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Evaluation of Cancer Risks Associated with Radon Concentration Measured in the Science Faculty Building Complex Basement of a Tertiary Institution in South West, Nigeria

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ABSTRACT: In this study, radon concentration was measured with an active detector (RAD 7) in the Science Faculty building complex basement of a tertiary institution in South West (SW), Nigeria. The attendant risk descriptors were determined with the help of mathematical models. The range of mean detectable radon concentration in the basement is 26.5 ±12.3 – 242 ± 50.7 Bq m^{-3} and the mean for all the rooms examined is 61.74 ± 58.48 Bq m^{-3}. The overall mean is less than the global mean of 100 Bq m^{-3}. The mean annual dose rate is found to be 0.97 ± 0.92 mSv y^{-1}. The mean annual effective doses for different subjects examined are 0.412 ± 0.391 mSv y^{-1} (worker), 0.0221 ± 0.0209 mSv y^{-1} (student in lab session), 0.515 ± 0.488 mSv y^{-1} (student who lives in the hostel) and 2.149 ± 2.036 mSv y^{-1} (home owner). Students and workers in the basement are not likely to develop serious health effects, however, if the basement is used as a living room, the radon concentration in Room I-R might lead to health effects. The range of calculated excess life cancer risks (ELCRs) are (0.64-5.82) x 10^{-3} and (1.16 -10.58) x 10^{-3} for student and homeowner respectively. The mean values for the two subjects examined fall below the maximum risk of 3.5 x 10^{-3}.

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Radon is a radioactive gas and the second leading agent that promotes lung cancer after tobacco. It is one of the noble gases which occurs naturally in the soil and rocks. It emanates from the decay of uranium and thorium which occurs naturally in soils and rocks (Chen *et al.,* 2012) and contributes to human exposures from natural radiation sources (UNSCEAR, 2000, UNSCEAR, 2006). The distribution of radon varies from one location to another. Radon is found in caves, crevices of rocks, household water and essentially in the basement of an apartment. Radon flows from soil into outdoor and indoor air due to the movement of gases in the soil (Feheem *et al.,* 2008). Since radon is a gas, its concentration outdoor can be very low because of ventilation and air speed. The nature of house construction related factors and heating affect indoor radon concentration (Murphy and Organo, 2008). Since ^{238}U is ubiquitously distributed elements within the earth's crust, radon concentration is primarily dependent on the quality of uranium and radium in the soil and rocks. It has been observed that the underground places such as basement, mines, recreational caves and waterworks [municipal dams] are radon-prone areas (Amin *et al.,* 2008). Earlier reports of regulatory bodies have shown that radon doses received by underground workers, and recreational cave workers usually exceed the action level for work places (Papachristodoulou, *et al.,* 2004) Variability in radon concentration has been observed during the measurement of radon levels in houses beside each other (Murphy and Organo, 2008). Underground mines such as uranium mines are found to contain elevated radon concentration (BEIR VI, 1999) and studies have shown that miners exposed to

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radon are more prone to lung cancer. There two isotopes of radon, these are ^{222}Ra and ^{220}Ra (known as thoron). Aside, radon with half-life of 3.8 days decays into a series of short lived progeny (^{218}Po, ^{214}Po, ^{214}Bi), and these progeny could be inhaled into the human and animal respiratory tracks leading to internal exposure (Guo *et al.*, 2012). Two of the alpha emitting decay products, namely ^{218}Po, ^{214}Po, deliver the majority of the radiogenic dose to the lungs (pulmonary epithelium) and have been identified as the primary cause of radon-induced lung cancer (EPA, 2016; NRC, 1999; Field, 2018). Alpha particle is massive and causes a great lot of ionization when it gets into contact with a body or ingested, and causes single strand and double strand DNA breaks. In addition to this, it causes indirect genotoxic and nongenotoxic effects on cells, which can lead to malignancy (NRC, 1999; WHO, 2018; CRCPD, 2018).

The level of awareness of the presence and effect of radon in Nigeria is still very low especially among the major part of the population. The little awareness is essentially found among scientists. Certain measurements have been carried out in the country with both active and passive dosimeters in the southwestern part of the country. Some of the work done include: Obed *et al.,* 2012; Ademola *et al.,* 2015; Ademola and Oyeleke, 2017; Ademola and Ojeniran, 2017; Usikalu *et al.*, 2017; Usikalu *et al.*, 2018; Usikalu *et al.*, 2020. The objective of this study is to evaluate the cancer risks associated with radon concentration in the science faculty building complex basement of a tertiary institution in South West, Nigeria.

MATERIALS AND METHODS

Calibrated portable active detector continuous radon monitor (RAD 7) was used to measure radon in the basement. A personal computer (PC) Software (CAPTURE) allows a graphic presentation and calculation of the average concentration in the measured period (Usikalu *et al.*, 2018).

The RAD7 continually measures radon and thoron concentration, showing both on a spectrum printout, and also functions as a sniffer with audible count signal to locate radon entry points. The unit features the fastest response and recovery time of any system on the market, and is able to measure radon concentrations at the 200 Bqm^{-3} action level (UK and EU new buildings) in less than 1hour with 10% standard deviation.

Prior to the measurement, doors and window were locked to allow buildup of radon. The rooms were coded as follows: A-PW (Physics Workshop), B-GW (Geology workshop), C-B3 (Lecture Room B3), D-B7 (Lecture room B7), E-FR (Furnace Room), F-SR1 (Store 1), G-SR2 (Store Room 2), H-CR (Staff Common Room and Canteen), I-R (Inner Room Under the Lecture Theater), J-FO (Staff Office A), K-TO (Staff Office B), L-F10 (other office 1), M-SO (other room 2), N-NO (other room 3), O-EO (other room 4). The door and window of the classroom monitored were locked up for a period of twenty four (24) hours before the measurement was done. To prevent intrusion into the rooms, labels indicating restriction were placed on the doors. The detector, RAD 7 was purged for five minutes before the measurement started. RAD 7 was set up in each room in AUTO mode for measurement, and this ran for a period of forty (40) minutes in each room.

Radon concentration (Bq m^{-3}) for each room was measured. Annual absorbed dose rate, D (mSv y^{-1}) was calculated from the measured radon concentration with the aid of equations (1).

$$D(AB) = K_{Rn}\, Dc_f\, F_{eq}\, O_f\, T_{Th} \qquad (1)$$

Where $D(AB)$ is the annual absorbed dose in mSv y^{-1}, K_{Rn} is the radon concentration (Bq m^{-3}); D_{cf} is the dose conversion factor (9.0 x 10^{-6} mSv h^{-1} per Bq m^{-3}); F_{eq} is equilibrium factor (0.5 was used) (Qureshi *et al*., 2000); T_{Th} = number of hours per year (8760 h if the basement is considered as living room); O_f is the occupancy factor (0.4).

An attempt to obtain the mean annual effective doses to both workers (Technologists) and students (both in practical class and hostel), it is reckoned that Technologist whose office is located at the basement spends seven (7) hours per day (excluding lunch time). This is equivalent to 35 hours per week. He takes a four-week vacation per year, and this result in 48 weeks per annum and 1680 hours per year. It is assumed that the basement is used for practical class or workshop (Geology and Physics labs) purpose and each student takes a one (1) unit practical class, which lasts for three hours per week (for each session), and the semester runs for fifteen (15) weeks. This implies that, each student spends 45 hours per semester in each workshop laboratory at the basement. Two such practical courses per session (per year when students are in the hall of residence) results in 90 hours of practical sessions. Since female and male hostels are 80 m and 100 m respectively from the basement (and with similar basement as hostel), an attempt was made to estimate the annual effective dose received by either male or female student if uniform radon distribution was assumed. Each student spends most part of the day time outdoor (classroom, laboratory, library, canteen, sport field), however, he spends the night time in the hostel, and this lasts for 10 hours (9:00 pm to 7:00 am) per day. This is 2100 hours per session (two semesters of 15 weeks each).

The cumulative radon exposures were obtained in working level month (WLM). This was developed for miner-based radon studies (Field *et al.,* 2018), and adapted to study radon in a basement (underground rooms) in this work. A working level is defined as any combination of the short-lived progeny of radon in 1 liter of air, under ambient temperature and pressure, that results in the ultimate emission of 13 x 10^5 MeV. One WL is equivalent 100 pCi/l (3700 Bq m^{-3}) of radon short-lived decay product on equilibrium. A WLM is a cumulative exposure equivalent to one WL for a working month (170 h) (Barros *et al.*, 2016).
These information were used with equation (2) (Qureshi *et al.*, 2000 and Amin *et al.*, 2008) to calculate annual working level month (A_{WLM}).

$$A_{WLM} = \frac{1\,Bqm^{-3}\ x\ F_{eq}\ x\ t_y}{3700\,Bqm^{-3}\ per\ WL\ x\ 170\ h\ per\ WM} \quad (2)$$

Where $1\,Bqm^{-3}$ is the unit radon concentration measured, F_{eq} is the equilibrium factor, and t_y is the time spent in the room over a year. An equilibrium factor of 0.5 (Qureshi *et al.,* 2000) was used in the calculation. To determine the annual effective dose from WLM y^{-1} to effective dose (mSv) by assuming 5 mSv/yr. The annual mean effective dose rate (nSv y^{-1}) was obtained by using the expression found in UNSCEAR (2000) and Maheso, (2021).

Where dose conversion factor used is $D_{cf} = 9$ nSv per Bqm^{-3} h^{-1}, O_f is taken in this study as 0.4 (and it is determined to be 0.22 for universities (Khali *et al.*, 2019)).

To determine the excess lifetime risk (R_{exc}), equation (3) was used with the mean annual effective doses (nSv y^{-1}) calculated. This is the estimate of the probability of developing lung cancer as a result of radon exposures over the mean lifetime of exposed population (Maheso, 2021).

$$R_{exc} = E(nSvy^{-1})\ x\ D_L(y)\ x\ R_f(Sv^{-1}) \quad (3)$$

Where $D_L(y)$ is the life expectancy of the exposed population (Nigeria-55.44 y (Macrotrends, 2022), R_f =0.05 Sv^{-1} for fatal risk factor (ICRP, 2008).

RESULTS AND DISCUSSION

Results of the radon concentration measured in the basement of a tertiary institution faculty complex are presented in Table 1. This show that radon concentration ranged between 26.5 ± 12.3 Bq m^{-3} (Room G-SR2) and 242.0 ± 50.7 Bq m^{-3} (Room I-R). The value recorded in Room D-B7 indicates that the radon present in the room is below the detectable value. Room D-B7 is the largest in the basement and it has three doors and several louvered-windows and effective cross ventilation. Many of the windows on the right hand side lead to open quadrangle, while others on the left side lead to an open field without any building behind it. The mean value of the radon concentration measured in this study is 61.74 ± 58.48 Bq m^{-3}. The mean value recorded in this study is lower than the mean value measured in Southern Italy underground rooms (mean of 165 ± 133) Bq m^{-3} (Quarto *et al.,* 2013), and it is lower than the global recommended limit of 100 Bq m^{-3} (Amin *et al.,* 2015). The apparently elevated radon concentrations in Room H-CR (131.7 ± 23.7) and Room I-R (242.0 ± 50.7) could be attributed to the fact that they have few windows and are located under the main University Auditorium. Room I-R serves as store while Room H-CR serves as canteen where staff could relax. Room H-CR has few window and adjacent to Room I-R.

Table 1: Radon concentration (Bqm^{-3}) in different rooms of the basement

Room code	Rn - 222 concentration (Bqm^{-3})		
	Min	Max	Mean
A-PW	17.4	52.2	35.1 ± 25.5
B-GW	17.6	52.6	35.4 ± 20.8
C-B3	17.4	35.1	29.3 ± 10.3
D-B7	0.00*	0.00	0.00*
E-FR	17.8	70.0	44.1 ± 22.7
F-SR1	18.0	42.9	32.1 ± 12.7
G-SR2	17.8	35.2	26.5 ± 12.3
H-CR	106.0	160.0	131.7 ± 23.7
I- R	211.0	317.0	242.0 ± 50.7
J-FO	17.4	70.0	54.3 ± 25.7
K-TO	--	--	35.2
L-F10	52.8	70.0	61.8 ± 33.8
M-SO	17.6	52.6	35.1± 17.5
N-NO	52.8	80.0	66.4 ± 19..2
O-EO	--	--	35.4 ± 24.8
Range			±123- 242 ± 50.7
Mean			61.74 ± 58.48

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Figure 1 is the annual absorbed dose rate calculated for different rooms examined. It is evident that results of several rooms such as A-PW, C-B3, F-SR1, K-TO, M-So and O-EO are comparable. However, H-CR and I-R are relatively higher than other rooms. The highest annual absorbed dose rate is found in I-R with a mean value of 3.82 mSvy^{-1}. This is followed by the dose recorded in H-CR with a mean value of 2.08 mSv y^{-1}. The range of mean absorbed dose rate is 0.41 - 3.82 mSv y^{-1}. The mean absorbed dose rate for the basement is 0.97 ± 0.92 mSv y^{-1}.

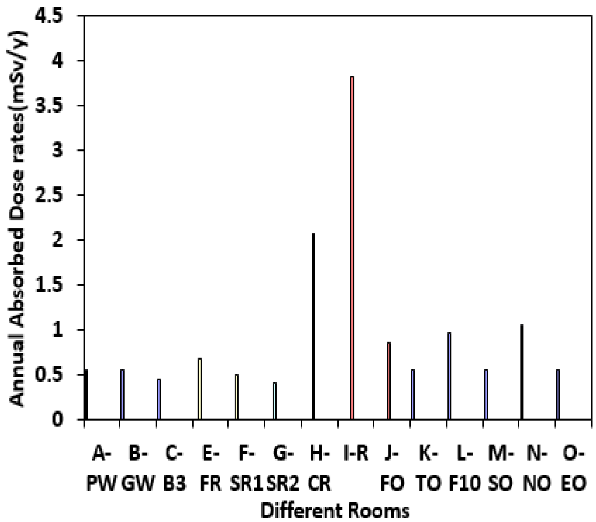

Fig 1: Annual Absorbed Dose Rates for Different Rooms

Table 2: Calculated annual working level month (WLM) for four subjects

Subject	Occupancy Period	A_{WLM} (WLM y^{-1}) 10^{-3}
Technologist (Worker)	1680	1.335
Student (Practical Session)	90	0.0715
Student (Hostel)	2100	1.669
Public (Home owner)	8760	6.963

Table 2 shows the calculated annual working level month for a worker (1.335 x 10^{-3} WLM y^{-1}), student (during lab session-0.0715 WLM y^{-1}), student (1.669 x 10^{-3} WLM y^{-1} who lived in the hostel within the campus), and the public (6.963 x 10^{-3} WLM y^{-1}-home owner- it is assumed that the basement in a living home). The total WLM y^{-1} for a student who attended a lab session and lives in the hostel is 1.7405 x 10^{-3} WLM.

The result in Table 3 shows the estimate of annual effective doses in different rooms for different subjects. This indicates that the range of annual effective dose and mean for worker (Technologist), student (lab session), student (hostel) and home owner are 0.177 – 1.616 (0.412 ± 0.391) mSv y^{-1}, 0.0095 – 0.087 (0.0221 ± 0.0209) mSv y^{-1}, 0.221 – 2.019 (0.515 ± 0.488) mSv y^{-1}, and 0.922 – 8.426 (2.149 ± 2.036) mSv y^{-1} respectively. The mean values of effective doses shown in column 2 (worker), column 3 (student-lab session) and column 4 (student – in hostel) as seen in Table 3, indicate that annual effective doses fall below the recommended value of 1 mSv y^{-1}. However column 6 with the mean value of 2.14 ± 2.036 mSv y^{-1} is higher by at least a factor of 2.0 units than the recommended limit of 1 mSv y^{-1}, the world average value for normal background radiation. Students and workers found at the basement may not be prone to danger of serious health effects.

However, if the basement is considered as a living room, the investigation shows that it can lead to health effects. It is essential that more cross -ventilation be allowed through the creation of more windows and free flow of air in the basement. Table 4 is a comparison of annual effective dose in various countries with the present study. The table shows that the mean value of the measured mean annual effective dose obtained from this study to workers (0.412 mSv y^{-1}) is relatively lower than the values of annual effective dose measured in Paskitan, Egypt, Australia, Southern Italy, UK and India. This study has shown that the effective dose to student during lab session (0.221 mSv y^{-1}) is less than the value measured (0.37 mSv y^{-1}) in Pakistani rural schools

Table 3: Estimate of Annual effective doses in different rooms and for different subjects

Room	Annual effective dose (mSvy-1) for Technologist (Worker)	Annual effective dose (mSvy-1) for Student (practical sessions)	Annual effective dose (mSvy-1) for Students in the hostel	Total annual effective dose (mSvy-1) for student (Practical and hostel)	Annual effective dose (mSvy-1) for Home owner
A-PW	0.234	0.0216	0.293	0.306	1.222
B-GW	0.236	0.0217	0.295	0.308	1.233
C-B3	0.196	0.0105	0.245	0.256	1.020
E-FR	0.294	0.0158	0.368	0.379	1.535
F-SR1	0.214	0.0115	0.268	0.280	1.118
G-SR2	0.177	0.0095	0.221	0.231	0.922
H-CR	0.879	0.0471	1.099	1.146	4.585
I-R	1.616	0.087	2.019	2.106	8.426
J-FO	0.363	0.0194	0.453	0.472	1.891
K-TO	0.234	0.0126	0.294	0.306	1.226
L-F10	0.413	0.0221	0.516	0.538	2.152
M-SO	0.234	0.0126	0.293	0.306	1.226
N-NO	0.443	0.0237	0.554	0.578	2.312
O-EO	0.236	0.0127	0.295	0.308	1.233
Mean (SD)	0.412 (0.391)	0.0221 (0.0209)	0.515 (0.488)	0.537 (0.509)	2.149 (2.036)

SD = Standard Deviation

Table 4: Comparison of annual effective doses in various countries with this study

Country (Location of study)	**Min. Annual Effective dose ($mSv\ y^{-1}$)**	**Max. Annual Effective dose ($mSv\ y^{-1}$)**	**Mean Annual effective dose ($mSv\ y^{-1}$)**
This study(Worker)	0.177	1.61	0.41
This study Student (Lab session)	0.0094	0.087	0.221
This study (Hostel)	0.221	2.019	0.52
Pakistan(coal mine)[(a)]	1.38	4.67	2.19
Pakistan (workplace)[(b)]	2.22	17.44	8.68
Pakistan (school)[(c)]	--	--	0.37 (rural school) 0.44 (urban)
Egypt (Cave) [(d)]	--	--	1.98 (worker)/ 12 µSv (visitor)
Australia[(e)]			0.50
Italy South (House)[(f)]	--	--	2.40
UK[(g)]	--	--	2.20 (Highest)
India (Cave)[(h)]	1.95	3.32	2.45
Poland[(i)]	--	--	0.35

[a] Qureshi et al. (2000), [b] Matiullah et al. (2012), [c]Rahman et al. (2009), [d] Amin et al. (2008), [e] Langroo et al. (1991) , [f] Quarto et al. (2013) [g] Madden et al. (1994), [h] Duggal et al. (2014) [i] Bem et al. (2013).

Table 5: Minimum, maximum and mean excess lifetime risk for indoor radon exposures in a home and university campus basement

Place	Excess life cancer risk ($x10^{-3}$)		
	Min. ($x10^{-3}$)	Max. ($x10^{-3}$)	Mean ($x10^{-3}$)
University(Campus)	0.64	5.82	1.48 ± 1.41
Home	1.16	10.58	2.69 ± 2.56

Results of minimum, maximum and mean excess lifetime risks (ELCRs) resulting from radon measurement in the basement (underground rooms) are shown in Table 5. This calculation is based on the life expectancy of 55.44 y in Nigeria. The range and the mean for student are (0.64 -5.82) x 10^{-3} and (1.48 ± 1.41) x 10^{-3} respectively. The range of risk for lung cancer for a homeowner if the basement is considered as the home of an individual is (1.16 -10.58) x 10^{-3} and the mean is (2.69 ± 2.56) x 10^{-3}. Results of calculated mean risk for student and homeowner fall below the maximum risk of 3.5 x 10^{-3} that yields the annual effective dose of 1 $mSvy^{-1}$ (Maheso, 2021). This does not mean that there is a safe level of radon in a building. It is essential to note that risk due to radon is one out of many sources of risk to the population. Others might arise from activity concentration of radionuclides (^{238}U, ^{232}Th ^{40}K), radiological examinations (one of the major sources of population dose) and other carcinogens in the environment.

Conclusion: This study examined the radon concentration in the basement of a tertiary institution faculty complex in the SW, Nigeria. The mean activity concentration for all the rooms examined is less than the global mean of 100 Bq kg^{-3}. The elevated value of the concentration is as result of the nature of the room and inadequate ventilation. The study indicates that the mean annual effective doses and the probability of incurring lung cancer (ELCR) are less than the recommended limits for all subjects examined. This is an indication that the subjects are not prone to health risks.

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