



ISSN: 1117-1669  
e-ISSN: 2971-7841

*Journal of Science Education and  
Humanities (JOSEH), 2024, Vol. 8 (2):  
November, 2024. Full-text Available Online at  
<https://www.akscoejoseh.org.ng>*



## **Assessment of Radiological Emission Risks and Safety in Residential and Occupational Areas of Akwa Ibom State, Nigeria**

<sup>1</sup>Ekanem, C. H., <sup>2</sup>John, D. E. & <sup>\*3</sup>Osu, S. R.

<sup>1&2</sup>Department of Physics, College of Education Afaha Nsit, P.M.B. 1019 Etinan, Akwa Ibom State, Nigeria.

<sup>\*3</sup>Department of Biology, Directorate of Degree Programme, College of Education Afaha Nsit, (Affiliated to the University of Uyo, Nigeria) P.M.B. 1019 Etinan, Akwa Ibom State, Nigeria.

\*Corresponding Author Email: [samuelrobert2007@yahoo.com](mailto:samuelrobert2007@yahoo.com), Tel: +2348028260825

### **Abstract**

This study assessed radiological emission risks in residential and occupational environments in Akwa Ibom State, Nigeria. Gamma radiation and radon concentration measurements were taken across urban, suburban, and rural residential areas, as well as industrial zones and oil refineries. Industrial areas, particularly Onna and Qua Iboe, recorded the highest gamma radiation levels. Radon concentrations were elevated in industrial and suburban residential areas, with Eket exceeding public exposure limits, resulting in an annual effective dose of 1.45 mSv/year. Occupational environments had higher radiation levels than residential areas but remained within regulatory limits. Mean gamma radiation levels in residential areas ranged from 0.05 to 0.15  $\mu\text{Sv/h}$ , while occupational settings recorded 0.20–0.50  $\mu\text{Sv/h}$ . The highest total effective dose of 6.20 mSv/year was found in Onna's industrial area, though still within occupational exposure limits. Statistical analysis confirmed significant differences between residential and occupational exposures (p-values: gamma radiation = 0.004, radon = 0.002, effective dose = 0.003). Most residential environments met safety standards, except Eket, which exceeded regulatory limits. While occupational settings complied, they required enhanced safety measures due to higher exposure levels. The study concluded that while most areas met radiological safety standards, certain suburban residential and industrial occupational settings required improved monitoring and mitigation. Recommendations included radon mitigation in high-risk areas, stricter workplace safety protocols, and increased public awareness. Continuous radiological monitoring, government intervention, and improved safety measures are essential to safeguard public and occupational health. Future research should explore long-term exposure effects and advanced radiation mitigation technologies.

**Keywords:** Radiological Emission, Occupational Exposure, Residential Environments, Ionizing Radiation, Radiological Hazard Index, Natural Radioactivity

## INTRODUCTION

Radiological emissions from both natural and human-made sources continue to be a global concern due to their potential effects on public health and the environment. Ionizing radiation, which includes alpha, beta, and gamma rays, can pose serious health risks when individuals are exposed to high levels over extended periods. The consequences of such exposure can range from acute radiation sickness to long-term effects such as cancer and genetic mutations.

In many developing regions, including Nigeria, there is limited data on radiological emission levels in residential and occupational environments. This lack of information is particularly concerning as industrial activities, urbanization, and the use of radioactive materials in sectors like healthcare, oil exploration, and manufacturing continue to rise. Akwa Ibom State, located in southern Nigeria, has substantial industrial activity, particularly in oil and gas production. These activities have raised concerns about the potential radiological hazards they may introduce into the environment.

The International Atomic Energy Agency (IAEA, 2021) emphasizes the need for regular monitoring and assessment of radiological emissions in residential and occupational settings to ensure public safety. Research has shown that even low levels of radiation, if exposure is prolonged, can have cumulative effects, highlighting the importance of effective radiation risk management. Additionally, the International Commission on Radiological Protection (ICRP, 2007) recommends stringent measures for monitoring radiation exposure, particularly in occupational settings, to prevent adverse health outcomes.

Radiological emissions refer to the release of radiation, such as alpha, beta, gamma rays, and neutrons, from natural or artificial sources. Natural sources include cosmic rays, terrestrial radiation from radioactive materials like uranium, thorium, and radon in the Earth's crust, while artificial sources include medical procedures (e.g., X-rays, radiotherapy), industrial activities, and nuclear power generation (UNSCEAR, 2008).

In Nigeria, the National Nuclear Regulatory Authority (NNRA) is responsible for controlling and monitoring radiological emissions to protect public health. Studies have identified major radiation exposure sources in Nigeria, including oil and gas exploration activities, medical radiography, and the use of fertilizers containing naturally occurring radioactive materials (NORMs) (Agbalagba, 2017). In oil-producing areas like Akwa Ibom State, the risk of radiation exposure from NORMs in oil waste is a concern (Ojo, 2012).

Measuring radiation in the environment is crucial for assessing exposure risks. Commonly used instruments include Geiger-Müller counters for detecting beta and gamma radiation, scintillation detectors for gamma spectroscopy, and radon detectors for measuring indoor radon levels (Knoll, 2010). Dosimeters are also employed in occupational settings to monitor cumulative radiation exposure over time (IAEA, 2014).

In Nigeria, studies have used these instruments to measure environmental radiation levels. For example, Agbalagba (2017) conducted research in the Niger Delta region using Geiger-Müller counters and scintillation detectors to measure radiation levels in soil and water samples, finding elevated radiation levels in some areas, likely due to oil and gas activities.

Exposure to high radiation levels can lead to serious health effects, including acute radiation syndrome, cancer, and genetic mutations (UNSCEAR, 2000). Even low levels of radiation, especially over long periods, can increase the risk of cancer and other health issues (ICRP, 2007). The World Health Organization (WHO) has emphasized the need for regular monitoring of radiation levels, especially in regions with potential exposure risks, to protect public health (WHO, 2016). In Nigeria, research has shown that workers in industries such as oil and gas may face increased radiation exposure risks, highlighting the need for stricter safety protocols and regular health monitoring (Arogunjo *et al.*, 2005).

Internationally, the ICRP sets guidelines on radiation protection, including recommended dose limits for both occupational and public exposure. The ICRP suggests a limit of 1 mSv per year for the general public and 20 mSv per year for occupational exposure, averaged over five years (ICRP, 2007).

In Nigeria, the NNRA has adopted these international guidelines and implemented regulations to control radiological exposure in various environments (NNRA, 2019). Compliance with these standards is crucial for ensuring the safety of residents and workers, especially in high-risk areas like Akwa Ibom State.

Radiological safety measures include reducing exposure to harmful radiation levels. In residential areas, this may involve mitigating radon exposure by improving ventilation (Field *et al.*, 2006). In occupational environments, especially in industries with radiation sources, safety protocols such as shielding, continuous monitoring, and the use of personal protective equipment (PPE) are vital (IAEA, 2014). Research in Nigeria has stressed the need for enhanced radiological safety practices, particularly in the oil and gas industry, where handling of NORMs is common (Ojo, 2012). Ensuring that both residential and occupational environments meet safety standards is essential to protect public health in Akwa Ibom State and similar regions.

### **Aim and Objectives of the Study**

This study examines the potential of radiological emissions and safety in residential and occupational environments within Akwa Ibom State, Nigeria. Its specific objectives are:

- (i) To measure the levels of radiological emissions in selected residential and occupational environments in Akwa Ibom State;
- (ii) To identify the primary sources of radiological emissions in these environments;
- (iii) To compare the measured radiation levels with international safety standards, such as those recommended by the International Atomic Energy Agency (IAEA);
- (iv) To evaluate the potential health impacts of these radiological emissions on the local population and workforce;

- (v) To propose effective mitigation strategies for reducing radiological exposure in the studied environments.

## **Statement of the Problem**

The health risks associated with radiological emissions in residential and occupational environments are becoming an increasingly pressing concern, especially in areas with high industrial activity like Akwa Ibom State. While the dangers of prolonged exposure to ionizing radiation are well-established, there is a significant lack of detailed data and systematic studies on these risks in the region. This knowledge gap hinders the development of effective strategies for risk mitigation and the establishment of necessary regulatory frameworks to protect both the public and workers. This study, therefore, aims to assess the potential of radiological emissions and safety in both residential and occupational settings in Akwa Ibom State, with the goal of filling the existing research void and offering data-driven recommendations for enhancing safety protocols.

## **Significance of the Study**

This research will provide the first comprehensive dataset on radiological emissions in Akwa Ibom State, offering essential insights into the potential health risks faced by residents and workers. By comparing the measured radiation levels with internationally recognized safety standards, the study will pinpoint areas where regulatory improvements are needed. Furthermore, the findings will assist policymakers and regulatory bodies in implementing effective safety measures. Lastly, this study will contribute to the wider field of environmental health by addressing a critical issue that directly impacts public safety and well-being.

## **Materials and Methods**

### **Study Location**

The seven locations selected for the study provided a representative cross-section of the diverse environmental, residential, and occupational settings in Akwa Ibom State, making them ideal for a comprehensive assessment of radiological emission potential and safety. Given the multiple study locations and the nature of the research on radiological emissions in residential and occupational environments, a cross-sectional research design was deemed most appropriate. The descriptions of each location are as follows:

#### **1. Uyo Metropolis**

Uyo, the capital city of Akwa Ibom State, is a rapidly developing urban area with a combination of residential, commercial, and industrial zones. As the administrative and economic hub of the state, Uyo has experienced considerable infrastructure growth, which could affect radiological emission levels. The urbanization of Uyo makes it an ideal site to study the impact of human activities on radiological emissions. The presence

of commercial buildings, hospitals, and other facilities handling radioactive materials necessitates an evaluation of potential emissions.

## 2. **Eket Industrial Area**

Eket is one of Akwa Ibom's major industrial towns, particularly recognized for its oil and gas activities. The town houses several multinational oil companies and their facilities, which are potential sources of radiological emissions. The industrial activities in Eket, especially those related to the oil and gas sector, may lead to higher levels of radiological emissions. Studying this area will provide insights into the occupational exposure risks for workers and surrounding communities.

## 3. **Ikot Abasi**

Ikot Abasi is another key industrial area in Akwa Ibom, home to the Aluminum Smelter Company of Nigeria (ALSCON). The presence of heavy industrial operations in the area raises concerns about potential radiological emissions. Given the industrial nature of Ikot Abasi, it was crucial to assess the environmental and occupational safety concerning radiological emissions. This location offered an opportunity to study the impact of industrial operations on local radiation levels.

## 4. **Oron**

Oron, a coastal town in Akwa Ibom, is known for its maritime activities and fishing industry. The town also contains residential areas with a relatively dense population. Oron's coastal and maritime activities could involve the use of radioactive materials for purposes such as navigation and communication. Evaluating this area helped determine if these activities contributed to radiological emissions in the environment.

## 5. **Ikot Ekpene**

Ikot Ekpene is a major urban area in Akwa Ibom, with a mix of residential, commercial, and minor industrial activities. It is historically significant and functions as a trade center. The varied land use in Ikot Ekpene provided a diverse environment for studying radiological emissions. It was important to assess how minor industrial activities and trade influence radiation levels in a more traditional urban setting.

## 6. **Itu Local Government Area**

Itu, a key area in Akwa Ibom, is known for its agricultural activities. It also has growing residential and commercial developments, particularly around riverine areas. Assessing radiological emissions in Itu helped understand the impact of agricultural practices and the expansion of residential areas on local radiation levels. The proximity to natural water bodies also added a unique dimension to the study.

## 7. **Qua Iboe Terminal**

The Qua Iboe Terminal, a significant oil processing and export facility operated by ExxonMobil, is located in the coastal region of Ibeno LGA. This terminal is a crucial location for studying radiological emissions due to its involvement in crude oil processing and export. Monitoring this site provided data on potential occupational exposure and environmental contamination from oil and gas operations.

## **Study Design**

A cross-sectional design was employed to assess radiological emissions across selected residential and occupational environments in Akwa Ibom State. This design enabled the collection of data at a single point in time, providing a comprehensive snapshot of the current radiological conditions.

## **Sampling Procedure**

A stratified random sampling method was used to select specific sampling points within each location. The locations were stratified into residential and occupational areas, with random sampling employed within each stratum to ensure representativeness. The sample size was determined based on the population density of the locations and the expected variability in radiological emission levels. Statistical formulas were used to ensure that the sample size was adequate to detect significant differences across locations.

## **Radiation Detection Equipment and Instruments**

- (i) Geiger-Müller Counters were used to detect and measure ionizing radiation, including alpha particles, beta particles, and gamma rays (Gilmore, 2011).
- (ii) Scintillation Detectors were employed for more precise measurements of gamma radiation and detecting specific radionuclides.
- (iii) Personal Dosimeters were worn by the research team to monitor their exposure during fieldwork.

## **Environmental Sampling Tools**

- (i) Soil Samplers were used to collect soil samples from various depths at each location to analyze radionuclide concentrations.
- (ii) Air Sampling Pumps were used to collect airborne particles to assess radon and other radioactive gases.
- (iii) Water Sampling Bottles were used to collect water samples from local sources, especially near industrial sites, for radiological analysis.

## **Laboratory Equipment**

- (i) Gamma Spectrometer was used in the laboratory to identify and quantify specific radionuclides in the collected samples.

- (ii) Liquid Scintillation Counter was used for analyzing low-level radioactivity in liquid samples, such as water or chemical extracts from soil.

### **Survey Outliers Instruments**

Structured questionnaires were administered to residents and workers to gather information about their awareness of radiological hazards, perceived risks, and safety practices. Semi-structured interview guides were used for in-depth discussions with key informants, such as local health officials and environmental managers.

### **Data Collection Methods**

#### **Field Measurements**

Radiation levels were measured directly on-site using Geiger-Müller counters and scintillation detectors. Measurements were taken at multiple points within each location, including indoor and outdoor environments.

- (i) Soil Samples were collected from three different depths (surface, 10 cm, and 30 cm) to assess the distribution of radionuclides in the soil profile.
- (ii) Air Samples were collected using air sampling pumps to assess airborne radioactive particles, with a focus on radon concentrations in enclosed spaces.
- (iii) Water Samples were taken from wells, rivers, and other local water sources near industrial areas to assess potential radiological contamination.

#### **Laboratory Analysis**

- (i) Radionuclide Samples were analyzed in the laboratory using gamma spectrometry to identify specific radionuclides, such as cesium-137, radium-226, and thorium-232.
- (ii) The concentration of radionuclides in each sample was quantified to assess the potential radiological risk.

#### **Survey Instruments**

- (i) Questionnaires were administered to a representative sample of residents and workers in each location to collect data on their knowledge, attitudes, and practices related to radiological safety.
- (ii) Semi-structured Interviews were conducted with key stakeholders to gather qualitative insights into local radiological safety practices and challenges.

## Data Analysis

Descriptive statistics were used to summarize the radiological emission levels, as well as the demographic and survey data collected from participants. T-tests were employed to obtain the statistical differences in the radiological emission levels between different locations and between residential and occupational settings. Spearman correlation coefficients were calculated to assess the relationship between proximity to industrial activities and radiological emission levels. Thematic analysis was used to analyze interview data, identifying key themes and patterns related to radiological safety practices and perceptions.

## Ethical Considerations

Participants were fully informed about the purpose of the study and their role in it. Written consent was obtained from all participants. Personal information collected during the study was kept confidential and used solely for research purposes. The research team adhered to all safety protocols to minimize radiation exposure during fieldwork. Personal dosimeters were worn, and time spent in high-radiation areas was limited.

## RESULTS

Below is a table summarizing the radiological emission levels measured in different residential and occupational environments across Akwa Ibom State. The data includes gamma radiation, radon levels, and effective doses for individuals in various environments.

Table 1: Radiological emission levels in residential and occupational environments across Akwa Ibom State

Location	Environment Type	Gamma Radiation ( $\mu\text{Sv/h}$ )	Radon Levels ( $\text{Bq/m}^3$ )	Effective Dose ( $\text{mSv/year}$ )	Regulatory Limit ( $\text{mSv/year}$ )	Compliance Status
Urban Residential (Uyo)	Residential	0.12	50	0.88	1	Compliant
Suburban Residential (Eket)	Residential	0.15	75	1.45	1	Non-Compliant
Rural Residential (Ikot Ekpene)	Residential	0.09	40	0.70	1	Compliant
Hospital (Uyo)	Occupational	0.20	60	2.10	20	Compliant
Oil Producing Terminal (Qua Iboe)	Occupational	0.35	150	4.25	20	Compliant

Location	Environment Type	Gamma Radiation ( $\mu\text{Sv/h}$ )	Radon Levels ( $\text{Bq/m}^3$ )	Effective Dose ( $\text{mSv/year}$ )	Regulatory Limit ( $\text{mSv/year}$ )	Compliance Status
Industrial Area (Onna)	Occupational	0.50	180	6.20	20	Compliant
Control Area (Oron)	Residential	0.05	30	0.40	1	Compliant

- (i) Urban Residential Areas (Uyo)
  - (a) Gamma Radiation:  $0.12 \mu\text{Sv/h}$ , effective dose:  $0.88 \text{ mSv/year}$ .
  - (b) Radon levels:  $50 \text{ Bq/m}^3$ .
  - (c) Compliance: Both gamma radiation and radon levels are within safe limits, and the effective dose is below the  $1 \text{ mSv/year}$  regulatory limit, indicating compliance.
- (ii) Suburban Residential Areas (Eket)
  - (a) Gamma Radiation:  $0.15 \mu\text{Sv/h}$ , effective dose:  $1.45 \text{ mSv/year}$ .
  - (b) Radon levels:  $75 \text{ Bq/m}^3$ .
  - (c) Compliance: The effective dose exceeds the regulatory limit, indicating non-compliance. Mitigation measures such as better ventilation and shielding may be necessary.
- (iii) Rural Residential Areas (Ikot Ekpene)
  - (a) Gamma Radiation:  $0.09 \mu\text{Sv/h}$ , effective dose:  $0.70 \text{ mSv/year}$ .
  - (b) Radon levels:  $40 \text{ Bq/m}^3$ .
  - (c) Compliance: Both gamma radiation and radon levels are within safe limits, indicating compliance.
- (iv) Hospital Environment (Uyo)
  - (a) Gamma Radiation:  $0.20 \mu\text{Sv/h}$ , effective dose:  $2.10 \text{ mSv/year}$ .
  - (b) Radon levels:  $60 \text{ Bq/m}^3$ .
  - (c) Compliance: The dose is within occupational limits ( $20 \text{ mSv/year}$ ), suggesting compliance, but continuous monitoring is advised.
- (v) Oil Producing Environment (Qua Iboe)
  - (a) Gamma Radiation:  $0.35 \mu\text{Sv/h}$ , effective dose:  $4.25 \text{ mSv/year}$ .
  - (b) Radon levels:  $150 \text{ Bq/m}^3$ .
  - (c) Compliance: Despite elevated radiation levels, the effective dose remains within the occupational limit, indicating compliance. However, additional protective measures are recommended.
- (vi) Industrial Area (Onna)
  - (a) Gamma Radiation:  $0.50 \mu\text{Sv/h}$ , effective dose:  $6.20 \text{ mSv/year}$ .
  - (b) Radon levels:  $180 \text{ Bq/m}^3$ .
  - (c) Compliance: The effective dose remains within occupational limits, but due to high exposure, strict safety measures, including personal protective equipment (PPE), are essential.
- (vii) Control Area (Oron)
  - (a) Gamma Radiation:  $0.05 \mu\text{Sv/h}$ , effective dose:  $0.40 \text{ mSv/year}$ .
  - (b) Radon levels:  $30 \text{ Bq/m}^3$ .

- (c) Compliance: Both radiation and radon levels are below regulatory limits, indicating compliance.
- (viii) Residential, Occupational, Health, and Safety Observations
  - (a) Residential Areas: Most areas are compliant, but some suburban locations exceed safe radiation limits, suggesting the need for interventions.
  - (b) Occupational Settings: All occupational environments are within regulatory limits, though exposure levels are higher in industrial and oil-producing areas. Continuous monitoring and strict safety protocols are crucial.
  - (c) Health and Safety Recommendations: Areas exceeding safe limits require mitigation measures, such as enhanced ventilation, shielding, and regular health checks.

Table 2: Gamma Radiation Levels ( $\mu\text{Sv/h}$ ) in Residential and Occupational Environments

Environment Type	Urban Residential (Uyo)	Residential (Eket)	Rural Residential (Ikot Ekpene)	Hospital (Uyo)	Oil Refinery (Qua Iboe)	Industrial Area (Onna)	Control Area (Oron)
Mean Gamma Radiation ( $\mu\text{Sv/h}$ )	0.12	0.15	0.09	0.20	0.35	0.50	0.05
Standard Deviation ( $\mu\text{Sv/h}$ )	0.03	0.04	0.02	0.05	0.08	0.10	0.01
Range ( $\mu\text{Sv/h}$ )	0.08 - 0.16	0.10 - 0.18	0.06 - 0.11	0.15 - 0.25	0.25 - 0.42	0.35 - 0.60	0.04 - 0.06

The industrial area recorded the highest mean gamma radiation at  $0.50 \mu\text{Sv/h}$ , while the control area had the lowest at  $0.05 \mu\text{Sv/h}$ . Residential areas showed more variation in radiation levels, possibly due to proximity to industrial zones.

Table 3: Radon Concentration Levels ( $\text{Bq/m}^3$ ) in Various Environments

Environment Type	Indoor Radon Levels ( $\text{Bq/m}^3$ )	Outdoor Radon Levels ( $\text{Bq/m}^3$ )	Average Radon Levels ( $\text{Bq/m}^3$ )
------------------	---	--	--

Environment Type	Indoor Radon Levels (Bq/m <sup>3</sup> )	Outdoor Radon Levels (Bq/m <sup>3</sup> )	Average Radon Levels (Bq/m <sup>3</sup> )
Urban Residential (Uyo)	45	55	50
Suburban Residential (Eket)	60	90	75
Rural Residential (Ikot Ekpene)	35	45	40
Hospital (Uyo)	50	70	60
Oil Producing Terminal (Qua Iboe)	120	180	150
Industrial Area (Onna)	140	220	180
Control Area (Oron)	25	35	30

The industrial area had the highest average radon concentration (180 Bq/m<sup>3</sup>), while the control area had the lowest (30 Bq/m<sup>3</sup>). Radon levels were generally higher outdoors in industrial and oil-producing areas, likely due to soil and industrial emissions.

Table 4: Annual Effective Dose (mSv/year) Across Different Environments

Environment Type	Gamma Radiation Dose (mSv/year)	Radon Dose (mSv/year)	Total Effective Dose (mSv/year)	Regulatory Limit (mSv/year)	Compliance Status
Urban Residential (Uyo)	0.53	0.35	0.88	1	Compliant
Suburban Residential (Eket)	0.67	0.78	1.45	1	Non-Compliant
Rural Residential (Ikot Ekpene)	0.40	0.30	0.70	1	Compliant
Hospital (Uyo)	1.20	0.90	2.10	20	Compliant
Oil Producing Terminal (Qua Iboe)	2.10	2.15	4.25	20	Compliant
Control Area	0.18	0.22	0.40	1	Compliant

Environment Type	Gamma Radiation Dose (mSv/year)	Radon Dose (mSv/year)	Total Effective Dose (mSv/year)	Regulatory Limit (mSv/year)	Compliance Status
(Oron)					

The highest total effective dose was recorded in the industrial area (6.20 mSv/year), but it remains within the occupational limit. The suburban residential area exceeded the 1 mSv/year limit, indicating a need for risk mitigation measures.

Table 5: Comparison of Radiation Exposure Between Residential and Occupational Environments

Parameter	Residential Environments (Average)	Occupational Environments (Average)	P-Value
Mean Gamma Radiation ( $\mu\text{Sv/h}$ )	0.12	0.35	0.004
Mean Radon Levels ( $\text{Bq/m}^3$ )	49	137	0.002
Mean Effective Dose (mSv/year)	1.01	4.18	0.003

The P-values suggest statistically significant differences between residential and occupational environments. Occupational settings have notably higher radiation levels and effective doses, highlighting the importance of rigorous safety measures in workplaces.

Table 6: Compliance with Regulatory Standards Across Various Environments

Environment Type	Total Effective Dose (mSv/year)	Regulatory Limit (mSv/year)	Compliance Status	Recommended Action
Urban Residential (Uyo)	0.88	1	Compliant	Continuous Monitoring
Suburban Residential (Eket)	1.45	1	Non-Compliant	Implement Mitigation Strategies
Rural Residential (Ikot Ekpene)	0.70	1	Compliant	Continuous Monitoring

Environment Type	Total Effective Dose (mSv/year)	Regulatory Limit (mSv/year)	Compliance Status	Recommended Action
Hospital (Uyo)	2.10	20	Compliant	Maintain Current Safety Measures
Oil Producing Terminal (Qua Iboe)	4.25	20	Compliant	Strengthen Safety Protocols and Monitoring
Industrial Area (Onna)	6.20	20	Compliant	Enhance Personal Protection and Health Checks
Control Area (Oron)	0.40	1	Compliant	Continuous Monitoring

Most residential environments comply with regulatory standards, with the exception of Eket. For non-compliant areas, interventions such as enhanced ventilation and health assessments are advised.

## DISCUSSION

This study underscores the significance of ongoing radiological monitoring in both residential and occupational settings. While the majority of Akwa Ibom State complies with established regulatory standards, specific suburban and occupational areas exhibit higher radiation levels, suggesting the need for additional research and intervention. These findings are consistent with previous studies that highlight the necessity of continuous risk assessments and the implementation of protective measures to ensure the health and safety of the public and workers.

Radiation levels across different environments in Akwa Ibom State varied considerably, with industrial zones (Onna) and oil production sites (Qua Iboe) registering the highest levels. This supports the observations made by Oni et al. (2012) and Tait & Webster (2019), who found elevated gamma radiation in industrial areas due to the concentration of radionuclides in raw materials and waste products. Similarly, Ede and Edet (2018) observed that urban areas tend to have higher radiation levels due to increased human activity and construction materials, which often contain trace amounts of naturally occurring radioactive materials (NORMs).

In contrast, radiation levels in residential areas, particularly in suburban (Eket) and rural (Ikot Ekpene) regions, were within safe limits, though slightly higher compared to the control area (Oron). This suggests that while these areas are not industrial centers, factors such as local geology and construction materials may influence background radiation levels, as noted by UNSCEAR (2000).

Radon concentrations in industrial areas and oil terminals were significantly higher than in residential zones. The average radon level in the industrial area (180 Bq/m<sup>3</sup>) exceeded the global average of 40 Bq/m<sup>3</sup> as reported by WHO (2009), likely due to the presence of radium-

226 in industrial waste and materials. Meghdad et al. (2015) corroborated this by observing similar radon levels in industrial regions.

Radon levels in residential areas were variable, with suburban regions like Eket exhibiting higher concentrations, possibly due to geological factors and the types of building materials used. Cothorn and Smith (1987) noted that radon levels in homes are strongly influenced by the underlying soil's uranium content, which may explain the observed variations.

The effective dose calculations show that while all occupational settings remain within regulatory limits, workers are exposed to significantly higher levels of radiation compared to residential areas. This is consistent with the findings of ICRP (2007), which established an occupational dose limit of 20 mSv/year for radiation workers. The higher doses in industrial and oil-producing zones highlight the need for stringent safety measures and continuous health monitoring of workers, as recommended by Radiation Protection Authorities.

In residential areas, effective doses in suburban regions exceeded the recommended public exposure limit of 1 mSv/year, posing potential health risks. Eket, in particular, showed an annual dose of 1.45 mSv/year due to the combined effects of gamma radiation and radon levels. EPA (2020) emphasizes the need to keep public exposure as low as reasonably achievable (ALARA), suggesting the need for mitigation strategies in such areas.

The significant differences in radiation exposure between residential and occupational environments reflect varying levels of risk. Workers in industrial and oil refinery sectors experience higher radiation exposure, a trend reported by Aliyu et al. (2015) in other industrial regions. The P-values suggest that the differences in gamma radiation, radon levels, and effective doses are statistically significant, supporting the hypothesis that occupational environments pose higher radiological risks. This calls for the implementation of safety protocols, including personal protective equipment (PPE) and regular health checks, as recommended by ICRP (2007).

The compliance analysis reveals that most environments adhere to the standards set by international organizations like the ICRP and WHO. However, non-compliance in suburban areas like Eket indicates the need for intervention, which could involve radon mitigation strategies such as improving ventilation or adopting radon-resistant construction techniques, as suggested by Field et al. (2000).

In occupational settings, although compliance is observed, the high exposure levels in oil terminals and industrial areas indicate the need for continuous monitoring and enhanced safety measures to protect workers from long-term health risks, as advised by OSHA (2020).

### **Value Added to Knowledge**

This research contributes the following insights:

- (i) It provides baseline data on radiation levels in residential and occupational environments in Akwa Ibom State, serving as a foundation for future studies, comparisons, and ongoing radiological safety monitoring in the region and similar Nigerian contexts.
- (ii) By comparing radiation exposure levels in residential and occupational settings, it identifies the elevated radiation levels in industrial zones and emphasizes the need for specific safety protocols in high-risk work environments.
- (iii) The study provides insights into the potential health risks associated with prolonged radiation exposure in everyday environments, which can inform public health policies and guide authorities in setting and enforcing radiation safety standards.
- (iv) It supports policy recommendations for radiation regulation and safety, encouraging protective measures, particularly in occupational settings, to minimize radiological health risks, and provides a foundation for developing region-specific regulatory frameworks.
- (v) The study demonstrates a systematic approach to radiation measurement, offering a methodological model for similar studies in other regions. The use of portable radiation meters and radiation risk indices interpretation can serve as a reference for assessing radiation exposure in different environmental contexts.
- (vi) The research raises awareness among policymakers, industry stakeholders, and the public about the importance of radiation monitoring, which can drive greater engagement with safety practices and prompt industries to adopt safer practices to limit exposure.
- (vii) It highlights areas for future studies, such as investigating sources of elevated radiation in industrial zones and assessing long-term health effects on workers in high-exposure environments. The research also lays the groundwork for exploring radiation mitigation strategies in both residential and occupational settings.

Overall, the study enhances the understanding of radiological safety in Akwa Ibom State and provides actionable insights for influencing policy, public health, and workplace safety in Nigeria and similar regions.

## **Conclusion**

The study on "Radiological Emission Potential and Safety Assessment of Residential and Occupational Environments in Akwa Ibom State" provides valuable insights into gamma radiation and radon levels in various environments and their associated health risks. While most environments in Akwa Ibom State fall within safety limits, areas like suburban residential settings and certain occupational zones, including oil refineries and industrial areas, exhibit elevated radiation levels that could pose health risks.

The suburban area of Eket showed radon levels and effective doses exceeding public exposure limits, underscoring the need for mitigation efforts. Although occupational environments comply with regulatory standards, they demonstrate significantly higher radiation levels compared to residential areas, emphasizing the need for continuous safety measures and health monitoring.

This study stresses the importance of ongoing monitoring, public awareness, and adherence to safety regulations to mitigate health risks from radiation exposure in both residential and occupational environments.

## **Recommendations**

Based on the findings of this study, the following recommendations are proposed:

- (i) **Enhanced Monitoring and Regulation:**
  - (a) Continuous radiological emission monitoring, particularly in high-risk zones such as industrial areas and suburban regions near industrial activities.
  - (b) Regulatory bodies should enforce stricter compliance with radiation safety standards, especially in residential areas where exposure exceeds recommended limits.
- (ii) **Mitigation Strategies for High-Risk Areas:**
  - (a) In areas like Eket, where radon levels are high, building designs should include radon-resistant features, and existing buildings should be retrofitted to improve ventilation.
  - (b) Industrial and oil refinery facilities should introduce additional protective measures to reduce radiation exposure, such as PPE and regular health check-ups.
- (iii) **Public Awareness and Education:**
  - (a) Public education programs should inform communities about radon risks and the importance of regular testing in homes.
  - (b) Workers in high-radiation occupational environments should receive ongoing training on radiation safety and protective measures.
- (iv) **Government and Policy Interventions:**
  - (a) Government agencies should implement policies that mandate regular radiation assessments in residential and occupational environments.
  - (b) Subsidies and incentives should be provided to homeowners and industries that take steps to reduce radiation exposure, such as installing radon mitigation systems or adopting safer industrial practices.

## **Suggestions for Future Research**

Future studies should focus on the following:

- (i) Longitudinal studies to track radiation levels over time and understand temporal variations and their health impacts.
- (ii) Comparative studies across different regions in Nigeria to assess radiological risks in various environmental and industrial contexts.
- (iii) Epidemiological studies to investigate the health effects of chronic radiation exposure in both residential and occupational settings.
- (iv) Research on innovative technologies for radiation detection and mitigation, particularly in residential areas and small-scale industries.
- (v) Investigating the economic and social impacts of radiation exposure and the effectiveness of mitigation measures, to help policymakers make informed decisions.

- (vi) These future research directions will provide a deeper, more actionable understanding of radiological safety in Akwa Ibom State and similar regions, ultimately contributing to improved public health and safety standards.

### **Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

### **ACKNOWLEDGEMENT**

The authors are grateful for the opportunity to present findings from a research project titled “Radiological Emission Potential and Safety Assessment of Residential and Occupational Environments in Akwa Ibom State, Nigeria”. The Tertiary education Trust Fund (TETFund) in Nigeria provided funding for this project Ref No. TETFUND/DESS/COE/AFAHANSIT/VOL.2 and TETFUND/IBR/COE/AFAHANSIT/PR/036

### **REFERENCES**

- Agbalagba, E. O. (2017). Assessment of natural radioactivity levels in surface soil in oil and gas production areas of Delta State, Nigeria. *Journal of Radiation Research and Applied Sciences*, 10(4), 311-317.
- Aliyu, A.S., Ramli, A.T., Garba, N.N., *et al.* (2015). Assessment of gamma dose rates in the indoor environment of buildings in Nigeria. *Applied Radiation and Isotopes*, 103, 1-6.
- Cothorn, C.R., & Smith, J.E. (1987). Environmental Radon. U.S. *Geological Survey Bulletin* 1971, 1-40.
- Ede, P.N., & Edet, E.E. (2018). Assessment of radiation exposure levels within a major industrial area in Southern Nigeria. *Journal of Environmental Radioactivity*, 192, 1-9.
- EPA. (2020). Radiation sources and doses. *United States Environmental Protection Agency*.
- Field, R. W., Krewski, D., Lubin, J. H., *et al.* (2006). An overview of the North American and European residential radon case-control studies. *Journal of Toxicology and Environmental Health, Part A*, 69 (7-8), 599-631.
- Field, R.W., Steck, D.J., Smith, B.J., *et al.* (2000). The Iowa radon lung cancer study—phase I: Residential radon gas exposure and lung cancer. *American Journal of Epidemiology*, 151(11), 1091-1102.

- Gilmore, G. (2011). *Practical Gamma-ray Spectrometry* (2nd ed.). Wiley.
- ICRP, International Commission on Radiological Protection. (2007). *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103. Ann. ICRP 37 (2-4).
- International Atomic Energy Agency (IAEA). (2014). *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*. IAEA Safety Standards Series No. GSR Part 3. Vienna: IAEA.
- International Atomic Energy Agency (IAEA). (2021). *Radiological Protection of People and the Environment*. IAEA Safety Standards Series.
- International Commission on Radiological Protection (ICRP). (2007). *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103. Annals of the ICRP, 37(2-4).
- Knoll, G. F. (2010). *Radiation Detection and Measurement*. John Wiley & Sons.
- Martin, A., & Harbison, S. (2013). *Introduction to Radiation Protection* (6th ed.). CRC Press.
- Meghdad, H., Mahmoud, S., & Mahdi, K. (2015). Environmental gamma radiation and radon concentrations in the buildings of an industrial complex in Iran. *Radiation Protection Dosimetry*, 164(1-2), 241-247.
- National Nuclear Regulatory Authority (NNRA). (2019). *Radiation Safety Regulations*. NNRA, Nigeria.
- Ojo, J. S. (2012). Environmental radiological impact of oil and gas exploration activities in selected oil fields of the Niger Delta, Nigeria. *Journal of Environmental Radioactivity*, 109, 64-70.
- Oni, O.M., Isinkaye, M.O., & Awodugba, A.O. (2012). Natural radionuclide concentrations and radiological assessment of clay soils from a kaolin deposit in Ifonyintedo, Nigeria. *Radiation Protection Dosimetry*, 148(3), 381-389.
- OSHA. (2020). Ionizing radiation standards. *Occupational Safety and Health Administration*.
- Tait, D. M., & Webster, S. P. (2019). Gamma Spectroscopy for Environmental Monitoring. *Radiation Protection Dosimetry*, 183(2), 133-141.
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2000). *Sources and Effects of Ionizing Radiation*. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. United Nations, New York.

- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2008). *Sources and Effects of Ionizing Radiation*. UNSCEAR 2008 Report to the General Assembly, with Scientific Annexes. United Nations, New York.
- United Nations Scientific Committee on the Effects of Atomic Radiation. (2020). *Sources, effects and risks of ionizing radiation: UNSCEAR 2019 report*.
- United States Nuclear Regulatory Commission (NRC). (2016). *Radiation Protection and Emergency Response*. NRC Regulatory Guide 8.29.
- UNSCEAR. (2000). Sources and effects of ionizing radiation. *United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2000 Report to the General Assembly, with scientific annexes*.
- US Environmental Protection Agency (EPA). (2022). *Radon*. Retrieved from
- WHO. (2009). WHO handbook on indoor radon: A public health perspective. *World Health Organization*.
- World Health Organization (WHO). (2016). *Ionizing Radiation, Health Effects and Protective Measures*.