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Original Article

ASSESSMENTS OF INDOOR RADON CONCENTRATION IN OFFICES AND ESTIMATION OF THE ANNUAL EFFECTIVE DOSE

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Abstract

Radon activities in the offices have been reported on five different floors to ascertain annual equivalent dose (AEqD) and excess lifetime cancer risk due to gamma radiations for a period of six months. *RAD7,* an electronic radon detector manufactured by Durridge Co. USA calibrated in-house was used to measure the indoor radon concentration levels in offices of the Administration block. Mean radon concentration from offices studied ranged from134.72 Bqm^{-3} - 536.98 Bqm^{-3} in all the offices. The mean of the annual effective dose due to 222Rn progeny (AEDR) in mSv/yr. is highest in GFL. This value is 2.344 x 10^{-3} mSv/yr. and it's lowest at the LFL with the value of 1.010 x 10^{-3} mSv/yr. The lung cancer cases mean, maximum and the 95th percentile per million people values obtained from offices and the obtained values are 85.81, 11.44, and 11.21. The obtained values were lower than the public limit of 1 mSvy^{-1} as recommended by ICRP, and these findings show a significant correlation between indoor radon effective doses obtained by other studies elsewhere.

Keywords*:* Radon; Annual effective dose; Excess lifetime cancer risk; Indoor radon; Effective dose to lung; Radiation dose Health risk.

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1. INTRODUCTION

Radon is a radioactive noble gas that results from alpha decay of radium. In the decay series of uranium (^{238}U), Radon (^{222}Rn) is a direct decay product of Radium (^{226}Ra) with half-life of 3.8 days while in the Thorium (^{232}Th) decay series, Radon (^{220}Rn) is a direct decay product of Radium (^{224}Ra) with half-life of 50 seconds (IAEA, 2010). It is an odorless and colorless radioactive gas which is highly carcinogenic. Radon decays into radioactive metal ions by alpha radiation. The most important of the radon decay products in the present context are the alpha emitters' polonium-218 (half-life 3.1 min) and polonium-214 (half-life 0.15 seconds). Immediately after the decay, the progeny are unattached, but a large portion is soon attached to particles in the air or to surfaces which is inhaled into the lungs. The short-lived progeny collectively has a half-life of about half an hour.

Certain rocks and soil, such as granites and shales, are the major sources of radon in the environment. Radon majorly enters the house from the soil under the house (IARC, 2021) and from building materials and water. The radon concentration in outdoor air is higher over large continents than over sea. The radon concentration outdoors has an annual average of about 10 Bqm^{-3} (ATSDR, 2012). During temperature inversions (a reversal of the normal atmospheric temperature gradient), levels may reach hundreds of Bqm^{-3} over regions with enhanced concentrations of uranium and radium in the ground (Robe *et al,* 2021). Indoor radon concentrations depend on the house construction and the underlying soil, climatic factors and human habits. Furthermore, the concentration varies between buildings and within rooms. The major radon source is ground soil; rooms in basements or in contact with the ground have higher radon concentrations than rooms on higher floors. Within rooms the radon concentrations may vary, for example near inlet or outlet ducts, and near points of high inflow of radon from the ground, building materials or radon-rich water.

Radon being the highest cause of cancer among non-smokers should be of concern to everyone knowing it is present everywhere in varying concentration. People exposed to Radon have an increased risk of lung cancer (Robe *et al,* 2021). The reason for this is that Radon and its daughter nuclei follow the air into the lungs where they can decay and deposit their radiation (Quarto *et al*, 2015). Radon and its daughter radionuclei are alpha emitters which cause damage to the lungs and when it becomes severe it leads to cancer, UNSCEAR estimates an average annual effective dose of 1 mSvy^{-1} to the general population due to inhalation of radon and its progenies. For this reason and considering that many people spend 80% of their time (UNSCEAR, 2000) indoors either in the workplace or at home, many investigations of domestic radon exposure have been aroused worldwide. It is quite unfortunate to hear from the educated that they have no knowledge of radon gas or its existence around them, the level of ignorance among office workers who worked indoor for a long period per day breaded this research work conducted in the senate building of the University of Lagos, Nigeria. The study area is located at 6°31'0"N 3°21'10"E which is the heart of the city where academics activities are at its peak. This is the first research to monitor indoor ^{222}Rn in offices using alpha track detectors in University of Lagos. Even though many works have been done in the investigation of radon in homes, schools etc. (Sanchez *et al.* 2012), conducted survey on different floors; about 1000 homes in Galicia, Spain, 21.3 % of dwellings have a radon concentration above 148 Bqm^{-3} while 12% with concentration above 200 Bqm^{-3}. According to his findings, the major factors that affected radon concentration are the age of the building, the building construction materials and the number of stories. For high rise building the upper floors have less concentration compared to the lower. Whereas Curado *et. al.* 2016, conducted survey on about 130 companies in Extremadura, Spain; more than 200 measurements were taken to determine the indoor concentration of radon in workplaces. The value obtained from low ventilation places like museums is very high. In the work of Ojo *et. al* 2015 they estimated the outdoor radon concentration in Ado Ekiti, Nigeria. According to him the local geography and the composition of the soil greatly determine the radon concentration and not significantly the age of the building. However, according to Asere *et. Al* 2017, they analyzed the concentration of 3-granitic single-family houses, in Barcelos, Portugal.

Measurements were performed during the summer and autumn season. According to the results human occupancy, mostly through passive ventilation processes, work as radon concentration mitigation factor Barros-Dios *et.al* 2007, in her study estimated the indoor radon and its progeny in Akoko, Ondo State, Nigeria, and its shows that the local soil origin greatly contributes to radon concentration recorded in the area. The aim of the present study is to measure ^{222}Rn concentration in the offices and estimate the Annual effective dose (AEDR) and the associated health risk on exposure to 222Rn in the offices. This study aimed to estimate the Excess Lifetime Cancer Risk (ELCR) and annual equivalent dose (AEqD) due to exposure to 222Rn at offices. Hence this study may serve presently as baseline data that could be used for future reference in Lagos State.

2. MATERIALS AND METHODS

Solid state device is a device of choice because of its ability to electrically determine the energy of alpha particle. RAD7 radon detectors use a semiconductor material that converts alpha radiation (RAD7 which before having been specifically designed only to detect alpha particles) into electrical signals directly. Thus, RAD7 was used for the measurement of the indoor radon activity levels. To measure the Radon concentration levels in the offices RAD7 radon detector was connected to a Drystik accessory (RAD 7, 2021) in a closed loop. Environmental protection agency (EPA) recommended that all continuous radon monitors be calibrated for at least six months in a radon calibration chamber of course this was done very recently before the commencements of our measurements. Radon-222 series decay by emitting alpha, beta or gamma radiation (IARC 1988). An in-situ measurement of radon concentration on five different floors in the Administrative office of the University of Lagos was performed using a digital radon monitor. The GPS coordinates of University of Lagos, Nigeria is on Latitude: 6.5167 and Longitude: 3.3850.

Twenty offices were sampled and coded as table 1 below the building, four different offices (rooms) from the ground floor (GFL), four from the first floor (FFL), four from the second floor (SFL), four from the third floor (TFL) and four from the fourth floor (LFL). The offices occupy between three to five office workers (personnel), and there are each table allocated to each of the personnel, so also the necessary office tools such as desktop computers, office file cabinet, and files all over the spaces stocked up in the office.

Table 1: Office floor sampling coded.

Office Sampling Floor	Coded	Office Room Number
Ground Floor	GFL	GFL1, GFL2, GFL3 & GFL4,
First Floor	FFL	FFL1, FFL2, FFL3 & FFL4
Second Floor	SFL	SFL1, SFL2, SFL3 & SFL4
Third Floor	TFL	TFL1, TFL2, TFL3 & TFL4
Fourth Floor	LFL	LFL1, LFL2, LFL3 & LFL4

The offices are fully equipped with air conditioners (A/C) and the windows are always locked up throughout the day, as a matter of fact, the offices are congested. The indoor radon concentration measurements were recorded directly in each of the offices in Bqm^{-3}. After taking the measurement for an office the digital radon detector is restarted for the 30 min test-purge, with the device connected to a clean desiccant (air sample drying unit) that allowed radon-free air to flow into the sample chamber via the inlet. The radon-free air cleared off previously sampled radon during test-purge. The RAD7 device has a pump to send the air over the detection system to be able to operate with a constant flow rate of 1 l/min.

2.1 Assessment parameters of health risk due radon exposure

Most of the parameters used in assessing health risk as a result of radon exposure are annual effective dose due to radon (***AEDR***); annual equivalent dose for lung (***AEqD***); exposure to radon progeny (E_{rp}), estimation of excess lifetime cancer risk (***ELCR***); estimation of the potential lung cancer risk (***EPLC***).

Working Level (WL) indicates that the concentration of the potential alpha energy of short-lived radon progeny. One WL is equal to 3700 Bq/m^3 (100pCi/L) in the air or 2.08 x 10^{-} J/m^3 (1.3 x 10^8 MeV/m^3). Working Level Month (WLM) is a unit that described the cumulative human exposure due to inhalation of the short-lived radon progeny. WLM is commonly used in occupational exposure assessment for radon. In addition, WLM represents an exposure of 1 WL for 170 hours, exposure to 1 Bq/m^3 of radon per year equals 4.4 x 10^{-3} WLM at home and 1.26 x 10^{-3} WLM at work by assuming 7000h/year indoors or 2000 h/year at work and an equilibrium factor of 0.4 (USEPA, 2003; ICRP, 1993; WHO, 2000; ICRP, 2009).

2.1.1 Annual effective dose of radon
Annual effective dose (AEDR) because of exposure to 222Rn may be computed with the equation (1):

$$AEDR = RC \times Df \times n \times T \times Ef \quad (1)$$

Where AEDR is the annual effective dose, mSv/year; RC is the radon concentration in Bq/m^3; D*f* is the dose conservation factor, 9 x 10^{-9} mSv/h per 1 Bq/m^3; n is the occupancy factor; E*f* is the equilibrium factor (0.4 for indoors) and T is the total hours in a year (Al-Hamidawi *et al*, 2016).

2.1.2 Annual equivalent dose for lung
The annual equivalent dose (AEqD) for lungs is computed from the equation (2):

$$AEqD = AEDR \times W_R \times W_T \quad (2)$$

Where W_R is the radiation weighting factor, and this is 20 for α particles; W_T is the tissue weighing factor and for lung the value is 0.12 (Salvato *et al*, 2003).

2.1.2.1 Exposure to radon progeny (*E_{rp}*)
Using the US EPA techniques (Ansre *et al*, 2017) for exposure to 222Rn progeny, the equation below is applied for the calculation (3

$$E_{rp} = RC \times Ef \times n \times \left(2.7 \times 10^{-4}\right) \times 8760/170 \quad (3)$$

Where E_{rp} is measured in WLM/y, RC is in Bq/m^3, 2.7 x 10-4 (1/3700Bq/m^3) is the constant to convert radon concentration to WL per Bq/m^3, Ef is the equilibrium factor (0.4 for indoors and 0.6 for the outdoors), n is the occupancy factor, 8760 is the total hours per year and the 170 is the total working hours per month (UNSC, 2009; Chen, *et al* 2018; Rafat, 2015). There are various reports about the value of the occupancy factor and these values vary between 0.33 and 0.8 for the indoors. US EPA took to consideration a 3% sampling error, with the facts that in America workers spend 67% of their time at home; this is also taken into consideration that Nigerians spends 33% of their time in the office (workplace). However, the recommended value of the occupancy factor n of 0.7 for indoor radon exposure (USEPA, 2003; Zeeb, 2009).

2.1.3 Estimation of excess lifetime cancer risk (*ELCR*)

In computing the ELCR due to exposure to 222Rn at the offices (workplace) the equation [19] below based on US EPA have been used (Rafat; 2015)

$$ELCR = E_{rp} \times ALE \times D_a \quad (4)$$

Where ALE is the average life expectancy and according to WHO's report in 2015, life expectancy is taken to be 55 years for Nigerian people (WHO, 2019). D_a is the detrimentaladjusted nominal risk coefficient which 5.0 x 10^{-4} WLM^{-1} (ICPR, 2009).

2.1.4 Estimation of the Potential lung cancer risk (*EPLC*)

This parameter describes the expected incidences that may be attributed to inhalation of radon gas and is computed (Shoeib *et*, *al.*, 2014) with equation (5).

$$EPLC = 18 \times AEqD \qquad (5)$$

3. RESULTS and DISCUSSIONS

3.1 Radon concentration measured per floor

The maximum, minimum, mean and the 95^{th} percentile of radon concentrations, in Bqm^{-3} in five different floors are presented in figure 1 below. Thus, the concentration level ranges from 134.72 Bqm^{-3} - 536.98 Bqm^{-3} and the value differs from offices on each floor. The measured values for GFL ranging from 316.42 - 536.98 Bqm^{-3}, FFL from 235.17 - 459.92 Bqm^{-3} , SFL from 219.12 - 355.47 Bqm^{-3} , TFL from 174.85 - 290.18 Bqm^{-3} and LFL from 134.72 - 218.96 Bqm^{-3} the 95^{th} percentile also differs from floor to floor, these values decreases as one ascend the floors upwards from the ground floor because the upper floors are well ventilated. In general it may be assumed that radon levels in upper stairs of multi-storey buildings will be intrinsically lower than at ground level, this is not always the case, since radon exhalation from the materials from which the building is constructed may contribute significantly to indoor levels. The overall average radon concentration level from the building studied was 286.88 Bqm^{-3}.

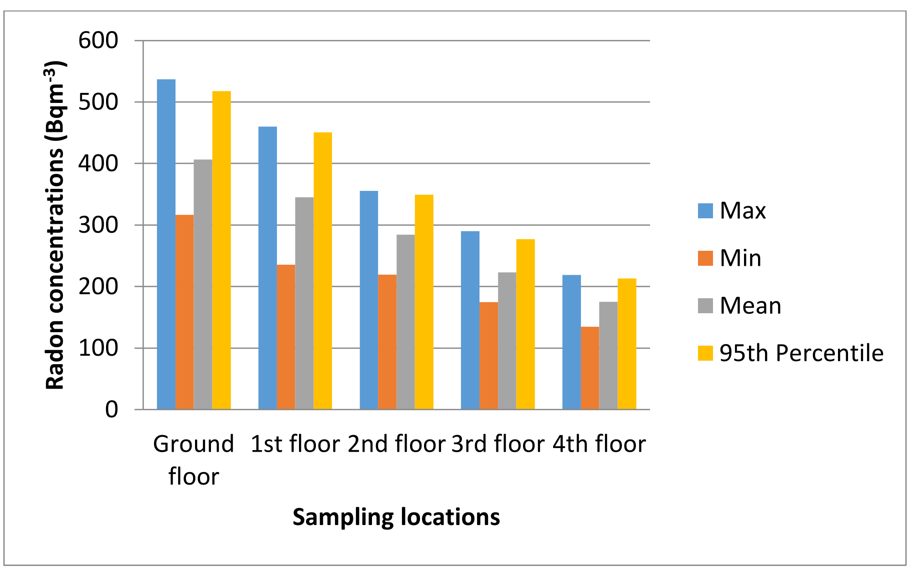

Figure 1: Radon measurements per floor, maximum, minimum and the 95^{th} percentile

The highest concentration was obtained on the ground floor with a value of 536.98 Bqm^{-3} while the lowest concentration was obtained from the fourth floor with a value of 134.72 Bqm^{-3}. Therefore, radon concentration ranges from 134.72 Bqm^{-3} - 536.98 Bqm^{-3}. In addition, 222Rn level was higher on the ground floor when compared with the other higher floors. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and ICRP recommended the reference level in the range of 100 – 300 Bq/m^3 (Lecomte *et, al* 2014; UNSC, 2019).

3.2 Assessments of the health risk

Radon is one of the most dangerous gases and the second most important cause of lung cancer. There is higher probability of Radon to cause cancer in people that inhaled ^{222}Rn progeny or those that smoked in life. Thus, ^{222} Rn may be the primary cause of lung cancer among people who have never smoked. Most of the radon-induced lunge cancers are caused by low or moderate radon concentrations; however, there is no known threshold concentration of radon below which radon exposure may not be risky. Epidemiological studies confirm that indoor radon increases the risk of lung cancer in the population, nevertheless; the proportion of all lung cancers linked to radon is estimated to lie between 3% and 14%, this depends on the average radon concentration from the locations of study (ICRP, 1993).

In this work exposure to 222Rn progeny and excess lifetime cancer risk have been estimated in different floors of an administrative offices made up of five different floors. Some of the parameters used in assessing the health risk of radon progeny are exposure to radon progeny (E_{rp}), estimation of excess lifetime cancer risk (***ELCR***); estimation of the potential lung cancer risk (***EPLC***), annual effective dose due to radon (***AEDR***) and annual equivalent dose for lung (***AEqD***). As shown in table 2 below, the exposure to radon progeny is measured in working level month (WLM) per year. The mean of the E_{rp} in GFL is 1.811 WLM/y, the maximum and the minimum values are 2.391 WLM/y and 1.408 WLM/y respectively, The E_{rp} value decreases as the level of the office increases upward hence the lowest values where obtained in the offices at LFL that is the mean, maximum and minimum values are 0.781 WLM/y, 0.974 WLM/y and 0.599 WLM/y respectively.

Table 2: 222Rn progeny inhalation exposure [WLM/y] and mean, maximum, and 95th percentile values of ELCR

Sampling offices	E_{rp} (WLM/y)			ELCR		
	Mean	**Max,**	Min	Mean	**Max,**	Min
GFL	1.811	**2.391**,	1.408	0.049	**0.066**,	0.039
FFL	1.535	**2.048**,	1.047	0.042	**0.056**,	0.028
SFL	1.265	**1.582**,	0.975	0.035	**0.044**,	0.027
TFL	0.994	**1.291**,	0.778	0.027	**0.036**,	0.021
LFL	0.781	**0.974,**	0.599	0.022	**0.026**,	0.016

Excess lung cancer risk has been estimated for each offices per floor level, thus the maximum and minimum values in each of these floor levels are as shown in the table 2 above. Here the highest value of ELCR is obtained from the GFL and the lowest from the LFL. ELCR mean values are in the order of GFL > FFL > SFL > TFL > LFL. In addition to the above parameters, the AEqD and AEDR were computed, thus the maximum, mean and 95th percentile for each floor is as shown in table 3 below. GFL and LFL have the highest and lowest mean values of the AEqD in mSv/yr and the 95th percentile is in that order too as indicated in table 2 below.

Table 3: 222Rn inhalation annual equivalent dose to lung and the annual effective dose, mean, maximum, and 95th percentile.

Sampling offices	AEqD (mSv/yr) x 10^{-3}			AEDR (mSv/yr) x 10^{-3}		
	Mean	Max	95th Percentile	Mean	Max	95th Percentile
GFL	5.626	7.423	7.158	2.344	3.093	2.982
FFL	4.767	6.357	6.229	1.986	2.649	2.595
SFL	3.926	4.914	4.824	1.636	2.047	2.010
TFL	3.085	4.011	3.826	1.285	1.671	1.594
LFL	2.424	3.026	2.948	1.010	1.261	1.228

The maximum values of the AEqD as obtained in this work decreases as the floors increase upward, this is an indication that those with offices in GFL are more exposed to 222Rn progeny than those on the upper floors of the offices. The mean of the AEDR in mSv/yr is highest in GFL this value is 2.344 x 10^{-3} mSv/yr and its lowest at the LFL with the value of 1.010 x 10^{-3} mSv/yr this implies that those with offices at LFL annually are exposed to lesser ^{222}Rn progeny than those at the GFL. The reason may be the fact that at higher levels, most of the alpha radiation has diffused or interact with the air and since windows were always opened for fresh air on the daily bases as compared to the ground level floor that the offices were always closed mostly all the time. The indoor annual effective dose fluctuates between the ground floor and the first floor with higher annual effective dose from the ground level.

The 95th of the AEDR decreases as the level of the floor increases upward, hence office workers at lower level floor are more exposed.

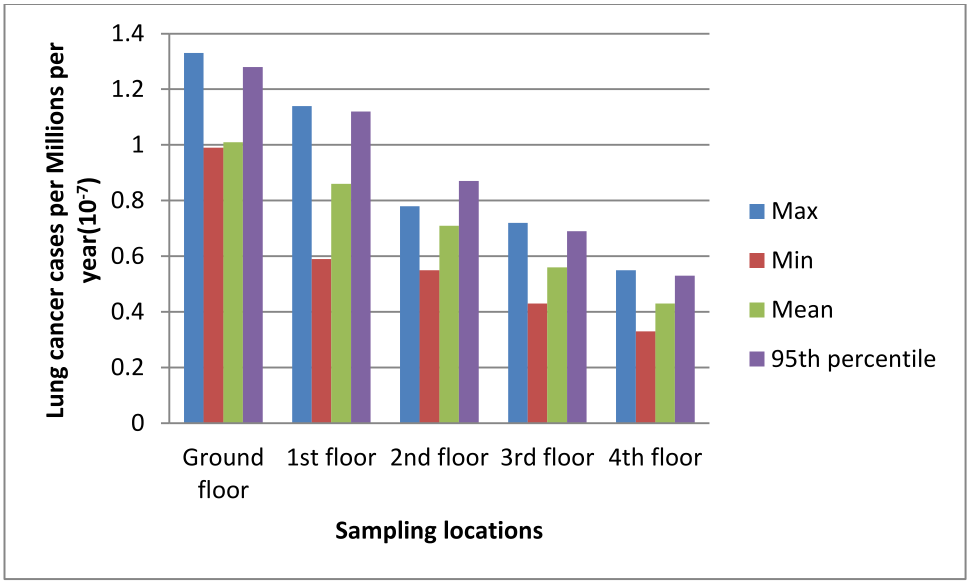

Figure 2: Lung cancer cases per millions per year

In this study, lung cancer cases per millions in a year due to 222Rn exposure in the offices have been estimated (see figure 2 above) in each floor GFL, the mean, maximum and the 95th percentile values are 10.13, 13.36 and 12.88 per million people respectively. The mean, maximum and the 95th percentile per million people values obtained from FFL and SFL are 85.81, 11.44, 11.21 and 70.68, 88.45 then 86.84 respectively. From TFL and LFL, due to the exposure of 222Rn; the mean, maximum and the 95th percentile obtained are 55.54, 72.21 and 68.87, then 43.64, 54.48 and 53.07 respectively.

4. Conclusion

This study has measured ^{222}Rn concentration in the offices and estimates the dose and the associated health risk on exposure to 222Rn in the offices. The overall 222Rn mean concentration level from the building studied is about 19.38% greater than the mean concentration of 222Rn was near the US EPA guidelines (148 Bq/m3). The highest concentration that was obtained from the GFL is about 300% higher than that of the US EPA guidelines' value. The lowest concentration of 222Rn obtained is from LFL and this is about 0.9% less than the US EPA guidelines' value. This is an indication that the lower-level offices in GFL have more of 222Rn progeny than the upper levels. The mean, maximum and the 95th percentile of the annual effective dose and annual equivalent dose to lung have been evaluated and these values were lower than the public limit of $1mSvy^{-1}$ as recommended by ICRP, so also; these findings show a significant correlation between indoor radon effective doses obtained by other studies elsewhere. In addition, the estimated mean, maximum, and 95th percentile of lung cancer cases per millions per year was below the range of 170–230 per million populations recommended by the ICRP. Hence, long-term exposure to 222Rn and its progeny may not pose a significant threat to the workers.

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Conflict of Interest

There is no known conflict of interest in this research work. The research work is purely academic for better scientific information within the scientific community and the society at large.

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