Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v35(s).2026.733
Volume 35(S), 2026

Assessment of Ambient Radiation Dose Levels in Selected Sections of the Conventional X-Ray Facility in FMC Jalingo, Taraba State, Nigeria

***[1]Abubakar Musa, [2]Osita O. Meludu and [3]Pascal Timtere**

[1]Department of Physics, Taraba State University, Jalingo.
[2]Department of Physics, Modibbo Adama University, Yola.
[3]Department of Physics, Modibbo Adama University, Yola.

*Corresponding Author's Email: abubakarm.musa@tsuniversity.edu.ng Phone: +23408060691616

Keywords:
Ambient Radiation Monitoring,
Geiger-Müller Counter,
Radiation Protection,
Diagnostic Radiology,
Annual Effective Dose

Submitted: 30 July 2026

Accepted: 20 Aug. 2026

Published: 16 Sept. 2026

ABSTRACT
This study evaluated ambient radiation dose rates under routine operational conditions at the Conventional X-ray Unit of the Federal Medical Centre (FMC), Jalingo, Nigeria, to establish a radiological baseline and assess structural shielding adequacy. Using a factory-calibrated GMC-320 Geiger-Müller detector positioned 1.0 m above the floor, in situ measurements were conducted across five key locations over 30 working days during peak hours (10:00 a.m. to 2:00 p.m.). The mean ambient radiation dose rates ranged from 0.183 ± 0.021 µSv/h in the waiting area (5.0 m from the source) to 0.258 ± 0.012 µSv/h inside the X-ray room (0.0 m), yielding an overall structural baseline of 0.216 ± 0.027 µSv/h. The measured dose rates exhibited a progressive, inverse relationship with distance from the X-ray tube. Extrapolated annualized continuous exposure estimates ranged from 1.603 mSv/year in the waiting area to 2.263 mSv/year in the examination room, with an overall average of 1.889 ± 0.239 mSv/year. While these values reflect conservative, worst-case continuous exposure scenarios, the elevated dose rates in occupied adjacent spaces like the control room (1.901 mSv/year) and dressing room (1.865 mSv/year) indicate the necessity for formal, occupancy-weighted risk adjustments. These findings provide a vital empirical baseline for optimizing local structural barriers and ensuring strict adherence to public and occupational radiation protection standards.

INTRODUCTION

The integration of diagnostic X-rays into modern healthcare has vastly improved clinical diagnostic capabilities, yet it demands rigorous radiation protection frameworks to manage the risks associated with ionizing radiation. During routine radiographic procedures, personnel and transient individuals are exposed not only to the primary beam but also to secondary scatter radiation generated by the patient and nearby objects, alongside potential hardware leakage from the X-ray tube assembly. While institutional safety programs rely heavily on personal dosimetry metrics to monitor individual staff members over time (Kinsara & Nassef, 2017), personal badges cannot map the spatial distribution of radiation fields or detect structural shielding breakdown. Consequently, localized ambient dose rate monitoring remains crucial to supplement standard personal records and identify dynamic spatial hotspots or structural vulnerabilities caused by fluctuating workloads and distinct room layouts (Mohammed et al., 2024).

Because ambient radiation levels vary dynamically with equipment workloads, specific exposure parameters, and architectural design, generalized safety assumptions are often insufficient (International Atomic Energy Agency [IAEA], 2014, 2018). This necessity for localized, empirical data is particularly evident in developing healthcare infrastructures. Within Nigeria, previous regional studies have consistently demonstrated significant fluctuations in operational radiation baselines. For instance, Amakom et al. (2018) documented elevated ambient dose rates during active equipment operation across diagnostic centers in Imo State, while Oladele and Arogunjo (2018) observed stark exposure discrepancies between energized and non-energized states in Ondo State radiology departments. These localized disparities underscore that facility-specific ambient measurements under real-world operating conditions are indispensable for validating shielding adequacy and ensuring the safety of workers, patients, and the public in adjacent spaces like waiting areas and control booths.

Against this background, the present study utilizes a Geiger-Müller (GM) radiation detector to evaluate the ambient radiation environment under routine operational conditions at the Conventional X-ray Unit of the Federal Medical Centre (FMC), Jalingo, Taraba State, Nigeria. By collecting real-time operational data across key structural locations, this paper extrapolates annual ambient dose estimates using localized occupancy assumptions. The resulting data establish a definitive radiological baseline for the facility, supporting the optimization of local radiation protection protocols and identifying specific structural zones that require immediate engineering or shielding intervention.

MATERIALS AND METHODS

The study adopted an in-situ measurement approach at the conventional X-ray unit of Federal Medical Centre (FMC), Jalingo, Taraba State, Nigeria, to assess ambient radiation dose rates at selected locations within and around the facility. A GMC-320 Geiger–Müller (GM) counter was used to obtain direct measurements of ambient radiation dose rate in microsieverts per hour (μSv/h). The instrument was operated in accordance with the manufacturer's specifications and relied on its manufacturer-provided factory calibration; no additional calibration was performed before the measurements. Before each measurement session, the GM counter was switched on and allowed to stabilize for approximately 5 min to ensure consistent and reliable readings (Knoll, 2010, pp. 201–222; Martin et al., 2012, pp. 88–92).

The measurements were conducted over thirty (30) working days, between 10:00 a.m. and 2:00 pm, a period selected to coincide with the expected high workload of the facility. During the measurement period, an average daily workload of approximately 25 X-ray examinations was observed. Measurements were obtained while the X-ray equipment was operational, thereby allowing the ambient radiation field associated with routine radiographic activities to be assessed under actual working conditions. The selected measurement period and time window were maintained consistently throughout the study to improve comparability of measurements across the different locations.

The GM counter detector was positioned at approximately 1.0 m above the floor at each measurement location to provide a consistent and reproducible reference height for ambient radiation measurements in occupied areas (IAEA, 2014). Ambient radiation dose rates were measured at selected locations within and around the X-ray unit, namely the X-ray room, control room, dressing room, corridor, and waiting area. Since radiation dose rates can vary with distance from the radiation source, the distance between the X-ray tube and each measurement location was determined using a measuring tape. The recorded distances were 0.0 m for the X-ray room, 3.0 m for the control room, 4.0 m for the dressing room, and 5.0 m for both the corridor and waiting area. The X-ray room measurement was taken within the examination area to characterize the radiation field during equipment operation.

At each selected location, three (3) consecutive ambient radiation dose-rate readings were obtained to minimize the influence of short-term fluctuations in detector response and radiation intensity. The arithmetic mean of the three readings was calculated and recorded as the representative ambient radiation dose rate for each location. average dose rate in μSv/hour was calculated. Subsequently, annual ambient radiation dose was estimated by multiplying the measured ambient dose rate (μSv/h) by 8,760 h/year and converting the resulting dose from microsieverts to millisieverts using Eq. (1). This calculation represents an annualized dose under the assumption of continuous exposure at the measured dose rate, enabling comparison with international dose limits.

$$D_{annual} = \frac{\dot{D} \times 8760}{1000} \quad (1)$$

where

$D_{annual} =$ estimated annual ambient radiation dose (mSv/year)

$\dot{D}$ = measured ambient radiation dose rate (μSv/h)

8760 = total hours in one year (24 × 365)

1000 = conversion factor from μSv to mSv.

RESULTS AND DISCUSSION

Results

Table 1 presents the measured ambient radiation dose rates at the five selected locations within and around the conventional X-ray unit. The results show variation in ambient dose rates across the investigated locations, with the highest value recorded in the X-ray room and the lowest in the waiting area. The table also presents the corresponding annualized ambient dose estimates and coefficients of variation for the measured locations.

Table 1: Ambient Radiation Dose Levels Across the Operational Sections

S/N	Location	Distance (m)	Mean ± SD (µSv/h)	CV (%)	Annualized ambient dose (mSv/year)
1	X-ray room	0	0.258 ± 0.012	4.47	2.263
2	Control room	3	0.217 ± 0.003	1.38	1.901
3	Dressing room	4	0.213 ± 0.010	4.90	1.865
4	Corridor	5	0.207 ± 0.008	3.83	1.814
5	Waiting area	5	0.183 ± 0.021	11.68	1.603
	Overall mean	—	0.216 ± 0.027	12.67	1.889 ± 0.239

Figure 1 illustrates the annualized ambient radiation dose levels across the investigated locations. The results show a gradual variation in dose levels, with the highest annualized dose observed in the X-ray room and the lowest in the waiting area. Therefore, the figure demonstrates a progressive decrease in annualized ambient radiation dose across the locations away from the X-ray source.

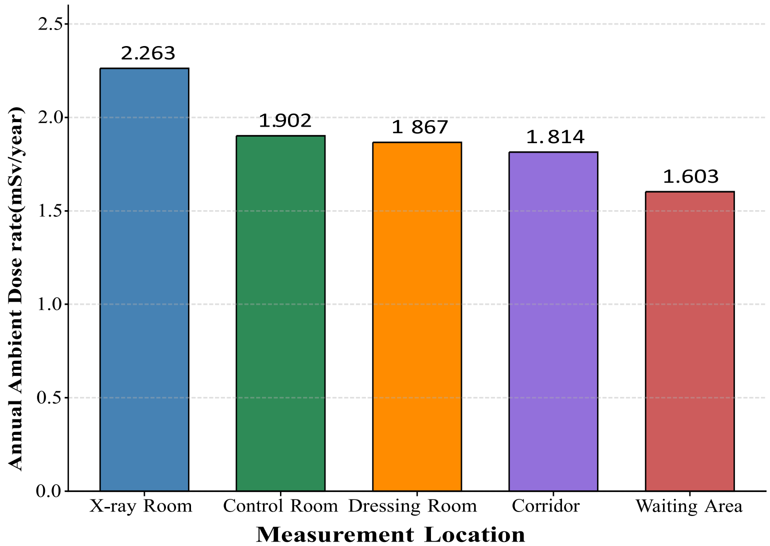

Figure 1: Plot of Annual Ambient Dose Level Across Five Monitored Operational Areas

Discussion

The empirical findings presented in Table 1 reveal measurable operational ambient radiation dose rates across all five investigated locations within and around the Conventional X-ray Unit of the Federal Medical Centre (FMC), Jalingo. Mean dose rates ranged from 0.183 ± 0.021 µSv/h in the waiting area to 0.258 ± 0.012 µSv/h within the X-ray examination room, establishing an overall structural baseline of 0.216 ± 0.027 µSv/h. The elevated radiation profile inside the X-ray room is fundamentally dictated by its immediate proximity to the primary beam and the corresponding generation of secondary scatter radiation from patients and internal structures, with minor contributions from potential X-ray tube assembly leakage.

A clear spatial gradient was observed as distance from the X-ray source increased, with mean ambient dose rates declining progressively from the examination room (0.258 µSv/h) to the control room (0.217 µSv/h), dressing room (0.213 µSv/h), corridor (0.207 µSv/h), and waiting area (0.183 µSv/h). This inverse relationship was statistically significant, as demonstrated by strong negative coefficients for both Pearson correlation ($r = -0.944$, $p = 0.016$) and Spearman rank correlation ($\rho = -0.975$, $p = 0.005$). Linear regression modeling further indicated that physical distance accounts for approximately 89.0% of the cross-sectional variance in localized dose rates ($R^2 = 0.890$). These strong statistical relationships validate the application of the inverse-square law and emphasize the structural role of spatial separation in mitigating ambient radiation fields.

However, this spatial attenuation cannot be mathematically attributed to distance alone. Because these measurements were recorded within an active clinical environment, the ambient radiation field is a complex product of physical distance, structural shielding barrier thickness (e.g., concrete walls and lead lining), room geometry, beam orientation, and scattered field dynamics. This multi-factorial influence explains why measurable radiation profiles penetrated into adjacent barrier-protected areas like the control room, dressing room, and corridors. While these adjacent levels remain lower than inside the energized examination room, their measurable baselines emphasize the need for robust structural shielding designs and systematic radiological monitoring to ensure that scattered fields do not compromise safe operational thresholds.

Extrapolating these raw operational dose rates over a full year (8,760 hours) yielded annualized ambient dose estimates ranging from 1.603 to 2.263 mSv/year, with an overall spatial average of 1.889 ± 0.239 mSv/year. Crucially, these values represent conservative, worst-case hypothetical estimates premised on continuous, uninterrupted occupancy (T = 1). Consequently, they serve as location-specific radiological indicators rather than real individual personal doses. Although these raw annualized estimates mathematically exceed the public exposure limit of 1 mSv/year (International Commission on Radiological Protection [ICRP], 2007; IAEA, 2014), direct comparison requires strict caution. The regulatory 1 mSv/year criterion governs true individual effective dose, whereas this study tracked fixed-point ambient fields. In practice, actual occupancy times for transient patients and non-classified staff in waiting areas or dressing rooms are highly variable and substantially brief. Incorporating standard occupancy factors (T < 1) would drastically reduce actual individual exposures to a small fraction of these baseline values.

Measurement variability across the 30-day monitoring window remained low, with coefficients of variation (CV) spanning 1.38% to 11.68%. This low variance confirms the reproducibility of the monitoring protocol and the operational consistency of the X-ray equipment. The minor increase in variability observed within the waiting area (CV = 11.68%) is likely an artifact of shifting patient workloads, variable exposure parameters (kVp and mAs settings), and changing localized scattering conditions during peak hours. This minor localized fluctuation did not disrupt the broader, statistically significant spatial gradient across the facility. Collectively, these insights provide an essential, facility-specific empirical baseline to support ongoing radiation optimization programs at FMC Jalingo.

CONCLUSION

This study successfully characterized the operational ambient radiation environment within and around the Conventional X-ray Unit at FMC Jalingo, mapping a mean dose rate spectrum from 0.183 ± 0.021 μSv/h to 0.258 ± 0.012 μSv/h. The data reveal a statistically significant inverse correlation between ambient exposure and distance from the X-ray source, confirming that spatial separation remains a critical pillar of localized radioprotection. Although conservative, unweighted annualized projections (1.603 to 2.263 mSv/year) exceed the standard 1 mSv/year public reference limit, these values represent a worst-case environmental boundary rather than actual individual effective doses. Ultimately, these findings establish a definitive empirical baseline for FMC Jalingo, reinforcing the value of routine area monitoring, structural barrier validation, and proactive optimization of clinical radiation safety protocols.

RECOMMENDATIONS

To maintain ALARA (As Low As Reasonably Achievable) safety standards and optimize the localized radiological environment, the following measures are recommended:

i. Establish Routine Area Monitoring: Implement a protocol for periodic ambient radiation surveys within and around the X-ray unit to identify shifting baseline fields, track longitudinal trends, and catch hardware degradation early.

ii. Conduct Shielding Integrity Appraisals: Perform engineering assessments of existing structural barriers (including wall density and lead-glass control viewports), with particular focus on heavily occupied zones adjacent to the primary room.

iii. Optimize Spatial Layouts: Where structurally feasible, maximize the physical distance between the X-ray tube assembly and adjacent high-occupancy areas, such as the control console and waiting benches, to exploit natural distance attenuation.

iv. Enforce Administrative and Access Controls: Restrict access to the primary examination room during active exposures through automated interlocks, visible radiation warning signage, and strict compliance with operational safety checklists.

v. Provide Continuous Safety Training: Maintain mandatory, up-to-date radiation protection training for radiographers, clinical technicians, and ancillary staff, emphasizing the optimization of exposure parameters and the proper application of mobile shielding.

REFERENCES

Achuka, A. J., Usikalu, M. R., Aweda, M. A., Onumejor, C. A., & Babarimisa, I. O. (2019). Background radiation dose in selected X-ray facilities in Southwest Nigeria. *Journal of Physics: Conference Series*, *1299*(1), Article 012103. https://doi.org/10.1088/1742-6596/1299/1/012103

Amakom, C. M., Orji, C. E., Nkwoada, U. A., Nnonah, D. C., & Umunnakwe, M. C. (2018). Radiation levels around some X-ray diagnostic centres in Owerri, Imo State, Nigeria. *International Journal of Research and Reviews in Applied Sciences*, *36*(1), 6–9. futo.edu.ng

Ilori, A. O., Ibitola, G., Ajanaku, O., & Utomewore, R. D. (2018). Entrance skin dose (radiation) measurement and evaluation (for all age groups) at the State Specialist Hospital, Okitipupa, Nigeria. *Open Science Journal*, *3*(2), 1–13. doi.org

International Atomic Energy Agency. (2014). *Radiation protection and safety of radiation sources: International basic safety standards* (IAEA Safety Standards Series No. GSR Part 3). iaea.org

International Commission on Radiological Protection. (2007). *The 2007 recommendations of the International Commission on Radiological Protection* (ICRP Publication 103). *Annals of the ICRP, 37*(2–4). ICRP Publication 103 official page

Kinsara, A. A., & Nassef, M. H. (2017). Occupational radiation dose for medical workers at a university hospital. *Journal of Taibah University for Science*, *11*(6), 1259–1266. https://doi.org/10.1016/j.jtusci.2017.01.010

Knoll, G. F. (2010). *Radiation detection and measurement* (4th ed.). John Wiley & Sons.

Martin, A., Harbison, S. A., Beach, K., & Cole, P. (2012). *An introduction to radiation protection* (6th ed.). Hodder Arnold.

Mohammed, M., Musa, A., Odoh, E. O., & Yerima, J. B. (2024). Assessment of occupational dose level from conventional X-ray on personnel in Federal Medical Centre, Jalingo, Taraba State, Nigeria. *Dutse Journal of Pure and Applied Sciences*, *10*(2C), 220–229. doi.org

Oladele, B. B., & Arogunjo, A. M. (2018). Assessment of background radiation levels in selected diagnostic radiology departments across Ondo State, Nigeria. *Nigerian Journal of Pure and Applied Physics*, *8*(1), 6–12. https://doi.org/10.4314/njpap.v8i1.2

Orduvwe, T. A., Avwiri, G. O., & Oghenenyerhovwo, A. E. (2025). Radiological risk assessment among occupational health workers in selected radiological centres in Warri City, Nigeria. *Trends in Social Sciences*, *1*(1), 1–9. https://doi.org/10.21124/tss.2025.01.09