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Assessment of Occupational Radon Exposure and Associated Health Risks in Campus Facilities at Adamawa State College of Education, Hong, Nigeria

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Abstract

This study evaluates the radon (Rn-222) concentration and associated health risks in the Campus facilities at Adamawa State College of Education, Hong, Nigeria. Radon concentrations were measured in 20 locations, including offices, laboratories, and residential quarters, using active radon monitoring devices (RAD7). The results revealed radon concentrations ranging from 8.6 Bq/m³ at the Deputy Provost's office to 53.1 Bq/m³ at the Geography Departmental office, with a mean concentration of 20.3 Bq/m³. The effective dose rate (ER) ranged from 0.005 WLM/y to 0.031 WLM/y, while the annual effective dose (Dy) varied between 0.1248 mSv/y and 0.7703 mSv/y. The excess lifetime cancer risk (ELCR) ranged from 0.0176% to 0.1086%, with the Geography Departmental office having the highest risk. Inhalation exposure (E_{inh}) and lifetime cancer cases (LCC) were also calculated, with values ranging from 0.2994 mSv/y to 1.8487 mSv/y and 5.39×10^{-6} to 3.33×10^{-5}, respectively. Radon concentrations, ELCR and D_y in most offices and staff quarters are within the World Health Organization (WHO) reference level of 100 Bq/m³ and the International Commission on Radiological Protection (ICRP) action level of 300 Bq/m³, 1.3% and 3 to 10 mSvy^{-1} for workplaces. However, the Geography Departmental office slightly exceeds the WHO reference level, warranting mitigation measures to ensure a safe working environment for staff and occupants.

Keywords: Radon; Exposure; Excess Lifetime Cancer Risk; Inhalation.

I. INTRODUCTION

Radon, which is found in rocks and soils, is a radioactive gas that has no smell, colour or taste, and it's produced from the natural radioactive decay of Uranium. It is also present in water, and escapes from the ground into the air, where it decays and produces further radioactive particles. As we breathe, these particles are deposited on the cells lining the airways, where they can damage deoxyribonucleic acid (DNA) and potentially cause lung cancer [1].

Radon is present in all terrestrial environments in varying quantities in three isotopes: ^{219}Rn, ^{220}Rn, and ^{222}Rn. Out of the various isotopes, the isotopes practically significant to the inhalation radiation dose are ^{222}Rn and ^{220}Rn, called radon and thoron. ^{222}Rn is more abundant, has a half-life of 3.8 days and comes from the decay of ^{226}Ra, while ^{220}Rn has a very short half-life of 55.6 s and comes from the decay of ^{224}Ra [2]. This isotope, produced by ^{226}Ra, belongs to the natural decay chains of ^{238}U, which is one of the main constituents of the Earth's crust [3 - 4]. Radon is carcinogenic and is found in some of the food we eat, most of the water we drink, and the air we inhale [5]. Radon gas is inert and disperses quickly when exposed to open air. Typically, the average radon concentration in outdoor air is around 10 Bq m^{-3}, although it is as low as 1 Bq m^{-3} in some places and higher than 100 Bq m^{-3} in others [6]. Radon contributes almost 50% of the overall highly effective annual dose to the population received from all sources of natural radioactivity. The harmful effects of radon have been proven in many epidemiological studies [7]. The radon problem got more space and importance at the latest recommendations of the International Atomic Energy Agency (IAEA) and Directive European Council Directive (EC) relating to the field of radiation protection [8 - 9]. The WHO identified radon as the second biggest cause of lung cancer [10]. Radon progenies are attached to the aerosol particles from the air, and such radioactive particles enter the body through inhalation. These radioactive aerosols deposited in the lungs emit alpha radiation. Protection of the health of workers against dangers arising from ionizing radiation is explicitly mentioned in Articles 2 and 30 of the Euratom Treaty [11], recognizing the importance of occupational radiation protection as a priority objective. Indoor radon levels can, however, also originate from water usage, outdoor air infiltration, and the presence of building materials containing radium [12]. When radon is inhaled for a long time, it gets into the lining of your lungs and gives off radiation. Over a long time, that can damage the cells there and lead to lung cancer [10]. The signs of radon poisoning manifest in several ways, such as persistent cough, hoarseness, wheezing, shortness of breath, coughing up blood, chest pain, frequent infections like bronchitis and pneumonia, and loss of appetite, among others [13]. Radon levels can vary widely from one office/home to another, even on the same street. With no smell, no colour, and no taste, the only way to know how much radon is in our office/home is to test it.

This study, therefore, sets out to measure radon levels in offices and staff quarters at Adamawa State College of Education, Hong Campus, to evaluate the various radiological risks associated with occupational exposure to radon isotopes.

II. MATERIALS AND METHODS

A. Study Area

Adamawa State College of Education is in Hong Local Government Area, Adamawa State, Northeastern Nigeria. Hong Settlement lies between longitude 12°50′E to13°00′E and latitude 10°05′N to 10°22′N. The area covers about 60 km^2 and is accessible through major and minor roads within the Adamawa highlands. The geological mapping undertaken in the study area revealed that the local geology comprises migmatites and porphyritic granite of Pan African age. The migmatites are composed of weak bands of fine-grained rocks with granitic composition, cut by numerous pegmatites and aplitic veins. The porphyritic granite forms an elongated dome to a sub-dome cluster of inselbergs. Field observation on the migmatitic and granitic outcrops shows moderate weathering and structural elements such as joints and faults [14].

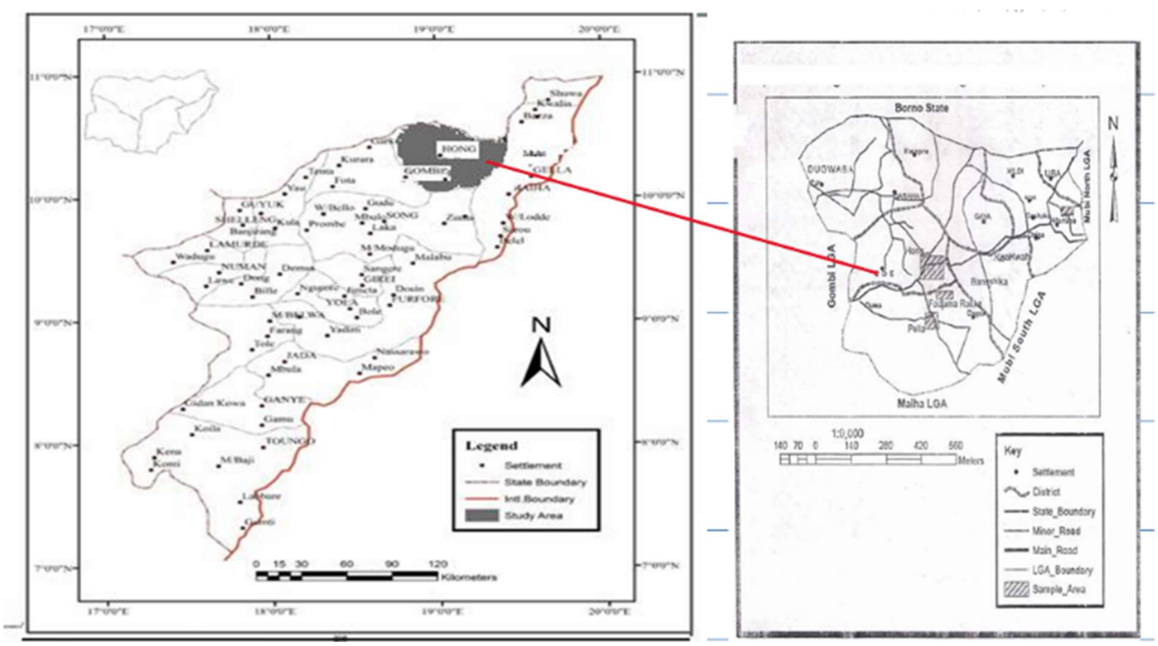

Fig. 1. Map of Adamawa State showing the Study Area modified from [14].

B. Materials

The study utilized DURRIDGE RAD7 (MA 01821/3332) and its accessories, the global positioning system, and version 6.2.5 capture software installed on a laptop.

C. Methods

1) Simultaneous Measurement of Radon and Thoron using RAD7

Radon and thoron levels in campus facilities of the Adamawa State College of Education were measured using active methods, i.e. RAD7 for short-term measurements to account for inhalation dose and diurnal variation. The RAD7 is a versatile, comprehensive device used to assess radon and thoron concentration instantaneously indoors and outdoors from the ambience air. It is a solid-state semiconductor detector-based device in which the detection limit of radon and thoron is between 4 and 400,000 Bq m^{-3}. Since RAD7 is a humidity-sensitive device, $KMnO_4$ is used as a desiccant. The diurnal variation of indoor radon and thoron concentration was studied using RAD7, manufactured by DURRIDGE Company, USA [15]. The measurements were carried out from office complexes and staff quarters of the study area for a day (24 hours) within a thirty-minute interval. The measurement setup is depicted in Fig. 2.

The RAD7 's internal sample cell is a 0.7-litre hemisphere, coated on the inside with an electrical conductor. A solid-state, Ion-implanted, Planar, Silicon alpha detector is at the centre of the hemisphere. The high voltage power circuit charges the inside conductor to a potential of 2000 to 2500 V, relative to the detector, creating an electric field throughout the volume of the cell. The electric field propels positively charged particles onto the detector. A radon-222 nucleus that decays within the cell leaves its transformed nucleus, polonium-218, as a positively charged ion. The electric field within the cell drives this positively charged ion to the detector, to which it sticks. When the short-lived polonium-218 nucleus decays upon the detector's active surface, its alpha particle has a 50% probability of entering the detector and producing an electrical signal proportional in strength to the energy of the alpha particle. Subsequent decays of the same nucleus produce beta particles, which are not detected, or alpha particles of different energies. Different isotopes have different alpha energies and produce different strength signals in the detector. The RAD7 amplifies, filters, and sorts the signals according to their strength. In SNIFF mode, the RAD7 uses only the polonium-218 signal to determine radon concentration, and the polonium-216 signal to determine thoron concentration, ignoring the subsequent and longer-lived radon daughters. In this way, RAD7 achieves a fast response to changes in radon concentration and fast recovery from high concentrations [15].

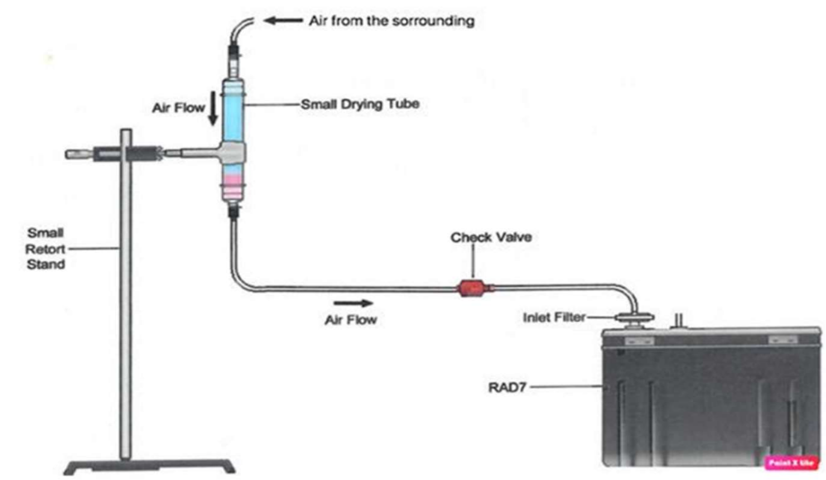

Fig. 2. Setup for Radon Measurement in Air [15].

2) Health Risk Evaluation

ELCR indicates the probability of cancer risk higher than the natural or background risk due to lifetime exposure to a carcinogenic agent [16 - 17]. Working Level (WL) points to the concentration of the potential alpha energy of short-lived radon progeny. One WL equals 3700 Bq/m^3 (100 pCi/L) in the air or 2.08×10^{-5} J/m^3 (1.3×10^8 MeV/m^3). Working Level Month (WLM) is a unit to describe the cumulative human exposure due to the inhalation of short-lived radon progeny. WLM is commonly used in occupational exposure assessment for radon. Consequently, WLM represents an exposure of 1 WL for 170 h. Exposure to 1 Bq/m^3 of radon per year equals 4.4×10^{-3} WLM at home and 1.26×10^{-3} WLM at work by assuming 7000 h/year indoors or 2000 h/year at work and an equilibrium factor of 0.4 [18 - 20].

i. Exposure to Radon Progeny ER (WLM/y)

Exposure to ^{222}Rn progeny was calculated based on the measured radon concentration using the United States

Environmental Protection Agency (USEPA) method as given by (1).

$$E_R = C_R \times F \times n \times (2.7 \times 10^{-4}) \times 8760/170 \quad (1)$$

Where E_R is the exposure to radon progeny in WLM/y; C_R is the radon concentration measured in Bq/m^3; 2.7×10^{-4} (1/3700 Bq/m^3) is the constant to convert radon concentration to WL per Bq/m^3; F is the equilibrium factor (0.4 for indoors and 0.6 for outdoors); n is the occupancy factor; 8760 is the total hours per year, and 170 is the total working hours per month [21 - 23]. The WHO and USEPA have recommended an occupancy factor (n) of 0.7 for indoor radon exposure [18] and [24]. In the present study, by assuming 7000 h for indoors (homes) and 2000 h for workplaces, the occupancy factors (n) of 0.8 and 0.23 were determined, respectively [20].

ii. Excess Lifetime Cancer Risk (ELCR)

The Excess Lifetime Cancer Risk (ELCR) was estimated based on the computed values of ER, using 2:

$$ELCR = E_R \times F_R \times LE \quad (2)$$

Where LE is the average life expectancy, which is 70 years for Nigerians according to the WHO's report in 2015 [25]. F_R is the detriment-adjusted nominal risk coefficient. Based on the International Commission on Radiological Protection (ICRP), the F_R value is 5.0×10^{-4} WLM^{-1} [20].

2) Estimation of lung cancer risk

Equations (3) – (5) were used to estimate the number of lung cancer cases per million people per year (LCC) [26].

i. Annual effective dose of radon

The annual effective dose (Dy) due to exposure to ^{222}Rn was calculated using (3).

$$D_y = C_R \times D \times F \times n \times T \quad (3)$$

ii. Annual Equivalent Dose for Lung Cancer (AED) of Radon

$$E_{inh} = D_y \times W_R \times W_T \quad (4)$$

Where W_R is the radiation weighting factor, 20 for α particles and W_T, the tissue weighting factor, 0.12 for lungs.

iii. Lung cancer cases per million people per year (LCC)

$$LCC = E_{inh} \times 18 \times 10^{-6} \quad (5)$$

Where 18×10^{-6} is the risk factor for lung cancer induction per mSv.

III. Results and Discussion

The radon concentration in offices and staff quarters of the Adamawa State College of Education, Hong, measured between September to October 2024, is shown in Table I. The results revealed radon concentrations ranging from 8.6 Bq/m³ at the Deputy Provost's office to 53.1 Bq/m³ at the Geography Departmental office, with a mean concentration of 20.3 Bq/m³. The effective dose rate (ER) ranged from 0.005 WLM/y to 0.031 WLM/y, while the annual effective dose (Dy) varied between 0.1248 mSv/y and 0.7703 mSv/y. The excess lifetime cancer risk (ELCR) ranged from 0.0176% to 0.1086%, with the Geography Departmental office showing the highest risk. Inhalation exposure (E_{inh}) and lifetime cancer cases (LCC) were also calculated, with values ranging from 0.2994 mSv/y to 1.8487 mSv/y and 5.39×10^{-6} to 3.33×10^{-5}, respectively.

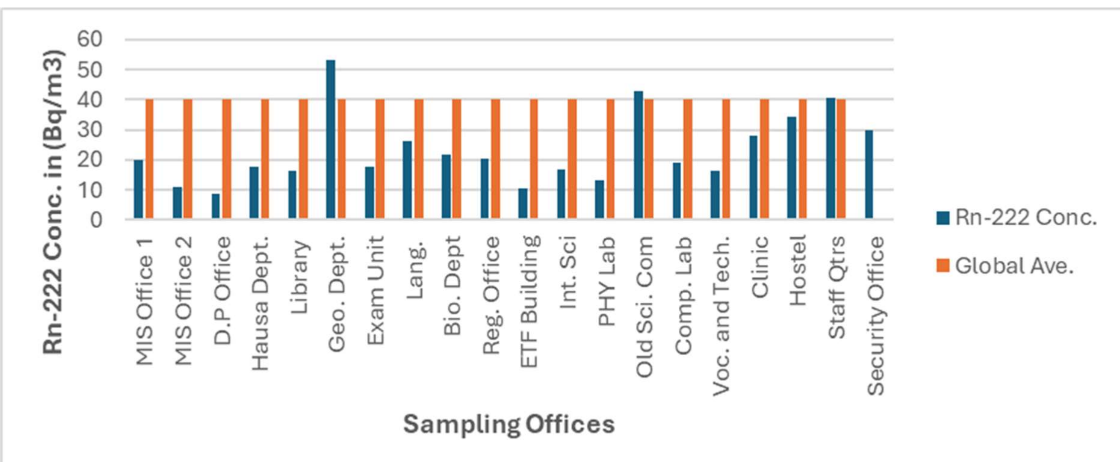

Fig. 3. Measured Radon Activity Concentration in Bqm^{-3} against sampling offices and staff quarters.

i. Radon Concentrations (Rn-222)

Fig. 3 shows the plot of measured Radon Activity Concentration against sampling offices and staff quarters. The Radon concentrations range from 8.6 Bq/m³ at the Deputy Provost's office to 53.1 Bq/m³ at the Geography Departmental office. The mean radon concentration across all locations is 20.3 Bq/m³. The International Commission on Radiological Protection (ICRP) recommends an action level of 300 Bq/m³ for radon in workplaces. Results obtained show that all locations are well below this limit. The WHO suggests a reference level of 100 Bq/m³ for indoor radon. The mean value of ^{222}Rn was found to be lower than the global average of 40 Bqm^{-3} for indoors. Only the Geography Departmental office (53.1 Bq/m³) exceeds this level, but it is still below the ICRP action level.

ii. Excess Lifetime Cancer Risk (ELCR)

The results presented in Fig. 4 showed that the ELCR ranges from 0.0176% at the Deputy Provost's office to 0.1086% at the Geography Departmental office, with the mean ELCR at 0.043%. The acceptable ELCR for occupational exposure is generally set at 1 in 1000 (0.1%) or lower. Results for all locations depicted in Table II are seen to be below this threshold, except for the Geography Departmental office (0.1086%), which slightly exceeds the acceptable limit.

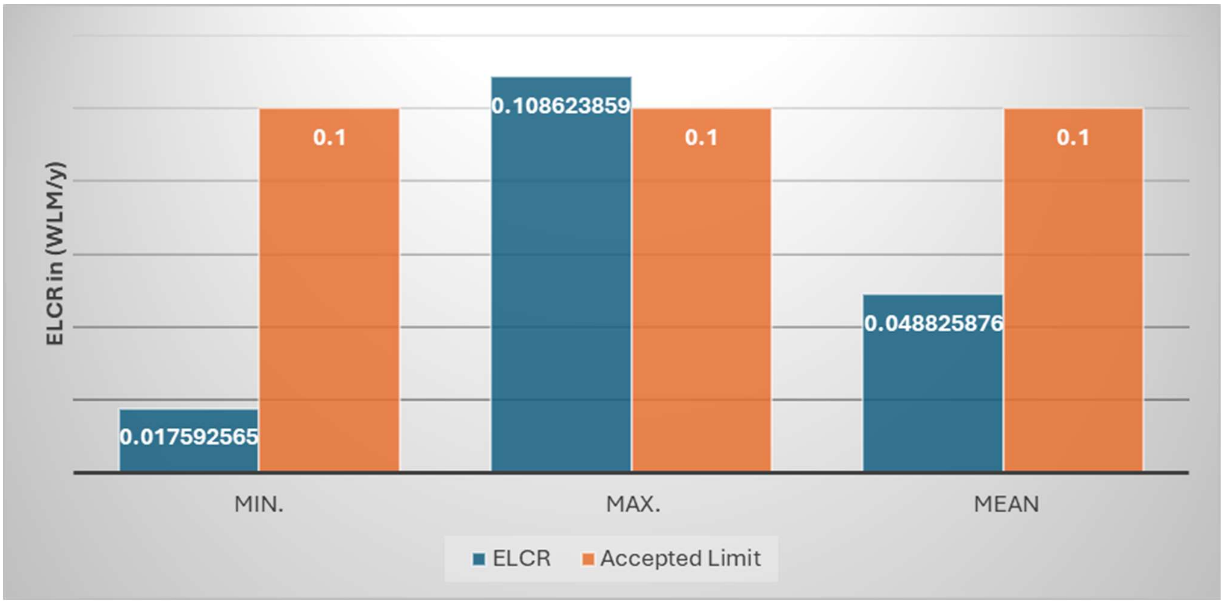

Fig. 4. Excess Lifetime Cancer Risk.

Table I. Results of the Measured activity concentration of R-222 Bqm^{-3} and calculated Exposure to Radon Progeny in WLM/y, Excess lifetime cancer Risk, Annual Effective Dose, Annual equivalent dose, and Lifetime cancer cases per million.

Location	Rn^{222} (Bq/m^3)	E_R (WLM/y)	ELCR (%)	D_y (mSv/y)	E_{inh} (mSv/y)	LCC
MIS Office 1	20.0	0.011689412	0.040912941	0.290131200	0.696314880	1.25337E-05
MIS Office 2	10.9	0.006370729	0.022297553	0.158121504	0.379491610	6.83085E-06
D.P Office	8.6	0.005026447	0.017592565	0.124756416	0.299415398	5.38948E-06
Hausa Dept.	17.6	0.010286682	0.036003388	0.255315456	0.612757094	1.10296E-05
Library	16.5	0.009643765	0.033753176	0.239358240	0.574459776	1.03403E-05
Geo. Dept.	53.1	0.031035388	0.108623859	0.770298336	1.848716006	3.32769E-05
Exam Unit	17.7	0.010345129	0.036207953	0.256766112	0.616238669	1.10923E-05
Lang.	26.0	0.015196235	0.053186824	0.377170560	0.905209344	1.62938E-05
Bio. Dept	21.5	0.012566118	0.043981412	0.311891040	0.748538496	1.34737E-05
Reg. Office	20.3	0.011864753	0.041526635	0.294483168	0.706759603	1.27217E-05
ETF Building	10.6	0.006195388	0.021683859	0.153769536	0.369046886	6.64284E-06
Int. Sci	16.8	0.009819106	0.034366871	0.243710208	0.584904499	1.05283E-05
Phy Lab	13.0	0.007598118	0.026593412	0.188585280	0.452604672	8.14688E-06
Old Sci. Com	43.0	0.025132235	0.087962824	0.623782080	1.497076992	2.69474E-05
Comp. Lab	19.2	0.011221835	0.039276424	0.278525952	0.668462285	1.20323E-05
Voc. and Tech.	16.3	0.009526871	0.033344047	0.236456928	0.567496627	1.02149E-05
Clinic	27.9	0.016306729	0.057073553	0.404733024	0.971359258	1.74845E-05
Hostel	34.2	0.019988894	0.069961129	0.496124352	1.190698445	2.14326E-05
Staff Qtrs.	40.5	0.023671059	0.082848706	0.587515680	1.410037632	2.53807E-05
Security Office	29.7	0.017358776	0.060755718	0.430844832	1.034027597	1.86125E-05

MIS = Management Information System, D.P = Deputy Provost, Dept. = Department, Geo. = Geography, Lang. = Language, Bio. = Biology, Reg. = Registrar, ETF = Education Trust Fund , Int. Sci. = Integrated Science, Phy. = Physics, Lab. = Laboratory, Com = Complex, Comp. = Computer, Voc. and Tech. = Vocational and Technical, Qtrs. = Quarters.

iii. Annual Effective Dose (D_y) in mSv/y

Fig. 5 depicts the Annual Effective Dose due to Inhalation of Radon Isotopes in offices and staff quarters. The annual effective dose ranges from 0.1248 mSv/y at the Deputy Provost's Office to 0.7703 mSv/y at the Geography Departmental Office, with the mean annual effective dose at 0.294 mSv/y.

According to the recommendations of the ICRP, the annual effective dose limit for occupational exposure is 20 mSv. Based on ICRP, the range of action and intervention for exposure to ^{222}Rn at the workplace is 3–10 mSv/y (ICRP,). The current study results revealed that the minimum, maximum, and mean values of the annual effective dose due to inhalation were less than the range recommended by the ICRP. Results obtained for all locations are well within this limit.

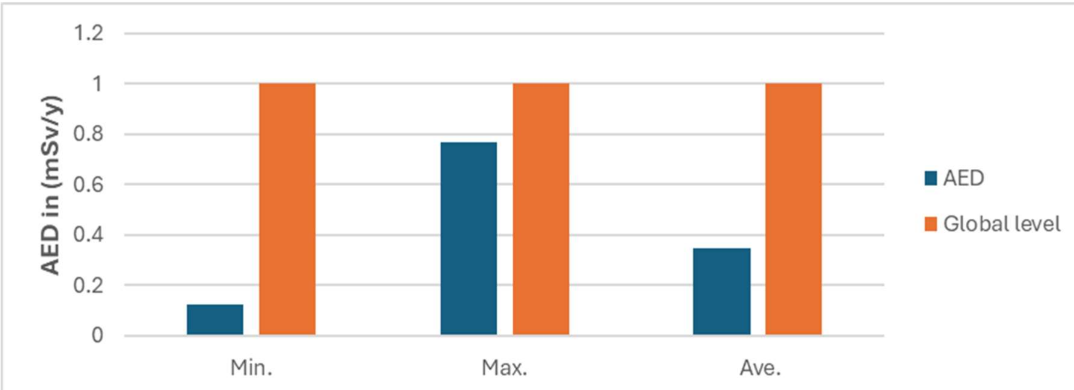

Fig. 5. Annual Effective Dose due to Inhalation of Radon Isotopes in offices and staff quarters.

iv. Lifetime Cancer Cases (LCC)

Fig. 6. depicts a plot of Lifetime Cancer Cases per Million People. The lifetime cancer cases range from 5.39×10^{-6} at the Deputy Provost's office to 3.33×10^{-5} at the Geography Departmental office, with the mean lifetime cancer cases at 1.27×10^{-5}. The LCC values represent the probability of developing cancer over a lifetime due to radon exposure. LCC values estimated from offices were below the range of 170–230 per million people recommended by the ICRP. The values are relatively low, indicating a low risk of cancer from radon exposure in the study area. According to the USEPA estimates, lifetime exposure to 74 Bq/m^3 in smokers and non-smokers led to 32 and 4 lung cancer cases per 1000 population, respectively [31]. Thus, the maximum value of Rn-222 measured 53.1 Bq/m^3 in some sampling sites in the current study could be hazardous to smokers.

The fluctuation in airborne radioactivity levels in the study area may be attributed to the different categories of dwellings and varied lifestyle of the office occupants, though there is no observable difference in geology within the study area.

A comparison of the Radon concentration and related radiological hazards in the study area with other studies carried out within Nigeria [27-29] (see Table II), aligns with global averages [2], [10], [30], [31] and [32]. However, the Geography Departmental office showed slightly higher values for Rn-222, ER, ELCR, and D_y, which may warrant further investigation or mitigation measures.

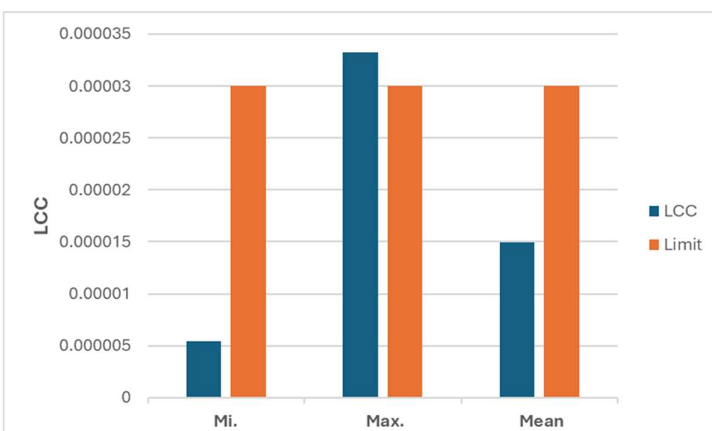

Fig. 6. Plot of a Lifetime Cancer Cases per Million People.

Table II. Comparison of the Ranged concentration of Rn-222, ER, ELCR, and LCC with other studies performed in Nigeria and the global averages.

Parameters	Other Studies	This Study	Global Range	References
Rn-222 (Bqm^{-3})	10.2 - 68.4	8.6 - 53.1	10 - 200 (Ave. 40)	[27] and [28]
E_R (WLM/y)	0.004 - 0.025	0.005 - 0.031	0.003 - 0.030	[29], [10], and [30]
ELCR (%)	0.014 - 0.088	0.017 - 0.108	0.01 - 0.10	[2], [31], [32].
AED (mSv/y)	0.10 - 0.60	0.124 - 0.770	0.10 - 1.0	
LCC	4.5E-06 - 2.5E-05	5.39E-06 - 3.33E-05	3.0E-06 - 3.0E-05	

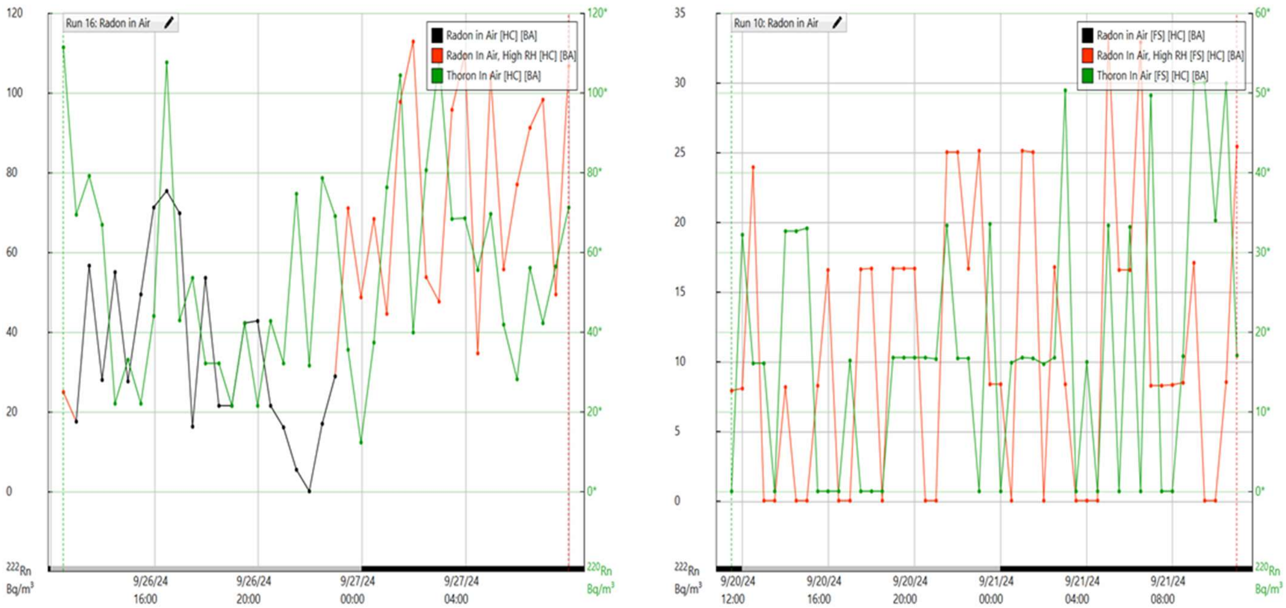

Fig. 7. Diurnal variation of Radon and Thoron Activity Concentration.

v. Diurnal variation

Radon concentrations vary considerably between adjacent buildings, as well as within a building from day to day and from hour to hour. These fluctuations necessitated the study of the diurnal variation of the short-term mean concentration of radon in indoor air by measurement for twenty-four hours. The diurnal behaviour of indoor radon and thoron levels helps in understanding the variation of these levels with the lifestyle of dwellers. The simultaneous measurements were made with RAD7 in selected offices. The acquisition of the data started at 12:00 pm on September 20, 2024, and continued till the next morning in intervals of thirty minutes. The measured radon and thoron levels are shown in Fig. 7. The concentration of radon shows a steadily growing trend from 23:00 h till around 6:00 h since the dwellers generally move to their various homes by closing the offices, and as a result, the radon gas accumulation takes place. The radon levels show a decreasing trend in the daytime because all the ventilation sources are open during the day, but there are some build-ups. During the nighttime, the radon levels are raised to a maximum again as the ventilation is poor. The activity concentration of the gas decreases to a minimum in the morning as human activity begins. The increase in the air exchange rate and the temperature gradient caused a decrease in activity concentration. Similar observations were also reported by [32 - 33].

IV. Conclusion

This study sets out to measure radon activity concentration in campus facilities at Adamawa State College of Education, Hong, to ascertain the level of radon build-up and its effect on workers. The study carried out continuous measurements in twenty offices for twenty-four hours in each case. The concentration of ^{222}Rn was measured, and the ELCR, Dy, and LCC due to exposure to ^{222}Rn and its progeny were all evaluated. The Geography Departmental office has the highest radon concentration (53.1 Bq/m³), effective dose rate (0.031 WLM/y), annual effective dose (0.770 mSv/y), and ELCR (0.1086%). This office may require mitigation measures to reduce radon exposure. The Deputy Provost's Office has the lowest radon concentration (8.6 Bq/m³), effective dose rate (0.005 WLM/y), annual effective dose (0.1248 mSv/y), and ELCR (0.0176%). This location poses the lowest risk among all locations. Most locations have radon concentrations and associated risks well within acceptable limits, except for the

Geography Departmental office, which slightly exceeds the WHO reference level for radon. In general, the results suggest that radon levels in most locations are within safe limits, but continuous monitoring is recommended to ensure compliance with international safety standards. Implementation of radon mitigation strategies, such as improved ventilation and sealing of cracks, in the Geography Departmental office to reduce radon concentrations and associated risks. Conduct regular monitoring of radon levels in all workplaces to ensure they remain within acceptable limits. Educate staff and occupants about the health risks associated with radon exposure and the importance of mitigation measures.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial or other interests that could have influenced this study.

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