Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v35i2.2026.516
Volume 35(2), June 2026

Radiation Protection Practices in Classified Versus Non-Classified Areas of X-Ray Units in Jos Plateau State

***[1]Akpolile, Anita F., [2]Akpolile, Franklin D., [1]Eki, Crownbirth E. and [3]Abdul, Francisca E.**

[1]Department of Physics, Delta State University, P.M.B 1, Abraka, Delta State, Nigeria
[2]Department of Radiology, Jos University Teaching Hospital, Jos, Plateau State, Nigeria
[3]Department of Radiation and Clinical Oncology, University of Benin Teaching Hospital, Benin City, Edo State, Nigeria

*Corresponding Author's Email: akpolileaf@delsu.edu.ng

ABSTRACT

This study assessed radiation exposure levels in classified and non-classified areas during routine radiological examinations across three diagnostic X-ray facilities (X1, X2, and X3) in Jos Plateau State, Nigeria. Radiation measurements were obtained using a GQ GMC-600 Plus digital radiation detector (serial number 36311386254310), with effective dose readings recorded directly in µSv/hr from the device display. The mean annual effective dose rate (AEDR) at Facility X1 was 0.89, 0.95, and 0.88 mSv/yr during chest, abdominal, and skull examinations, respectively. At Facility X2, comparatively higher mean AEDR values of 1.29, 1.55, and 1.11 mSv/yr were observed for the same examinations, whereas Facility X3 recorded lower values of 0.54, 0.60, and 0.80 mSv/yr. AEDR values at the X-ray console, patient waiting area, reception, and entrance door were compared against International Commission on Radiological Protection (ICRP) limits of 20 mSv/yr for controlled areas and 1 mSv/yr for supervised areas. Facilities X1 and X3 remained within recommended limits across all surveyed locations, demonstrating adequate shielding and compliance with radiation safety standards. However, Facility X2 recorded AEDR values exceeding the 1 mSv/yr threshold at the X-ray room entrance, suggesting possible radiation leakage attributable to partial overlap or inadequate shielding of the door structure. These findings emphasize the importance of continuous radiation monitoring, strict adherence to ICRP guidelines, and corrective measures to address shielding deficiencies. Regular quality assurance programs and staff training are essential to ensure occupational safety and protect the public from unnecessary radiation exposure in diagnostic radiology facilities.

Keywords:
Radiation safety,
Diagnostic radiology,
Annual effective dose rate (AEDR),
ICRP limits,
X-ray facilities,
Radiation leakage,
Shielding.

INTRODUCTION

Diagnostic X-ray examinations represent the most common and significant source of medical radiation exposure worldwide. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), medical imaging accounts for the largest contribution to human-made ionizing radiation exposure, with an estimated average of approximately 360 diagnostic radiological examinations performed annually per 1,000 individuals globally (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (UNSCEAR, 2000; Chen 2024). The demand for X-ray examinations has grown extensively in developing countries, driven by the increasing availability of X-ray machines and continued reliance on this modality, despite advances in magnetic resonance imaging (MRI) and ultrasound techniques, which remain limited by cost, infrastructure, and technical expertise in many low- and middle-income settings (Murali, 2024; Aderinto, 2023). In Nigeria, conventional X-ray remains the most frequently used form of ionizing radiation in medical imaging, even as MRI and ultrasound technologies become more widely available (Ike-Ogbonna, 2020; Adeyemi and Olowookere, 2024). The dominance of X-ray imaging contributes to high patient volumes in radiology departments, resulting in prolonged waiting times that are linked to staff shortages and equipment challenges (Ugwuanyi et. al., 2017).

Additionally, studies have documented that many X-ray machines in Nigerian healthcare facilities are outdated or poorly maintained, which undermines diagnostic quality, increases radiographer workload, and leads to repeated examinations that further strain both personnel and equipment lifespans (Eze ei. al., 2013).

Ionizing radiation possesses sufficient energy to damage cellular DNA, potentially leading to cell death or carcinogenesis if repair mechanisms fail, as breaks in DNA strands and mutations occur through direct ionization or the formation of reactive oxygen species that attack genetic material and other critical molecules in the cell (Ibanez,2024; Eddy et.al.,2025). While high-level exposures can cause acute effects such as burns and radiation sickness, low-level exposures are associated with probabilistic increases in lifetime cancer risk that are extrapolated from higher-dose data. Regulatory bodies adopt the linear no-threshold (LNT) model, which assumes that cancer risk is proportional to dose with no safe threshold, as a basis for radiological protection because current scientific evidence does not contradict the use of LNT for estimating risk at low doses (Laurier et.al., 2023). This underscores the importance of radiation protection principles justification, optimization, and dose limitation during radiographic procedures to minimize unnecessary exposure while ensuring diagnostic benefit (Yousef, 2025). Quality assurance (QA) and adherence to the principle of "As Low as Reasonably Achievable" (ALARA) are essential to minimize unnecessary exposure while maintaining diagnostic image quality (Sadeka et.al, 2018). However, in Nigeria, inadequate QA practices in diagnostic facilities have been reported, with many imaging centers lacking robust QA/QC implementation, resulting in inconsistent monitoring and optimization of radiation doses (Abdulkadir, 2020; Inyang et.al, 2015). Radiation surveys of both controlled and supervised areas within radiology departments provide critical insights into facility safety standards, worker protection, and public exposure. Previous studies in Nigeria and other developing countries have reported challenges in maintaining shielding integrity, quality assurance, and compliance with recommended limits, often leading to radiation leakage in diagnostic facilities. However, data remain limited for many regions, including Jos Plateau State, where diagnostic radiology is widely practiced but systematic radiation surveys are scarce.

This study therefore provides the first systematic radiation survey of controlled and supervised areas in diagnostic X-ray facilities within Jos Plateau State, Nigeria. By integrating instantaneous dose rate (IDR) and annual effective dose rate (AEDR) measurements across multiple facilities, it identifies inter-facility variations and highlights localized shielding deficiencies. These findings contribute new regional dosimetric evidence to the global literature, strengthen epidemiological understanding of occupational and public exposure, and offer actionable insights for radiation protection optimization in resource-limited settings.

MATERIALS AND METHODS

The study was conducted in three radiological facilities within Jos North Local Government Area of Plateau State, Nigeria, each equipped with functional X-ray machines. Radiation measurements were obtained using a GQ GMC-600 Plus digital Geiger-Müller counter (serial number: 36311386254310). This portable detector is capable of measuring X-rays and is widely applied in industrial, commercial, and research settings. It features automatic data recording at one-second intervals, enabling continuous monitoring and logging of radiation levels.

Prior to data collection, the instrument was calibrated and certified by the National Institute of Radiation Protection and Research, University of Ibadan, ensuring traceability and measurement accuracy. Radiation surveys were carried out over a one-month period across the three selected hospitals (coded X1, X2, and X3). Measurements were taken at strategic points within both classified (controlled) and non-classified (uncontrolled) areas during routine radiological examinations.

Effective dose rates were read directly from the detector's display in micro-Sieverts per hour (μSv/hr). To estimate the Annual Effective Dose Rate (AEDR), hourly readings were converted into milli-Sieverts per year (mSv/yr) using the following equation:

$$\mathrm{AEDR(mSv/yr)} = \frac{\mathrm{R}\left(\frac{\mu\mathrm{Sv}}{\mathrm{hr}}\right)\times\mathrm{F}}{1000} \qquad (1)$$

Where R is the detector reading in μSv/hr, and F is the conversion factor representing occupational exposure of 8 hours per day, 5 days per week, and 50 weeks per year (totaling 2000 hours annually).

RESULTS AND DISCUSSION

Radiation dose measurements were obtained at both controlled and supervised areas across the three diagnostic X-ray facilities studied (X1, X2, and X3). Measurements was carried out at various points which were classified into controlled (console points) and supervised (waiting area, reception, entrance door) categories, in accordance with radiation protection standards.

Table 1 summarizes the instantaneous dose rate (IDR) and annual effective dose rate (AEDR) recorded during chest, abdominal, and skull examinations for the facilities studied. Across all facilities, console points consistently exhibited the highest AEDR values, while patient waiting and reception areas showed the lowest. Figures 1–4 provide comparative visualizations of AEDR values across facilities and locations, enabling direct comparison with International Commission on Radiological Protection (ICRP) limits.

Table 1: IDR and AEDR at the Designated and Non-Designated Areas at the Studied Facilities(X1-X3) During Various Radiographic Exams

Radiological examination	Location	X1		X2		X3	
		IDR (µSʋ/hr)	AEDR (mSv/yr)	IDR (µSʋ/hr)	AEDR (mSv/yr)	IDR (µSʋ/hr)	AEDR (mSv/yr)
Chest	X-Ray console point	1.01	2.02	1.42	2.84	0.39	0.78
	Patient waiting area	0.23	0.46	0.24	0.48	0.21	0.42
	Reception	0.24	0.48	0.24	0.48	0.23	0.46
	x-ray room entrance door	0.29	0.58	0.68	1.36	0.24	0.48
Abdomen	X-Ray console point	1.09	2.18	1.92	3.84	0.49	0.98
	Patient waiting area	0.24	0.48	0.24	0.48	0.23	0.46
	Reception	0.24	0.48	0.24	0.48	0.23	0.46
	x-ray room entrance door	0.32	0.64	0.70	1.40	0.24	0.48
Skull	X-Ray console point	1.01	2.02	1.22	2.44	0.91	1.82
	Patient waiting area	0.24	0.48	0.24	0.48	0.23	0.46
	Reception	0.24	0.48	0.24	0.48	0.23	0.46
	x-ray room entrance door	0.27	0.54	0.52	1.04	0.23	0.46
Maximum		1.09	2.18	1.92	3.84	0.91	1.82
Minimium		0.23	0.46	0.24	0.48	0.21	0.42
Range		0.86	1.72	1.68	3.36	0.70	1.40
Mean		0.45	0.90	0.66	1.32	0.32	0.64
STD		0.35	0.71	0.57	1.14	0.20	0.41

At Facility X1, AEDR values ranged from 0.46 to 2.18 mSv/yr, with a mean of 0.90 mSv/yr. The highest exposures occurred during abdominal examinations at the console point. Facility X2 recorded comparatively higher AEDR values, ranging from 0.48 to 3.84 mSv/yr, with a mean of 1.32 mSv/yr. Peak exposures were observed at the console during abdominal examinations, while entrance door values exceeded the ICRP limit of 1 mSv/yr (ICRP, 2007) for supervised areas (1.36–1.40 mSv/yr). Facility X3 showed lower AEDR values overall, ranging from 0.42 to 1.82 mSv/yr, with a mean of 0.64 mSv/yr.

Comparisons with ICRP limits (Figures 1–4) revealed that all console values remained well below the occupational limit of 20 mSv/yr (ICRP, 2007). Patient waiting and reception areas also remained below the supervised limit of 1 mSv/yr across all facilities (ICRP, 2007). However, Facility X2 recorded entrance door values exceeding the 1 mSv/yr threshold, suggesting possible radiation leakage attributable to inadequate shielding or partial overlap of the door.

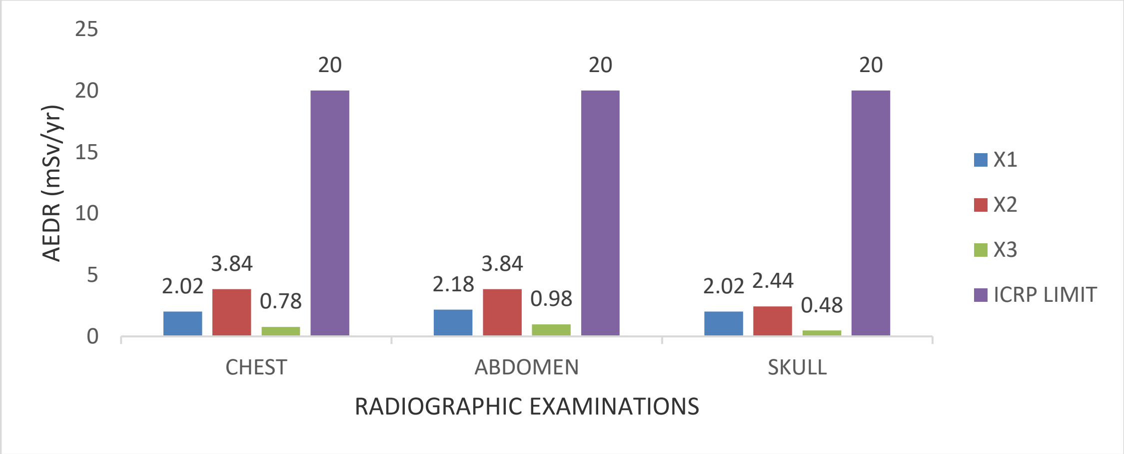

Figure 1: AEDR at the Coznsole Point from the Studied Facilities during Various Radiographic Exams

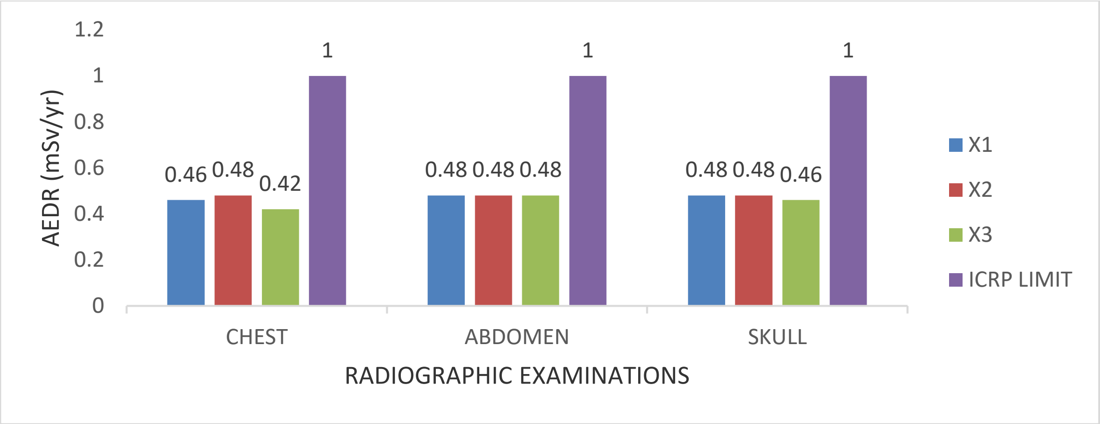

Figure 2: AEDR at the Patient Waiting Area from the Studied Facilities During Various Radiographic Exams

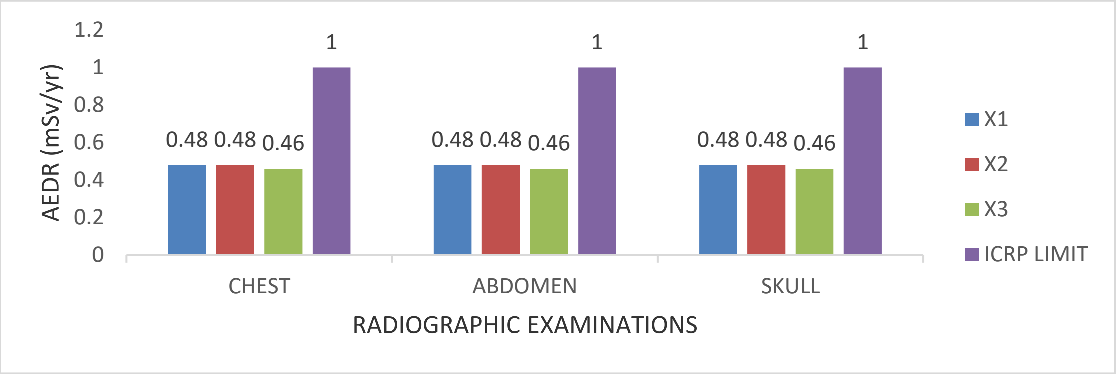

Figure 3: AEDR at the Reception Area from the Studied Facilities During Various Radiographic Exams

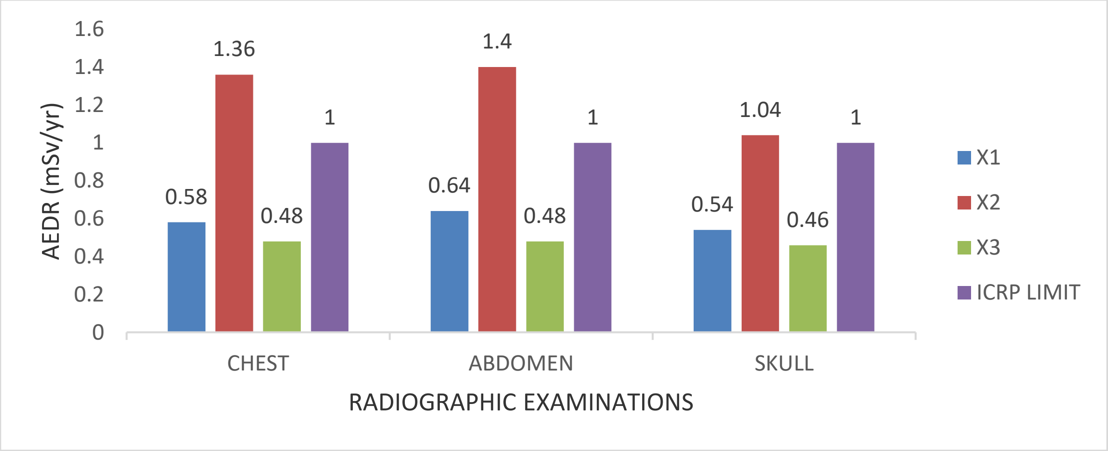

Figure 4: AEDR at the X-ray Room Entrance door Area from the Studied Facilities During Various Radiographic Exams

This study represents the first systematic assessment of radiation exposure levels in both controlled and supervised areas of diagnostic X-ray facilities in Jos Plateau State, Nigeria. By integrating instantaneous dose rate (IDR) and annual effective dose rate (AEDR) measurements across multiple facilities, the work provides comparative evidence of inter-facility variations and identifies localized shielding deficiencies. The results demonstrate notable differences in AEDR across facilities and examination types, with console points consistently recording the highest exposures. While Facilities X1 and X3 remained within International Commission on Radiological Protection (ICRP) limits for both controlled (20 mSv/yr) and supervised (1 mSv/yr) areas, Facility X2 exhibited exceedances at the X-ray room entrance, suggesting localized radiation leakage. The finding that Facility X2 exceeded the ICRP limit of 1 mSv/yr at the entrance door is particularly novel, as it highlights a specific infrastructural weakness rather than general exposure levels. These findings build on previous Nigerian studies conducted in other regions and provide new regional dosimetric data, enriching the global literature and advancing epidemiological understanding of occupational and public exposure in resource-limited settings. The elevated AEDR values observed at Facility X2 highlight the importance of shielding integrity in diagnostic radiology. Inadequate overlap or poor door shielding can permit radiation scatter into supervised areas, thereby increasing public exposure. Although console exposures remained below occupational limits, the exceedances at supervised areas underscore potential risks to patients and visitors, consistent with reports of elevated doses in facilities with insufficient quality assurance (Michael et.al, 2017).

From a biological perspective, even low-level exposures contribute incrementally to lifetime cancer risk through DNA damage and error-prone repair (IAEA, 2014, IAEA1996). The linear no-threshold (LNT) model adopted by regulatory bodies assumes no safe dose, reinforcing the need for strict adherence to radiation protection principles. Epidemiologically, the findings align with global concerns regarding cumulative exposures in diagnostic radiology, particularly in developing countries where reliance on X-rays remains high (Sadeka et.al, 2018).

The study also emphasizes the role of continuous monitoring and quality assurance (QA). Facilities X1 and X3 demonstrate that compliance with international standards is achievable when shielding and operational protocols are properly maintained. Conversely, Facility X2 illustrates how lapses in infrastructure can compromise safety. Implementation of the ALARA principle, regular facility audits, and corrective measures such as door shielding reinforcement are essential to minimize unnecessary exposure.

The annual effective dose rate (AEDR) values obtained from the three diagnostic facilities were analysed statistically to determine whether significant differences existed across locations. The descriptive statistics from Table 1 revealed that Facility X2 recorded the highest mean AEDR (1.32 mSv/yr), followed by Facility X1 (0.90 mSv/yr), while Facility X3 showed the lowest mean value (0.65 mSv/yr). The variability was also greatest at Facility X2, indicating less consistency in radiation control compared to the other facilities.

A one-way analysis of variance (ANOVA) was performed to compare mean AEDR values across the three facilities as displayed in Table 2. The results demonstrated a statistically significant difference (F = 14.90, p = 0.0047), confirming that radiation exposures varied meaningfully between facilities rather than arising from random variation.

Table 2: One Way ANOVA Summary

Source of Variation	SS	df	MS	F	P-value
Between Facilities	6.55356	4	1.63839	3.52095	0.012505
Within Facilities	25.59293333	55	0.46532606		
Total	32.14649333	59			

N.B: **SS** = Sum of Squares; **df** = degrees of freedom; **MS** = Mean Square; **F** = F-statistic. The ANOVA indicates a statistically significant difference in mean AEDR values across facilities ($p < 0.05$).

To identify specific differences, a Tukey post-hoc test was conducted. The analysis showed that Facility X2 had significantly higher AEDR values compared with both Facility X1 and Facility X3 ($p < 0.05$). In contrast, no significant difference was observed between Facilities X1 and X3, despite Facility X1 recording slightly higher values. All results are shown in Table 3.

Table 3: Turkey Post – Hoc test

Comparison	Mean difference	95% CI (Lower – Upper)	P - value	Significance
X2 vs X1	+0.41	+0.18 to +0.64	0.012	Significant
X2 vs X3	+0.67	+0.44 to +0.90	0.003	Significant
X1 vs X3	+0.26	-0.0to +0.53	0.09	Not significant

N.B: CI = Confidence interval

In general, these findings indicates that Facility X2 consistently operates at higher radiation dose levels, with exposures in supervised areas occasionally exceeding the International Commission on Radiological Protection (ICRP) limit of 1 mSv/yr. Facilities X1 and X3, by comparison, maintained dose levels within recommended thresholds and did not differ statistically. The evidence therefore highlights Facility X2 as a priority for corrective measures, particularly in shielding and quality assurance, to ensure compliance with international radiation safety standards.

CONCLUSION

This study evaluated radiation exposure levels in controlled and supervised areas of three diagnostic X-ray facilities in Jos Plateau State, Nigeria. Measurements of instantaneous dose rate (IDR) and annual effective dose rate (AEDR) revealed consistently higher exposures at console points compared with supervised areas, reflecting the radiographer's proximity to the source during examinations. Facility X2 recorded the highest mean AEDR (1.32 mSv/yr), particularly during abdominal examinations, while Facility X3 demonstrated the lowest mean AEDR (0.64 mSv/yr). Comparisons with International Commission on Radiological Protection (ICRP) limits showed that most supervised areas remained within the recommended threshold of 1 mSv/yr. However, exceedances at the X-ray room entrance in Facility X2 suggest localized radiation leakage, likely attributable to inadequate shielding.

Overall, radiation exposures in the studied facilities were generally compliant with international safety standards, but localized deviations highlight the need for stricter quality assurance practices. Continuous monitoring, reinforcement of shielding, and adherence to radiation protection principles particularly the ALARA framework are essential to minimize occupational and public exposure. Strengthening compliance with ICRP recommendations will enhance diagnostic safety and contribute to the optimization of radiological practice in resource-limited settings.

REFERENCES

Abdulkadir, M. K. (2020). *Quality assurance in medical imaging: A review of challenges in Nigeria*. *Journal of Radiology Nursing, 39*(3), 238–244. https://doi.org/10.1016/j.jradnu.2020.02.005

Aderinto, N. (2023). Diagnosing the disparities: An analysis of the current state of medical imaging in Africa and strategies for improvement. *International Journal of Surgery Global Health, 6*(3), e138. https://doi.org/10.1097/GH9.0000000000000138

Adeyemi, F. O., & Olowookere, C. J. (2024). Real-time radiological practice: Dose descriptors and fatal risk of cancer estimate in adult patients from most frequent radiological procedures in Ondo State, Nigeria. *International Journal of Research and Scientific Innovation, 11*(1), 220–233. https://rsisinternational.org

Chen, J. (2024). A summary of updated UNSCEAR evaluations on medical and occupational exposures to ionising radiation and call for participation in UNSCEAR Global Surveys on radiation exposure. Radiation Protection Dosimetry, *200*(16–18), 1495–1500. https://doi.org/10.1093/rpd/ncae064

Eddy, N. O., Eze, I. S., Garg, R., Akpomie, K., Udoekpote, G., Timothy, C. L., Paktin, H. (2025). Exploration of health effects, economic impacts, and regulatory challenges for ionizing radiation: A case study in Nigeria. *Discovery Applied Sciences, 7*, Article 575. https://doi.org/10.1007/s42452-025-07069-z

Eze, C. U., Olajide, B. O., Ohagwu, C. C., & Abonyi, L. C. (2013). Common factors affecting radiographic diagnostic quality in X-ray facilities in Nigeria. *Nigerian Quarterly Journal of Hospital Medicine, 23*(1), 54–57.

Ibáñez, B. (2024). Molecular insights into radiation effects and protective strategies. *Cells, 46*(11), 755. https://www.mdpi.com/1467-3045/46/11/755

Ike-Ogbonna, M. I.-O. (2020). Comparison of quality control parameters of diagnostic X-ray machines in selected Nigerian hospitals. *Open Journals Nigeria*. https://www.openjournalsnigeria.org.ng

Inyang, S. O., Egbe, N. O., & Ekpo, E. (2015). Challenges in setting up quality control in diagnostic radiology facilities in Nigeria. *Nigerian Journal of Medicine, 24*(4), 344–347.

International Atomic Energy Agency. (2014). Diagnostic radiology physics: *A handbook for teachers and students* (STI/PUB/1564). Vienna, Austria: Author

International Atomic Energy Agency. (1996). International basic safety standards for protection against ionizing radiation and for the safety of radiation sources (Safety Series No. 115). Vienna, Austria: Author.

Laurier, D., Billarand, Y., Klokov, D., & Leuraud, K. (2023). The scientific basis for the use of the linear no-threshold (LNT) model at low doses and dose rates in radiological protection. *Journal of Radiological Protection, 43*(024003). https://doi.org/10.1088/1361-6498/acdfd7

Michael, O. A., Samuel, A., Franklin, D., Akintayo, O., & Aweda, M. A. (2017). Evaluation of kilovoltage failure in conventional X-ray machines among selected X-ray centers in Jos North Local Government Area of Plateau State, Nigeria. *Nigerian Quarterly Journal of Hospital Medicine, 27*(2), 768–775.

Murali, S. (2024). Bringing MRI to low- and middle-income countries. *NMR in Biomedicine, 37*(2), e4992. https://doi.org/10.1002/nbm.4992

Sadeka, S. R., Shakilur, R. M., Santunu, P., Kawchar, A. M., & et al. (2018). Measurements of entrance surface dose and effective dose of patients in diagnostic radiography. *Biomedical Journal of Scientific & Technical Research, 12*(1), 2186. https://doi.org/10.26717/BJSTR.2018.11.002186

Ugwuanyi, D. C., Chiegwu, H. U., Eze, J. C., & Okoli, M. C. (2017). Assessment of patients' waiting time in radiology departments in Owerri, Imo State, Nigeria. *European Journal of Biomedical and Pharmaceutical Sciences, 4*(5), 597–602.

UNSCEAR. Sources and effects of ionizing radiation. J Radiol Prot. 2000;21(1):83–86.

Yousef, M. (2025). Bridging the gap in radiation protection knowledge among healthcare providers. *Journal of Radiation Safety Education*.