Occupational Exposure of Workers in Industrial Radiography at Selected Sites in Rivers State

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Abstract

Assessment of radiological health hazard in industrial radiography practice in five (5) selected sites in Port Harcourt and its environs was carried out, using Digilert 200 Nuclear Radiation monitor and GPS 72H Garmin Geographical Positioning System. The mean exposure rates for the facilities (A, B, C, D & E) were 5.15mR/h respectively. The mean absorbed dose rates were 44684nGy/h respectively. Estimated average annual Effective dose equivalent obtained for outdoor exposures stood at 68.5mSv/y for all the facilities visited. The mean excess lifetime cancer risk calculated for these facilities were 239.7 x 10^{-3} respectively. The radiological parameters calculated for these facilities had values that were higher than the individual world permissible ICRP limit of 20mSv or 50mSv averaged over 5years. The Annual effective dose calculated for individual workers were lower than world standards while the excess lifetime cancer risks were slightly higher. The calculated organ doses show that the Testes have the highest doses while the liver recorded the least. The overall results from the study indicates that workers are exposed to doses exceeding limits, therefore employers and other stake holders should ensure that radiation workers are adequately trained, strict adherence to work procedures should be complied to, adequate shielding, optimization of distance, wearing of appropriate PPE and use of collimators should be embraced, inorder to keep doses as low as reasonably achievable (ALARA).

Keywords- *Activity Concentration, Assessment, Exposure, Health Hazard*

Introduction

Humans are constantly exposed to ionizing radiation from a variety of sources such as naturally occurring radioactive materials (NORM), occupational exposures from Industrial Radiography (IR), medical applications, and other man-made sources as observed from various epidemiological studies of occupational exposure to ionizing radiation conducted in the form of national or international collaborative studies (Songwon *et al*., 2018). Adverse health effects, such as all cancers other than leukaemia combined, lung cancer, leukaemia excluding chronic lymphocytic leukaemia and circulatory diseases, have been reported in some single-nation studies, from the UK, Russia, the USA, Canada and France. Moreover, given that baseline risks possibly differ from nation to nation, generalizations of the findings to other populations like in Nigeria context should be made with caution.

In Nigeria, workers in radiation-related occupations such as Industrial Radiography are registered with one or two government regulatory agencies, depending on their occupation: diagnostic radiation workers under the relevant medical professional bodies and Industrial Radiography under the Nuclear Safety and Radiation Protection Act 19 of 1995, administered by the Nigerian Nuclear Regulatory Authority (NNRA). Ionizing radiations are widely used throughout the world, particularly in medical, industry, agriculture and research sectors. In the coastal areas of Nigeria which include Rivers State, the dominating industry is the oil exploration and production industry. In Nigeria specifically Rivers State, apart from medical exposure, the petroleum industry is the largest importer and consumer of radioactive sources in the industry covering both upstream and downstream operations (Elegba, 1993).

The post-colonial Nigeria in order to stay competitive have placed more demand on crude Oil production and exploration, activities which calls for the peaceful application of nuclear technology. Such technology as industrial radiography, which provides means of verifying the physical integrity of equipment and structures such as vessels, pipes, welded joints, castings and other devices used in the oil related industries. The structural integrity of such equipment and structures affects not only the safety and quality of the products but also the protection of workers, the public and the environment (Lenka & Jizeng, 2018). Presently in Nigeria, NDT Industrial radiography makes use of x ray machines (in kV range) and radioactive sources, of which Iridium -192 is the most common, the application of radiation in NDT depends on the principle of measuring defects based on the presented radiation scattering characteristics when radiation penetrates the tested materials. NDT by its nature is carried out under difficult working conditions, such as in confined spaces, in extreme cold or heat, or during the night in remote or urban areas, with little supervision, and with strong radiation sources.

In some cases, the use of radioactive sources could lead to occupational exposures, both in normal operations and in accident situations. Related accidents and incidents occur in the NDT industry, and the dose rates received to a source or a device may be high enough to cause overexposure of extremities, and could potentially result in the loss of a limb and cancer risk.

Industrial radiography has been reported to not only have the highest effective dose, but also to account for the majority of occupational cancer incidence among all radiation-related occupations. However, industrial radiographers have been relatively neglected compared with nuclear power plant workers (Songwon et al., 2018). Industrial radiographers are considered one of the most critical group of radiation workers. The annual average effective dose received by industrial radiographers is higher than that of other radiation workers (Rahman et al., 2016). Therefore, adequate standards and working procedures must be in put in place to safeguard the lives of workers and the public.

Considering the observed trends of failure to adhere to working procedures or a lack of training which could be adjudged responsible for potential safety failures and higher exposures in the NDT industry and this prompted this study.

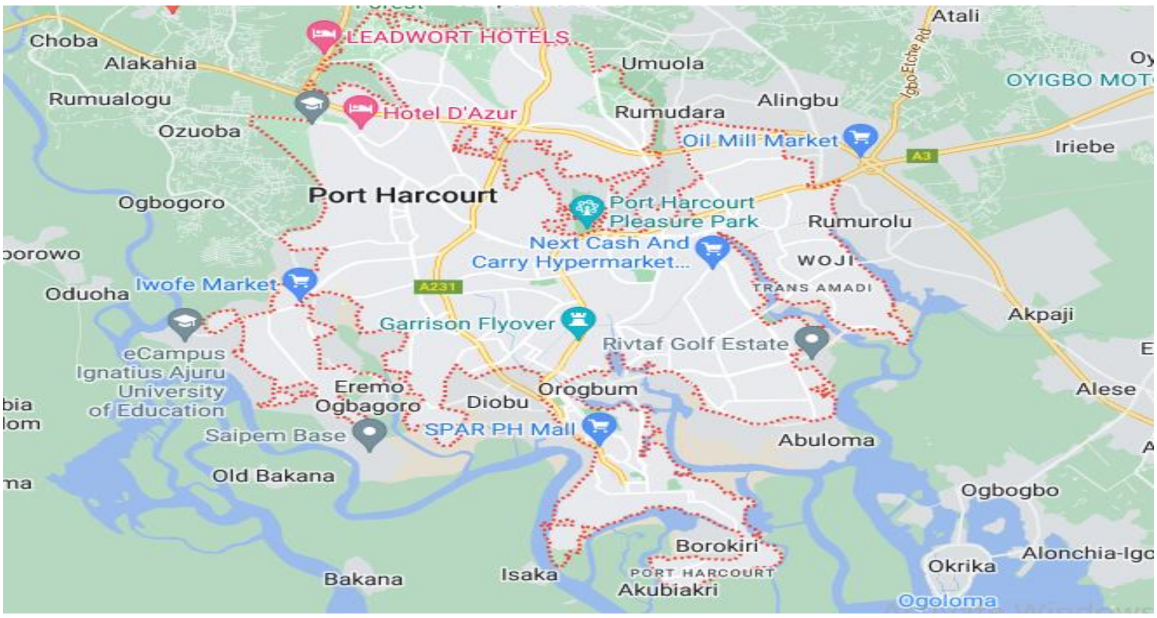
1.1 Study Area

Port Harcourt is one of the twenty-three (23) local government areas in Rivers state and the fifth largest Nigerian city by population of about 1,865,000 residents (Britannica). It is bounded by Obio /Akpor, Degema, Okrika and Eleme local Government Areas. Port Harcourt sits on a land area of about 369km^2 and lies along the Bonny river (an eastern distributary of the Niger

River) 66km upstream from the Gulf of Guinea. Climate: Port Harcourt has a tropical climate, rainfall is significant most part of the year with very short dry season, average annual rainfall is 26,40C. Max maximum monthly temperature range from 28˚C to 33˚C while the minimum monthly temperature are in the range of 17˚C to 24˚C. The mean monthly temperature is in the range of 25°C to 28°C. The mean annual temperature for Rivers State is 26°C. The hottest months are February to May. The difference between the dry season and wet season temperatures is only about 2°C. Relative humidity is high in the State throughout the year and decreases slightly in the dry season (Salawu 1993).

Port Harcourt plays host to many manufacturing, oil and gas exploration and production industries and also a refinery, the activities of this industries put Rivers state as the largest importer and user of radioactive sources. Radioactive sources and equipment generating radiation are widely used in the oil and gas industries and particularly in industrial radiography, currently there are quite a number of multinationals and privately-owned companies in Port Harcourt who are involved in Non-Destructive Testing. The population of this study comprises the field NDT workers and management staff of oil-servicing firms in Trans Amadi industrial Layout, Eleme & Igbo Etche communities in Rivers State, who are affected directly or indirectly by the method of operations during NDT activities. Every of the facility visited had at least 5 NDT workers.

The selected location includes, Trans Amadi industrial layout, Eleme and Igbo Etche axis. The facilities chosen are fully operational and licensed by the Nigerian Nuclear Regulatory Authority, a body which is responsible for regulating the use of ionizing radiation within the country. Five (5) facilities were selected and designated as facility A, B, C, D & E. Two (2) sites were chosen within Trans Amadi Area due to the large number of facilities located around this area. Most of the facilities chosen used gamma radiography for testing integrity of pipelines and other welded components, X ray is seldom used because of its complexity. Fig 3.1 shows the map of Rivers



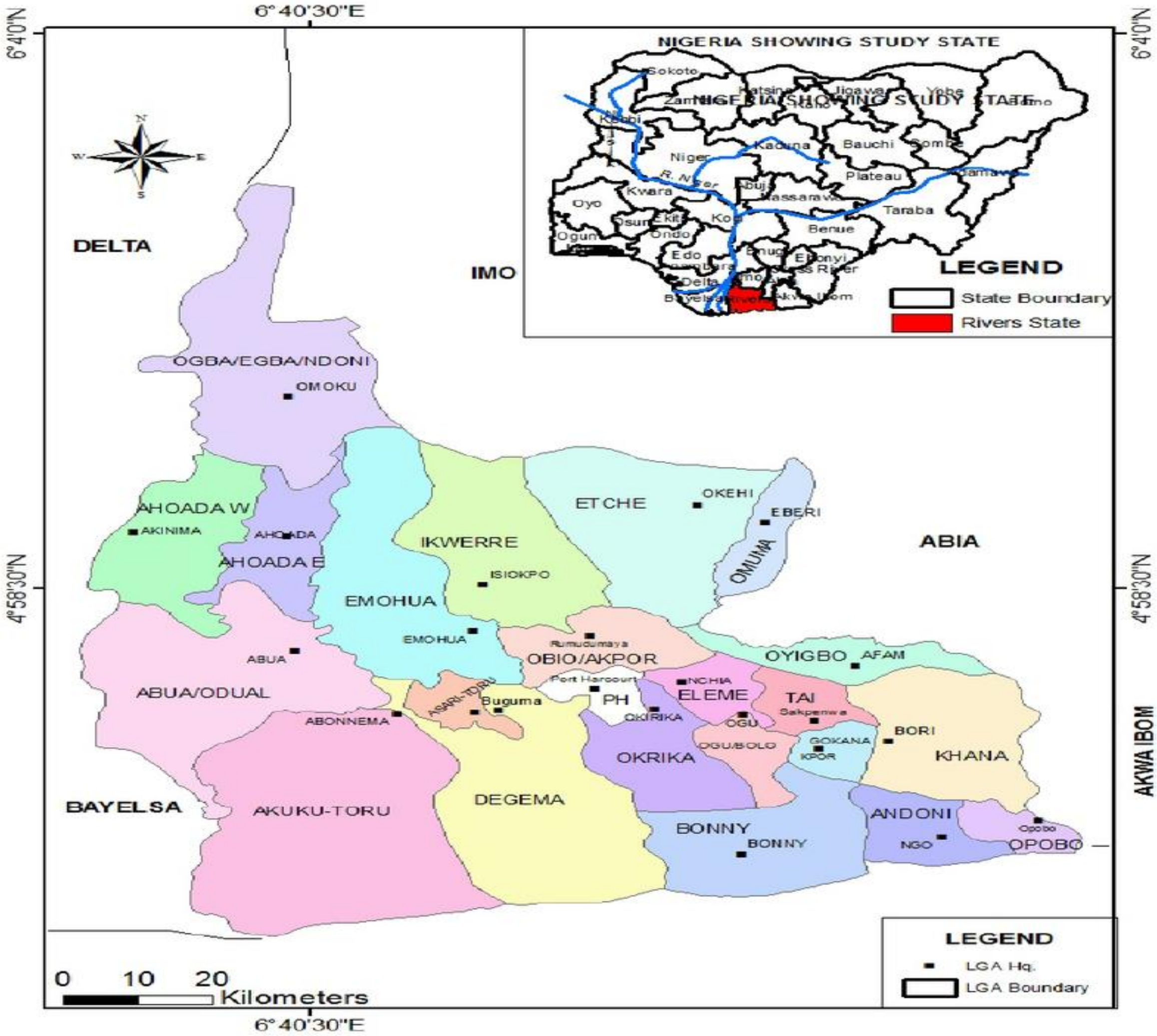


Fig.1: Base Map of the study area, Port Harcourt City.

1.1 Method of Data Collection / Instrumentation
Materials:

The following materials and instruments were used in carrying out this research work. A hand held Digitlert 200 Nuclear Radiation Monitor, GPS 72H Garmin Geographical Positioning System, Measuring Tape, radiation caution tape, warning lights, Industrial radiography projector incorporating a radioactive source, camera, time piece, pendosimeters, Dosimetry reports.

the survey meter had valid calibration traceable to a secondary dosimetry laboratory under the Nigerian Nuclear Regulatory Authority, the device provides a real time dynamic indication of the radiation rate. The Geiger-muller tube generates a pulse current each time radiation passes through the tube and causes ionization. Each pulse is electronically detected and registered as a count. The radiation meters were calibrated with a ^{137}Cs source of specific energy and set to measure exposures rate in milli Roentgen per hour (mR/h). The meter has an accuracy of ±15%,

1.3. Measurement of Ambient ionizing radiation

Primary data collection was done through an in-situ measurements of ambient gamma dose levels around controlled areas at 10 different points during radiographic non- destructive testing using a hand held survey meter. At every location, measurement points were marked out within and around the controlled area using measuring tapes. Source strength used at different location varies between 2Ci – 8Ci. Measurement for gamma dose rates using a survey meters held above the ground at about 1m while facing the direction of the source, measurements were taken at 10m away from the source and every 5m apart at ten (10) different points in all locations. Readings were repeated at every point and these measurements were averaged to a single value. The entire controlled areas were cordoned off with caution tapes. Geographic Positioning system (GPS) was used to determine the exact coordinates of each sites. Control readings were taken meters away from the radiographic set up.

The recommended quantities include the Absorbed dose (D) Equivalent dose (H), Annual Effective Dose Equivalent (AEDE), Excess Lifetime Cancer risk (ELCR) and Organ doses (D_{organ})

The mean exposure rate at each point which was measured in mRh^{-1} was converted to absorbed dose rate ($nGyh^{-1}$) using the conversion factor (Ononugbo *et al.*, 2015)

$$1\mu R/h \quad = 8.7\ nGy/h \quad = 8.7 \times 10^{-3} \mu Gy/(1/8760\, y) \tag{3.1}$$

a) Absorbed dose (D)

The Absorbed dose represents the dose received in an open by the gamma radiation emitted by the radionuclide available in that vicinity. The absorbed dose to workers from ambient ionizing radiation was calculated using the equation

$$1\ \mu Rh^{-1} \ = 8.7\ nGyh^{-1} = \frac{8.7\ x\ 10^{-3}}{\left(\frac{1}{8760y}\right)} \ = 76.212\ \mu Gyy^{-1} = 76.212\ \mu Gyy^{-1} \tag{3.2}$$

b) Equivalent Dose Rate

The exposure rate measured was also used to estimate the whole-body equivalent dose rate over a period of one year, The National Council on Radiation Protection and Measurement's recommendation was used

$$1\ mRh^{-1} = \frac{0.96\ x\ 24\ x\ 365}{100}\ mSvy^{-1} \tag{3.3}$$

c) Annual Effective Dose Equivalent (AEDE)

Exposure rate to any individual due to absorbed dose is estimated in terms of the annual effective dose equivalent (AEDE). The computed absorbed dose rates were used to calculate (AEDE) received by the workers. In calculating AEDE, dose conversion factor of 0.7 Sv/Gy and the occupancy factor for outdoor of 0.25 (6 hours out of 24 hours) was used, this is because the workers spends an average of 6 – 8 hours outside while working in site radiography. The annual effective dose was estimated using the following relation. (Kolo et al., 2017)

$AEDE\ (Outdoor)(mSvy^{-1}) = Absorbed\ dose\ rate\ (nGyh^{-1}) \times 8760hy^{-1} \times \frac{0.7Sv}{Gy} \times 0.25X10^{-6}$ (3.4)

$$AEDE(mSvy^{-1)}) = D_R\ X\ 1.21\ X10^{-3} \quad (3.5)$$

d) Excess Life Cancer Risk (ELCR)

The probability of cancer to any population from exposure to radiation is a measure of the ELCR. This is calculated based on the calculated AEDE, Excess Lifetime Cancer Risk (ELCR) was estimated using equation (3.5)

$$\boldsymbol{ELCR = AEDE\ \times Average\ duration\ of\ life\ \times Risk\ factor\ Rf} \quad (3.6)$$

Where AEDE, DL and RF is the annual effective dose equivalent, Average Duration of life according to ICRP 60 & NiBIRR is 50 years and 70 years for adults & children respectively, For low dose background radiations which are considered to produce stochastic effects, ICRP 60 uses values of 0.05 for the public exposure

e) Effective Dose Rate D_{organ} in $mSvy^{-1}$ to different organs and tissues

The effective dose rate to a particular organ can be calculated using the relations (Ovuomarie -kevin et al., 2019)

$$D_{organ}\,(mSvy^{-1}) = O \times AEDE \times F \quad (3.7)$$

Where AEDE is annual Effective Dose Equivalent, O is the occupancy factor 0.8 and F is the conversion factor for organ dose from ingestion. The F values for lungs, ovaries, bone marrow, testes, kidneys, liver and whole body are 0.64, 0.58, 0.69, 0.82, 0.62, 0.46 and 0.68 respectively as obtained from ICRP 2007. The model of the annual effective dose to organs estimates the amount of radiation intake by a person that enters and accumulates in various body organs and tissues and this is dependent on the turnover of the target tissue or organ.

Dosimetry Readings

The exposure readings from the TLD are obtained by loading the dosimeters into a Manual TLD reader connected to a personal computer with a software specifically designed to read and interpret doses. The charges produced by electrons due to annealing process are read out as outputs and this is further converted into absorbed dose (Gy) using the equations (Rahman et al, 2016)

$$Absorbed\ dose = \frac{Equivalent\ dose}{quality\ factor} \quad (3.8)$$

For all individual doses, the minimum detection level (MDL) is 0.05 mSv for 3 months after background subtraction. The MDL is a dose recording level, therefore worker who received doses lower than MDL is considered as unexposed.

Annual Effective Dose from TLD readout can be calculated using the equation (Essien et al, 2017).

$$AED = H_T \times 0.7 \quad (3.8)$$

Where H_T is equivalent dose and 0.7 is the conversion factor from equivalent dose to effective dose.

Results and Discussions

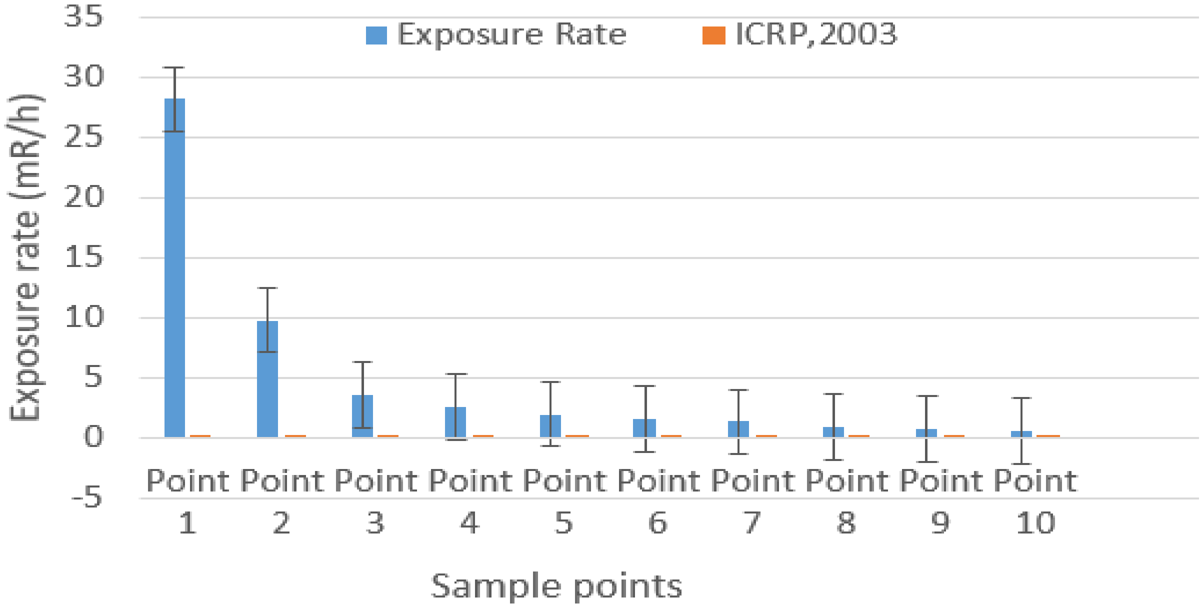
Exposure Rates and Radiation Risk Parameters

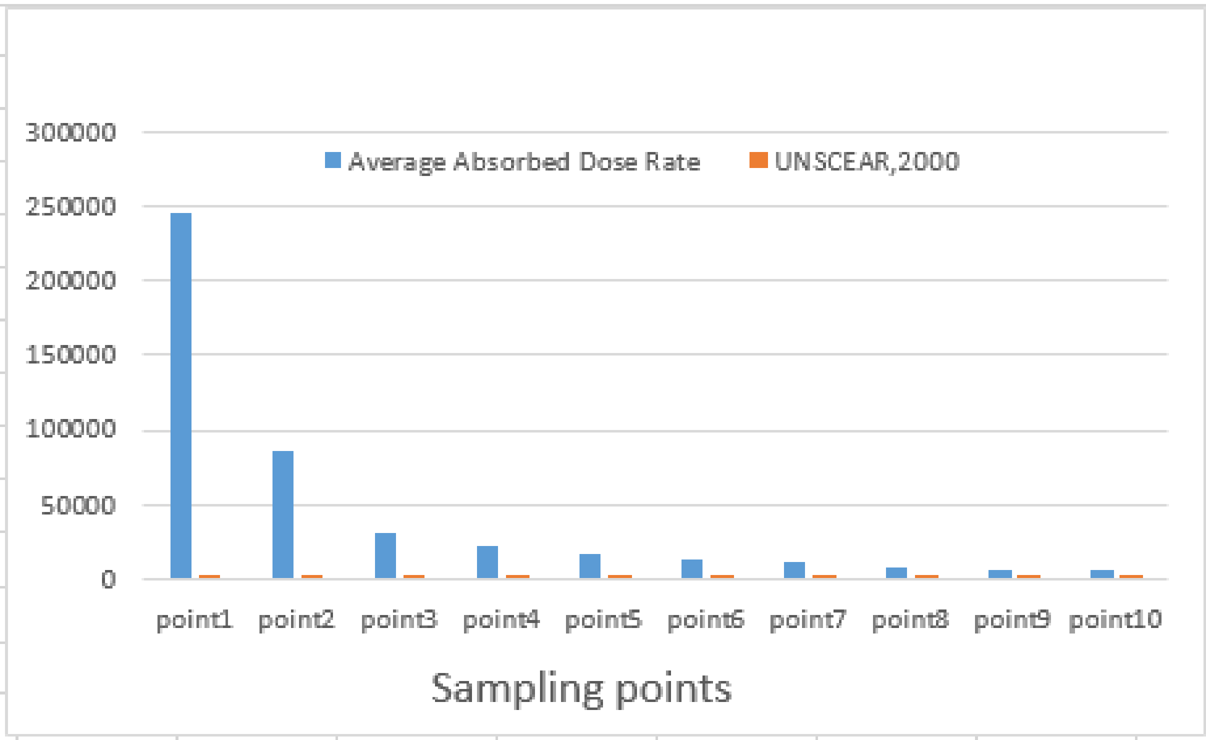
The measured exposure rates of the ambient and their computed radiation risk parameters are shown in Table 4.1 – 4.5.

Table 4.1: Exposure rate and Radiation Risk Parameters for Facility A

Coordinates: N04˚51.479′, E007˚05.485′ ; Source strength = 2.3Ci ; Source type = Ir - 192

Point of Interest	**Distance from Source(m)**	**Exposure Rate (mR/h)**	**Absorbed Dose (nGy/h)**	**AEDE (mSv/y)**	ELCR (10^{-3})	EDR (mSvy-1)
Point 1	10	28.24	245688	376.6	1318.2	2374.9
Point 2	15	9.81	85347	130.8	457.9	824.9
Point 3	20	3.556	30937	47.4	165.9	299.0
Point 4	25	2.615	22750	34.9	122.1	219.9
Point 5	30	1.9523	16985	26.0	91.1	164.2
Point 6	35	1.552	13502	20.7	72.4	130.5
Point 7	40	1.3632	11895	18.2	63.6	114.6
Point 8	45	0.9138	7950	12.2	42.7	76.8
Point 9	50	0.777	6760	10.4	36.3	65.3
Point 10	55	0.5824	5067	7.8	27.2	48.9
Mean		**5.14**	**44684**	**68.5**	**239.7**	**431.9**
CONTROL		**0.009**	**0.757**	**78.32**	**0.120**	**0.420**


Exposure Rate
ICRP,2003
Exposure rate (mR/h)
35
30
25
20
15
10
5
0
-5
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7
Point 8
Point 9
Point 10
Sample points


Average Absorbed Dose Rate
UNSCEAR,2000
300000
250000
200000
150000
100000
50000
0
point1
point2
point3
point4
point5
point6
point7
point8
point9
point10
Sampling points

4.1.2 Effective Dose to Different Organs

The calculated effective doses rates delivered to different organs are presented in tables 4.6 to 4.11

Table 4.6: Mean Effective Dose rate (Dorgan(mSv/y) to different organs and tissues from all facility visited.

Points of Interest	CAL. AEDE	ORGAN DOSES LUNGS	OVARIES	(mSv/y) B/MARROW	TESTES	KIDNEYS	LIVER	W/BODY
Point 1	376.6	241.0	218.4	259.9	308.8	233.5	173.2	256.1
Point2	130.8	83.7	75.9	90.3	107.3	81.1	60.2	88.9
Point 3	47.4	30.3	27.5	32.7	38.9	29.4	21.8	32.2
Point 4	34.9	22.3	20.2	24.1	28.6	21.6	16.1	23.7
Point 5	26.0	16.6	15.1	17.9	21.3	16.1	11.9	17.7
Point 6	20.7	13.2	12.0	14.3	16.9	12.8	9.5	14.1
Point 7	18.2	11.6	10.6	12.6	14.9	11.3	8.4	12.4
Point8	12.2	7.8	7.10	8.4	10.0	7.6	5.6	8.3
Point 9	10.4	6.6	6.0	7.2	8.5	6.4	4.8	7.1
Point 10	7.8	4.9	4.5	5.4	6.4	4.8	3.6	5.3
Mean	**68.5**	**43.8**	**39.7**	**47.3**	**56.2**	**42.5**	**31.5**	**46.6**
Control	0.120	0.006	0.006	0.007	0.008	0.006	0.004	0.006

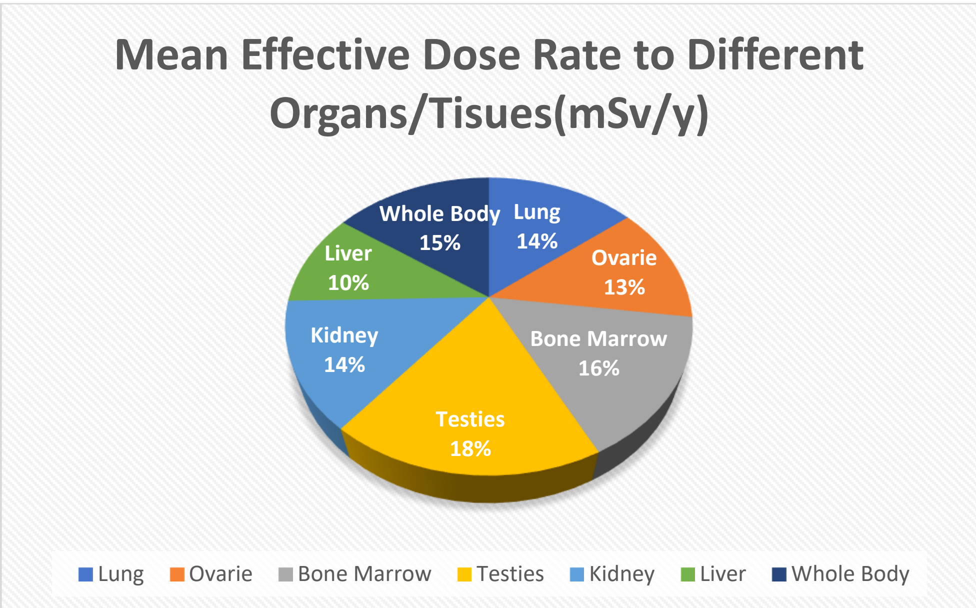


Fig 4.10: Mean Effective dose Rate to Different Organs/Tisues across the Facilities visited.

4.3 Discussion of Results

4.3.1 **Discussion of Exposure Rate**

Results of gamma dose levels measured at various facilities during non - destructive testing procedures are represented on Table 4.1 & 4.2 respectively. The lowest average exposure rate values of 0.914mR/h, 0.777mR/h and 0.582mR/h was recorded at 45m, 50m and 55m respectively from the source of radiation, which confirmed the principle of optimization of distance in radiation protection. On the other hand, high exposure rate value of 28.24mR/h was recorded at 10m from the source as well. The values when compared are higher than the ICRP 2003 permissible limits of 0.013mR/h for background radiation. The high results can be attributed to the type and activity of the radioactive source and the energy of the radiation produced. Another contributory factor to this high value could be the distance from the source to the measurement point. This results correlates well with the inverse-square-law, which states that exposure is inversely proportional to the distance from the radioactive source. Similarly, every other radio-parameters also show their respective characteristics. Absorbed Dose recorded a mean value of 44684nGy/h, AEDE has its mean value as 68.5mSv/y, ELCR has its mean value as 239.7 x 10^{-3} and Equivalent Dose Rate has its mean as 431.9mSv/y respectively. Comparing obtained results with their various UNSCEAR permissible limits of 89nGy/h, 20mSv/y or 50mSv averaged over 5 years and 0.29 10^{-3} all indicated anomalous elevation and extreme higher ranges.

The higher dose recorded could be attributed to the energy of the radiation source and inadequate radiation protection measures. Radiation workers at most of the sites visited were not protected, collimators and proper shielding were not in used to reduce the exposure rates. All workers received doses higher than the 1.3 mSv reported for industrial radiographers in Nigeria by Muhammad (2017), 2.43mSv reported for Bangladesh by Rahman *et al*, (2016) and 5.80mSv reported for Bosnia by Basic *et al*, (2010).

The implication of this result is that workers might receive higher doses to tissues and organs than the recommended values. The high result if protracted may results in adverse health risk

The result of the Excess Lifetime Cancer Risk of personnel in the study location due to gamma radiation shows positive when compared with UNSCEAR permissible limits of 0.29 10^{-3}. This implies that workers and the populace around these work sites stand the risk of getting cancer due to protracted exposure over a long period of time.

5.2 Conclusion

The high results recorded in the study are attributed to the energy and intensity of the radioactive sources used in non-destructing procedures, which ranged between (2 – 8) Ci without collimators and shielding in place. Most of the radiological parameters assessed were higher than the International Commission on Radiological Protection (ICRP) and United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) standards and Nigerian Nuclear Regulatory Authority limits. This translates to the fact that NDT operations contributes largely to the doses received by workers and poses high radiological risks to workers and residents around work sites. Therefore, more stringent measures such as optimization of distance, adequate shielding and use of functional collimators should be promoted in order to minimize exposure of workers and general public to the harmful effect of ionizing radiation.

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