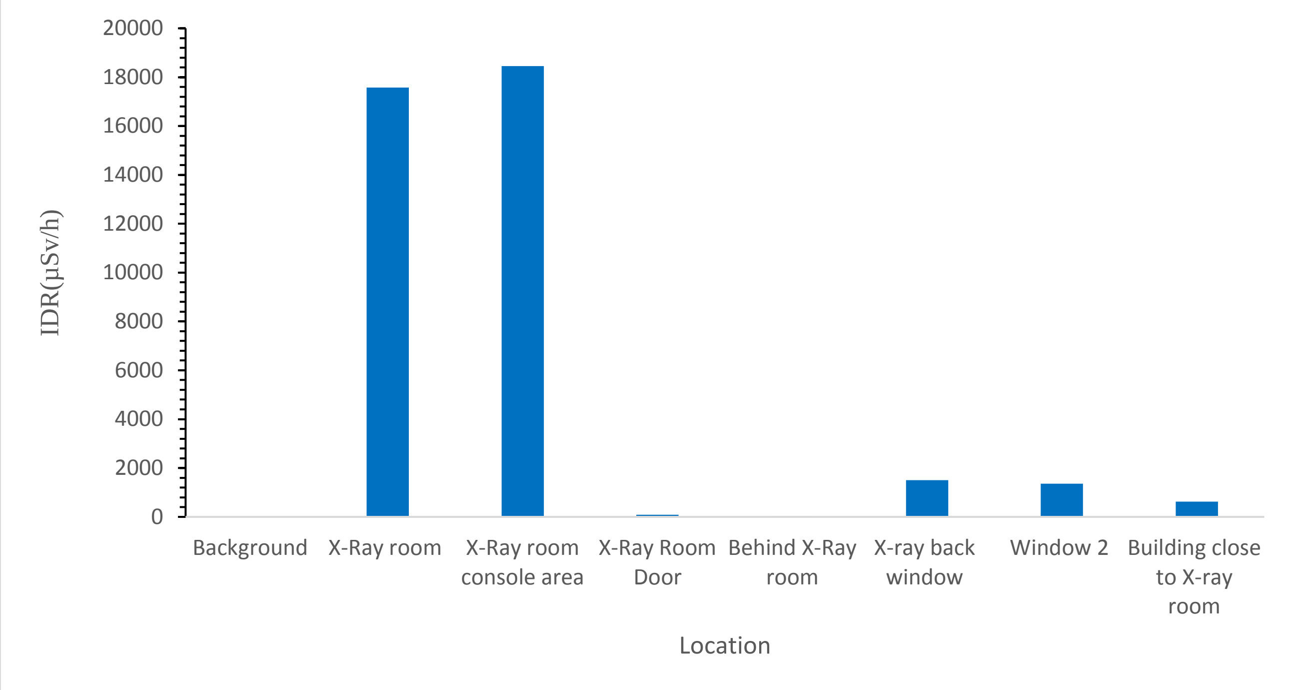

Figure 7: Radiological facility G Radiation Dose rate at different locations

Diagnostic Centre H as shown in Figure 8, the background radiation dose is normal. The radiation dose rate in this facility is 0.25μSv/hr – 3,560μSv/h which is hazardous to the personnel and the public. The technician takes exposure with only her lead apron which is enough to protect her as she stays in the same room while exposing no consol area was noticed. The does rate is extremely high as seen in the estimated annual dose (0.015mSv/h – 213.6mSv/h). The X-ray machine model is F100 surgicare, installed 2020 and Manufactured August 2007. Maximum/Minimum rang of kVp and mAs **(**40 – 80 kVp and 15 – 60 mAs). 80 kVp and 60 mAs was used for the assessment.

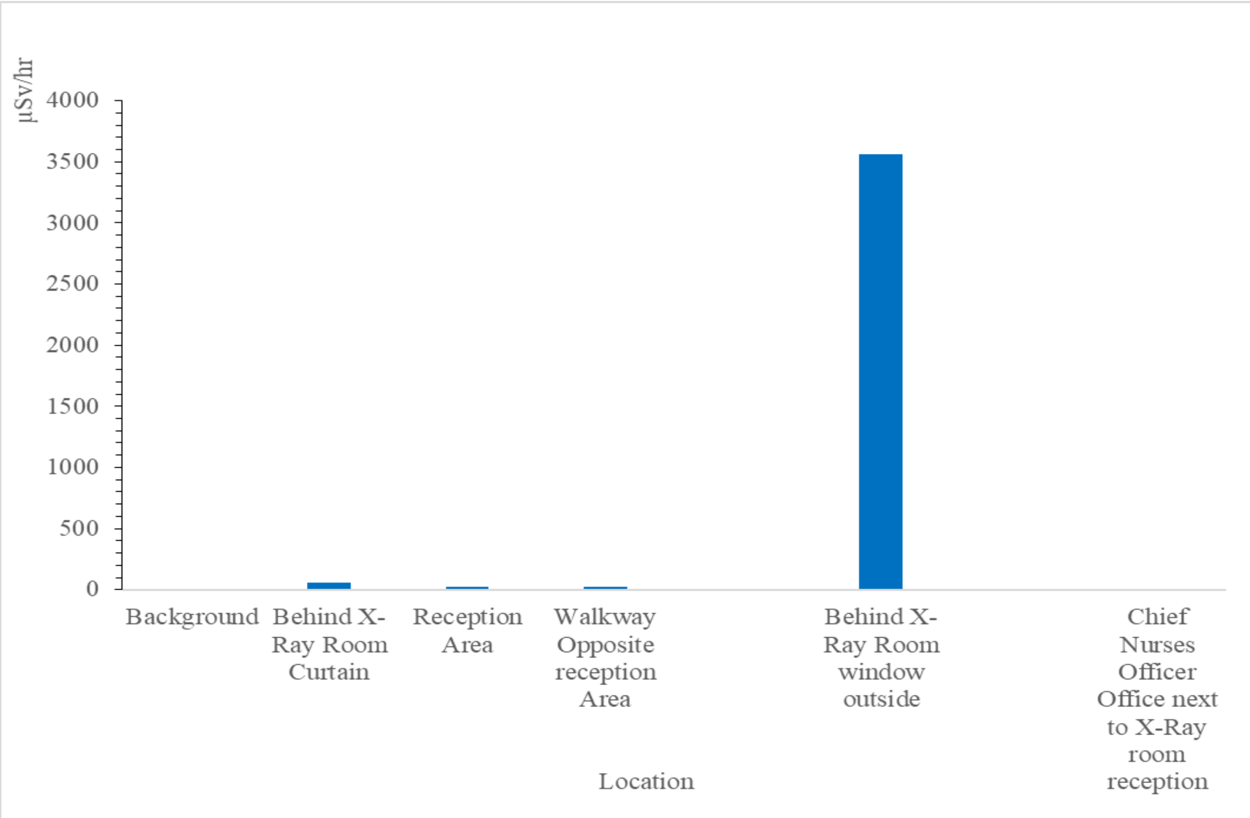

Figure 8: Radiological facility H Radiation Dose rate at different locations

Diagnostic Centre 1 is a diagnostic center with an average of 60 examinations per week, Annual dosimeter readings showed values lower than the recommended regulatory limits. The mean dosimeters report is 0.16mSv/h. The radiation levels immediately outside the X-ray room (by the door) and the H/R area, laundry room (when imaging is the done using the table top), reception area and the upstairs above the X-ray room were found to be minimal (0.08 -1.76μSv/h) and satisfactory. However, instantaneous dose rates obtained at the console area 11.9 – 19.75μSv/hr depending on whether the table top or chest stand is used in the laundry room using chest support (12.85μSv/h) and behind the X-ray room window (34.3 – 45.2μSv/hr) are not minimal (Figure 9). The X-ray model is MARS 6R Allengers, manufactured November 2016 and installed July 2020. The machine has a kVp range of (40 -125kVp) and mAs rage of (1 – 200mAs). 120kAp and 80 mAs were used respectively for the assessment. The distance was 1.01m.

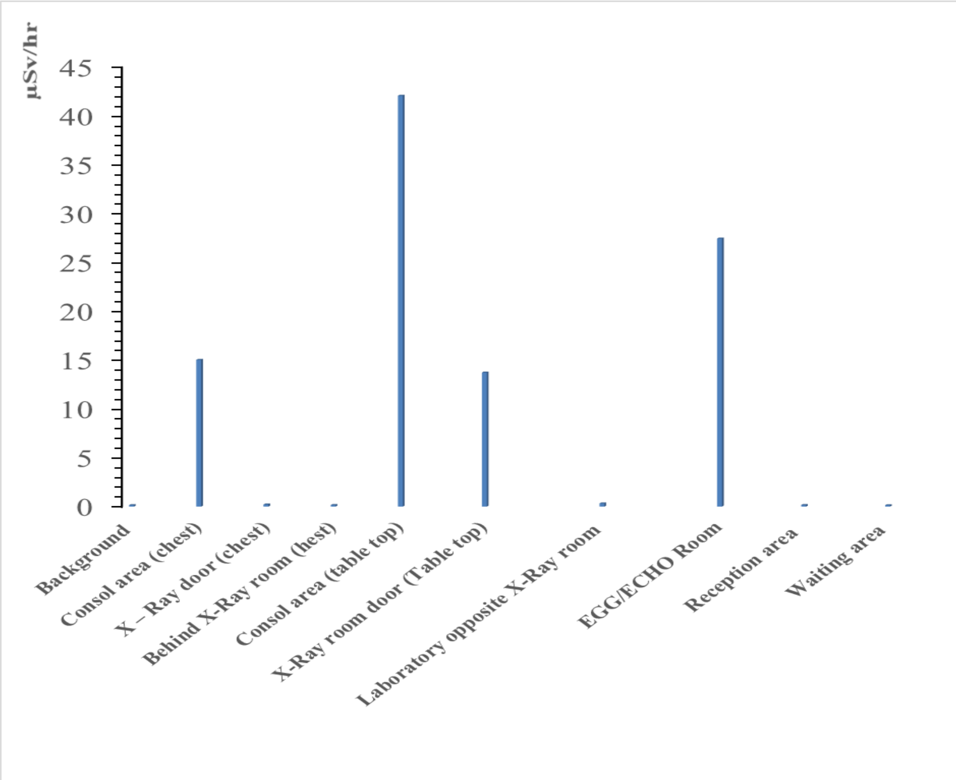

Figure 9: Radiological Facility Radiation Dose Rate

From Table 10 facility J, the receptionist's area, general waiting area and the laboratory room opposite the X-ray room were found to have a minimal level (<0.5μSv/hr) of radiation. However, the EEG/ECHO room and the console area were found to have radiation dose rates (27 - 42μSv/hr) higher than the required normal rage. The model of the X-ray machine is Siemens Mobile ETT plus Hp manufactured 2003 and installed 2017. Distance of 1.5m was used during the assessment. The machine has kVp range of 40 – 133 and mAs rage of 0.50 – 32kVp. However, kVp of 81 and mAs of 28 was used (Figure 10).

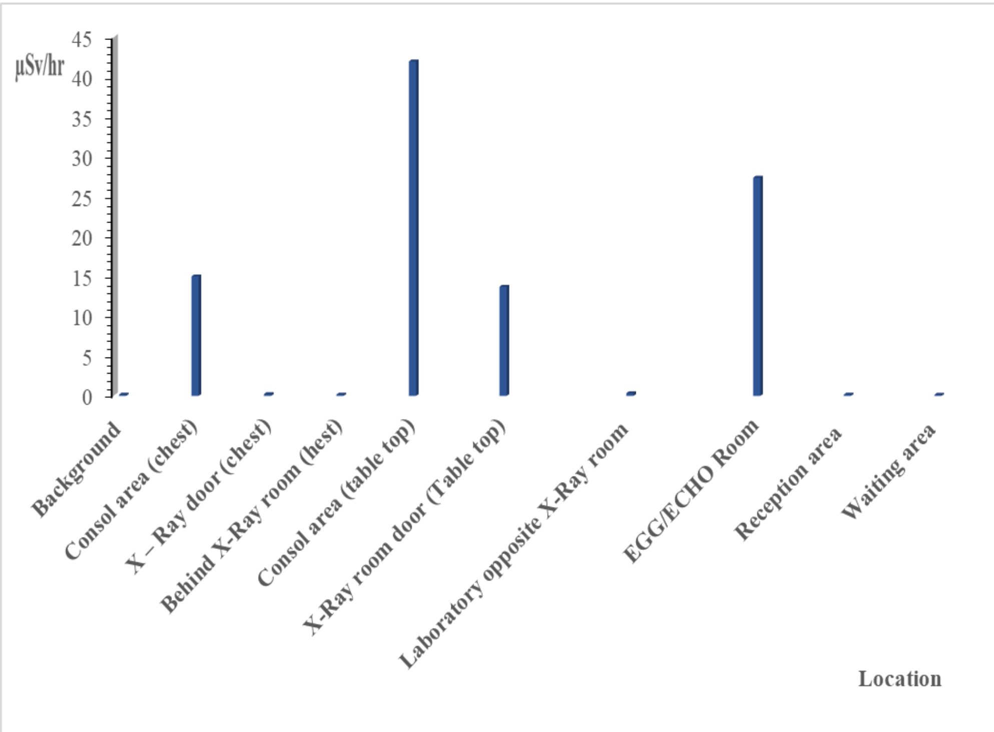

Figure 10: Radiological Facility J Radiation Dose Rate

From the ten diagnostic facilities, 60% of the workers are not aware of NNRA regulations and practices. No shielding of any kind was found in center G and H but there are few lead aprons in the examination room. The Nigeria Nuclear Regulatory Authority (NNRA) recommends a minimum radiographic room area of at least $16m^2$. A study jointly sponsored by the international Labor Organization (ILO), International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) recommend a radiographic room dimension of not less than 6 x 4 x 3 in length, breath and height. Therefore, this gives a room area of at least $24m^2$. The Atomic Energy Regulatory Board (AERB) and a work by recommended a minimum room dimension ranging from $16m^2$ to $20m^2$ (Ekong et al., 2022). Figure 1 to 5 shows the room area of the five (5) radiographic rooms with Diagnostic Centre A ($20m^2$), Diagnostic Centre D ($16.54m^2$), and Diagnostic Centre E ($17.8m^2$), respectively met all recommended standards. Diagnostic Centre B, C, F, G, H, I and J which read $13.2m^2$, $12.4m^2$, $10.21m^2$, $9.11m^2$, $14.01m^2$, $12.4m^2$, and $11.8m^2$respectively did not meet any of the standards.

The implication of the above measurements is that the rooms designated as X-ray rooms in the studied centers largely suggest poor radiation protection to the operator and perhaps, other people within the controlled area during operation (Ekong et al., 2022). This is inversely proportional to the square of the distance from the radiation source. From radiation protection perspective, the larger the room dimension; the more distance would be between the X-ray tube and the control room (operator's booth), therefore the lesser the radiation that will reach the operator and the wall of the radiographic room. It is recommended that the X-ray tube is not closer than 1m to the operator's booth Thus, doubling the distance reduces the dose by a factor of four (Nilantha et al., 2015; Mohammed et al., 2020).

Furthermore, the distance between the operator to the radiation source and operator's consol to the chest stand should be at least 3m as recommended by whereas, according to Atomic Energy Authority of Sri Lanka, the minimum distance between the operator and source should be 2m (Skam et al., 2017). The findings from this study showed a distance less than recommended value in Diagnostic Centre B, C, F, G, H, I and J. this implies that more radiation would be reaching the operator of the X-ray machine in these facilities. This is undesirable in the face of the likelihood of the operator exceeding the maximum permissible occupational dose.

Some corrective measures are recommended. Eight (8) out of the ten (10) centers studied has walls of their radiographic rooms lined with 2mm lead equivalent which satisfied the recommendations of NNRA and the Radiological Protection Institute of Ireland. Two (2) centers was found not to have any shielding at all, Structural shielding which should be calculated by qualified physicist in order to ensure adequate radiation protection was done. There was adequate use of lead aprons in all the X-ray rooms. The use of radiation monitoring devices (thermos-luminescent dosimeter) by the staff in Diagnostic Centre D and E were very impressive while there were no personnel monitoring devices of the staff in Diagnostic Centre A, B, C, F, G, H, I and J. More so, warning lights and warning signs were used at the entrances of five X-ray room doors while three had the indication with white chalk.

6. Conclusion

The foregoing revealed that while facilities developed from existing buildings may not be adequate in room size, shielding of the radiographic room walls and doors, provision of warning, lights and signs, optimization of radiation protection could be achieved through careful consideration of the radiographic room design and layout by adherence to room specifications by regulatory bodies each X-ray installation should be provided adequate shielding facilities as per national and international Standards. Introduction of shielding in diagnostic radiological facilities plays vital role in order to ensure radiation safety workers and the public working in and around the facilities. However, the assumptions or approximations are utilized in shielding calculations in different approach may overestimate or underestimated the barrier thickness of the facility.

The overestimation of the barrier thickness may increase the cost of the shielding and influence the user to loose commitment about radiation safety. Even though the dose rate measured around the facilities are found within the regulatory limit most of the cases, but it is also evident that doses in Diagnostic Centre F, G and H are not optimized. However, the dose rate is measured utilizing many other techniques such as using TLD could give more precise results basically for the effective dose. Findings from this study concur with results in the existing body of literature that most diagnostic X-ray room in developing countries are not designed based in recommended standard specifications. The ten radio-diagnostic Centres covered in this study have given us ten different structural designs of diagnostic X-ray rooms, types of shielding materials used and radiation transmission through barriers. The following safety need to be put in place;

i. The evaluation of personnel radiation monitoring in the selected diagnostic centres shows that personnel radiation monitoring (dosimeter badge) is available in two of the Diagnostic Centers, though not all of the staff are monitored. All staff who work in the X-ray facility are excepted to always wear one.

ii. The absence of staff dose history needs to be visited to enable the monitoring of radiation risk to staff. There is a need for Nigeria Nuclear Regulatory Authority to enforce the standards of radiation protection as published in their various safety reports.

iii. The concluded research showed that a lot of radio-diagnostic centers are not regulated, as some do not even know about the practices of NNRA. These findings call for standardization in radiology room designs and regular radiation safety assessment as recommended by regulatory bodies.

iv. Specifically, replacement of the ordinary wooden door to the X-ray room with one suitable for radiation protection for center F.

v. Use of radiation warning stickers on the door around the X-ray room (Centre F, G and H). Suspension of the use of the X-ray equipment till some reasonable safety measures are put in place (Centre F, G and H) this include proper lead-lining of the X-ray room and use of other shielding barriers.

The results of this work show that dose rate in most of the facilities are relatively higher than the recommended NCRP safety standard. Therefore, further research work should be directed towards health risk of radiation exposure from diagnostic facilities in Ibadan. With the proliferation of X-ray facilities in Ibadan and the increase in the number of X-ray examinations carried out, it is needful for NNRA to design and sponsor an extensive Shielding and dose monitoring through the use of research students.

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