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Assessment of Indoor Radon around the Student Environment in LAUTECH Ogbomoso, Oyo State, and Its Radiological Effect on Human Organs

[1]Emmanuel A. Oni, *[2]Mustapha K. Lawal, [2]Olatunde M. Oni, [2]Abraham A. Aremu, [1]Olukunle O. Oladapo, [2]Paul S. Ayanlola and [2]Oluwaseun O. Oloyede

Department of Science Laboratory Technology, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria.
[2]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria.

*Corresponding author's email: mklawal92@lautech.edu.ng

ABSTRACT

Indoor radon exposure constitutes a significant public health concern, being the second leading cause of lung cancer after cigarette smoking. Upon inhalation, radon dissolves in blood and is distributed to multiple body organs. This study measured indoor radon concentrations in 50 rooms at LAUTECH Ogbomoso using a calibrated RAD7 active electronic detector. Measured concentrations were subsequently integrated into a validated Physiologically Based Pharmacokinetic (PBPK) model to simulate radon uptake and organ distribution. Concentrations ranged from 2.44 to 183.44 Bq/m³ (mean = 76.46 Bq/m³), clustered as: low (1–10 Bq/m³, 32%), moderate (30–100 Bq/m³, 28%), and high (100–180 Bq/m³, 40%). The mean remained below the WHO reference level of 100 Bq/m³. Bone marrow exhibited the highest radon retention (47.4%) and the highest annual effective dose (0.1776 mSv/y), while the heart recorded the lowest retention (2.3%) and effective dose (0.0007 mSv/y). All organ effective doses were below the 1 mSv/y limit recommended by the International Commission on Radiological Protection (ICRP). The findings indicate that students in this environment are not at immediate radiological risk; however, continuous monitoring, improved ventilation, and adherence to the ALARA principle are strongly recommended.

Keywords:
Indoor radon,
RAD7,
PBPK model,
PBPK model,
Bone Marrow,
LAUTECH.

INTRODUCTION

Radon (Rn-222) is a naturally occurring, colourless, odourless radioactive noble gas produced from the radioactive decay of uranium in soils and rocks. Being approximately seven times denser than air, it migrates readily through the earth's crust and accumulates in enclosed, poorly ventilated spaces such as residential buildings, schools, and workplaces (Adesina *et al.*, 2025). The World Health Organization (WHO, 2021) designates a reference level of 100 Bq/m³ for indoor radon concentration, with a maximum permissible level of 300 Bq/m³ where the lower level cannot be achieved. Prolonged inhalation of radon and its short-lived alpha-emitting progeny particularly Polonium-218 (Po-218) and Polonium-214 (Po-214) deposits energy on airway epithelial cells, inducing DNA damage and carcinogenic changes in lung tissue (NCI, 2023; Quarto *et al.*, 2015). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) estimates a mean annual effective dose of 1 mSv/y to the general population from radon inhalation. Radon is established as the second leading cause of lung cancer after smoking (Oni *et al.*, 2022). Despite this, awareness of radon hazards remains critically low, even among educated populations (Esan *et al.*, 2020; Cori *et al.*, 2022).

Importantly, radon is not confined in its effects to the lung only, once inhaled, it dissolves in blood and is transported systemically, accumulating in other organs according to their respective partition coefficients (Parent 2005). The majority of published studies focus exclusively on pulmonary risk, creating a knowledge gap regarding systemic radiological burden. The present study addresses this gap by integrating field measurements with a PBPK model to estimate organ-specific radon retention and effective dose in students at Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria.

MATERIALS AND METHODS

Study Area and Sampling Design

Indoor radon concentrations were measured in 50 rooms across student hostels at LAUTECH Ogbomoso. Two independent measurements were conducted in each room to ensure reproducibility. The RAD7 detector was calibrated in an EPA-certified radon calibration chamber within six months prior to measurements, in compliance with EPA recommendations.

Instrumentation: RAD7 Radon Detector

The RAD7 (Durridge Company) is a solid-state active electronic radon detector equipped with a silicon alpha-particle detector housed within a 0.7-litre hemispherical measurement chamber as showed in figure 1a,b,c. A high-voltage field of 2,000–2,500 V accelerates positively ionised polonium daughter ions towards the detector upon radon decay. The detector records alpha emissions at characteristic energies corresponding to Po-218 (energy window A) and Po-214 (energy window C). Secular equilibrium between Rn-222 and Po-218 is achieved at approximately 20 minutes; full equilibrium including Po-214 is reached after approximately 3 hours (Lorenz et al., 2011; Mohammed, 2014; Tokonami *et al*., 2005).

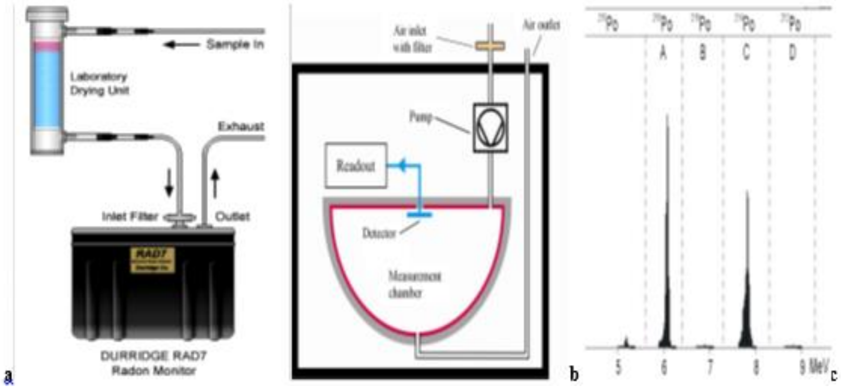

Figure 1: Diagram of the RAD7 Equipment for Measuring Indoor Radon (Mohammed, 2014)

The radon concentration in the measurement cell is governed by the differential equation (1) Mohammed, 2014.

$$\frac{dC(t)}{dt} = -\lambda C(t) \quad (1)$$

After a certain time of pumping, the radon gas concentration in the internal cell of RAD7 equal to that of the environment C_0 written in equation (2) Mohammed, 2014.

$$dC_{P_0}(t)\, dt = \lambda_{P_0} C_0 - \lambda_{P_0} C_{P_0}(t) \quad (2)$$

At equilibrium, the concentration in the cell equals the ambient concentration C_0 (Tokonami *et al*., 2005; Tan and Xiao, 2005). The RAD7 was connected via tubing to a Drierite desiccant ($CaSO_4$) to maintain internal humidity below 10%, ensuring accurate alpha spectroscopy (Mohammed, 2014). Measurements were logged in 20-minute cycles, recording radon concentration (Bq/m³), relative humidity (%), and ambient temperature (°C).

The initial condition is given in equation (3) Tokonami *et al*., 2005

$$C_{P_0}(0) = 0 \quad (3)$$

Dose Calculation

Annual absorbed dose and annual effective dose were computed using equation (4) and (5) UNSCEAR, (2006) : Annual Absorbed Dose (mSv/y) = $C_{Rn} \times D \times F \times H \times T$ (4) Where: C_{Rn} is the measured Rn-222 activity concentration (Bq/m³), D is the dose conversion factor (9×10^{-6} mSv·h^{-1} per Bq/m³), F is the indoor equilibrium factor (0.4), H is the indoor occupancy factor (0.8),T is the annual occupancy time (8,760 h/y), Annual Effective Dose (mSv/y) = Annual Absorbed Dose × $W_R \times W_T$, (5) Where W_R = 20 (alpha particle radiation weighting factor) and W_T = organ-specific tissue weighting factor (UNSCEAR, 2006; Serge *et al*., 2023).

Physiologically based Pharmacokinetic Modelling (PBPK)

Measured concentrations were incorporated into a validated Physiologically Based Pharmacokinetic (PBPK) model developed with MATLAB code to simulate radon uptake and distribution across 14 human organs and tissues. Organ retention fractions were derived from partition coefficient data embedded in the model interface in figure 2.

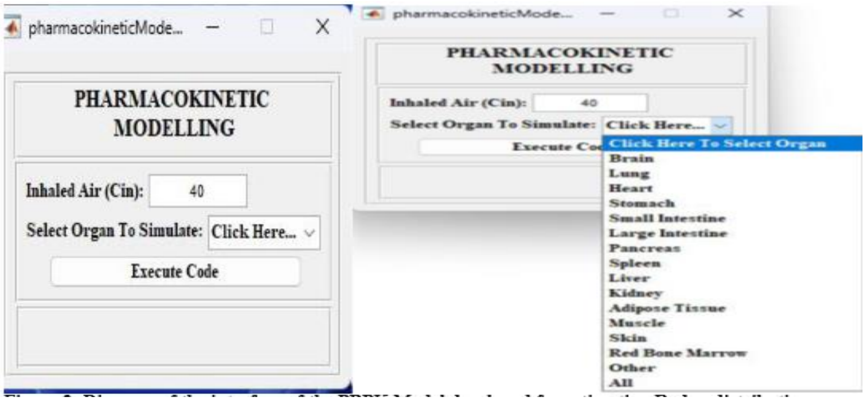

Figure 2: Diagram of the Interface of the PBPK Model Developed For Estimating Radon Distribution

Statistical Analysis

A one-way Analysis of Variance (ANOVA) was applied to test for statistically significant differences between Measurement 1 and Measurement 2 across all 50 rooms. The null hypothesis (H_0) stated no significant difference between repeated measurements; the alternative hypothesis (H_1) stated a significant difference exists. Significance was assessed at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Indoor Radon Concentrations

Table 1 present result of indoor radon concentration around hostels in LAUTECH with range of 2.44 - 183.24 Bq/m^3 and a mean value of 76.46 Bq/m^3 which is below the World Health Organization WHO safe limit of 100 Bq/m^3 while those above the 100 Bq/m^3 are lower than the maximum value of 300 Bq/m^3. The high standard deviated (63.5 Bq/m^3) reflects substantial room-to- room variability attributable to difference in ventilation building materials, and subfloor geology.

Table 1 Radon Indoor Measurement around LAUTECH Hostel Ogbomoso

ROOM ID	Measurement 1 (Bq/m^3)	Measurement 2 (Bq/m^3)	Mean (Bq/m^3)
1	4.71	6.43	5.57
2	9.5	1.05	5.28
3	3.41	5.37	4.39
4	3.57	9.57	6.57
5	9.27	4.32	6.79
6	5.25	2.11	3.68
7	3.34	4.1	3.72
8	6.81	4.15	5.48
9	5.81	6.15	5.98
10	128.81	142.54	135.68
11	9.59	3.73	6.66
12	6.99	3.06	5.03
13	3.84	1.46	2.65
14	1.06	3.81	2.44
15	188.43	136.84	162.64
16	75.7	23.92	49.81
17	5.71	5.11	5.41
18	35.38	70.09	52.73
19	54.89	94.89	74.89
20	29.71	89.34	59.53
21	123.94	184.95	154.45
22	85.23	10.29	47.76

ROOM ID	Measurement 1 (Bq/m³)	Measurement 2 (Bq/m³)	Mean (Bq/m³)
23	12.48	94.87	53.68
24	52.1	93.33	72.72
25	35.37	40.28	37.83
26	65.01	99.86	82.44
27	87.23	82.21	84.72
28	18.29	41.54	29.91
29	98.49	71.93	85.21
30	74.18	66.76	70.47
31	5.38	1.08	3.23
32	126.01	191.45	158.73
33	131.76	131.15	131.46
34	159.43	171.47	165.45
35	174.56	173.52	174.04
36	176.14	190.33	183.24
37	111.5	119.26	115.38
38	122.91	147.56	135.24
39	170.77	172.95	171.86
40	168.4	152.21	160.31
41	170.92	106.75	138.84
42	172.49	139.84	156.17
43	139.99	157.33	148.66
44	42.37	32.88	37.62
45	162.55	106.33	134.44
46	118.92	114.16	116.54
47	137.48	128.84	133.16
48	142.18	107.35	142.36
49	4.56	4.09	4.32
50	113.2	116.33	114.77
Mean	**74.63**	**78.29**	**76.46**

The Radon concentration levels was categorized as showed in table 2 as low, moderate and elevated. Most of the rooms (60%) were below the WHO recommendation of 100 Bq/m³ while just 40 % were above the 100 Bq/m³.

Table 2

Category	Range (Bq/m³)	Proportion of Rooms
Low	1 – 10	32 (%)
Moderate	30 – 100	28 (%)
Elevated	> 100	40 (%)

ANOVA Results

The F-value of 0.113 ($p > 0.05$) confirms no statistically significant difference between the two repeated measurements, as showed in table 3, demonstrating the reproducibility and reliability of the RAD7 detector under field conditions

Table 3: ANOVA Analysis table

Source	Sum of Squares	Degree of freedom	Mean Square	F- statistic
Between Groups	188166.914615	3	62722.3	0.113
Within Groups	8461.957913	46	183.956	—
Total	196628.872528	49		—

The histogram illustrated in figure 3 shows the frequency distribution of indoor radon concentration measured around LAUTECH hostel. The superimposed normal distribution curve enables visual comparison between the observed data distribution and the theoretical normal distribution. The distribution demonstrates variability in radon concentration levels across hostel rooms, with some measurements extending towards higher concentration values. The shape of the histogram suggests moderate asymmetry, indicating that the dataset may not perfectly follow a normal distribution.

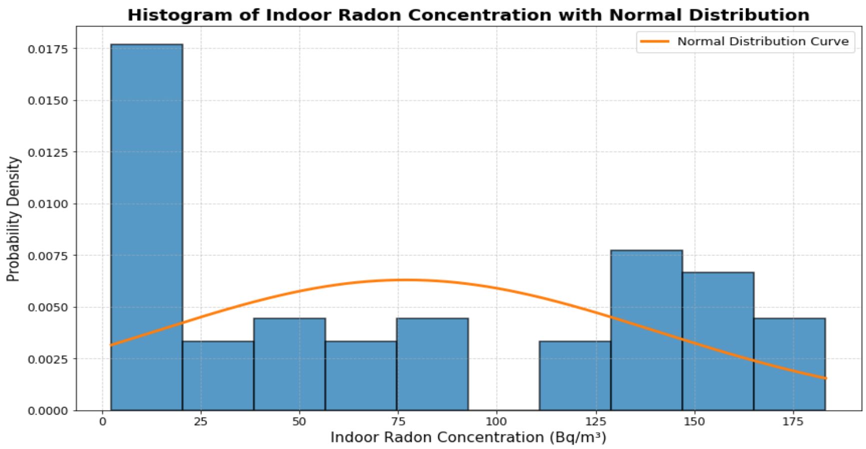

Figure 3: Histogram of Indoor Radon Concentration with Normal Distribution

Organ Retention and Effective Dose

PBPK modelling indicated that bone marrow (BM) and adipose tissue (AT) accounted for the highest radon retention, at 47.4% and 21.3% respectively. The annual effective dose was highest in bone marrow (0.1776 mSv/y) and lowest in the heart (0.0007 mSv/y). All organ-specific effective doses remained below the ICRP-recommended limit of 1 mSv/y which are summarised table 4. Figure 4 shows the simulation of radon to the different organs where Bone marrow and Adipose tissue show more accumulation, other organs were stable before 5 hours. Both bone marrow and Adipose tissue were still accumulating radon at 10 hours. This is as a result of their higher partition coefficient and fat- rich nature. However, bone marrow unlike adipose tissue still has higher effective dose. The effective dose in Adipose tissue was significantly low compare to it high retention. Which is as a result of its low sensitivity to radiation, the tissue weighting factor is 0.01 while that of bone marrow is 0.12.

Table 4: Effective Dose for Different Organ at Mean Indoor Radon Concentration of 76.46 Bq/m^3

Organ	Radon Conc. (Bq/m³)	W_T	Annual Effective Dose (mSv/y)
Bone Marrow	58.69	0.12	0.1776
Adipose Tissue	26.36	0.01	0.0067
Liver	3.93	0.04	0.0040
Lung	3.93	0.12	0.0119
Stomach	3.93	0.12	0.0119
Large Intestine	3.73	0.12	0.0113
Heart	2.80	0.01	0.0007

W_T is Tissue weighting factor

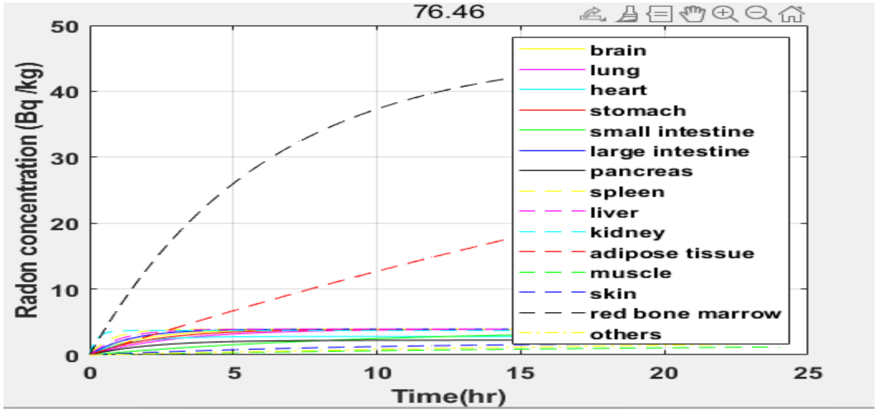

Figure 4: Graph Showing Distribution of Distribution of Radon Retained In Different Human Organs

Discussion

The mean indoor radon concentration of 76.46 Bq/m³ is below the WHO (2021) reference level of 100 Bq/m³; however, 40% of rooms exceeded this threshold, indicating localised risk in specific hostel buildings. Variability in radon levels is attributed to structural differences, ventilation quality, and underlying geological formations factors consistent with findings reported by Usikalu *et al*. (2017) and Adesina *et al*. (2025) for other Nigerian indoor environments. The PBPK modelling results reveals a critical finding: radon's radiological impact extends well beyond the lung. Bone marrow received the highest effective dose (0.1776 mSv/y), driven by its high retention fraction and tissue weighting factor (W_T = 0.12). This finding has potential implications for hematological health and warrants dedicated follow-up studies. Adipose tissue, while storing a significant radon fraction (21.3%), contributed minimally to effective dose (0.0067 mSv/y) due to its low tissue weighting factor (W_T = 0.01). The lung and stomach, despite relatively low retention fractions, recorded notable effective doses (0.0119 mSv/y each) due to their elevated radiological sensitivity a finding consistent with Serge et al. (2023). All effective doses were below the ICRP limit of 1 mSv/y, indicating that the current exposure levels at LAUTECH do not pose immediate radiological risk. Nonetheless, adherence to the ALARA (As Low As Reasonably Achievable) principle is imperative, given that no threshold for radiation-induced carcinogenesis is universally accepted (NCI, 2023; WHO, 2009).

CONCLUSION

This study provides the first PBPK-integrated assessment of indoor radon exposure and multi-organ radiological burden in the student environment at LAUTECH Ogbomoso. Indoor radon concentrations ranged from 2.44 to 183.44 Bq/m³ (mean = 76.46 Bq/m³), with 40% of rooms exceeding the WHO reference level of 100 Bq/m³. All calculated organ effective doses were below the ICRP limit of 1 mSv/y, indicating overall safety for current occupants. However, bone marrow emerged as the organ of greatest radiological concern due to its high retention fraction and effective dose. The study affirms that radon risk assessment must adopt a whole-body, multi-organ perspective rather than a lung-centric one. Continuous monitoring, improved hostel ventilation, and targeted health education are recommended.

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