BIOPHYSICS OF RADON: A CASE STUDY OF THE EFFECT ON CELLULAR METABOLISM AND ENERGY PRODUCTION AND ITS EFFECT AS A THERAPEUTIC AGENT OF METABOLISM DISORDER

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CERTIFICATION

This is to certify that this study, "BIOPHYSICS OF RADON: A CASE STUDY OF THE EFFECT ON CELLULAR METABOLISM AND ENERGY PRODUCTION AND ITS EFFECT AS A THERAPEUTIC AGENT OF METABOLISM DISORDER." Was carried out by Emeka Daniel with matriculation number PSC1809206 of the Department of Physics, University of Benin, Benin City Edo state Nigeria.

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DEDICATION

I hereby dedicate this research papers to the Almighty God for seeing me through this research journey.

And to my parents, MR and MRS Emeka for the advice, prayers and finance they had assisted me with during my degree program.

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College based supervisor Signature & Date

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I am most grateful to God Almighty for his guidance and enabling grace.

My special gratitude goes to my amazing parents who financially supported my educational pursuit, my friends for their unquantifiable love, may God bless you all.

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ABSTRACT

Radon is an odourless, invisible, radioactive gas naturally released from rocks, soils and water. Radon can get into homes and buildings through small cracks or holes and build up in the air. Over time, breathing in high levels of radon can cause lung cancer.

Radon-222 is a naturally occurring radioactive gas that accounts for approximately half of the human annual background radiation exposure globally. Chronic exposure to radon and its decay products is estimated to be the second leading cause of lung cancer behind smoking (WHO, 2009; UNSCEAR 2000). Ionizing radiation emitted as a result of much energy from radon and its progeny can induce variety of cytogenetic effects that can be biologically damaging and results in an increased risk of carcinogenesis (The process in which normal cell are transformed into cancer cell). Suggested effects of alpha particle emission from Radon include mutation, chromosome aberrations, generation of reactive oxygen species, modification of cell cycle, up or down regulation of cytokines and the increased production of proteins associated with cell-cycle regulation and the transformation of normal cell into cancer cells.

The Environmental Protection Agency recommends 148 Bq/m^3 as the action level. On the other hand, International Commission for Radiation Protection (ICRP) recommends 200 Bq/m^3 as the action level, while WHO recommended 100Bq/m^3 as action level.

The main objective of this study is focuse on how radon is established as a health hazard, its effects on cellular metabolism and energy production, and the potential of

radon as a therapeutic agent for metabolism disorder, way of radon detection and measurements, methods of reducing and controlling high indoor radon concentration, and what are the recommended international action levels of radon concentrations. It mainly focuses on the health perspective of radon studies because it is a crucial and hot issue in the world today. In most developing countries like Nigeria, radon studies are not well investigated and the high mortality rate of lung cancer is of the increase.

CHAPTER ONE

INTRODUCTION

1.1 General introduction

Radon (Rn) is a decay product of radium (Ra), which is a member of the uranium (U) decay chain. The physical and chemical properties of radon such as colorless, odorless, and tasteless radioactive nature makes it difficult to detect without special equipment (Guadieet al, 2021). Radon has three well-known isotopes, radon (^{222}Rn), thoron (^{220}Rn), and actinon (^{219}Rn), which are found from the decay series of uranium isotopes (^{238}U, ^{236}U, and ^{236}U), respectively. The three isotopes of radon (^{222}Rn, ^{220}Rn, and ^{219}Rn) have a half-life of 3.82 days, 55.8 seconds, and 3.98 seconds, respectively. Radon is among the leading contributors to ionizing radiation and it has been identified as a health hazard for mankind. It is the most leading source of the background radiation dose (55%) received by the environment and it is found in variable concentrations from location to location and even from season to season. Since radon is an unstable atom when it undergoes radioactive decay, it forms a number of short-lived radioactive decay products (called radon progeny), which include polonium (^{218}Po), lead (^{214}Pb), bismuth (^{214}Bi), and polonium

(^{214}Po). Alpha, beta, or sometimes gamma radiation is emitted out under each radioactive transformation.

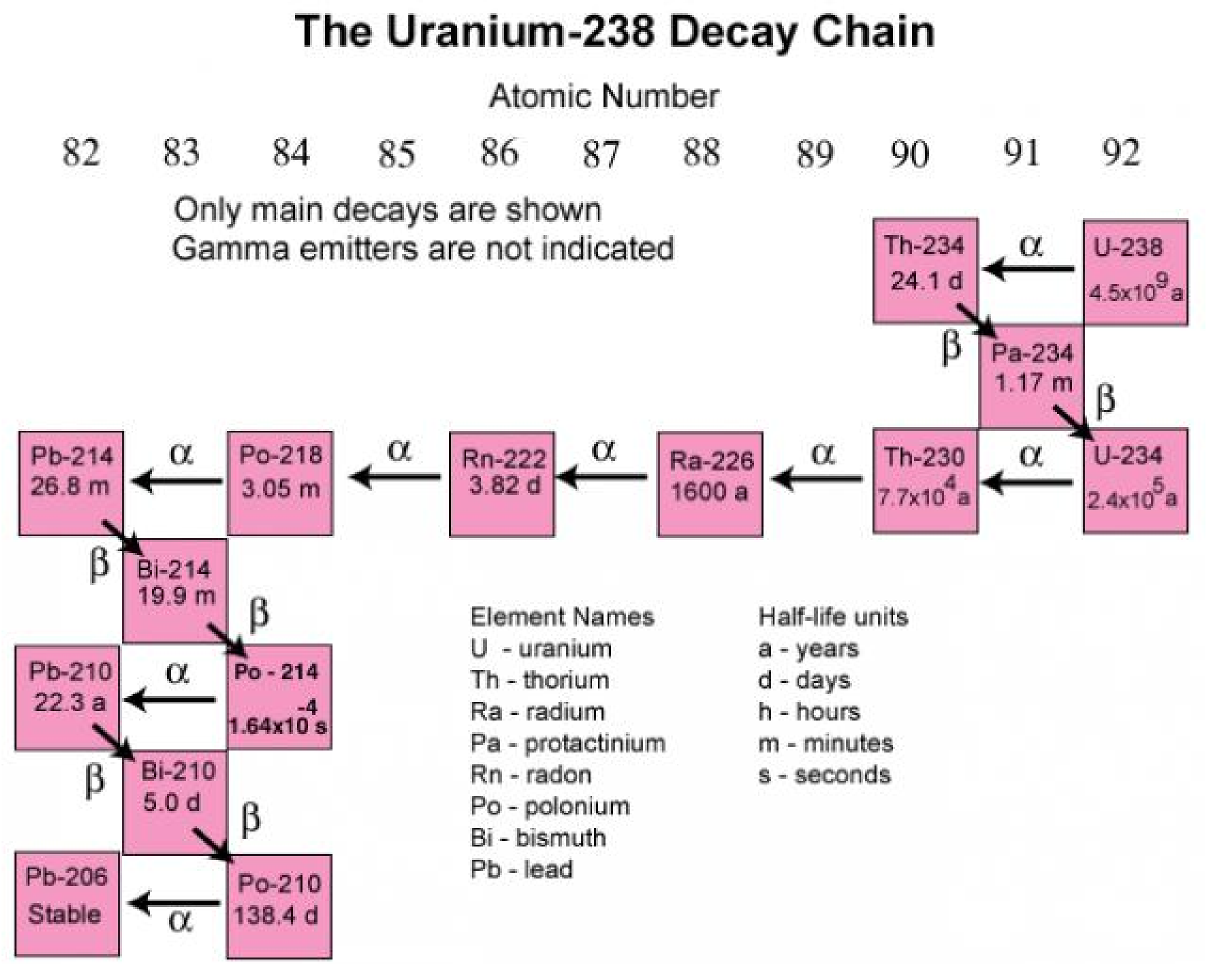


Fig 1.1: Uranium-238 decay chain (www.epa.gov)

The successive radioactive transformation continues up to stable lead (^{206}Pb) which is the last element of the decay series. Among these radon daughters, the alpha emitter's polonium (^{218}Po) and lead (^{214}Pb) contribute to the maximum of the radiation dose (over 90%) from exposure of radon. Radon is an inert gas; therefore, it is a noble gas. It is the last member of the noble gas family. Radon does not react with air, water, and others, but its decay daughters are electrically charged so that they are reactive and they are the cause of radiological health effects to humans. Radon is a radioactive gas that comes from the natural radioactive decay series of uranium in soil, rock, building materials, groundwater, and mining areas. Confined areas of the house such as basements where the air is not moving freely, some openings, and holes of the homes are also sources of radon. Different building materials such as cement, rock, concrete, marble, paints, and gypsum always contain uranium and radium. Nevertheless, the ground is the major radon sources. Up to several thousand Becquerel per liter (Bq/l), radon concentration can be measured in water from drilled wells. Radon reaches the surface of the Earth through emanation and exhalation. The radon atom which escaped from the mineral grain into the pore space undergoes decay within the recoil distance of the grain surface. In common minerals, water, and air, the recoil distance of radon (^{222}Rn) is (20–70) nm, 100nm, and 63µm, respectively. Radon atoms entering the pore space are then transported by diffusion and advection through this space until they in turn decay or are released into the atmosphere (exhalation). Radon generation and transport in porous materials involve the solid, liquid, and gas phases in the process of emanation, diffusion, advection, absorption in the liquid phase, and adsorption in the solid phase. The amount of radon atoms that is released into rock or soil pore space from a radium-bearing grain is called the emanation coefficient. The grain size and shape predominantly determine the emanation of radon in the soil. Radon decay products in the air become attached to the monodispersed and polydisperse aerosols due to their electrostatics nature. Depending on the aerosol concentration of the surrounding environment, the electrostatic charge of the radon progeny and humidity of the surrounding environment about 80% of the decay products will be attached to the aerosols in the air that we breathe in. It can be inhaled and emit radiation that bombards sensitive tissues in the lung causing DNA damage.

1.2 RADON AND ENERGY PRODUCTION

While radon is not mainly used as a source of energy production, it can act as a relevant product in the energy cycle as shown below;

1.2.1 Nuclear power production: Radon is the decay product of uranium and thorium, both of which are used as nuclear fuel in nuclear power plants. During nuclear fission, uranium and thorium atoms undergo radioactive decay, releasing radon gas as one of the by-products. Although radon is not the primary source of energy in this case, it is a relevant product in the nuclear energy cycle (EPA, 2023).

1.2.2 Geothermal power generation

Radon can be found in high concentrations in some geothermal areas. Geothermal energy harnesses the Earth's internal heat to generate electricity. In areas with high radon levels, radon can serve as an indicator of potential geothermal activity and help identify suitable locations for geothermal power plants (Cemil et al, 2010).

1.2.3 Radiation in generating equipment

The radioactive nature of radon can cause problems in some power generation equipment, especially in situations where natural gas or other hydrocarbons are used. Radon can be present in natural gas extracted from underground reservoirs and, if not managed properly, can lead to the accumulation of radioactive decay products in gas turbines or generators.

1.3 RADON AS A THERAPEUTIC AGENT

Despite the aforementioned risk associated with radon exposure, it is used as a therapeutic agent. In ancient history, the applications of “hot baths” as well as inhalation were basic medical principles applied to the treatment of inflammatory diseases. In the early 20th century, radon was discovered as a therapeutic agent in some hot springs (Deetjen et al, 2014, Becker, 2004) Thus, the rise of the so-called radon gymnasium began, and the application of radon to relieve pain caused by chronic degenerative diseases became widespread. Although there is only clinical experience, the results of several recent trials suggest a positive effect of radon treatment in relation to pain relief (Deetjen et al, 2014, Becker, 2004, Santos, 2016, Zdrojewicz, 2006). Currently, the main therapeutic application of radon is bathing in old mines or bathing in water containing radon. As the application procedures and indications for treatment expanded, EURADON (European Association of Radon Spas e.v.) was established and began to define indications for radon application, i.e. musculoskeletal and chronic pain diseases, as well as lung and gynaecological diseases (see Table 1.2).

Table 1.1: Some spa locations around the world.

Country	Place (city)
Austria	Bad Gastein, Bad Hofgastein, Bad Zell, Gasteiner Heilstollen
Bulgaria	Hisarja
Czech Republic	Jáchymov
Chile	Jahucl Hot Springs
China	Nanshui, Taishan
France	Plombiers
Greece	Ikaria, Polichnitos, Eftalou
USA	Boulder (Montana)

Above is Table 1.1 showing some selected spa locations around the world (Deetjen et al., 2014, Becker K, 2004, Zdrojewicz et al., 2006, Gillmore G.K, 2018).

Table 1.2: Disorders that results in therapeutic solutions by radon spas

Musculoskeletal disorders and chronic pain diseases	Ankylosing spondylitis and other spondyloarthropathies (AS) Arthrosis and osteoarthritis (OA) Degenerative diseases of the spinal column Auxiliary treatment consecutive to intervertebral disc operations Non-inflammatory soft tissue rheumatism (e.g., fibromyalgia)
Cutaneous disorders and diseases	Insufficiently healing wounds (e.g., ulcus cruris) Low grade circulatory problems of the skin
Pulmonary diseases	Asthma bronchial Chronic-obstructive pulmonary diseases (COPD)
Gynecological diseases	Paraclimactic and climacteric Disorders Pelvipethia spastica

Table 1.2 above shows the kind of disorders that is aided by the use of radon spas in bathing (Maier, A. et al., 2020).

Figure 1.2 showing the radon spa in Montana (USA). (Photo credit radonmine.com

1.4 Statement of problem

This review seeks to state the alarming effects of radon to the wellbeing of lives. The radiological health hazards of radon are not limited to the underground miners only; humans inside the buildings and houses are also exposed to radon and its decay products. The major parts of the Earth's crust consist of uranium; soils and various building materials containing uranium. The radon gas that emanates from building materials and soils can deposit in confined places such as buildings and houses; as a result, room occupants can easily inhale radon and its progeny. Radon in the indoor environment can be accumulated to significant levels. The types of construction materials of the building and the soil composition around the house determine the amount of indoor radon concentration. The emanation and diffusion of radon (^{222}Rn) gas that migrates to the house depends on those factors. The air pressure difference between the house and the soil causes the emanated radon gas to move from the soil to the house, that is, from high pressure to low pressure. The exhalation of ^{222}Rn is more in permeable soils, such as coarse sand and gravel than through impermeable soils, such as clays. The design, construction, and ventilation of the house are the major factors that determine the amount of indoor radon (^{222}Rn) concentration. The soil gas emanations from soils before decaying, off-gassing of waterborne ^{222}Rn into indoor air, building materials, and outdoor air are the major sources of radon in homes. In the indoor environment especially, confined spaces in houses and other buildings where air exchange is not allowed, radon and its daughters can be deposited to harmful levels. Because of its adverse health effect on human, one needs to act if the radon concentration exceeds the recommended action levels. With regard to this, according to the world health organization (WHO) report, continuous exposure to 100 Bq/m^3 radon concentrations from 1000 inhabitants, 13–50 persons will have a chance of inducing lung cancer. On the other hand, the International Commission for Radiation Protection (ICRP) recommends 200 Bq/m^3 as an action level. So, one should act to reduce its concentration. There are several radon mitigation methods in the indoor environment, including the sealing of cracks in floors and walls and adjusting the design of the building to change the flow of air into the building. Improving the ventilation of the house, sealing of cracks and other openings on the walls, improving the ventilation of the room, installing a radon pump system, opening of windows, doors, and vents of the house (called natural ventilation), and house pressurization. Using fan to blow air into the basement can reduce radon concentration. Improving the ventilation in radon prone region can help to reduce radon concentration to about 50%.

1.5 Justification of study

The subject of this study highlights the contribution of radon to the prevalence of lung cancer, and as the leading cause of lung cancer among non-smokers. It's a very important subject to examine closely because of its impact of which about 21,000 lung cancer death every year. And about 2,900 of these deaths occurs among people who have never smoked (United States environmental protection agency, EPA).

The fact that radon is a colourless, odourless gas makes it very difficult to detect except using special equipment. As a result of this, radon concentration can be high in our homes, offices and among miners without we knowing the amount of cancer causing substance that is been deposited on our lungs overtime. The study of radon is less researched, especially in our country Nigeria.

1.6 Aim and objectives of study

Aim

The aim of this study is to investigate the impact of radon on cellular metabolism and energy production, and its potential as a therapeutic agent for metabolism disorders.

Objectives

The objectives of these study are to:

1. Highlight clearly the health effect of radon exposure to cellular Metabolism
2. Model the data of radon concentrations in some selected Nigerian states
3. Explore the therapeutic effect of radon exposure

CHAPTER TWO

LITERATURE REVIEW

2.1 BACKGROUND ON RADON AND CELLULAR METABOLISM

Natural radioactive gas called radon is produced when uranium in soil, rocks, and water decays. Due to its alpha particle-emitting radon offspring, which can be absorbed and deposit in the pulmonary system, it is the second largest cause of lung cancer (National Research Council, 1999). The contribution of radon on cancer are well known, but in recent years, research has focused more and more on how it affects cellular metabolism.

Cellular metabolism describes the chemical reactions that take place inside of cells to ensure their survival and continued function. It involves numerous interrelated pathways that are involved in the synthesis of biomolecules, the production of energy, and the consumption of nutrients. In order for cells to develop, maintain, and repair themselves, energy and building blocks are essential (Alberts et al., 2002).

Radon exposure has been found to affect cellular metabolism, changing how energy is produced and how metabolic pathways work. Numerous researches have examined how radon affects cellular metabolism, concentrating on how it affects activities that produce energy, like mitochondrial activity and oxidative phosphorylation (Finkel & Holbrook, 2000; Misra & Fridovich, 1972). The fundamental energy source of the cell, ATP (adenosine triphosphate), can be affected by radon-induced disturbances in mitochondrial function, which can result in metabolic imbalances and cellular damage.

Inhaling radon gas does not actually pose any health risk to the metabolic process; the real danger comes from its progenies, Po-218 and Po-214 that are high alpha emitter (Oni *et al* 2012). The alpha particles get dangerous if they are inhaled or ingested into the body system through eating or drinking. The deposition of these alpha particles in the lungs can lead to damage in the DNA (oni et al, 2012; obed et al, 2012).

2.2 RADON: BIOPHYSICAL PROPERTIES AND SOURCES OF EXPOSTURE

Radon is a colourless, odourless, and tasteless radioactive gas that occurs naturally in the environment. It is formed through the decay of uranium and radium, which are found in varying concentrations in soil, rocks, and water sources (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

The biophysical properties of radon are important for understanding its behaviour and potential health effects. Here are some key points:

2.2.1 Radioactivity: Radon is a radioactive gas that emits alpha particles during its decay process. These alpha particles have a high ionizing power, making radon a significant source of radiation exposure (UNSCEAR, 2000).

2.2.2 Half-life: Radon-222, the most common isotope of radon, has a half-life of about 3.8 days. This relatively short half-life means that radon concentrations can vary over time, influenced by factors such as ventilation and geological characteristics (UNSCEAR, 2000).

2.2.3 Diffusion and solubility: Radon is highly diffusible, which means it can easily move through soil, rocks, and building materials. It can seep into indoor environments through cracks and gaps in foundations, walls, and floors. Radon is also soluble in water, and elevated levels can be found in groundwater sources (UNSCEAR, 2000).

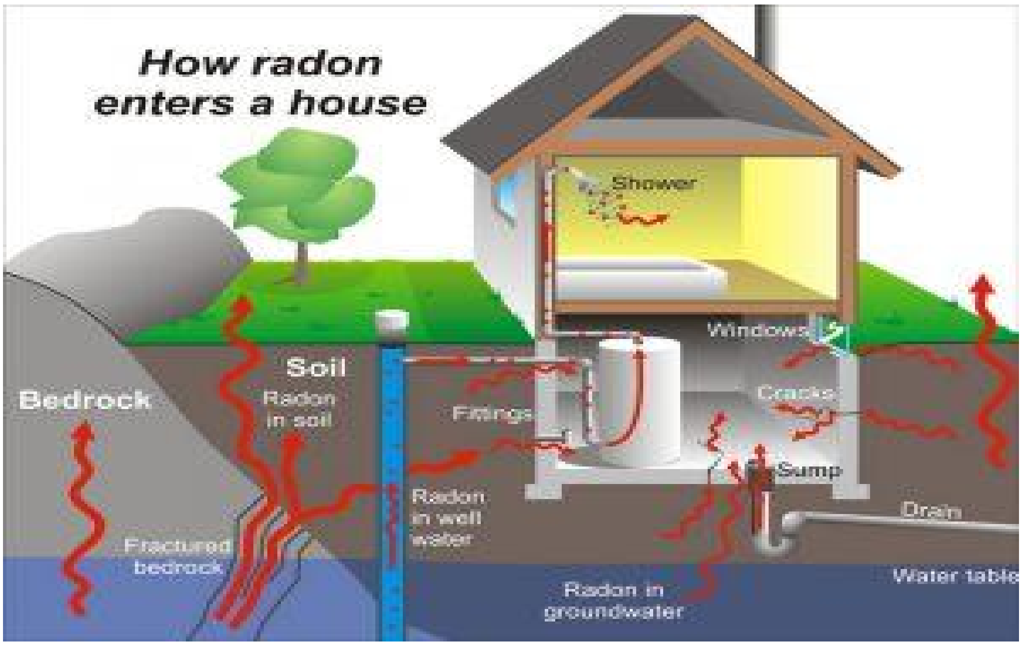


Fig 2.1: Mechanism of radon movement into a building

The diffusion coefficient of radon in air is influenced by several factors, including temperature, pressure, and the presence of other gases.

1. **Temperature**: The diffusion coefficient of radon in air generally increases with increasing temperature. Higher temperatures provide more energy to the radon molecules, leading to increased random motion and faster diffusion.
2. **Pressure:** Pressure affects the density and packing of gas molecules, which can influence the diffusion of radon. However, the effect of pressure on radon diffusion in air is relatively small compared to other factors.
3. **Presence of Other Gases:** The diffusion coefficient of radon in air can be affected by the presence of other gases. The diffusion process involves interactions between radon molecules and other gas molecules, which can hinder or facilitate the movement of radon. The composition of the gas mixture can influence the effective diffusion coefficient of radon.

2.2.4 Radon progeny: Radon undergoes a series of radioactive decay steps, producing short-lived decay products called radon progeny or radon daughters. These progenies attach to airborne particles and can be inhaled, contributing to the radiation dose to the respiratory system (UNSCEAR, 2000).

Sources of radon exposure include both indoor and outdoor environments. The primary sources include:

1. **Soil and rocks:** Radon are released from the soil and rocks, and it can accumulate in enclosed spaces such as basements and crawl spaces. The levels of radon in soil depend on the underlying geology and the presence of uranium and radium deposits (UNSCEAR, 2000).

2. **Building materials:** Radon can enter indoor environments through building materials, particularly those derived from natural sources such as concrete, bricks, and certain types of stone (UNSCEAR, 2000).
3. **Groundwater:** Radon can dissolve in groundwater, and when water containing radon is used for household purposes, such as bathing or washing, radon can be released into the indoor air (UNSCEAR, 2000).

Understanding the biophysical properties of radon and its sources of exposure is crucial for assessing the potential risks to human health and implementing appropriate mitigation strategies to reduce radon levels in indoor environments.

2.3 EFFECTS OF RADON ON CELLULAR METABOLISM

Natural radioactive gas like radon has the ability to affect cellular metabolism in a number of ways. Here are some of the main ways that radon affects cellular metabolism:

2.3.1 Oxidative stress: Radon and the by-products of its decay can cause cells to produce reactive oxygen species (ROS). Highly reactive chemicals known as ROS have the potential to induce oxidative stress, which can harm biological components like proteins, lipids, and DNA. By changing the activity of enzymes involved in metabolic pathways, oxidative stress distorts cellular metabolism (Kumar et al., 2018).

Radon exposure has been linked to mitochondrial malfunction, which can have a significant impact on cellular metabolism. Through oxidative phosphorylation and the Krebs cycle, mitochondria play a critical part in the creation of energy. These processes can be hampered by radon-induced mitochondrial damage, leading to decreased ATP production and disrupted metabolic homeostasis (Misra & Fridovich, 1972).

2.3.2 Changes in enzymatic activity: It has been discovered that exposure to radon affects the activity of a number of enzymes involved in cellular metabolism. For instance, studies have shown that radon exposure alters the activity of glycolytic enzymes such hexokinase and phosphofructokinase, which affects how the body processes glucose (Ferreira et al., 2020). Such changes in enzyme activity can interfere with metabolic processes and cause an imbalance in how nutrients and energy are used.

Radon exposure can result in DNA damage and genetic alterations, which may have an impact on cellular metabolism in the future. Metabolic deregulation can result from genetic changes that affect the expression and activity of enzymes involved in metabolic processes. Additionally, exposure to radon can result in epigenetic changes such DNA methylation and histone alterations, which can further affect cellular and gene expression and cellular metabolism (Ward, 2010).

2.3.3 Immune response and inflammation: Exposure to radon has been linked to immune system activation and inflammation. By changing the activity of metabolic enzymes and signalling pathways involved in energy metabolism, inflammatory processes and immunological responses can have a considerable impact on cellular metabolism (Yu et al., 2001).

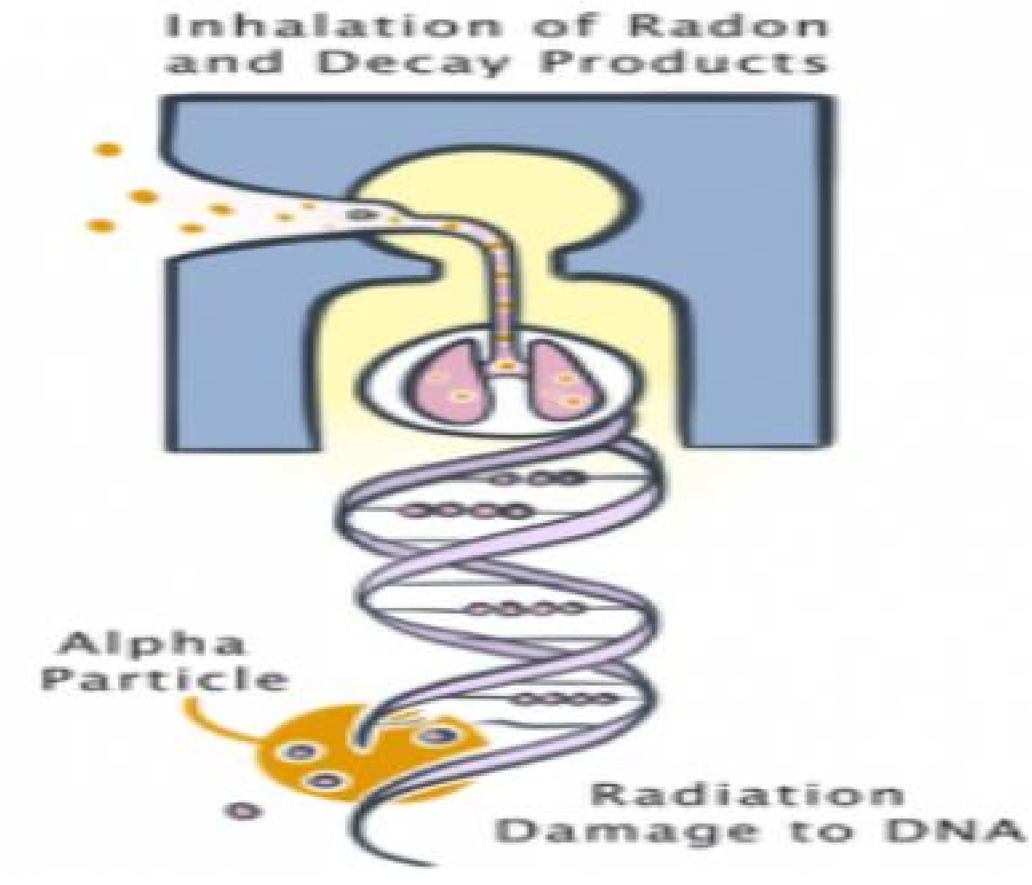


Fig 2.2: Inhalation of radon and its decay products through the respiratory tract.

2.4 RADON AND ENERGY PRODUCTION

Radon predominantly influences the generation of ATP through interactions with metabolic pathways that are involved in cellular energy production. Here are some crucial details:

2.4.1 Mitochondrial function: Mitochondria are the energy centres of the cell and are essential for oxidative phosphorylation, which is the process through which energy is produced. According to research by Misra and Fridovich (1972), radon exposure has been proven to disrupt mitochondrial function and reduce the synthesis of ATP.

2.4.2 Electron transport chain: Radon can disrupt the electron transport chain, a key component of oxidative phosphorylation. By interfering with electron flow, radon can hinder the generation of ATP molecules, impacting cellular energy levels (Misra and Fridovich, 1972).

2.4.3 Metabolic enzyme activity: Radon exposure has been found to influence the activity of various metabolic enzymes involved in energy production pathways. Alterations in enzyme activity can disrupt metabolic flux and lead to decreased ATP synthesis (Ferreira et al., 2020).

2.4.4 Oxidative stress: Radon exposure can induce oxidative stress within cells, which can directly affect energy production. Increased levels of reactive oxygen species (ROS) can damage components of the electron transport chain and impair ATP synthesis (Kumar et al., 2018).

2.5 RADON AS A THERAPEUTIC AGENT FOR METABOLSIM DISORDER

2.5.1 Radon treatment: Radon therapy, commonly referred to as radon balneotherapy, entails exposure to small quantities of radon gas in carefully regulated settings, such as mines, caves, or spas.

According to Hussain et al, (2017). Metabolic disorders are among the many medical diseases for which this therapy has traditionally been utilized as a treatment.

2.5.2 Modulation of cellular metabolism: It has been suggested that radon therapy can alter cellular metabolism by reducing inflammation and oxidative stress. Radon therapy has the ability to reduce metabolic dysfunctions linked to conditions like diabetes and obesity by modulating metabolic pathways and cellular signalling (Falkenbach et al., 2017).

2.5.3 Anti-inflammatory effects: Radon therapy has been reported to exhibit anti-inflammatory effects. Inflammation plays a critical role in metabolic disorders, and by reducing inflammation, radon therapy may contribute to the improvement of metabolic parameters (Sato et al., 2016).

2.5.4 Antioxidant properties: Radon and its decay products have been shown to possess antioxidant properties. Antioxidants can mitigate oxidative stress, which is implicated in metabolic disorders. Radon therapy may help restore redox balance and improve metabolic outcomes (Sato et al., 2016).

2.5.5 Clinical studies: Clinical studies evaluating the effects of radon therapy on metabolism disorders are limited but show promising results. For example, a study on patients with metabolic syndrome reported improvements in lipid profiles and glucose metabolism following radon therapy (Falkenbach et al., 2017).

CHAPTER THREE

MATERIALS AND METHODS

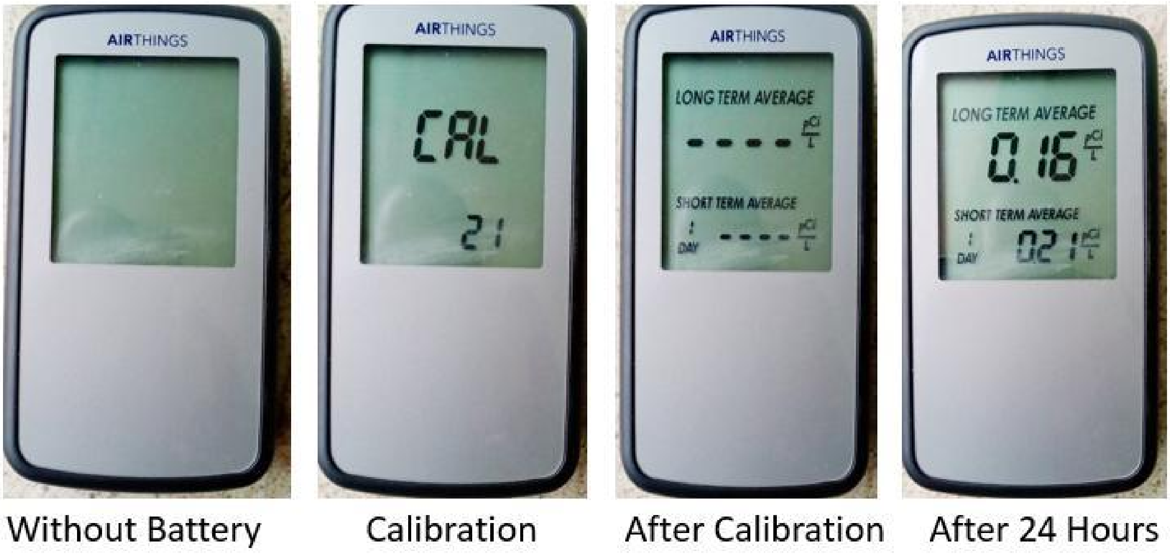
Due to the limited experimental resources like the Airthings radon monitor for measuring radon, already measured radon data is been cited from the publication of Garba Danjumma Sani et al, (2022).

The following equipment are used:

1. Airthings radon monitor
2. Excel worksheet
3. Python IDE (PyCharm)

3.1 Airthings radon monitor: The Airthings Radon Monitor is a popular device used for monitoring and measuring radon levels in indoor environments. It provides continuous monitoring and allows users to track radon levels over time. The Airthings Radon Monitor uses advanced sensors and technology to provide accurate and reliable measurements which can vary from daily, weekly and long-term concentration which the recorded data is measured on the LCD screen. The Airthings detector measures the concentration of radon in picocuries per litres (pCi/L), which is equivalent to 37 Bq/m^3. The pictorial view of the working of the Airthings detector is depicted below and their working conditions. The units in pCi/L is going to be converted to Bq/m^3, because Becquerel per meters is the standard unit for measuring radiation according to world health organization (WHO) and international commission on radiological protection (ICRP).

The Airthings detector measures radon concentrations both for short term average and long-term average.



Without Battery Calibration After Calibration After 24 Hours

Figure 3.1: Working conditions of Airthings detector

3.2 The Excel worksheet: The excel worksheet is used in entering data that is recorded by the Airthings radon monitor, and the data can then be filtered for modeling using python. The excel worksheet would also be used in carrying out some data analysis and virtualization of the acquired data.

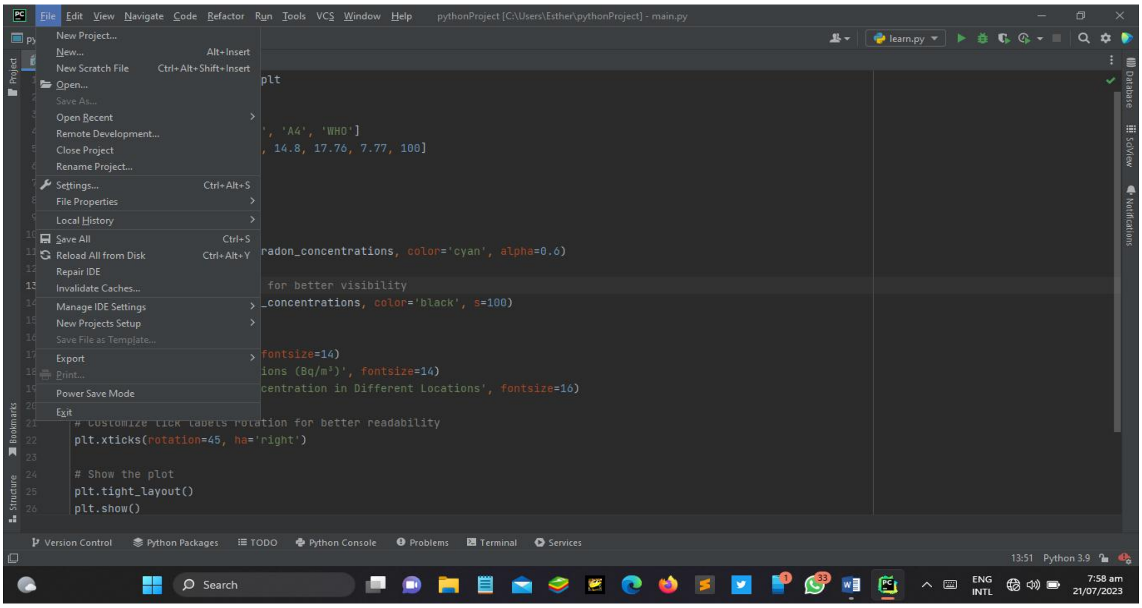
3.3 PYTHON IDE (PYCHARM): PyCharm is an integrated development environment used in running python coded language. It's easy to use and to deploying python codes into it. The PyCharm is integrated with python 3.0, that enables it run codes and to make them produce the required result.

3.4 Installing and activating PyCharm software: To install the integrated development environment that would be used for modeling our data, the following steps are used:

Step 1 Navigate to chrome browser or any other favorite browser and search for **www.jetbrains.com/pycharm/download/?section=windows** and then click on download to get the software for windows version

Step 2 install the software and complete the necessary setup, while the file extension is saved with .py

Step 3 we now have a working environment where we can write our code and run it, as shown in **figure 3.2** below. This can be done by creating a file in the new project section as shown below, and then the file name is named with main.py, while the python 3.0 extension is imported to the IDE.



```
plt

', 'A4', 'WHO']
, 14.8, 17.76, 7.77, 100]

radon_concentrations, color='cyan', alpha=0.6)

 for better visibility
_concentrations, color='black', s=100)

fontsize=14)
ions (Bq/m³)', fontsize=14)
centration in Different Locations', fontsize=16)

# Customize tick labels rotation for better readability
plt.xticks(rotation=45, ha='right')

# Show the plot
plt.tight_layout()
plt.show()
```

Figure 3.2: selecting new project and naming it with .py

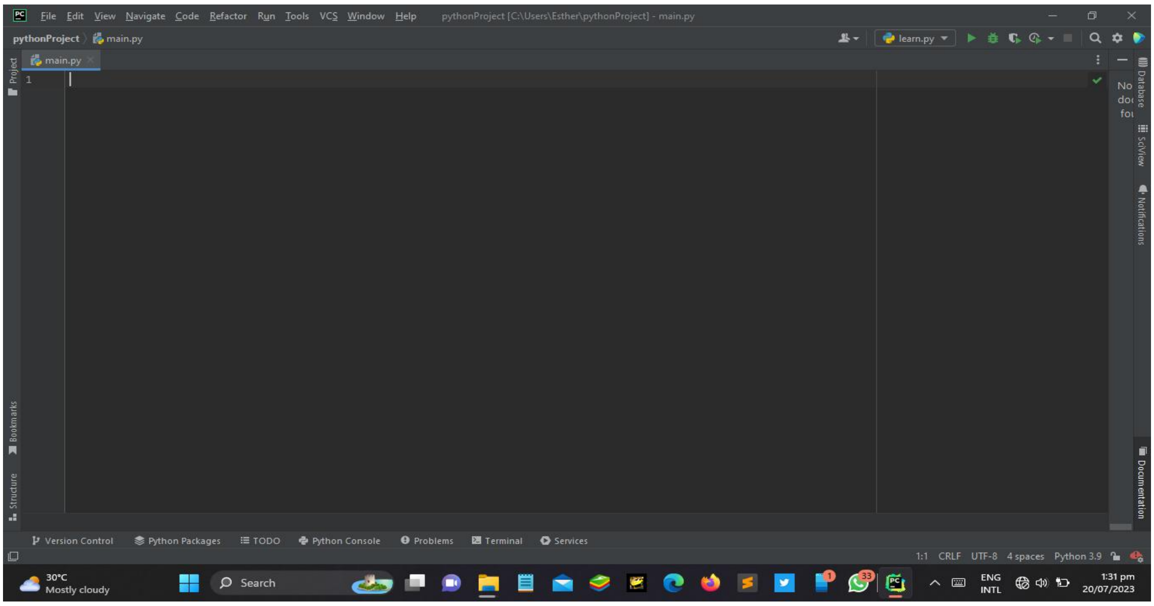
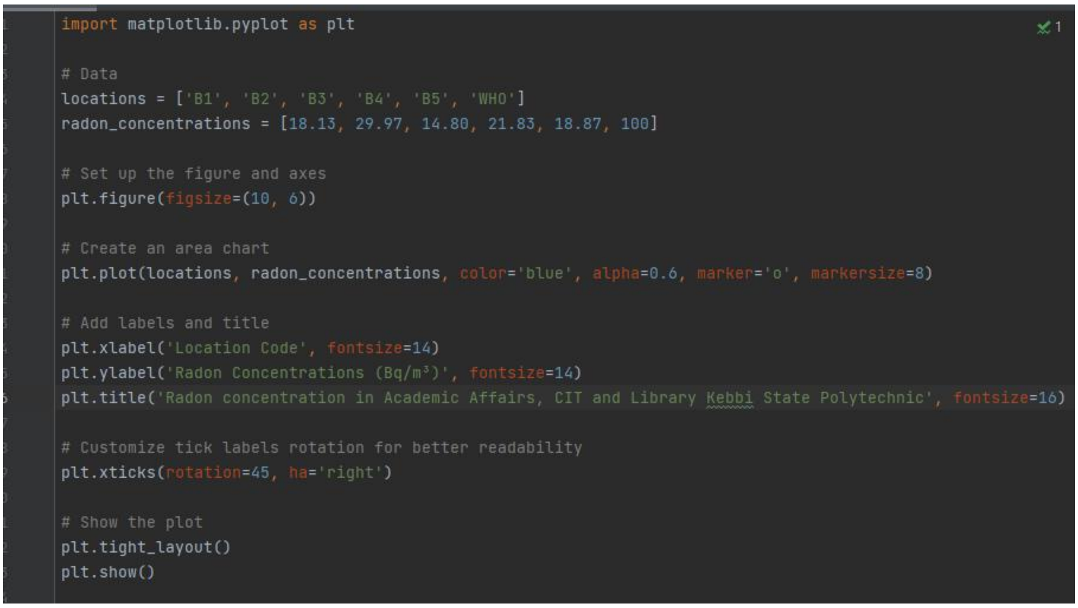


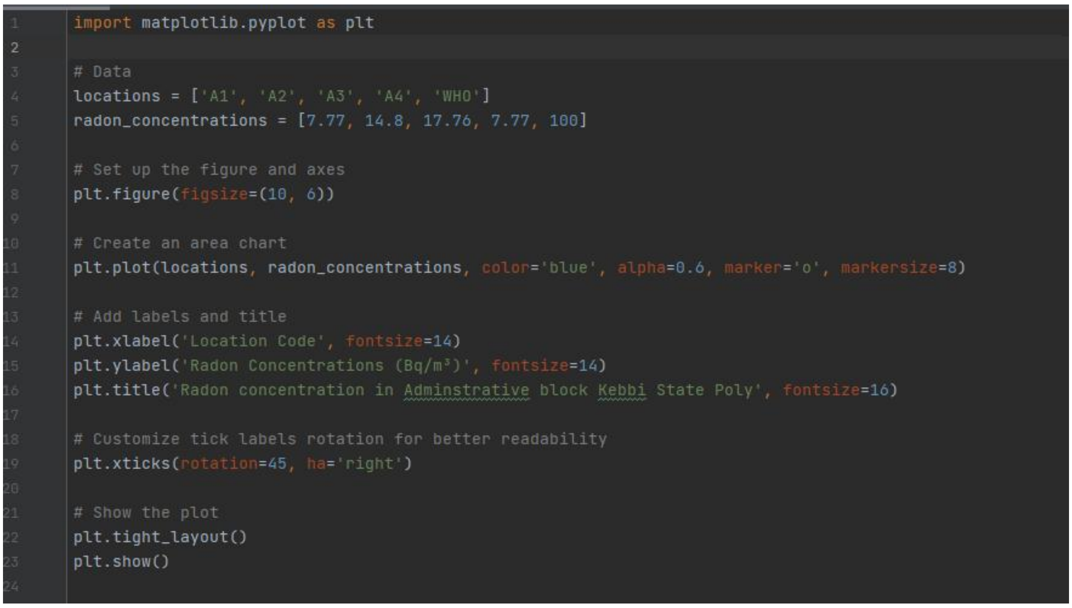
Fig 3.3: The working environment of PyCharm

Step 4 writing the python code that would produce a graphical representation of our first data which is drawn from (Garba Danjumma Sani et al 2022), representing the radon concentration in Kebbi state polytechnic, the offices at Students and Academic Affairs, CIT and Library.



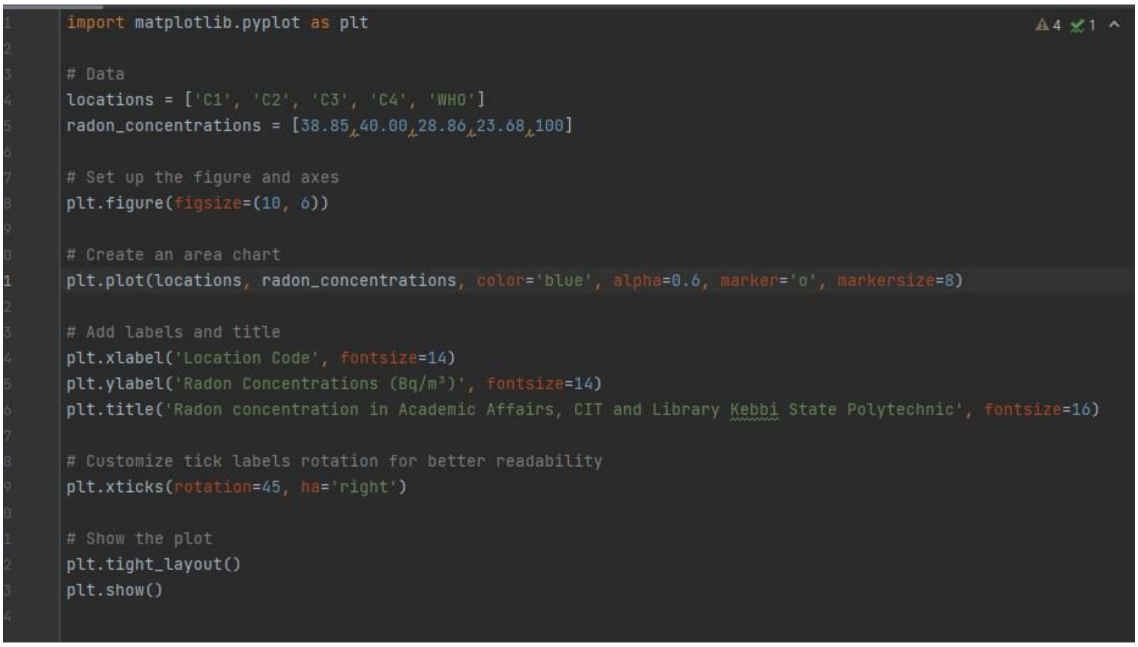
```python
import matplotlib.pyplot as plt

# Data
locations = ['B1', 'B2', 'B3', 'B4', 'B5', 'WHO']
radon_concentrations = [18.13, 29.97, 14.80, 21.83, 18.87, 100]

# Set up the figure and axes
plt.figure(figsize=(10, 6))

# Create an area chart
plt.plot(locations, radon_concentrations, color='blue', alpha=0.6, marker='o', markersize=8)

# Add labels and title
plt.xlabel('Location Code', fontsize=14)
plt.ylabel('Radon Concentrations (Bq/m³)', fontsize=14)
plt.title('Radon concentration in Academic Affairs, CIT and Library Kebbi State Polytechnic', fontsize=16)

# Customize tick labels rotation for better readability
plt.xticks(rotation=45, ha='right')

# Show the plot
plt.tight_layout()
plt.show()
```

Fig 3.4 python code for our first data set



```python
import matplotlib.pyplot as plt

# Data
locations = ['A1', 'A2', 'A3', 'A4', 'WHO']
radon_concentrations = [7.77, 14.8, 17.76, 7.77, 100]

# Set up the figure and axes
plt.figure(figsize=(10, 6))

# Create an area chart
plt.plot(locations, radon_concentrations, color='blue', alpha=0.6, marker='o', markersize=8)

# Add labels and title
plt.xlabel('Location Code', fontsize=14)
plt.ylabel('Radon Concentrations (Bq/m³)', fontsize=14)
plt.title('Radon concentration in Adminstrative block Kebbi State Poly', fontsize=16)

# Customize tick labels rotation for better readability
plt.xticks(rotation=45, ha='right')

# Show the plot
plt.tight_layout()
plt.show()

```

Fig 3.5: Code of the second data recorded from the administrative block



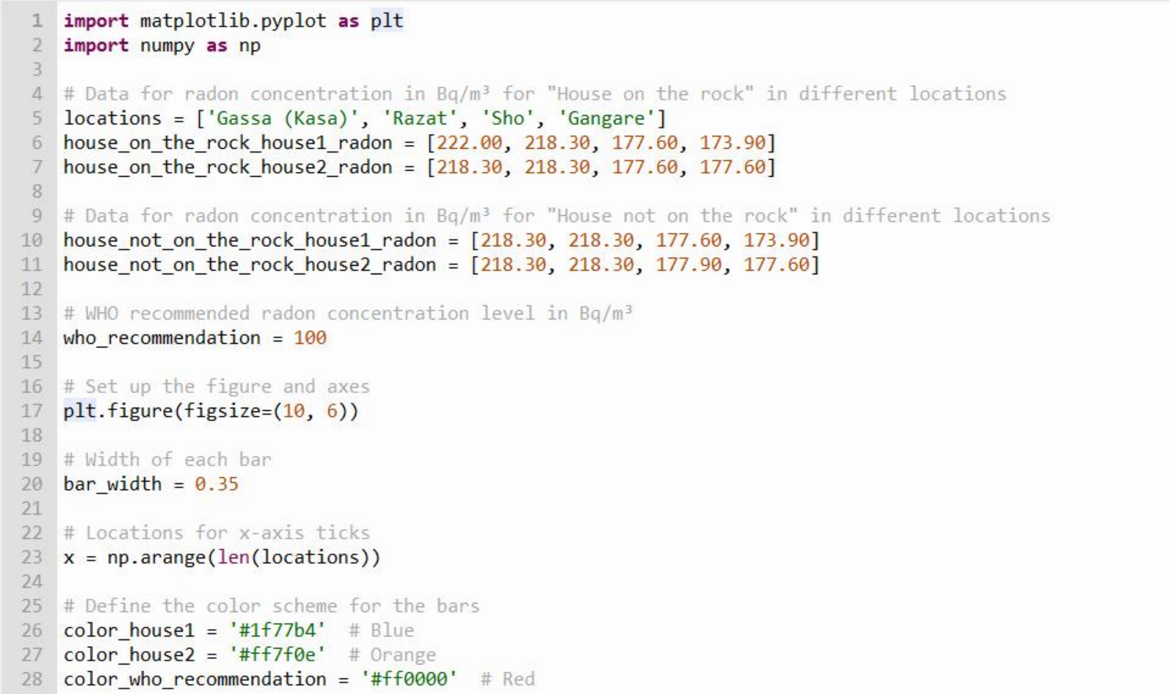
```python
import matplotlib.pyplot as plt

# Data
locations = ['C1', 'C2', 'C3', 'C4', 'WHO']
radon_concentrations = [38.85,40.00,28.86,23.68,100]

# Set up the figure and axes
plt.figure(figsize=(10, 6))

# Create an area chart
plt.plot(locations, radon_concentrations, color='blue', alpha=0.6, marker='o', markersize=8)

# Add labels and title
plt.xlabel('Location Code', fontsize=14)
plt.ylabel('Radon Concentrations (Bq/m³)', fontsize=14)
plt.title('Radon concentration in Academic Affairs, CIT and Library Kebbi State Polytechnic', fontsize=16)

# Customize tick labels rotation for better readability
plt.xticks(rotation=45, ha='right')

# Show the plot
plt.tight_layout()
plt.show()
```

Fig 3.6: Code for offices in the laboratories

Fig 3.6 shows the python code used to code the data of radon concentration in the offices in the laboratories in Kebbi state polytechnic with radon concentration in Becquerel per metre cube is plotted against C1 – C4 parameters.

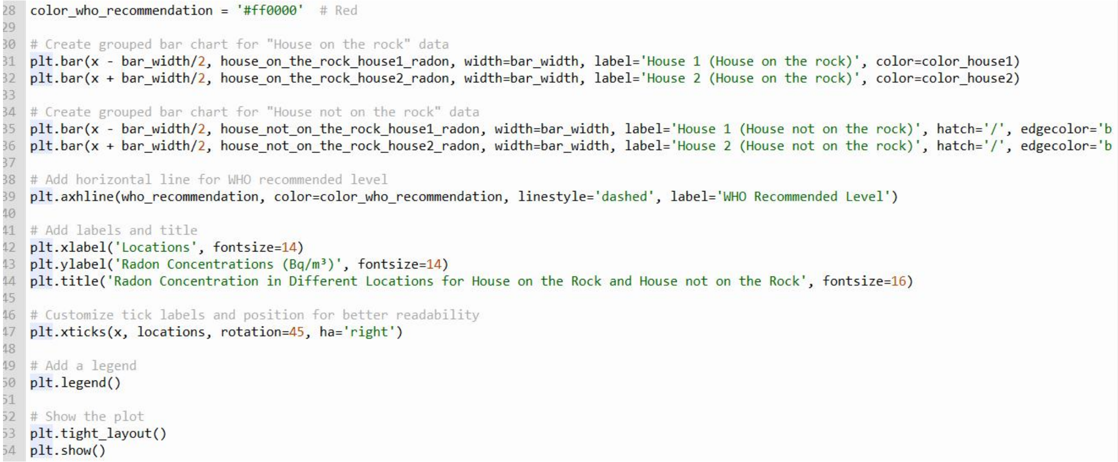
Also, radon concentration data measured in four areas in Nigeria (Chenko et al, 2019) is measured using a safety siren pro Series 3 radon gas detector an electronic device that provides instantaneous radon gas concentration in a place over a period of time was used to determine the concentration of 222Radon gas present in some residents in selected homes in community of Plateau State Nigeria. The safely siren pro radon gas detector is powered by a standard 111-120 DC battery. The device has a numeric led display which shows the level of radon gas in Pico curies per litter of air (pCi/L). The detector was kept in a sitting room where it cannot be disturbed, at least three feet away from doors, windows and walls of the building for about 1hr 30mins. After which the reading displayed on the numeric led of the siren pro detector was read in pCi/L.

The data recorded by the detector is collected and analysed using python code running on a Thorny IDE software as shown in figure (3.7) below, and also showing the python code that is used to present the data gotten from the four different locations in Jos Nigeria.



```python
import matplotlib.pyplot as plt
import numpy as np

# Data for radon concentration in Bq/m³ for "House on the rock" in different locations
locations = ['Gassa (Kasa)', 'Razat', 'Sho', 'Gangare']
house_on_the_rock_house1_radon = [222.00, 218.30, 177.60, 173.90]
house_on_the_rock_house2_radon = [218.30, 218.30, 177.60, 177.60]

# Data for radon concentration in Bq/m³ for "House not on the rock" in different locations
house_not_on_the_rock_house1_radon = [218.30, 218.30, 177.60, 173.90]
house_not_on_the_rock_house2_radon = [218.30, 218.30, 177.90, 177.60]

# WHO recommended radon concentration level in Bq/m³
who_recommendation = 100

# Set up the figure and axes
plt.figure(figsize=(10, 6))

# Width of each bar
bar_width = 0.35

# Locations for x-axis ticks
x = np.arange(len(locations))

# Define the color scheme for the bars
color_house1 = '#1f77b4'  # Blue
color_house2 = '#ff7f0e'  # Orange
color_who_recommendation = '#ff0000'  # Red
```

Fig 3.7: Showing the python code used to represent data from Jos



```python
color_who_recommendation = '#ff0000'  # Red

# Create grouped bar chart for "House on the rock" data
plt.bar(x - bar_width/2, house_on_the_rock_house1_radon, width=bar_width, label='House 1 (House on the rock)', color=color_house1)
plt.bar(x + bar_width/2, house_on_the_rock_house2_radon, width=bar_width, label='House 2 (House on the rock)', color=color_house2)

# Create grouped bar chart for "House not on the rock" data
plt.bar(x - bar_width/2, house_not_on_the_rock_house1_radon, width=bar_width, label='House 1 (House not on the rock)', hatch='/', edgecolor='b
plt.bar(x + bar_width/2, house_not_on_the_rock_house2_radon, width=bar_width, label='House 2 (House not on the rock)', hatch='/', edgecolor='b

# Add horizontal line for WHO recommended level
plt.axhline(who_recommendation, color=color_who_recommendation, linestyle='dashed', label='WHO Recommended Level')

# Add labels and title
plt.xlabel('Locations', fontsize=14)
plt.ylabel('Radon Concentrations (Bq/m³)', fontsize=14)
plt.title('Radon Concentration in Different Locations for House on the Rock and House not on the Rock', fontsize=16)

# Customize tick labels and position for better readability
plt.xticks(x, locations, rotation=45, ha='right')

# Add a legend
plt.legend()

# Show the plot
plt.tight_layout()
plt.show()
```

Fig 3.8: Python code used to represent data from Jos

The annual absorbed dose of radon is calculated using the highest radon concentration measured in the calculated states in Nigeria.

Annual absorbed dose rate, D (msv/y) was calculated from measured radon concentration

$$D\ (AB) = K_{Rn}\, DC_f\, F_{eq}\, O_f\, T_{th} \ldots\ldots\ldots\ldots\ldots\ldots \text{Equ (3.1)}$$

Where: K_{Rn} = radon concentration

DC_f = dose conversion factor

F_{eq} = equilibrium factor

O_f = occupancy factor

T_{th}= number of hours per year

For a 218Bq/m3, the annual absorbed dose was calculated to be 2.75msv/y

The annual absorbed dose helps to check for the radon concentration in a location with respect to the number of hours the occupant spends in that location over a given period of time, and rate of radon inhalation and accumulation in the organism over a period of time, specifically over a period of one year.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RADON CONCENTRATION IN KEBBI, NIGERIA

Below (Table 4.1) is the data obtained at the offices of the students and Academic Affairs, CIT and Library Kebbi State Polytechnic Dakingari, Nigeria.

Table 4.1: Data from CIT, Kebbi Polytechnic

S/N	Location codes	Geographical position	Radon conc (pCi/L)	Radon conc (Bq /m^3)
1	B1	11.665741, 4.063762	0.49	18.13
2	B2	11.646888, 4.044548	0.81	29.97
3	B3	11.666844, 4.063473	0.40	14.80
4	B4	11.666056, 4.064323	0.59	21.83
5	B5	11.665220, 4.063922	0.51	18.87
	Avr + SD		0.56 ± 0.16	20.72 ± 5.92

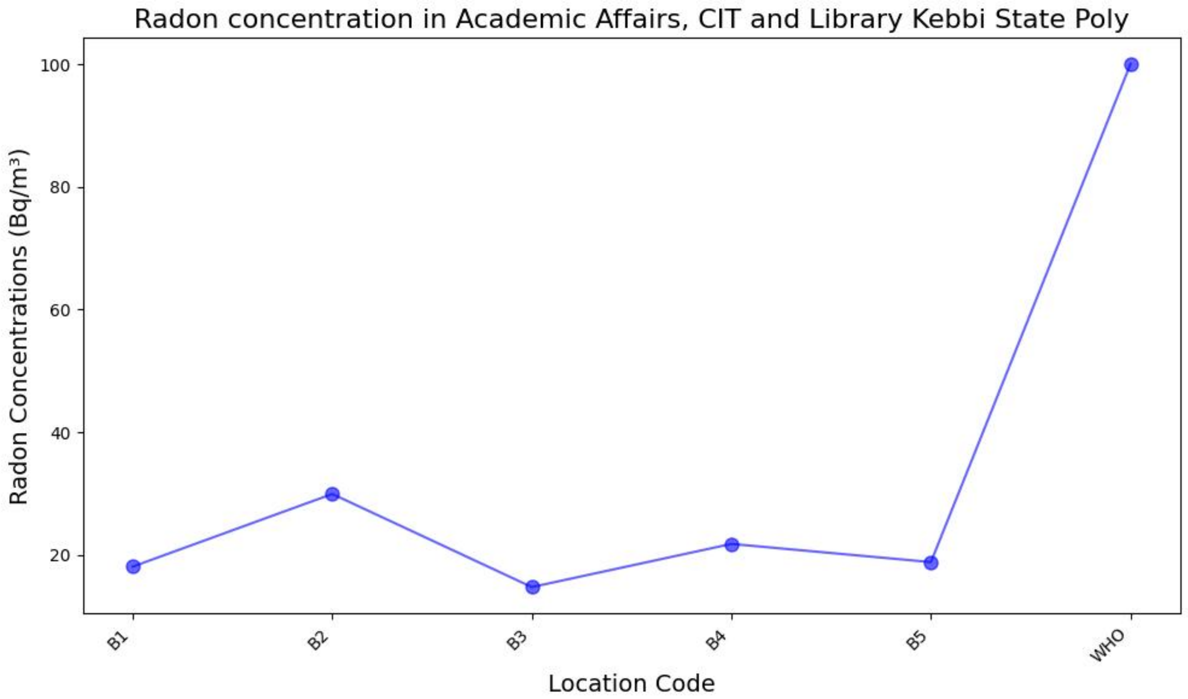


Fig 4.1: Analysis from CIT comparing with WHO recommended limit

WHO recommended level = 100Bq/m^3 Result when the data is analysed with some python selected data analysis libraries.

Figure 4.1 Comparison of Radon Concentration in CIT in Kebbi state polytechnic and WHO Recommended Radon level.

Comparing the result obtained with the radon level set by WHO, by which the minimum radon level recorded in the offices is 14.80 Bq/m^3 and the maximum recorded value is 29.97 Bq/^{3}, which is quite below the recommended radon level by WHO. So, those occupants in these offices are exposed to less radon concentration.

Table 4.2 shows the radon concentration in the Administrative block of Kebbi state polytechnic.

S/N	Location codes	Geographical position	Radon conc (pCi/L)	Radon conc (Bq /m^3)
1	A1	11.665741, 4.063762	0.21	18.13
2	A2	11.665659, 4.063924	0.40	29.97
3	A3	11.665847,4.062992	0.48	14.80
4	A4	11.665859, 4.063723	0.21	21.83
	Avr + SD		0.33 ± 0.14	12.03 ± 5.06

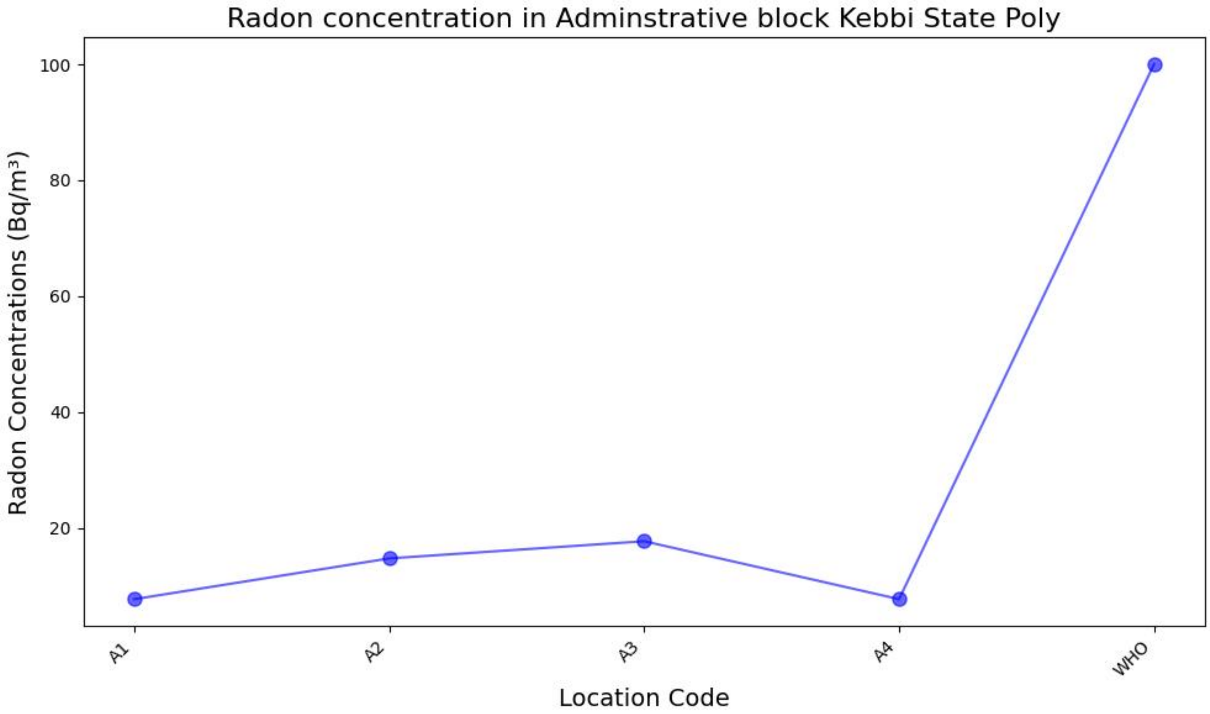


Fig 4.2: Showing the data of Radon level in administrative block of Kebbi state polytechnic.

The minimum radon level recorded is 7.77Bq/m^3

And the highest level of radon recorded was 17.76Bq/m^3

Table 4.3 showing the data of radon concentration in the offices in the laboratories.

S/N	Location codes	Geographical position	Radon conc (pCi/L)	Radon conc (Bq /m^3)
1	C1	11.665847, 4.062992	1.05	38.85
2	C2	11.646966, 4.04445	1.10	40.00
3	C3	11.666310, 4.064427	0.78	28.86
4	C4	11.666138, 4.064225	0.64	23.68
	Avr + SD		0.89 ± 0.22	32.85±7.90

Figure 4.3 shows the data of radon concentration in offices in the laboratories in Kebbi state polytechnic, from the line chart the highest radon concentration is in the C2 location which has a radon concentration of 40.00Bq/m^3 and the lowest concentration in C4 location showing a radon concentration of 23.68Bq/m^3. From my analysis, those at the C4 location will be more exposed to radon than those in the C4 location, and the radon concentration is still within a considerable limit, comparing with WHO recommended radon level which is 100Bq/m^3.

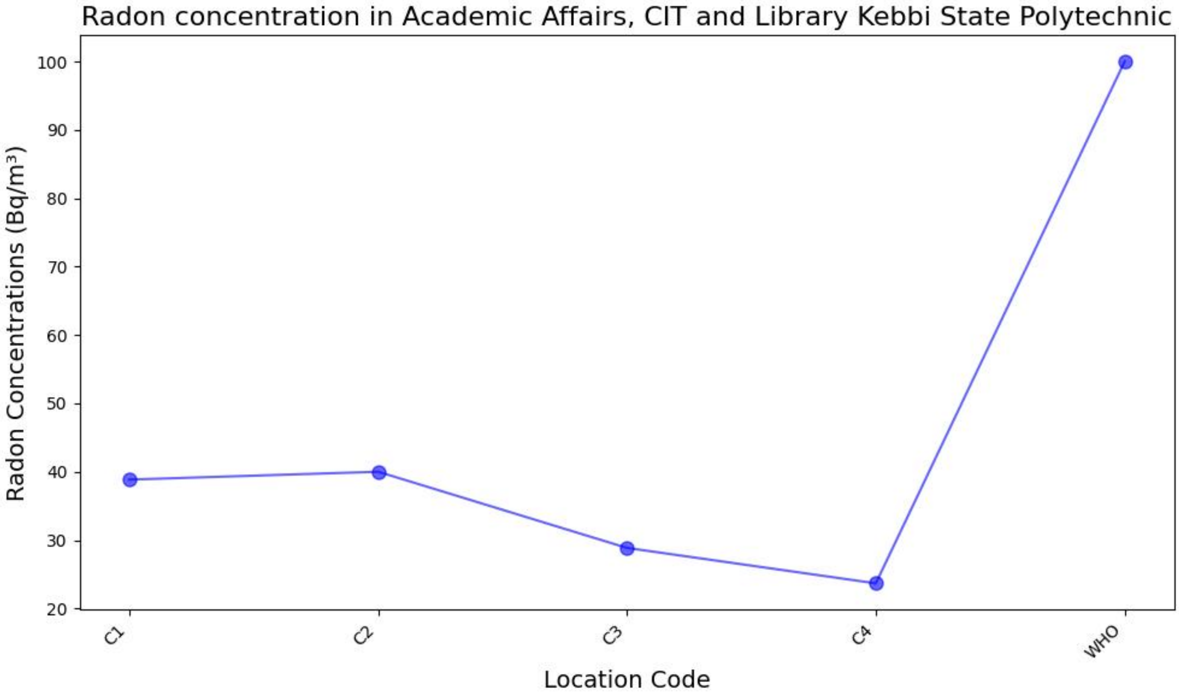


Fig 4.3: Analysis of radon concentrations in offices in the laboratories.

Table 4.4: Data of radon concentration academic department

S/N	Location codes	Geographical position	Radon conc (pCi/L)	Radon conc (Bq /m^3)
1	D1	11.667180, 4.063560	0.64	24.79
2	D2	11.666780, 4.063463	0.94	34.78
3	D3	11.666890, 4.063324	0.70	25.90
4	D4	11.666825, 4.063299	0.32	11.84
5	D5	11.666878, 4.063687	0.51	18.87
AVR ± SD	0.62±0.23		23.24 ± 8.54	

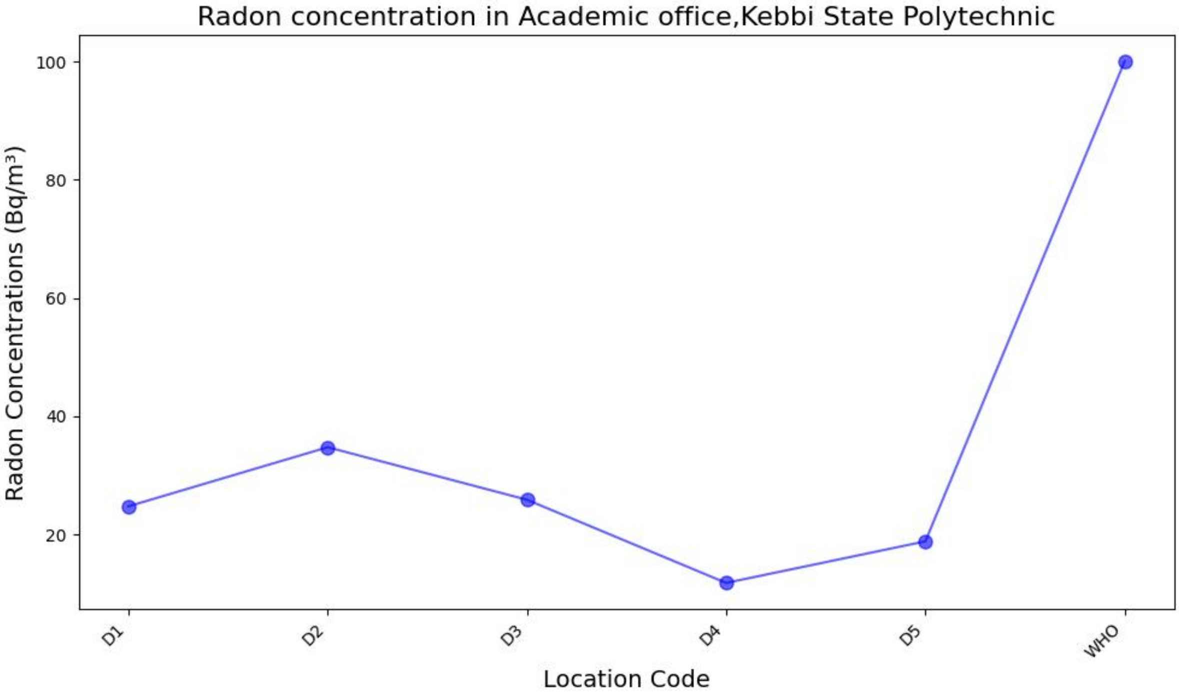


Fig 4.4: Analysis of radon concentration in the academic department

From Figure 4.4 above, the location with the highest radon exposure is D2, and the location with the lowest radon concentration is D4 which is far less than the recommended radon level by WHO which is 100Bq/m^3. A python modeled data showing the line chart of table 4.4 is shown above, showing the graph of radon concentration in the academic department of Kebbi state polytechnic to that of the WHO recommended level.

From the above radon concentration collated in Kebbi state polytechnic from the academic department, we would observe that the radon concentration is quite below the radon concentration recommended level by WHO which is 100Bq/m^3. Radon concentration from these regions above can be better reduced by increasing ventilation in the building. So, radon gas concentration would reduce to its minimum level.

The following results shown above represent the data gotten from Kebbi state polytechnic, from all indications, the measured radon level from the four (4)

Different location is less than WHO recommended level, as a result of this, occupants within these locations would be less exposed to radiation.

Data two

These gathered data would be compared with that measured in Jos Nigeria by Chenko et al, (2019) by which radon concentration is collected in four different location which are; Gassa (Kassa), Razat, Sho and Gangare. The resulting radon concentration can vary with temperature in different locations (ICRP).

4.2 RADON CONCENTRATION IN JOS NIGERIA

Here are the data collected from the four different locations in Jos, Nigeria.

Table 4.5: Radon concentration in the above designated area in Jos

Location	House on the rock	Pci/L	Bq/m3	House not on the rock	Pci/L	Bq/m3
Gassa (Kasa)	House 1	6.00	222.00	House 1	5.90	218.30
	House 2	5.90	218.30	House 2	5.90	218.30
Razat	House 1	5.90	218.30	House 1	5.90	218.30
		5.90	218.30	House 2	5.90	218.30
Sho	House 1	4.80	177.60	House 1	4.80	177.60
	House 2	4.80	177.60	House 2	4.70	173.90
Gangare	House 1	4.70	173.90	House 1	4.70	173.90
	House 2	4.80	177.60	House 2	4.70	173.90

The data below represents the analysed data with python of table 4.5 above, a well detailed bar chart is reproduced with the aid of python coded language in figure 4.5 below.

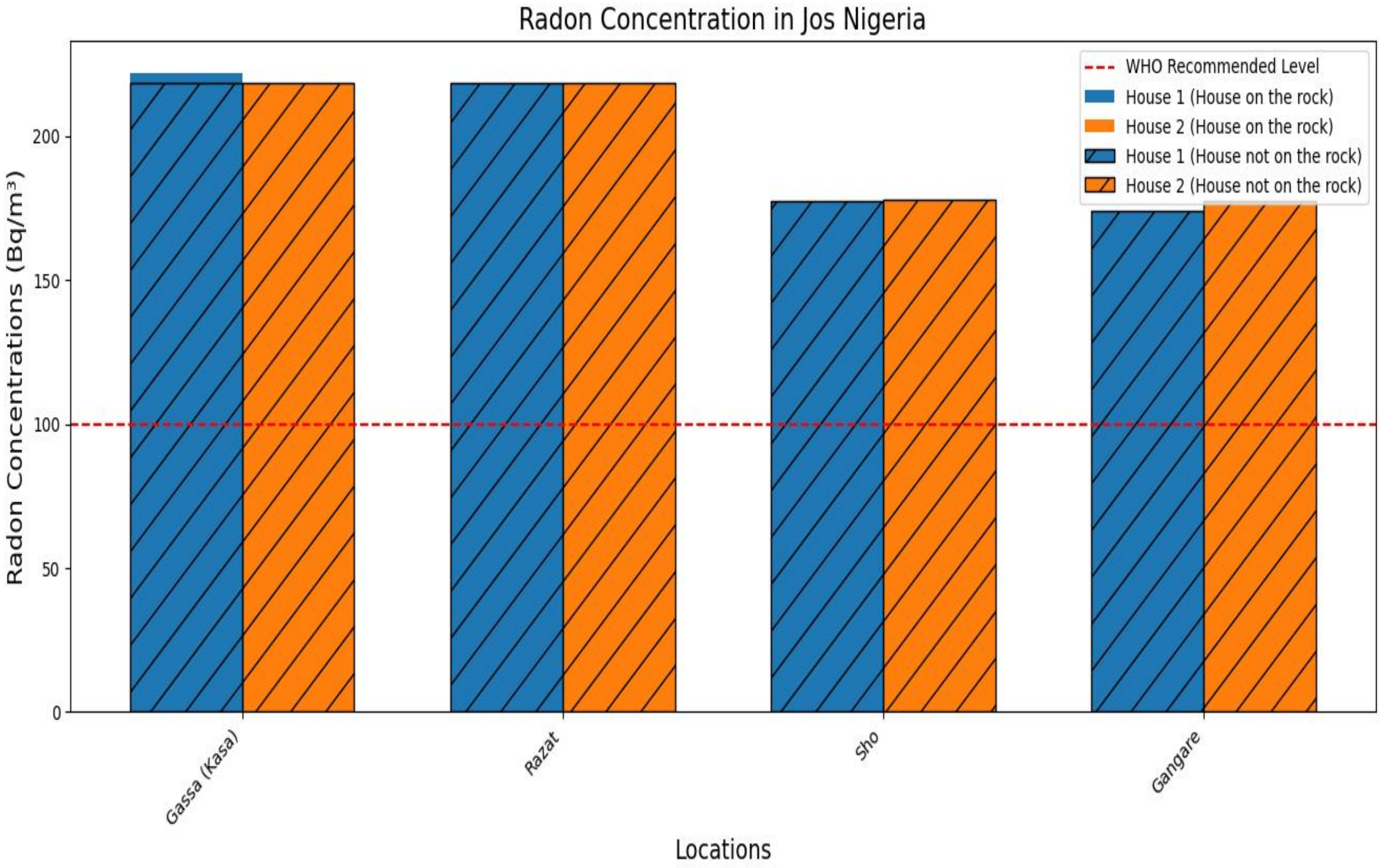


Fig 4.5: Bar chat of radon concentration in some selected areas in Jos, Nigeria.

The dotted line represents the WHO recommended radon limit and it is pegged at 100Bq/m3.

4.3 CUMMULATIVE RADON CONCENTRATION IN KEBBI, NIGERIA

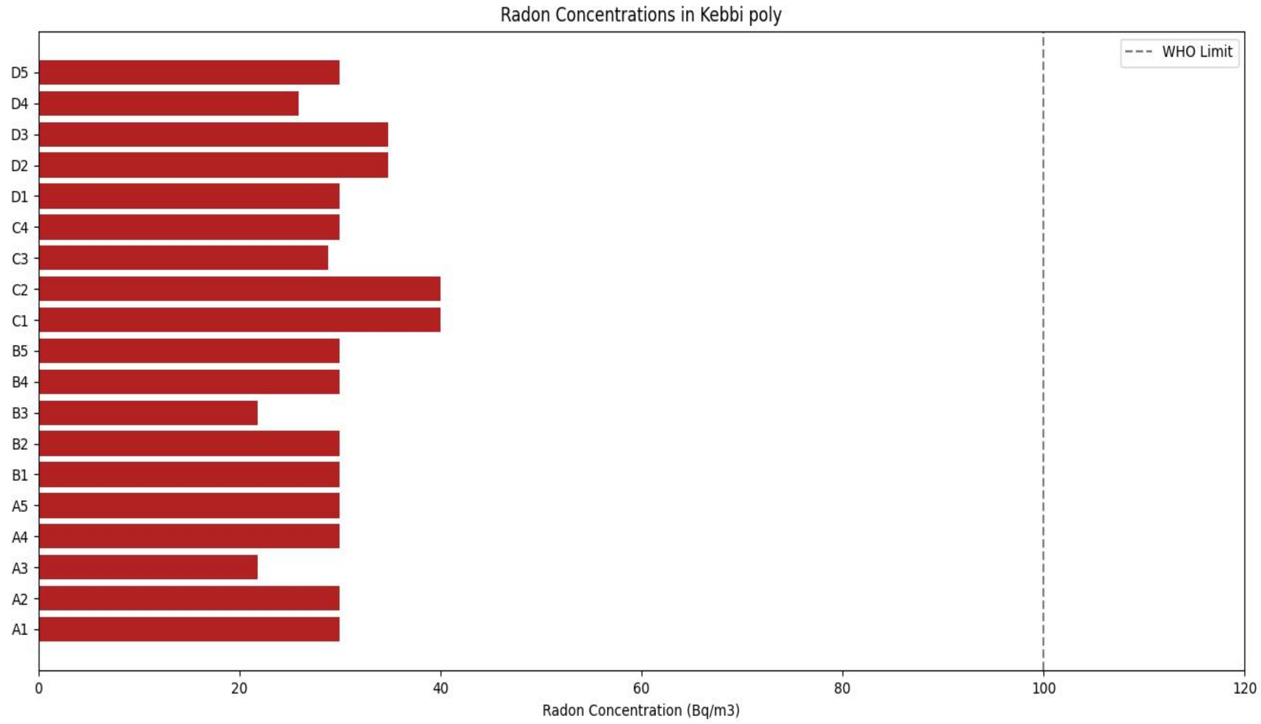


Fig 5.5: cumulative radon concentration in A1 to D5 locations in Kebbi state polytechnic

From the above, comparing the radon concentration from Kebbi state polytechnic and some selected area in Jos Nigeria, we would observe that the maximum radon concentration from Kebbi state given as 40.00Bq/m^3 is quite below the radon recommendation limit given by WHO of 100Bq/m^3 and that for Jos recorded as 218.30Bq/m^3 is far above the WHO recommended level. From the above, we would observe that those staying around the area of Jos recording the aforementioned radon concentration would be exposed to harmful radon gas concentration in the surrounding air, which can result to alpha decay deposition into their lungs, which in turn would result to lung cancer on a long run.

CHAPTER FIVE

CONCLUSION

In these studies, the Airthings detector and the siren pro Series 3 radon gas detector were used to study the indoor radon concentrations in locations in Kebbi state and plateau state respectively, all in Nigeria. It is observed that radon concentration measured in Kebbi state and that measured in Jos Nigeria varies, which could be as a result of temperature variations between the two different locations, and the type of soil that made up the specific study locations. Changes in temperature can affect pressure in the ground, leading to changes in radon mobility. In addition, lower temperatures generally lead to higher condensation, which can limit radon diffusion, thereby causing high concentration of radon, accounting to the case of Jos area of Nigeria.

The alarming rise in lung cancer cases is of researcher's greatest concern, and with the help of emerging technologies to study the causes of these lung cancer is emerging gradually, due to the role radon gas plays as one of the major causes of lung cancer, it is of researcher's concern to dig dip into a way of reducing one of these major causes of lung cancer, which is the Radon gas.

Educating occupants of the radon concentrated areas as we have that of Plateau state, Nigeria from our study would go a long way in putting up measures that would help reduce the concentration of radon in that area to it's minimal.

From the graphs generated from Kebbi state polytechnic also shows some amount of radon concentration in that particular area, and comparing with WHO recommended limit, those areas are still quite considerable and would pose no harm to its occupants on a long run.

5.1 RECOMMENDATIONS

To combat the rising cases of radon gas carcinogens in Nigeria, the individuals should be encouraged to make use of some of these radon meters to make measurements of radon concentrations in their homes, especially those buildings that are located in cold and rocky regions.

The room should always be kept ventilated to ease the radon in the room, this also calls for the attention of the Architect to design homes that would have easier than confined ventilation.

The government should play a role in educating the individual on the effect of radon gas so appropriate measures would be taken.

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