Indoor Radon Concentration Survey in Bank Basements in Three Nigerian Cities

I. K. Adegun 1, B. E. Anyaegbuna 1,3* and O. A. Olayemi 2

1Mechanical Engineering Department, University of Ilorin, Ilorin, Nigeria.
2Department of Aeronautical and Astronautical Engineering, Kwara State University, Malete, Kwara State, Nigeria.
3Max-Impact Engineering Consultants, Lagos, Nigeria.
*Corresponding Author: benanyaegbuna@yahoo.com

Abstract-
Basement workplaces are considered as confined environment with challenging indoor air quality having higher than normal pollutants particularly that of soil gas origin. Radon a major soil gas infiltrates and accumulates within indoor spaces and becomes harmful in the absence of natural or mechanical ventilation. Radon level in bank basements in Ilorin, Lagos and Akure have been sampled and analysed in this study. The paper presents the investigations conducted to measure the radon concentration in the occupied basement component of the bank buildings. Most workers in basements are unaware of radon, and there is limited documented research on its health hazards in Nigeria. The survey parameters were radon concentrations, floor levels, geographical locations and the influence of atmospheric conditions. Corentium monitor, a continuous, digital radon monitor, in addition to, temperature meters and Prologue wireless weather station were used for the experiment. The result showed an indoor radon concentration and effective doses annual mean values of 23 Bq/m3 and 0.0896mSv/y respectively in the occupied basements.

Key words: Radon, indoor air quality, occupied basement, effective doses, radon concentration.

1. Introduction
Air quality studies in basements have recently generated interest owing to the increased human occupation as against its traditional usage as a utility storage space. These basements are gradually finding wider application as offices, lecture and entertainment theatres, shopping malls, and so on. These current trends therefore have brought to fore issues of indoor air quality in these confined spaces. There is also the issue of low or poor awareness on the health risks of below-grade building and their peculiar challenges of moisture, soil gases and radon intrusion, back drafting and proper ventilation [1]. One of the soil gases that has being of much concern to the health, environmental and building industry is Radon gas. Radon is long known to be a major cause of lung cancer in humans [2]. Exposure to radon is often considered firstly a primary source of ionizing radiations before medical exposure in many countries [3]. The increasing incidence in lung cancer occasioned by the rise in the indoor air concentration of radon has been recognized as a radiation health hazard. Radon is detectable everywhere in workplaces and dwellings, but levels vary from place to place and over time. The main radon source with high concentrations is the soil, but there can also be significant contributions from building materials, groundwater, storage and processing of large amounts of materials with elevated concentrations of radium [4].
Basement vaults are listed by Canadian Centre for Occupational Health and Safety (CCOHS) as a confined place that require additional safety and health regulation [5]. Occupied basements with air-tightener built envelopes, are particularly utilized in the Banking industry in Nigeria, where the vault is often located in the basement. These bank basements not only accommodate their vaults but are substantially used for workspaces for the treasury staff. Money stored in the basements vaults as in the case with the Central Bank of Nigeria buildings and large deposit banks poses additional discomfort and health challenge to workers in these confined spaces. Uneke and Ogbu [6] observed that 90% of Nigerian currency notes in circulation were contaminated with either bacteria or fungi. Indoor air in these basements are already contaminated by their contents if the ventilation is not effective and the workers that spend substantial fraction of their time within these confined spaces of the buildings are at risk of contracting Building Related Illness (BRI). Unfortunately, most of these basements vaults are not tested for Radon and other chemical and microbiological infestations in third world countries and in most cases the only protection available to workers in these confined environments is the face mask.

Radon, a typical soil gas normally dissipates harmlessly into outdoor air, but it also flows into buildings through cracks and gaps in the foundation, eventually reaching unsafe levels in lower floors and basements [7]. It becomes an indoor air pollution problem when it penetrates into buildings directly from the soil and accumulates inside the buildings [8]. Radon (222Rn) is a radioactive gas formed from radium (226Ra), which is a decay product of Uranium (238U). It has a half-life of 3.8 days, and tends to concentrate in enclosed spaces like underground mines, basements and crawl spaces [9, 10]. 222Rn concentrations in buildings depend on meteorological and geological conditions, construction materials, and ventilation [11]. Radon has been identified as one of the most pervasive and serious global indoor air threat by various international organizations which include the International Atomic Energy Agency (IAEA), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) International Commission on Radiological Protection (ICRP) and the European Commission (EC). Their collaborative efforts and interventions have resulted on the setting of radon reference/action levels for radon in air, production of maps delineating high radon potential countries, regions and areas. [12, 13, 14, 4].

The U.S EPA [15] recommends taking actions to reduce radon exposure if levels exceed four picocuries per liter of air (4 pCi/L). At the action level of 200 Bq/m³, there is approximately a 3% life time risk developing cancer as a result of radon exposure. [16, 17].

The occupational exposure to radon in Nigeria has not generated much study as expected. Obed, et al [11] conducted an Indoor Radon Survey in a University Campus of Nigeria. They measured the Radon concentration in 24 offices in University of Ibadan, Nigeria and found out an average of 293.3 Bq/m³ in the offices. Afolabi, et al [18] measured the radon levels in selected offices at the Obafemi Awolowo University, Ile-Ife. Their result showed the radon level measured in the sampled offices ranged from 0.0 to 5.3 pCi/L (196 Bq/m³). Of the few studies and surveys of indoor radon concentrations carried out in Nigeria, no systematic study has investigated radon levels in occupied basements.
2. Methodology
This experimental study was carried out in three Bank complexes with occupied basements. The
basements serve as vaults and office spaces with a daily human occupation of eight hours. The
top floors serve as banking halls, offices and conference rooms. The Bank Buildings are perfect
eamples of complex buildings that utilizes only Mechanical Ventilations.

Experimental Procedures
The experimental approach involved the collection of data through sensors and data acquisition
software from the selected occupied commercial buildings with basements operating only
mechanical ventilation. The selected instruments are digital continuous monitoring instruments
that enables effective, and flexible measurement of the desired parameters. The instruments are
able to monitor continuously indoor air quality (IAQ) parameters, both indoor and outdoor
environments, in real-time, thereby eliminating the problems associated with sampling and
laboratory analysis.

The Corentium monitor offers two measurements display modes for the Radon concentration,
the ‘short term’ and ‘long term’ averages. The advantage of the ‘short term’ mode is the quick
response to concentration changes which enables a reading after 24 hours, while the ‘long term’
mode gives a 7 days average reading with a sensitivity twice as high compared with the ‘short
term’ mode. It has an accuracy level of ±7% + 0.12 pCi/L after 24 hours and ±5% + 0.05 pCi/L
after 7 days. The Corentium monitor requires no annual calibrations. The radon measuring
instrument is of American origin and therefore the concentration of radon in the air was
measured in units of picocuries per litre (pCi/L). The international system (SI) units of radon
measurement is in Becquerel per cubic meter (Bq/m3). One pCi/L is equivalent to 37 Bq/m3.
The values are later converted to the unit of Bq/m3.

Indoor and outdoor temperature and humidity were monitored with the Prologue Wireless
Weather Station. The weather station comprises of wireless sensors which were placed at
predetermined locations within and outside the basements. The measurements were carried out
in a total of 12 offices in the banks complexes in Ilorin, Lagos and Akure. The measurements
required that a closed space conditioned is maintained 12 hours before commencing testing.
This is achieved by ensuring that the continuous radon monitor is in place at the close of work
at 5:00pm prior to the start of the days’ work at 8:00am in the morning. The test monitor is
placed at a least 600mm above the floor level at a location where it will not be disturbed
throughout the duration of the testing. The unit is left on throughout the testing period which
runs for a minimum of 48 hrs but gives a short-term result after 24 hrs. Some of the
measurements were made during the weekends when the offices were closed for two days-
Saturdays and Sundays.

Outdoor temperature and relative humidity measurements were obtained from the digital
wireless weather station. The database consists of measurements taken between August 2015
and September 2016. The placement of radon instrumentation inside the vaults were performed
by bank company staff, properly instructed on the modalities and operations of the test monitors
and provided with appropriate forms for data collection. This is because the vault located within
the basement is a confined and secured environment. The researcher, however, had some limited
access to the vault as result of the ventilation upgrade being undertaken by his firm to the bank.
3. Result and discussions

Average Radon Concentration in the Basement Workplaces

The results measured in 3 banks’ occupied basements is reported in Table 1. The radon annual averages ranged between 0.67 and 107.3 Bq/m³, with a mean of 23.68 Bq/m³, and standard deviation value of 16.6 Bq/m³. The radon values obtained through the experimental measurements of basement workplaces were below the action level approved by the United States Environmental Protection Agency of 4pc/l (148 Bq/m³) [19]. The values are also below the upper value of the ICRP reference levels of 1500 Bq/m³ for underground workplaces [20]. The variation of radon concentration in the basement workplaces measured is shown in Figure 1.

Table 1: Summary of annual average radon concentration in the basement workplaces

| Summary of Parameters | Radon Measurements (Bq/m³) |
|-----------------------|---------------------------|
| Min                   | 0.67                      |
| Max                   | 107.3                     |
| Mean                  | 23.68                     |
| SD                    | 16.6                      |

Figure 1: Variation of radon concentration in the basement workplaces of Ilorin, Akure and Lagos.
Average Annual Concentration of Radon (Bq/m³) for the Three Cities

The estimation of annual average radon concentration in each bank’s workplace was derived by averaging individual results obtained in the underground workplaces of each of the considered city over a thirteen-month testing period. Radon average values of the bank basements have been calculated for the three cities which are spread within two geo-political zone (North-Central and South-West) in Nigeria. The average radon values in the basement workplaces in the cities are presented in Table 2.

Table 2: Average Annual Concentration of Radon in Basement Workplaces in the three cities.

| Location | Radon (Bq/m³) | Min (Bq/m³) | Max (Bq/m³) | SD (Bq/m³) |
|----------|---------------|-------------|-------------|------------|
| Ilorin   | 23.68         | 4.09        | 107.3       | 5.88       |
| Lagos    | 5.18          | 0.67        | 8.14        | 1.40       |
| Akure    | 6.92          | 1.07        | 17.1        | 3.31       |

The annual radon averages varied from 5.18 Bq/m³ up to 23.68 Bq/m³ with the south west regions, Akure, (6.92 Bq/m³) and Lagos (5.18 Bq/m³) showing quite low regional averages when compared with the North-Central zone city of Ilorin (23 Bq/m³). This variation may be attributed to geological differences. The results from Ilorin city are in good agreement with previous studies performed in dwellings and wells in Zaria [21]. Ilorin and Zaria are within the North-Central geo-political zones of Nigeria.

Analysis of Variance (ANOVA) was used to test if there is any significant difference between the radon concentrations in Akure, Ilorin, and Lagos. The radon concentration in the three cities are considered significantly different between the radon concentrations in the three locations if p-value < 0.05. The F statistics was calculated as 3.072, at 5 percent level of significance under 2 degrees of freedom, the returned p-value of 0.071 was found greater than the level of significance (0.05); p > 0.05. Thus, there is no significant difference between the radon concentrations in the three selected locations. However, the difference between the radon concentrations in the three selected locations is significant at 0.1 level of significance.

Effects of Other Floors on Basement Indoor Radon Concentration

Table 3 below shows that Ilorin has the highest Radon concentration in the basement and other upper floors. Akure has the lowest Radon concentration in the 2nd floor, while Lagos has the least Radon concentration across floors except in 2nd floor. More so, Ilorin has the highest mean and standard deviation (11.05 Bq/m³; 5.882 Bq/m³), while Lagos has the least (5.45 Bq/m³; 1.40 Bq/m³). Figure 2 shows the Radon Concentration within the floors and across the three geographical locations.
Table 3: Radon Concentration by Geographical Locations

| Location/Floor | Basement (Bq/m³) | Ground Floor (Bq/m³) | 1st Floor (Bq/m³) | 2nd Floor (Bq/m³) | Mean (Bq/m³) | STD (Bq/m³) |
|----------------|------------------|----------------------|-------------------|-------------------|--------------|-------------|
| Akure          | 6.32             | 5.62                 | 5.15              | 2.21              | 7.35         | 3.313       |
| Ilorin         | 23.68            | 11.84                | 5.18              | 5.92              | 11.05        | 5.882       |
| Lagos          | 5.92             | 4.81                 | 4.07              | 3.68              | 5.45         | 1.401       |

Figure 2: Radon Concentration across the three geographical locations

**Effective dose of Radon**

The implication of the variation in radon concentration across the floor can be further understood by estimating the radiation dose the workers in the basement and other floors are exposed by virtue of their locations in the bank building. The effective dose of radon in the Ilorin study location was analyzed as a case study.

The effective dose of radon in mSv/y at any location depends upon the occupancy factor. The banks management as a policy allow workers to alternate their work periods on 2-week off and on basis. The bank’s basement workers occupancy factor was determined as below:

\[ 40 \text{ h/wk} \times 26 \text{ wk/yr} = 1040 \text{h/yr} \]

The Occupancy factor (H) = 1040h/8760h = 0.12

The bank’s workers in other floors will have an occupancy factor determined as below:

\[ 40 \text{ h/wk} \times 44 \text{ wk/yr} = 1760 \text{h/yr} \]

The Occupancy factor (H) = 1760h/8760h = 0.20

The annual mean effective dose to the occupants of these offices due to exposure to radon was estimated using the following [22].
\[ E = C_{Rn} \cdot H \cdot F \cdot D \cdot T \]
Where \( C_{Rn} \): is the radon concentration (Bq/m³)
\( H \): is the occupancy factor (0.12 for basement; 0.20 for other floors occupants)
\( F \): is the equilibrium factor (0.4)
\( T \): is hours in a year (8760)
\( D \): is the dose conversion factor \([9 \times 10^{-6} \text{ mSv/h/(Bq/m}^3\text{)]}\).

### Table 4: The annual mean effective dose to the occupants in the floors.

| Space type   | Radon Concentration \((C_{Rn})\) (Bq/m³) | Effective Dose \((E)\) (mSv/y) |
|--------------|------------------------------------------|-------------------------------|
| Basement     | 23.68                                    | 0.0896                        |
| Ground Floor | 11.84                                    | 0.0747                        |
| First Floor  | 5.18                                     | 0.0326                        |
| Second Floor | 5.92                                     | 0.0377                        |

The workers exposure to radon is a function of the occupancy in the workplaces. By the bank’s policy the basement workers alternate their working periods on a bi-weekly on and off-duty basis. This can be observed from the ground floor with a radon concentration (11.84 Bq/m³), but with almost an equivalent annual mean of radon effective dose exposure of 0.0747 mSv/y and 0.0896 mSv/y in the ground floor and basement respectively. The radon concentration and effective dose where found to be lower in the first floor than the second floor. This can be explained by the space conditions of the measured floors. The first floor is a mezzanine floor which allows higher air flow from the mechanical ventilations system than is obtainable at the second floor.

**The Effect of weather at the different geographical locations.**

Indoor air qualities are greatly impacted by the air quality outside of the buildings. The time that the data were taken was divided between dry and wet seasons. Dry season has been set between October and April, and Wet set between May and September. A weather station was setup 20 meters from the building and records all relevant weather data hourly.

The result of the seasons are as shown in Tables 5, 6, 7 and 8. The tables displays the maximum radon concentration, humidity, air temperature and wind speed. Table 7 and 8 show that Ilorin has the highest Radon concentration in both dry and wet seasons, followed by Akure, while Lagos has the least Radon concentration. More so, Radon Concentrations in Ilorin has the highest mean and standard deviation. The table shows further that the Radon concentrations in dry season across the three geographical locations are higher than those of the wet season.

The humidity in Lagos is highest in the two seasons, while the air temperature and wind speed varies across the cities. The air temperature appears to have little effect on the radon concentration, while humidity has an inverse relationship with the radon concentration which reduces as the humidity increases. The result is in agreement with the findings of Schumann and Owen [23] that suggested that precipitation and barometric pressure are important factors.
that influence radon transport. In wet seasons, soil moisture as a result of precipitation blocks soil pores, reducing the gas permeability which results in lower radon values. Figure 3 shows the Radon Concentration by Atmospheric Conditions prevailing in the different cities.

Table 5: Dry Season (October-April)

| Location | Max Radon (Bq/m³) | Humidity (%) | Air Temp. (°C) | Wind Speed (m/s) |
|----------|------------------|--------------|----------------|-----------------|
| Ilorin   | 107.8            | 56.38        | 32.46          | 1.07            |
| Lagos    | 17.9             | 78           | 27.8           | 0.44            |
| Akure    | 21.51            | 62.3         | 31.5           | 1.94            |

Table 6: Outdoor – Wet Season (May-September)

| Location | Max Radon (Bq/m³) | Humidity (%) | Air Temp. (°C) | Wind Speed (m/s) |
|----------|------------------|--------------|----------------|-----------------|
| Ilorin   | 46.8             | 68.38        | 28.0           | 0.77            |
| Lagos    | 11.07            | 86.38        | 32.46          | 0.33            |
| Akure    | 14.81            | 71.5         | 27.4           | 0.54            |

Table 7: Radon Concentration by Atmospheric Conditions

| Location/Season | Dry Season | Mean  | STD  |
|-----------------|------------|-------|------|
| Akure           | 21.51      | 12.16 | 6.350|
| Ilorin          | 107.8      | 34.30 | 17.500|
| Lagos           | 17.9       | 10.99 | 6.915|

Table 8: Radon Concentration by Atmospheric Conditions

| Location/Season | Wet Season | Mean  | STD  |
|-----------------|------------|-------|------|
| Akure           | 14.81      | 8.13  | 3.580|
| Ilorin          | 46.80      | 20.45 | 7.700|
| Lagos           | 11.07      | 6.79  | 2.645|
T-test was used to test the significant difference between the radon concentrations in dry and wet seasons in the selected geographical location, at 0.05 level of significance. It was noted that the radon concentration in dry season had a higher mean score of 29.4033 than the radon concentration in wet season with a lower mean score of 8.8933. The significance of this however is tested and presented in table below:

Table 10: t-test of Significant Difference between Radon Concentrations in Dry and Wet Seasons

| Group Statistics | Atmospheric Condition | N  | Mean  | Std. Deviation | Std. Error Mean |
|------------------|-----------------------|----|-------|----------------|-----------------|
| Radon Concentration | Dry Season | 3  | 29.4033 | 19.39848       | 11.19972        |
|                   | Wet Season    | 3  | 8.8933  | 6.90242        | 3.98512         |

| t-test for Equality of Means |
|-----------------------------|
| Radon Concentration          |
| t   | Df  | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference |
|-----|-----|-----------------|-----------------|-----------------------|------------------------------------------|
| 1.725 | 4  | .160            | 20.51000        | 11.88759              | -12.49524 - 53.51524                     |

The t-test statistics was calculated as 1.725, at 5 percent level of significance under 4 degrees of freedom, the returned p-value of 0.160 was found greater than the level of significance (0.05); p > 0.05. Thus, it is concluded that there is no significant difference between the radon concentration in dry and wet seasons.

4. Conclusion

The survey covered 12 bank workplaces in three cities within the south-west and north-central geopolitical zones of Nigeria. This study reports the results of a survey carried out to evaluate...
the radon concentration in selected workplaces with particular emphasis on the basement section of the buildings. The results of the present work confirms the presence of indoor radon in basement workplaces. For the workplaces of the cities sampled, radon annual averages have been found higher in the north-central than the south-west geopolitical zones. There is also a correlation between the respective radon average concentration and bank floors decreasing with the floors levels from the basement upward.

5. Recommendation
The Nigerian worker from our experimental results still operates below the exposure limit but not totally free from radon exposure as there are still lung cancer risks from prolonged exposure to indoor radon even at low level of exposure. Hence the necessity to pay attention to the radiological protection of workers operating in confined environments. There is also the need for a local reference radon exposure level limit for workers operating in our peculiar environments where workspaces Building Related Illnesses are becoming common, though not often documented.

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