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Research Article

A Multi-Center Assessment of Occupational Radiation Exposure Levels Due to Radio-Diagnostic Activities in Four Specialist Hospitals in Northwestern Nigeria

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Abstract

Medical applications of ionizing radiation, such as X-rays, fluoroscopy, mammography, and computed tomography, are indispensable for diagnosis and treatment but pose potential health risks to occupational workers. Concerns about ionizing radiation exposure highlight the critical need for effective radiation protection and continuous monitoring. This study evaluated occupational radiation exposure among workers in radio-diagnostic activities across four specialist hospitals in Northwestern Nigeria over a 12-month period (March 2024–March 2025). Using 20 thermo-luminescence dosimeters (TLDs) distributed across the centers, quarterly readings were processed at the Centre for Energy Research and Training (CERT), Zaria, to determine annual surface skin dose (Hp(0.07)) and deep skin dose (Hp(10)). The mean annual Hp(0.07) and Hp(10) across all hospitals were 1.03 mSv and 2.16 mSv, respectively, with individual doses ranging from 0.11 mSv to 1.70 mSv for Hp(0.07) and 0.14 mSv to 3.92 mSv for Hp(10). One-way ANOVA revealed no statistically significant differences in mean annual doses among the four hospitals ($F=0.335$, $p=0.800$ for Hp(0.07); $F=0.327$, $p=0.806$ for Hp(10)). These exposure levels were consistently well within national (NNRA: 20 mSv/year) and international (ICRP: 5 mSv/year effective dose) limits, indicating effective radiation protection. The observed consistency across centers underscores the importance of continued personnel monitoring and adherence to the ALARA principle to minimize stochastic effects.

Keywords

Occupational Exposure, Radiation Workers, Radio-diagnostic, TLD, Dose Limits, Health Physics, ANOVA, Northwest Nigeria

1. Introduction

The remarkable advancements in medical imaging technologies have revolutionized diagnostics and therapeutic interventions, significantly improving patient care worldwide. Procedures involving ionizing radiation, such as conventional radiography (X-rays), fluoroscopy, mammography, and computed tomography (CT), are cornerstones of modern medicine, providing invaluable insights into human health and disease [10]. However, the escalating use of these modalities has justifiably raised concerns regarding the potential for increased radiation exposure, not only for patients but also, critically, for occupational workers routinely exposed in these environments [15]. The medical application of ionizing radiation now constitutes the second largest contribution to the collective dose of ionizing radiation globally. [1]

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Exposure to ionizing radiation, even at low doses, carries associated biological hazards [13]. These effects are broadly categorized into two main groups: deterministic effects and stochastic effects. Deterministic effects, such as skin injury, hair loss, and sterility, are dose-dependent, exhibit a threshold, and typically manifest acutely, from hours to months post-exposure. In contrast, stochastic effects are non-threshold dependent, meaning there is no safe dose below which the probability of occurrence is zero, with their likelihood proportional to the accumulated radiation dose. These effects, which include radiation-induced cancers and genetic mutations, are typically delayed, appearing years to decades after exposure [3, 12, 14]. Several studies have consistently demonstrated that occupational workers in radiology departments face an elevated risk of these health effects due to their routine exposure during diagnostic procedures.

To mitigate these risks, the fundamental principle of radiation protection is to maintain radiation exposure As Low As Reasonably Achievable (ALARA), taking into account economic and social factors. International and national regulatory bodies play a pivotal role in establishing and enforcing dose limits to safeguard occupational workers [2, 4]. The International Commission on Radiation Protection (ICRP) recommends specific occupational dose limits, including an effective dose limit of 5 mSv per year, an eye lens equivalent dose limit of 20 mSv/year, and skin, hand, and foot equivalent dose limits of 500 mSv/year [9]. In Nigeria, the Nigerian Nuclear Regulatory Authority (NNRA) stipulates an occupational exposure dose limit of 20 mSv per year, averaged over a period of five consecutive years [7, 16]. Adherence to these limits, alongside the judicious use of personal protective equipment (e.g., lead aprons, lead glasses), is crucial for significantly reducing occupational radiation exposure [8, 12].

Personnel monitoring is therefore an indispensable component of any robust radiation protection program, ensuring compliance with established dose limits and identifying areas for improvement. Thermo-luminescence Dosimetry (TLDs) is widely recognized as the most reliable and valuable method for the quantitative measurement of ionizing radiation in personnel monitoring. TLDs, available in various forms (e.g., badges, rings), are worn by workers to record their accumulated radiation dose, providing crucial data for assessing occupational exposure [8, 3]. The occupational effective dose is typically measured as personal dose equivalent at 10 mm depth (Hp(10)) for deep skin dose and at 0.07 mm depth (Hp(0.07)) for surface skin dose [11].

Despite the undeniable benefits of ionizing radiation in healthcare, the poor implementation of quality assurance programs and the lack of consistent personnel monitoring in many healthcare facilities, particularly in developing regions, remains a significant concern. While ionizing radiation is vital for patient diagnosis and treatment, unmonitored or inadequately protected healthcare workers are continuously exposed to potential hazards. Previous studies have highlighted the occupational risks, yet a comprehensive assessment of radiation exposure levels across multiple facilities in the Northwestern region of Nigeria has been limited [6]. This study specifically aims to address this critical gap by evaluating the occupational exposure of radiation workers in four selected specialist hospitals, comparing their exposure levels against national and international regulatory limits, and providing data-driven recommendations.

The significance of this study is profound. By providing empirical data on occupational radiation exposure in multiple radio-diagnostic centers across Northwestern Nigeria, it will enable hospital boards and regulatory bodies in the region to develop and implement evidence-based policies. These policies can focus on optimizing radiation usage in diagnostic procedures, enforcing effective personal protective equipment (PPE) protocols, and establishing safe work practices and continuous training programs for occupational workers. Such measures are crucial for safeguarding the health and well-being of the healthcare workforce.

2. Materials and Methods

This quantitative study retrospectively assessed occupational radiation exposure in the Radiology Departments of four specialist hospitals in Northwestern Nigeria: Murtala Mohammed Specialist Hospital (Kano), Federal Medical Center (Katsina), Rasheed Shekoni Federal University Teaching Hospital (Dutse) and Federal Medical Center (Birnin Kudu). These departments utilize conventional X-ray, CT and mammography units. A total of 20 active radio-diagnostic health workers (five per center) were included based on their direct involvement with ionizing radiation machines and the availability of TLD data. Excluded were workers not directly involved in radiation-emitting procedures or those with uncalibrated TLDs. Thermo-luminescence Dosimeters (TLDs) were distributed and worn by participants at chest level, under lead aprons, for 12 months (March 2024 to March 2025). The TLD badges were collected quarterly and processed using a Harshaw Model 4500 Manual TLD Reader and its integrated Windows Radiation Evaluation and Management System (WinREMS) software at the Centre for Energy Research and Training (CERT), Zaria. This system facilitated precise glow curve analysis and automated dose conversion, ensuring accurate measurement of accumulated radiation exposure. ECC and RCF values were established through routine calibration procedures at CERT, Zaria, in accordance with international standards.

The Harshaw Model 4500 system comprises several hardware components:

1. A Model 4500 Harshaw TLD reader unit, which integrates data processing electronics, a sample drawer assembly, a precision light measurement system, a detector heating system, a light voltage power supply, and internal data storage facilities.
2. A Video Display Unit (VDU) for graphical data display, operating instructions, and system messages.

3. A Keyboard serving as the interactive central interface with the TLD reader.
4. A set of floppy disks (or equivalent modern storage) for data backup.

The Model 4500 Reader is versatile, capable of reading various forms of thermo luminescence dosimeters, including whole-body and environmental dosimeters. It incorporates two Photomultiplier Tubes within a sliding housing and supports both planchet and hot gas (nitrogen or air) heating methods. Hot gas heating is typically employed for whole-body and environmental TL cards, as well as extremity dosimeters (Chipstrates and Ringlets), while planchet heating is used for unmounted TL elements such as chips, disks, rods, and powders.

The TLD system consists of two major interconnected components: the TLD Reader hardware and the Windows Radiation Evaluation and Management System (WinREMS) software. The WinREMS software resides on a personal computer (PC) that is connected to the Reader via an RS-232-C serial communication port. The dosimetric functions are distributed between the Reader and the WinREMS software. All dosimetric data storage, instrument control, and operator inputs are managed on the PC via WinREMS, while transport subsystem control, gas and vacuum controls, and signal acquisition and conditioning are performed directly by the Reader hardware.

3. Data Analysis and Dose Calculation

Raw TLD readings, captured as glow peak counts (nano-coulombs), were rigorously converted into dose equivalents (mSv) using established dose algorithms and calibration factors within the Windows Radiation Evaluation and Management System (WinREMS) software. The WinREMS facilitated this process through its integrated dosimetric functions, including Glow Curve Analysis for characterizing detector response, Glow Curve Deconvolution for precise individual peak measurement, and a comprehensive Chain of Custody and Health Physics Record System for robust data management and dose tracking. Dose conversion from the peak glow curve charge (Q) was automated using the formula:

$$\text{Dose}=\frac{Q \times ECC}{RCF} \tag{1}$$

Where:

1. Q is the charge (the glow peak value, in nano-coulombs, nC).
2. ECC is the Element Correction Coefficient, which was determined to be 3749.
3. RCF is the Reader Calibration Factor, which was 0.0171.

Specific calibration factors applied were 0.51×10−5 mSv/count for surface skin dose (Hp(0.07)) and 0.53×10−5 mSv/count for deep skin dose (Hp(10)). Quarterly dose data for each worker were used to calculate individual, overall, and hospital-specific mean doses on both quarterly and annual bases. Compliance of these calculated exposure levels was rigorously assessed against the recommended occupational radiation dose limits set by the International Commission on Radiation Protection (ICRP) and the Nigerian Nuclear Regulatory Authority (NNRA). To compare mean annual deep skin doses and surface skin doses across the four hospitals, a One-way Analysis of Variance (ANOVA) was performed. All statistical analyses were conducted using Python (version 3.x) with the SciPy and Statsmodels libraries, at a significance level of $\alpha=0.05$.

4. Results and Discussion

This section presents the findings from the 12-month occupational radiation exposure monitoring campaign conducted across four specialist hospitals in Northwestern Nigeria. The data collection period spanned from March 2024 to March 2025, encompassing four quarterly measurements for 20 thermo-luminescence dosimeters (TLDs).

4.1. Quarterly Occupational Radiation Doses

Table 1 summarizes the mean surface skin dose (Hp(0.07)) and deep skin dose (Hp(10)) for occupational workers across all participating hospitals for each of the four quarters.

Table 1. *Mean Quarterly Occupational Radiation Doses (mSv) for All Participating Hospitals (March 2024 - February 2025).*

Quarter	Period	Mean Surface Skin Dose (Hp(0.07)) (mSv)	Mean Deep Skin Dose (Hp(10)) (mSv)
Q1	March 2024 - May 2024	0.25	0.33
Q2	June 2024 - August 2024	0.25	0.91
Q3	September 2024 - November 2024	0.22	0.34
Q4	December 2024 - February 2025	0.32	0.58

The mean quarterly doses remained relatively low throughout the monitoring period. The highest mean deep skin dose was observed in Q2 (0.91 mSv), while the highest mean surface skin dose was in Q4 (0.32 mSv).

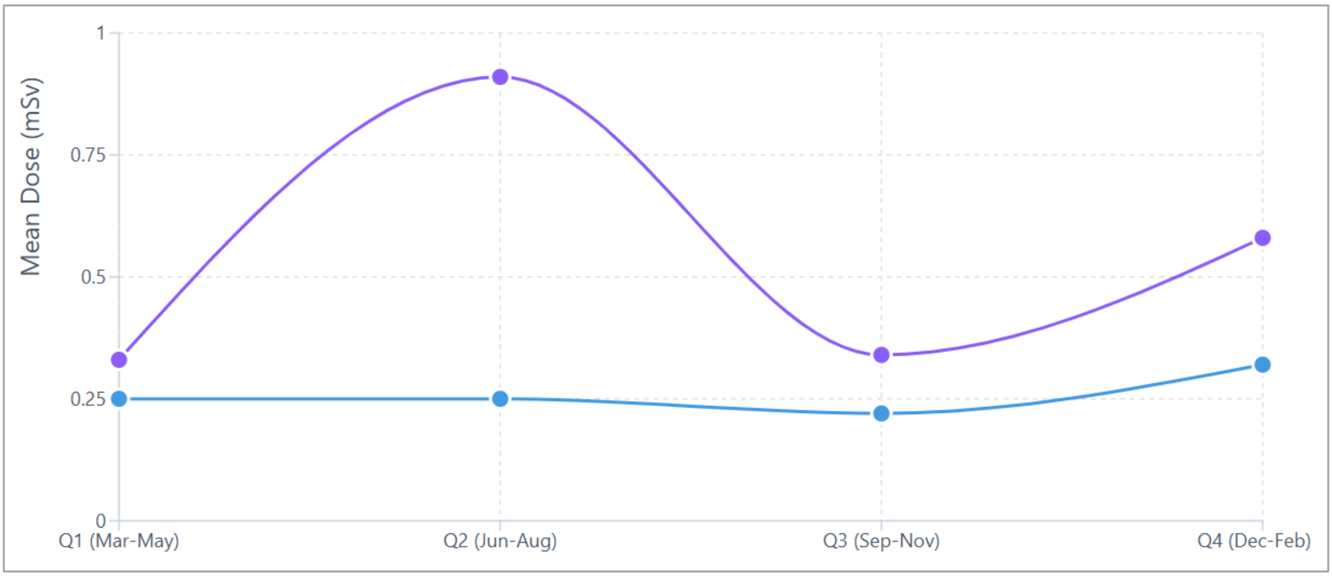

Figure 1. Quarterly Mean Occupational Radiation Doses Line Graph.

Surface Skin Dose (mSv)
Deep Skin Dose (mSv)

Doses are measured in milliSieverts (mSv).
Hp(0.07): Personal dose equivalent at 0.07 mm tissue depth (Surface Skin Dose)
HP(10): Personal dose equivalent at 10 mm tissue depth (Deep Skin Dose)

4.2. Annual Accumulated Occupational Radiation Doses for Individual Workers

Table 2 presents the individual annual accumulated doses for both surface skin dose and deep skin dose for each of the 20 occupational workers monitored across the four hospitals.

Table 2. Annual Accumulated Occupational Radiation Doses (mSv) for Individual Workers (March 2024 - March 2025).

S/No.	Annual Surface Skin Dose (Hp(0.07)) (mSv)	Annual Deep Skin Dose (Hp(10)) (mSv)
TLD1	1.56	2.33
TLD2	1.48	3.92
TLD3	0.11	0.14
TLD4	0.86	1.63
TLD5	1.34	3.21
TLD6	0.82	2.11
TLD7	1.03	2.59
TLD8	1.00	2.19
TLD9	0.76	1.54
TLD10	1.02	2.36
TLD11	0.90	1.90

S/No.	Annual Surface Skin Dose (Hp(0.07)) (mSv)	Annual Deep Skin Dose (Hp(10)) (mSv)
TLD12	1.23	2.04
TLD13	1.43	2.74
TLD14	0.66	1.77
TLD15	1.70	3.49
TLD16	0.97	1.67
TLD17	0.43	1.89
TLD18	1.27	2.54
TLD19	1.66	1.58
TLD20	0.44	1.65

The individual annual occupational doses ranged from 0.11 mSv to 1.70 mSv for surface skin dose and from 0.14 mSv to 3.92 mSv for deep skin dose.

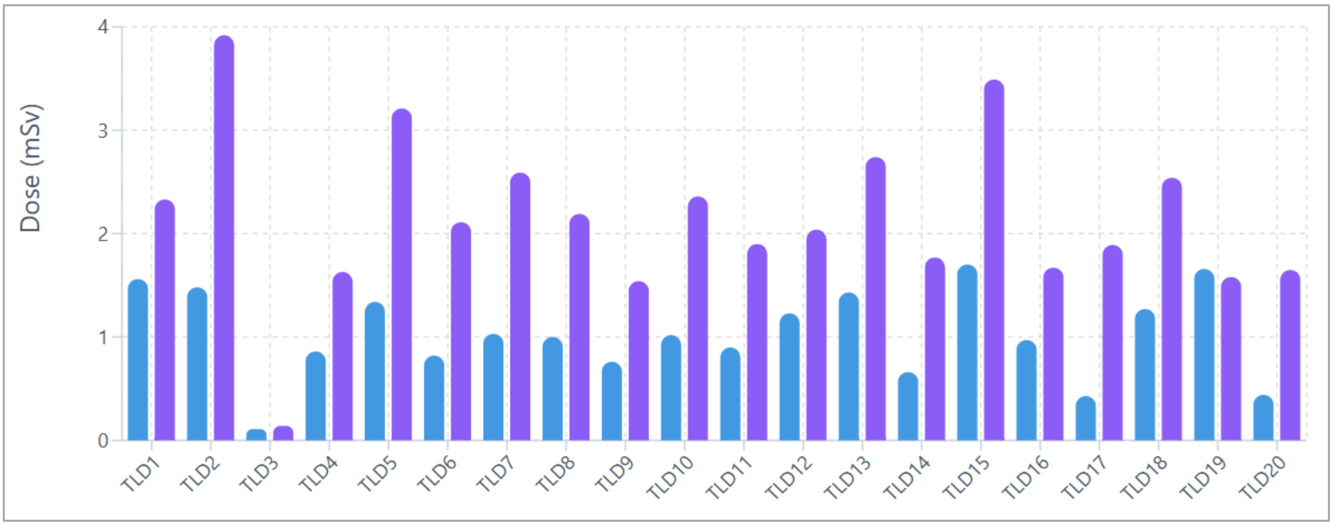

Figure 2. *Annual Radiation Dose Bar Chart per TLD.*

Surface Skin Dose (mSv)
Deep Skin Dose (mSv)

4.3. Overall and Hospital-Specific Annual Mean Doses

The overall annual mean surface skin dose (Hp(0.07)) across all 20 monitored workers was 1.03 mSv. The overall annual mean deep skin dose (Hp(10)) was 2.16 mSv.

Table 3 provides a breakdown of the annual mean surface and deep skin doses for occupational workers in each of the four participating hospitals.

Table 3. *Annual Mean Occupational Radiation Doses (mSv) per Hospital (March 2024 - March 2025).*

Hospital	Mean Surface Skin Dose (Hp(0.07)) (mSv)	Mean Deep Skin Dose (Hp(10)) (mSv)
A	1.07	2.25
B	0.93	2.16

Hospital	Mean Surface Skin Dose (Hp(0.07)) (mSv)	Mean Deep Skin Dose (Hp(10)) (mSv)
C	1.18	2.39
D	0.95	1.87

Hospital C recorded the highest mean annual surface skin dose (1.18 mSv) and deep skin dose (2.39 mSv), while Hospital B showed the lowest mean surface skin dose (0.93 mSv), and Hospital D the lowest mean deep skin dose (1.87 mSv).

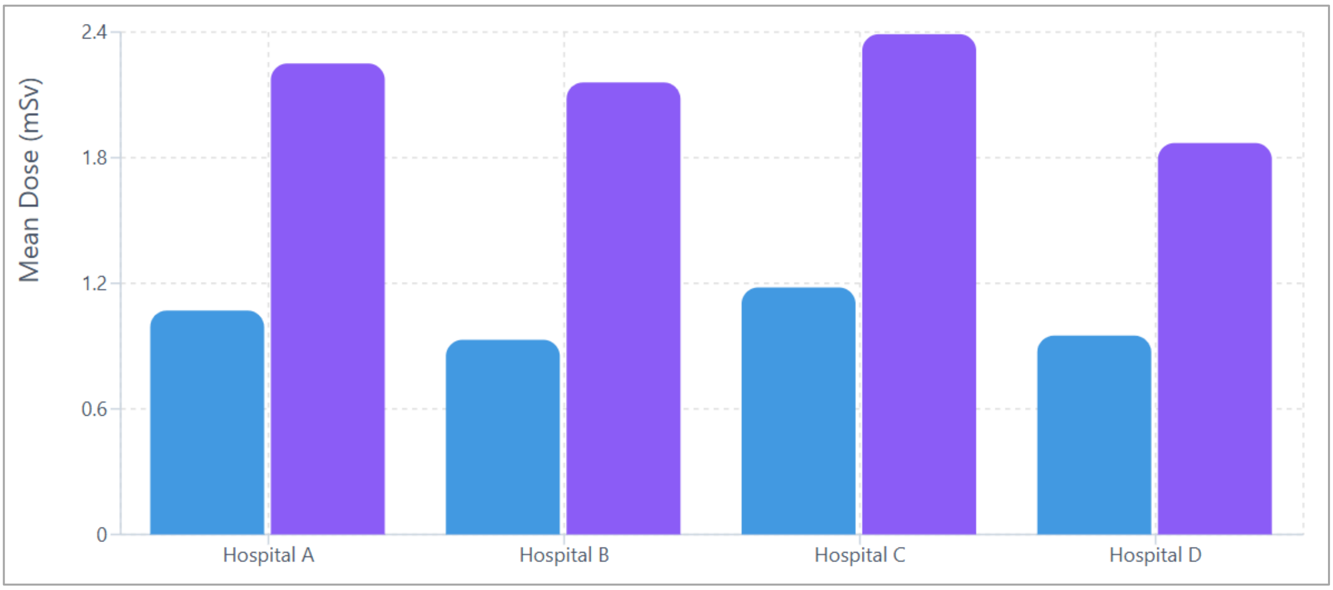

Figure 3. *Annual Mean Radiation Doses per Hospital Bar Chart.*

Surface Skin Dose (mSv)
Deep Skin Dose (mSv)

4.4. Compliance with Recommended Dose Limits

The measured occupational radiation exposure levels, both quarterly and annually, were compared against established national and international regulatory dose limits.

1. The International Commission on Radiation Protection (ICRP) recommends an effective dose limit of 20 mSv per year averaged over 5 consecutive years, with an annual effective dose limit of 50 mSv in any single year. For the lens of the eye, the limit is 20 mSv/year, and for the skin, hands, and feet, it is 500 mSv/year [9].
2. The Nigerian Nuclear Regulatory Authority (NNRA) stipulates an occupational exposure dose limit of 20 mSv per year, averaged over a period of 5 consecutive years [5].

Based on these standards, the highest individual annual deep skin dose recorded in this study was 3.92 mSv, and the highest individual annual surface skin dose was 1.70 mSv. Both the overall and individual annual mean doses are consistently well below the recommended effective dose limits set by both ICRP and NNRA. No occupational worker exceeded any of the annual dose limits for effective dose, eye lens, or skin. This indicates a general compliance with radiation safety standards within the monitored facilities.

4.5. Statistical Comparison of Doses Across Hospitals

To assess if occupational radiation exposure varied significantly across the four hospitals, a One-way Analysis of Variance (ANOVA) was conducted for both annual surface skin dose (Hp(0.07)) and annual deep skin dose (Hp(10)). The analyses revealed no statistically significant differences in mean annual doses among the hospitals. For Hp(0.07), the ANOVA yielded $F=0.335$ with a p-value of 0.800, and for Hp(10), $F=0.327$ with a p-value of 0.806. As both p-values were well above the significance level of $\alpha=0.05$, post-hoc tests were not required, affirming a consistent level of occupational exposure across all surveyed facilities.

5. Discussion

This study provides a comprehensive 12-month assessment of occupational radiation exposure among radio-diagnostic health workers in four Northwestern Nigerian specialist hospitals, offering crucial insights into regional radiation protection efficacy against national and international standards. Our findings demonstrate consistently low exposure levels, with overall annual mean deep skin dose (Hp(10)) of 2.16 mSv and surface skin dose (Hp(0.07)) of 1.03 mSv. Individual maximum annual doses were 3.92 mSv (Hp(10)) and 1.70 mSv (Hp(0.07)), all well below ICRP and NNRA limits, indicating largely effective existing safety measures. Crucially, One-way ANOVA revealed no statistically significant differences in annual doses among the four hospitals ($p=0.800$ for Hp(0.07) and $p=0.806$ for Hp(10)), suggesting a remarkable and reassuring consistency in radiation protection practices across these diverse settings. This consistency implies prevalent similar operational procedures and safety protocol adherence. Our results align with previous regional studies, such as, which reported comparable dose ranges, but significantly expand upon them. The multi-center approach and statistical validation of consistent exposure levels represent a unique strength of this study, enhancing the generalizability and robustness of conclusions for the entire Northwestern Nigerian region. While occasional "0.00 mSv" readings were observed, possibly indicating minimal exposure or TLD usage issues, they do not detract from the overall conclusion of low and well-controlled occupational exposure. This research offers a more comprehensive and statistically sound regional overview of radiation safety, broadening the applicability of its findings for future safety enhancements.

6. Recommendations and Conclusion

This study conclusively demonstrates that occupational radiation exposure levels for health workers in four specialist hospitals across Northwestern Nigeria are consistently low and well within national and international safety limits over a 12-month period. These encouraging findings suggest the effectiveness and uniformity of current radiation protection measures across the facilities. However, given the non-threshold nature of stochastic effects, continuous vigilance and adherence to the As Low As Reasonably Achievable (ALARA) principle remain paramount. The study underscores the critical importance of sustained personnel monitoring, regular comprehensive training, and robust quality assurance programs to further minimize exposure and safeguard long-term worker safety. While this research provides a vital regional snapshot, future longitudinal studies, broader national investigations, and increased inter-hospital collaboration are recommended to enhance our understanding and ensure a consistently high standard of radiation safety across the healthcare sector.

Conflicts of Interest

The authors declare no conflicts of interest.

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