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Assessment of occupational Radiation Exposure Levels and Temporal Patterns Associated with Radio-Diagnostic Activities in Four Specialist Hospitals in Northwestern Nigeria

Peter Emmanuel Anzaku[1*], Tijani Saleh Bichi[1], Mustapha Shuaibu Hikima[2] and Nasir, Alhassan Kabo[3]

[1]*Department of Physics Aliko Dangote University of Science and Technology, Wudil.*

[2]*Department of Radiology Maternity and Children Hospital, Rafha, Saudi Arabia.*

[3]*Department of Radiology Federal Medical Center Birnin Kudu, Jigawa.*

***Correspondence author**
Peter Emmanuel Anzaku,
Department of Physics Aliko Dangote University of Science and Technology, Wudil.

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Abstract

Occupational exposure to ionizing radiation remains an important radiation-protection concern among diagnostic radiology personnel because repeated low-level exposure may accumulate over time. Continuous personnel monitoring is therefore essential for evaluating occupational exposure and maintaining radiation doses As Low as Reasonably Achievable (ALARA). This study assessed occupational radiation exposure levels among radio-diagnostic personnel in four specialist hospitals in Northwestern Nigeria and evaluated temporal variations and inter-centre differences in personnel dose. A longitudinal prospective study was conducted from March 2024 to March 2025 among occupationally exposed radiology personnel at Murtala Muhammad Specialist Hospital, Kano; Federal Medical Centre, Katsina; Rasheed Shekoni Federal University Teaching Hospital, Dutse; and Federal Medical Centre, Birnin Kudu. Personnel radiation doses were monitored quarterly using calibrated TLD-100 thermoluminescent dosimeters. Environmental radiation surveys were conducted concurrently to assess ambient radiation levels during background and routine equipment operation. Deep dose equivalent, Hp(10), and shallow dose equivalent, Hp(0.07), were evaluated from the quarterly dosimetric records. Descriptive statistics were used to determine dose distributions, while one-way analysis of variance (ANOVA) was employed to assess differences in occupational dose among the four study centres at a significance level of $p < 0.05$.

Ambient background radiation levels across the study centres ranged from 0.10 to 0.11 µSv/h. During equipment operation, the highest measured ambient radiation level was 0.148 µSv/h in the X-ray room at Rasheed Shekoni Federal University Teaching Hospital, Dutse. The mean quarterly Hp(10) values were 0.456, 0.914, 0.336, and 0.582 mSv for the first, second, third, and fourth quarters, respectively, giving a mean annual cumulative Hp(10) of 2.288 mSv. Corresponding mean quarterly Hp(0.07) values were 0.284, 0.252, 0.217, and 0.319 mSv, respectively, with a mean annual cumulative Hp(0.07) of 1.072 mSv. The highest individual annual cumulative Hp(10) was 3.92 mSv, while the lowest was 0.14 mSv. All monitored personnel therefore remained substantially below the occupational dose limit of 20 mSv per year recommended by the International Commission on Radiological Protection (ICRP) and adopted within Nigerian radiation-protection requirements. The quarterly Hp(10) values showed temporal variation, with the highest mean dose occurring during the second quarter. One-way ANOVA indicated no statistically significant difference in mean occupational radiation dose among the four study centres ($F = 0.4616$, $p = 0.7126$) at $\alpha = 0.05$.

The findings demonstrate that occupational radiation exposure among the monitored radio-diagnostic personnel remained well below the recommended annual occupational dose limit throughout the study period. The relatively low environmental radiation levels and absence of statistically significant differences among the participating hospitals suggest generally comparable radiation-protection conditions across the study centres. Continued personnel dosimetry, effective shielding, appropriate use of personal protective equipment, staff awareness, and consistent application of the ALARA principle are recommended to sustain occupational radiation safety and prevent unnecessary cumulative exposure among radio-diagnostic personnel in Northwestern Nigeria.

Keywords: Occupational radiation exposure; TLD-100; Hp(10); Hp(0.07); radio-diagnostic personnel; radiation protection; ALARA; Northwestern Nigeria; environmental radiation; occupational dose.

Introduction
Background

Ionizing radiation has become indispensable in modern diagnostic medicine through its application in conventional radiography, computed tomography (CT), fluoroscopy and mammography. While these technologies contribute significantly to disease diagnosis and patient management, they simultaneously expose healthcare workers to chronic low-dose radiation. Prolonged occupational exposure has been associated with stochastic biological effects including carcinogenesis, cataract formation and genetic alterations.

Globally, occupational radiation monitoring programmes have reported annual effective doses ranging from 0.5 to 5.0 mSv among diagnostic radiology personnel, with higher values frequently reported in high-workload facilities and interventional imaging units. Studies from Europe, Asia and North America consistently demonstrate that workload intensity, procedural complexity and compliance with radiation protection measures are major determinants of occupational dose accumulation.

In Africa, studies conducted in Ghana, Tanzania and Egypt reported annual occupational doses ranging between 1.2 and 4.5 mSv among radiology personnel. Nigerian studies have similarly documented annual effective doses below regulatory limits but highlighted concerns regarding inconsistent personnel monitoring and variations in radiation protection practices across healthcare institutions.

Despite increasing utilization of diagnostic imaging services in Northwestern Nigeria, comprehensive multicentre data on occupational radiation exposure and predictive exposure trends remain limited. This study therefore assessed occupational radiation exposure levels, identified determinants of dose variability and explored predictive indicators of occupational radiation risk among diagnostic personnel in four specialist hospitals using thermoluminescent dosimetry.

Aim and Objectives of the Study

The aim of this study is to conduct a rigorous assessment of the Occupational Radiation Exposure (ORE) levels due to radio-diagnostic activities in four selected specialist hospitals in Northwestern Nigeria. During the course of this research the following objectives were achieved;

1. Provide evidence-based optimization and risk-mitigation strategies tailored to the unique operational challenges of multi-center specialist settings in Northwestern Nigeria.
2. Quantified the annual personal dose equivalents, Hp (10), received by occupationally exposed personnel across the four specialist hospitals.
3. Confirmed the level of compliance of the measured doses in each facility relative to the mandatory limits set by the International Commission on Radiological Protection (ICRP) and the Nigerian Nuclear Regulatory Authority (NNRA).
4. Provide the mean annual doses among the sampled hospitals to establish regional performance standards and identify institutions exhibiting statistically significant differences in exposure levels.

Theoretical Review

Radiation Interaction with Matter and Biological Hazards

The interaction of ionizing radiation with matter is a fundamental cornerstone of radiation physics, medical imaging and occupational safety. When ionizing radiation traverses a medium, it transfers energy to atoms and molecules through various physical processes, resulting in atomic ionization and excitation (Turner, 2007). The nature and extent of these interactions depend heavily on the radiation type, photon energy and the atomic number and density of the absorbing material (Bushberg et al., 2012). In diagnostic radiology, electromagnetic radiation in the form of X-rays interacts with tissues primarily through the photoelectric effect and Compton scattering, as the third major mechanism pair production requires energies exceeding 1.02 MeV, well above the conventional diagnostic threshold (Cember & Johnson, 2008).

The photoelectric effect occurs when an incident X-ray photon transfers its entire energy to an inner-shell electron, causing complete photon absorption and electron ejection (Bushberg et al., 2012). Highly dependent on atomic number, this effect provides the attenuation differentials necessary for diagnostic image contrast, though it concurrently increases the patient's absorbed dose. Conversely, Compton scattering is the predominant interaction within the diagnostic energy range. Here, an incident photon transfers only a fraction of its energy to an outer-shell electron, resulting in electron ejection and the deflection of a lower-energy scattered photon (Hall & Giaccia, 2019). In the context of occupational radiation protection, Compton scattering is the primary source of radiation exposure to healthcare workers during diagnostic and interventional procedures. The intensity of this scattered radiation fluctuates based on beam energy, field size, patient thickness and overall imaging workload.

The biological significance of these interactions stems directly from the resulting ionization within living tissues. Energy deposited at the cellular level damages vital biomolecules such as DNA, proteins and cellular membranes, precipitating a chain of biological hazards that are broadly categorized into deterministic and stochastic effects (Hall & Giaccia, 2019). Deterministic effects such as skin erythema, epilation, and sterility are dose-dependent, exhibit a distinct severity threshold and typically manifest acutely within hours to months post-exposure. Conversely, stochastic effects operate on a non-threshold model, meaning there is no entirely safe dose below which the probability of occurrence is zero. The likelihood of a stochastic effect, such as radiation-induced carcinogenesis or genetic mutations, is directly proportional to the cumulative radiation dose, with clinical symptoms typically delaying presentation for years or decades (Dumonceau et al., 2012; Leyton et al., 2014). Because radiology department personnel face an elevated risk of cumulative stochastic injuries due to routine exposure to scattered radiation, continuous monitoring and exposure optimization are legally and clinically mandatory.

Radiation Protection Principles and Regulatory Frameworks

To mitigate these occupational risks, modern radiation safety practices center on the fundamental philosophy of maintaining exposure As Low as Reasonably Achievable (ALARA), balancing economic and social factors (Wilson-Stewart et al., 2018). Effective implementation of ALARA relies on robust physical shielding utilizing high-atomic-number materials like lead to strongly attenuate the primary and scattered beams alongside strict regulatory oversight. International and national regulatory bodies establish mandatory dose limits to safeguard healthcare professionals. Globally, the International Commission on Radiological Protection (ICRP) recommends specific occupational limits, including an effective dose limit of 5 mSv per year, an eye lens equivalent dose of 20 mSv/year and equivalent dose limits of 500 mSv/year for the skin, hands and feet (ICRP, 2017).

Domestically, the Nigerian Nuclear Regulatory Authority (NNRA) enforces an occupational exposure dose limit of 20 mSv per year, averaged over a period of five consecutive years (NNRA, 2004; IAEA, 2011; Muhogora et al., 2013). Strict adherence to these national guidelines, combined with the consistent use of personal protective equipment (PPE) such as lead aprons and thyroid shields, forms the technical foundation for modern personnel dosimetry (ICRP, 2005; Leyton et al., 2014). Ultimately, integrating a thorough understanding of radiation interaction mechanisms with stringent regulatory compliance is vital for evaluating occupational doses and optimizing the safety ecosystem within Northwestern Nigerian clinical environments.

Materials and Methods

Study Design

This study employed a prospective multicentre occupational radiation dosimetry design to assess radiation exposure levels among radio-diagnostic personnel in four specialist hospitals located in Northwestern Nigeria. Personnel monitoring was conducted over a twelve-month period from March 2024 to March 2025 using Thermoluminescent Dosimeters (TLD-100), the Harshaw Model 4500 system comprises several hardware components:

5. 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.
6. A Video Display Unit (VDU) for graphical data display, operating instructions and system messages.
7. A Keyboard serving as the interactive central interface with the TLD reader.
8. 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. also environmental radiation surveys were performed to evaluate shielding effectiveness and ambient radiation conditions within the selected facilities.

Study Area

The study was conducted in four specialist Hospital providing diagnostic radiology services within Northwestern Nigeria. The participating centres included Murtala Muhammad Specialist Hospital (MMSH), Kano State; Federal Medical Centre (FMC), Katsina State; Rashid Shekoni Teaching Hospital (RSTH), Dutse, Jigawa State; and Federal Medical Centre (FMC), Birnin Kudu, Jigawa State. These hospitals were selected because they represent major referral centres with active diagnostic radiology departments utilizing conventional radiography, computed tomography (CT), mammography and other X-ray–based imaging modalities.

Figure 1: Cartographic Distribution of Participating Specialist Hospitals in Northwestern Nigeria.

Study Population

The study population comprised healthcare professionals routinely exposed to ionizing radiation during diagnostic imaging procedures. These included radiographers, radiologists and X-ray technicians directly involved in the operation of radiation-emitting equipment. A total of twenty occupationally exposed workers were recruited through purposive sampling, with five participants selected from each hospital based on their active involvement in radio-diagnostic procedures and willingness to participate in the study.

Inclusion and Exclusion Criteria

Participants were eligible for inclusion if they were actively involved in operating radiation-producing equipment such as conventional X-ray units, computed tomography scanners or mammography systems and provided informed consent to participate in the study. Personnel, who worked exclusively with non-ionizing imaging modalities, including magnetic resonance imaging (MRI) and ultrasonography, were excluded. Individuals who declined participation or failed to comply with the dosimetry protocol were also excluded from the study.

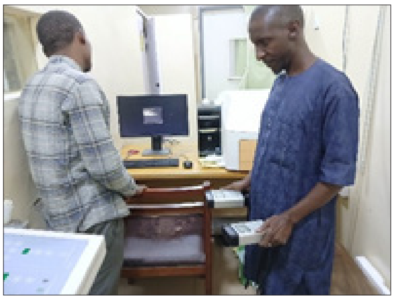
Personnel Dosimetry

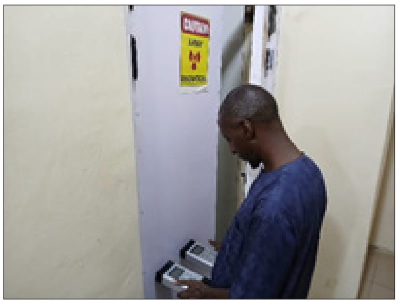
Occupational radiation exposure was assessed using TLD-100 (LiF,Ti) thermoluminescent dosimeters supplied by the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The dosimeters were selected because of their high sensitivity, good reproducibility and near-tissue equivalence. Each participant was issued a calibrated TLD badge at the beginning of every monitoring cycle and instructed to wear the dosimeter at chest level beneath protective lead aprons where applicable. The monitoring programme was conducted in four consecutive quarterly cycles, each lasting approximately ninety days.

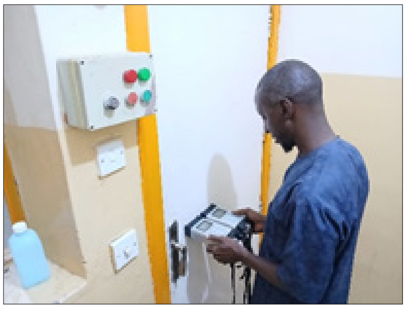
At the end of each monitoring period, exposed dosimeters were retrieved and replaced with freshly annealed badges. To minimize non-occupational exposure, participants were instructed to store their dosimeters in designated radiation-safe locations after duty hours. Personal dose equivalents at 10 mm and 0.07 mm tissue depths, Hp(10) and Hp(0.07), respectively, were determined for each monitoring cycle.

Environmental Radiation Survey

Environmental radiation measurements were performed using RDS-120 Universal Survey Meters to assess ambient radiation levels and verify the effectiveness of structural shielding within the diagnostic facilities. Measurements were obtained at selected locations including X-ray rooms, control booths, staff offices, reception areas, corridors and changing rooms. The survey meter was positioned approximately one metre above floor level and three independent measurements were obtained at each location. To ensure statistical rigor and account for potential fluctuations in the radiation field, a triplicate measurement protocol was adopted. Three independent readings were recorded at each sampling location by both monitors.







The final ambient dose rate for each point was derived from the arithmetic mean of these six total data points, thereby minimizing random instrumental error and enhancing the precision of the primary dataset. Mathematically expressed as:

$$\bar{H}_{\text{ambient}} = \frac{1}{6}\sum_{i=1}^{3}(M_{1,i} + M_{2,i}) \quad (1)$$

where

$\bar{H}_{\text{ambient}}$: The final verified ambient dose rate, measured in microsieverts per hour ($\mu\text{Sv/h}$).

$M_{1,i}$: The i-th reading (from a set of three) recorded by **Survey Meter 1**.

$M_{2,i}$: The i-th reading (from a set of three) recorded by **Survey Meter 2**.

TLD Processing and Calibration

All retrieved dosimeters were processed at the Centre for Energy Research and Training (CERT), Zaria, using a Harshaw Model 4500 Manual Thermoluminescent Dosimeter Reader interfaced with the Windows Radiation Evaluation and Management System (WinREMS) software. Prior to dose reconstruction, the TLD reader was calibrated using standard irradiated reference dosimeters exposed to a known dose from a calibrated 137Cs source. The RCF serves as the fundamental conversion constant between the integrated charges (nC) generated by the Photomultiplier Tube (PMT) and the final absorbed dose (mSv). Express mathematically as:

$$RCF = \frac{\bar{Q}}{D_{std}} \quad (2)$$

Where:

$\bar{Q}$ is the mean integrated charge (nC) obtained from the irradiated Golden TLDs.

D_{std} is the standard reference dose 10 mSv

Consequently, the individual occupational dose (H_p (10) for the participants in the four specialist hospitals was calculated using:

$$H_p(10) = \left(\frac{Q_{\text{raw}} \times \text{ECC}}{\text{RCF}}\right) - D_{\text{bg}} \quad (3)$$

Where:

$H_p(10)$ = Personal Dose Equivalent: The dose delivered to soft tissue at a depth of 10 mm (measured in mSv).

Q_{raw} = Raw Charge/Readout: The raw signal (usually in nanocoulombs, nC) measured by the TLD reader.

ECC = Element Correction Coefficient: A unique factor for each individual TLD chip to account for slight variations in sensitivity between chips.

RCF = Reader Calibration Factor: A constant that converts the corrected charge (nC) into a dose unit (mSv), determined by calibrating the reader with known doses.

D_{bg} = Background Dose: The natural background radiation or noise signal that is subtracted to ensure you are only measuring the occupational exposure.

The RCF serves as the fundamental conversion constant between the integrated charge (nC) generated by the Photomultiplier Tube (PMT) and the final absorbed dose (mSv). This calibration process ensures that the thermoluminescent output is traceable to international standards and accounts for the specific sensitivity of the LiF:Mg,Ti crystal lattice (McKeever et al., 1995). Quality assurance procedures included the determination of Reader Calibration Factors (RCF), Element Correction Coefficients (ECC), optimization of the Time–Temperature Profile (TTP), and nitrogen gas purging during readout to minimize signal interference and oxidation effects. Glow curve analysis was performed for each dosimeter, and occupational doses were reconstructed after calibration corrections and background subtraction. The personal dose equivalent, Hp(10), was calculated from the corrected thermoluminescent signal using established calibration procedures traceable to international dosimetry standards.

Individual Annual Effective Dose

The Annual Effective Dose (E) for each staff member was calculated by aggregating the Personal Dose Equivalent, Hp (10), across the four quarterly monitoring cycles. This ensures the results reflect a full year of occupational activity

$$E = \sum_{i=1}^{4} [H_p(10)]_i \quad (4)$$

Where:
E: The total Annual Effective Dose (mSv/year).
i: Represents each 90-day (quarterly) monitoring period (1, 2, 3, 4).
$(H_p(10))I$: The personal dose equivalent recorded for the i^{th} quarter.

Collective Effective Dose

The Collective Effective Dose (S) represents the total exposure for the personnel across all selected facilities (1, 2, 3, and 4). It is expressed as the sum of the individual annual doses:

$$S = \sum_{j=1}^{N} E_j \quad (5)$$

Where:
S: The collective dose (person-Sv).
E_j: The annual effective dose of the j^{th} individual.
n: The total number of monitored personnel across the four facilities.

Descriptive statistics including mean, standard deviation, minimum, and maximum dose values were also computed.

Statistical Analysis

Descriptive statistical analyses were performed to determine mean values, standard deviations, minimum values and maximum values of the recorded occupational doses. Annual effective doses were obtained by summing the quarterly Hp(10) values for each participant. Collective effective dose was calculated as the sum of all individual annual effective doses recorded across the study population.

To evaluate differences in occupational radiation exposure among the four participating hospitals, a one-way Analysis of Variance (ANOVA) was conducted. Statistical significance was assessed at a 95% confidence level with a significance threshold of $p < 0.05$. All analyses were performed using Python statistical libraries, including SciPy and Statsmodels.

Results and Discussion

Table 1: Environmental Radiation Survey (µsv/Hr)

Facility	Location	Before Exposure (Mean)	During Exposure (Mean)	Observed Increase
MMSH Kano	X-ray Room	0.110	0.122	+0.012
	Staff Office	0.108	0.112	+0.004
	Reception	0.110	0.110	Negligible
FMC Katsina	X-ray Room	0.112	0.137	+0.025
	Control Room	0.103	0.115	+0.012
	Corridor/Entrance	0.100	0.100	None
RS Teaching Hospital Dutse	X-ray Room	0.113	0.148	+0.035
	Control Room	0.112	0.115	+0.003
	Changing Rooms	0.100	0.110	+0.010
FMC Birnin Kudu	X-ray Room	0.110	0.122	+0.012
	Control Room	0.103	0.110	+0.007
	Dark Room	0.100	0.100	None

Quarterly Occupational Dose Assessment

Table 2: First Quarter TLD-100 Personal Dose Equivalent Readings

S/No.	personal dose equivalent Hp(0.07) (mSv)	personal dose equivalent Hp(10) (mSv)
TLD1A	0.59	0.68
TLD2A	0.54	0.62
TLD3A	0.11	0.14
TLD4A	0.25	0.50
TLD5A	0.58	0.68
TLD6B	0.27	0.26
TLD7B	0.19	0.18
TLD8B	0.43	0.57
TLD9B	0.21	0.30
TLD10B	0.25	0.47
TLD11C	0.25	0.35
TLD12C	0.34	0.50
TLD13C	0.10	0.14
TLD14C	0.24	0.64
TLD15C	0.56	0.63
LTD16D	0.13	0.47
TLD17D	0.12	0.47
TLD18D	0.17	0.51
TLD19D	0.17	0.52
TLD20D	0.17	0.49

Table 3: Second Quarter TLD-100 Personal Dose Equivalent Readings

S/No.	personal dose equivalent Hp(0.07) (mSv)	personal dose equivalent Hp(10) (mSv)
TLD1A	0.36	0.79
TLD2A	0.33	2.02
TLD3A	0.00	0.00
TLD4A	0.23	0.60
TLD5A	0.24	1.58
TLD6B	0.15	0.94
TLD7B	0.16	1.15
TLD8B	0.24	1.17
TLD9B	0.12	0.30
TLD10B	0.26	1.12
TLD11C	0.25	0.67
TLD12C	0.23	0.69
TLD13C	0.32	1.13
TLD14C	0.14	0.37
TLD15C	0.50	1.74
TLD16D	0.28	0.58
TLD17D	0.13	1.03
TLD18D	0.25	1.22
TLD19D	0.68	0.55
TLD20D	0.18	0.63

Table 4: Third Quarter TLD-100 Personal Dose Equivalent Readings

S/No.	personal dose equivalent Hp(0.07) (mSv)	personal dose equivalent Hp(10) (mSv)
TLD1A	0.29	0.32
TLD2A	0.36	0.51
TLD3A	0.00	0.00
TLD4A	0.21	0.21
TLD5A	0.29	0.15
LTD6B	0.13	0.31
TLD7B	0.19	0.30
TLD8B	0.14	0.27
TLD9B	0.10	0.19
TLD10B	0.22	0.20
TLD11C	0.19	0.42
TLD12C	0.17	0.27
TLD13C	0.13	0.48
TLD14C	0.14	0.26
TLD15C	0.39	0.55
TLD16D	0.13	0.46
TLD17D	0.14	0.59
TLD18D	0.46	0.60
TLD19D	0.55	0.31
TLD20D	0.11	0.31

Table 5: Fourth Quarter TLD-100 Personal Dose Equivalent Readings

S/No.	personal dose equivalent Hp(0.07) (mSv)	personal dose equivalent Hp(10) (mSv)
TLD1A	0.32	0.54
TLD2A	0.25	0.77
TLD3A	0.00	0.00
TLD4A	0.17	0.32
TLD5A	0.23	0.80
TLD6B	0.27	0.60
TLD7B	0.49	0.96
TLD8B	0.19	0.18
TLD9B	0.33	0.75
TLD10B	0.29	0.57
TLD11C	0.21	0.46
TLD12C	0.49	0.58
TLD13C	0.88	0.99
TLD14C	0.14	0.50
TLD15C	0.25	0.57
TLD16D	0.56	0.63
TLD17D	0.16	0.27
TLD18D	0.56	0.72
TLD19D	0.43	0.72
TLD20D	0.15	0.71

Annual Cumulative Occupational Dose Distribution

Table 6: Annual Accumulated TLD-100 Personal Dose Equivalent Readings (TLD1 – TLD20).

S/No.	personal dose equivalent Hp(0.07) (mSv)	personal dose equivalent Hp(10) (mSv)
TLD1	0.59+0.36+0.29+0.32=1.56	0.68+0.79+0.32+0.54=2.33
TLD2	0.54+0.33+0.36+0.25=1.48	0.62+2.02+0.51+0.77=3.92
TLD3	0.11+0.00+0.00+0.00=0.11	0.14+0.00+0.00+0.00=0.14
TLD4	0.25+0.23+0.21+0.17=0.86	0.50+0.60+0.21+0.32=1.63
TLD5	0.58+0.24+0.29+0.23=1.34	0.68+1.58+0.15+0.80=3.21
TLD6	0.27+0.15+0.13+0.27=0.82	0.26+0.94+0.31+0.60=2.11
TLD7	0.19+0.16+0.19+0.49=1.03	0.18+1.15+0.30+0.96=2.59
TLD8	0.43+0.24+0.14+0.19=1.00	0.57+1.17+0.27+0.18=2.19
TLD9	0.21+0.12+0.10+0.33=0.76	0.30+0.30+0.19+0.75=1.54
TLD10	0.25+0.26+0.22+0.29=1.02	0.47+1.12+0.20+0.57=2.36
TLD11	0.25+0.25+0.19+0.21=0.90	0.35+0.67+0.42+0.46=1.90
TLD12	0.34+0.23+0.17+0.49=1.23	0.50+0.69+0.27+0.58=2.04
TLD13	0.10+0.32+0.13+0.88=1.43	0.14+1.13+0.48+0.99=2.74
TLD14	0.24+0.14+0.14+0.14=0.66	0.64+0.37+0.26+0.50=1.77
TLD15	0.56+0.50+0.39+0.25=1.70	0.63+1.74+0.55+0.57=3.49
TLD16	0.13+0.28+0.13+0.56=1.10	0.47+0.58+0.46+0.63=2.14
TLD17	0.12+0.13+0.14+0.16=0.55	0.47+1.03+0.59+0.27=2.36
TLD18	0.17+0.25+0.46+0.56=1.44	0.51+1.22+0.60+0.72=3.05
TLD19	0.17+0.68+0.55+0.43=1.83	0.52+0.55+0.31+0.72=2.10
TLD20	0.17+0.18+0.11+0.15=0.61	0.49+0.63+0.31+0.71=2.14

Comparative Quarterly Trends

Table 7: Summary of Mean Quarterly and Annual Cumulative Radiation Doses (mSv)

Assessment Period	Mean personal dose equivalent Hp(0.07) (mSv)	Mean personal dose equivalent Hp(10) (mSv)
1st Quarter	0.284	0.456
2nd Quarter	0.253	0.914
3rd Quarter	0.217	0.336
4th Quarter	0.319	0.582
Annual Total	1.073	2.288

Anova Analysis

Table 8: Summary of Statistical Analysis for All Quarters

Period	Mean personal dose equivalent Hp(10) (mSv)	Standard Deviation (σ)	Range (Min - Max)
1st Quarter	0.456	0.173	0.14 – 0.68
2nd Quarter	0.914	0.499	0.00 – 2.02
3rd Quarter	0.336	0.158	0.00 – 0.60
4th Quarter	0.582	0.248	0.00 – 0.99
Annual Cumulative	2.288	0.796	0.14 – 3.92

Discussion of Results

Table 1: Environmental radiation survey results for the four study centres.

The environmental radiation survey was conducted in the radiology departments, control rooms, administrative offices and surrounding areas of the four participating hospitals. The objective was to establish baseline radiation levels and evaluate the effectiveness of existing structural shielding during routine diagnostic radiological procedures.

The measured ambient background radiation levels ranged from 0.10 to 0.11 μSv/h across all study centres. During active radiographic examinations, radiation levels within examination rooms increased slightly but remained within acceptable limits. The highest instantaneous value recorded was 0.148 μSv/h at Rasheed Shekoni Teaching Hospital (RSTH), Dutse. However, radiation levels in adjacent control rooms and administrative offices remained comparable to natural background levels, demonstrating adequate attenuation of scattered radiation by installed shielding structures.

The findings indicate that the shielding systems in the participating hospitals are functioning effectively and comply with recommended radiation protection standards established by the Nigerian Nuclear Regulatory Authority (NNRA, 2006) and the International Atomic Energy Agency (IAEA, 2014).

Table 2: Quarterly occupational radiation dose assessment among radiology personnel.

Quarterly personnel monitoring was carried out using TLD-100 dosimeters over a 12-month period from March 2024 to March 2025. Personal dose equivalents at 10 mm depth, Hp(10), and at 0.07 mm depth, Hp(0.07), were evaluated for all participating occupationally exposed workers.

The results revealed temporal variations in occupational radiation exposure across the study period. The mean quarterly Hp(10) values were 0.456 mSv, 0.914 mSv, 0.336 mSv, and 0.582 mSv for the first, second, third, and fourth quarters, respectively. The second quarter recorded the highest mean Hp(10), while the third quarter recorded the lowest. This temporal variation may reflect differences in clinical workload, patient throughput, procedural demands, and equipment utilization during the monitoring periods.

The corresponding mean quarterly Hp(0.07) values were 0.284 mSv, 0.252 mSv, 0.217 mSv, and 0.319 mSv, respectively. The quarterly Hp(10) values were generally higher than the corresponding Hp(0.07) values. Because the TLD badges were worn beneath protective lead aprons where applicable, the observed pattern may reflect differential attenuation of incident scattered radiation at the dosimeter location. This observation should, however, be interpreted in relation to dosimeter placement and shielding conditions rather than as a direct measure of organ dose.

Table 3: Annual cumulative occupational dose distribution among monitored personnel.

Annual cumulative personal dose equivalents were calculated by summing the four quarterly Hp(10) measurements for each monitored worker. The corrected annual distribution showed generally low occupational radiation exposure across the study population. The mean annual Hp(10) was 2.288 ± 0.796 mSv, with individual cumulative values ranging from 0.14 to 3.92 mSv.

The highest cumulative annual Hp(10) of 3.92 mSv was recorded for TLD2, while the lowest recorded cumulative value was 0.14 mSv for TLD3. All recorded annual Hp(10) values were substantially below the occupational effective-dose limit of 20 mSv per year averaged over five years. These findings indicate that the monitored workers remained well below the applicable regulatory dose constraint during the study period.

The relatively low cumulative doses observed across the study population are consistent with effective application of time, distance, shielding, personnel monitoring and other radiation-protection measures. However, the observed variability among individual workers emphasizes the importance of continued routine dosimetry and periodic review of occupational work practices.

Table 4: Comparative quarterly occupational dose trends across the four hospitals.

Comparative analysis of quarterly dose trends showed a similar exposure pattern across the four hospitals. Occupational doses increased during the second quarter, decreased substantially in the third quarter, and rose moderately in the fourth quarter.

Centre A (MMSH Kano) recorded the highest cumulative annual mean dose, whereas the remaining centres demonstrated relatively similar exposure profiles. Despite minor institutional differences, the observed trends suggest that workload fluctuations rather than facility-specific deficiencies were the primary determinants of occupational exposure.

The temporal variation observed throughout the monitoring period highlights the influence of patient throughput, procedure complexity, and equipment utilization on occupational radiation dose accumulation.

Table 5: One-way ANOVA comparing occupational radiation doses among the four study centres.

A one-way Analysis of Variance (ANOVA) was performed to determine whether significant differences existed in occupational radiation exposure among the four participating hospitals.

The analysis yielded an F-statistic of 0.4616 and a p-value of 0.7126. Since the p-value exceeded the significance threshold of 0.05, the null hypothesis was retained, indicating that there was no statistically significant difference in mean occupational radiation dose among the study centres.

These findings suggest a high degree of uniformity in radiation protection practices, operational procedures, and occupational safety standards across the participating hospitals.

ANOVA Summary

- F-value = 0.4616
- p-value = 0.7126
- Significance level (α) = 0.05

Since:

p=0.7126>0.05p = 0.7126 > 0.05p=0.7126>0.05

the null hypothesis:

H0:μA=μB=μC=μDH_0: \mu_A = \mu_B = \mu_C = \mu_DH0

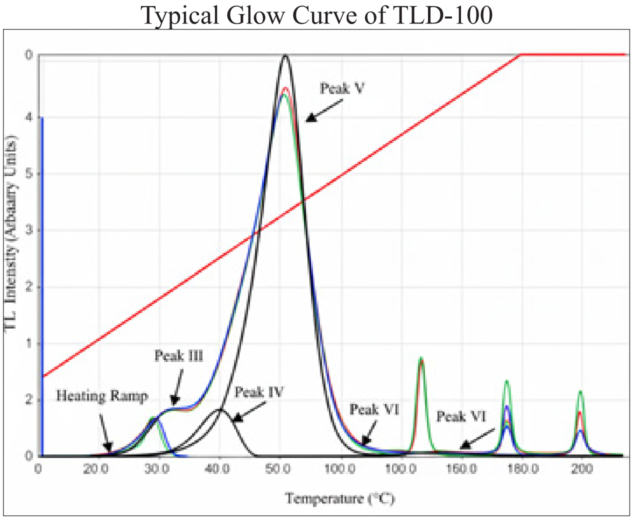


Figure 1: Representative thermoluminescent dosimeter (TLD-100) glow curve showing the characteristic dosimetric peak used for occupational dose estimation.

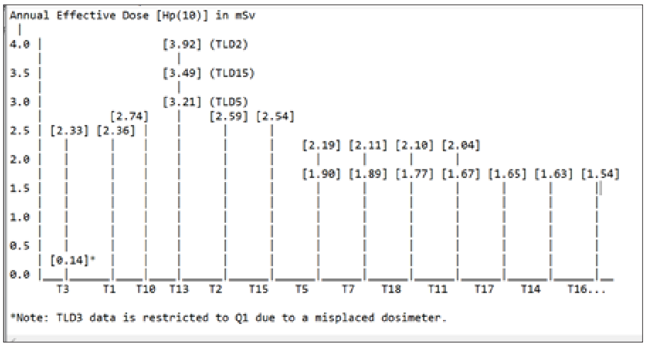


Figure 2: Distribution of annual cumulative deep dose equivalent Hp(10) among monitored occupationally exposed workers in the four specialist hospitals.

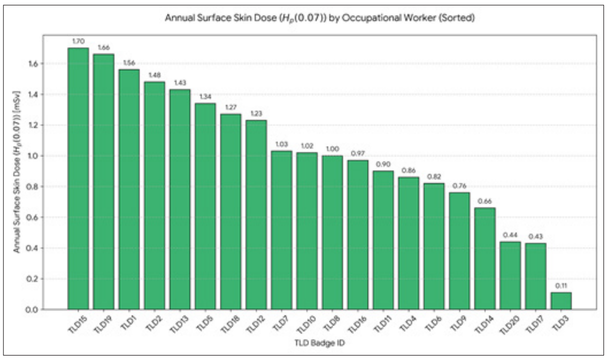


Figure 3: Distribution of annual cumulative shallow dose equivalent Hp(0.07) among monitored occupationally exposed workers.

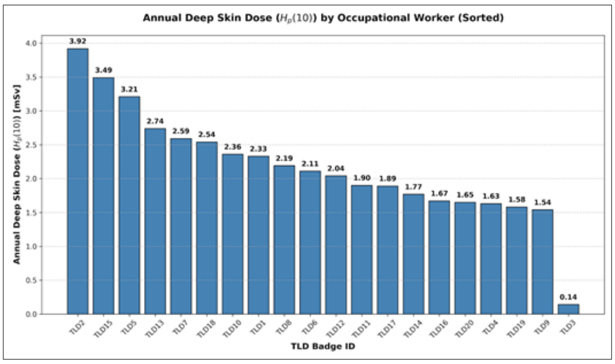


Figure 4: Annual deep dose equivalent Hp(10) recorded for individual occupationally exposed workers during the study period.

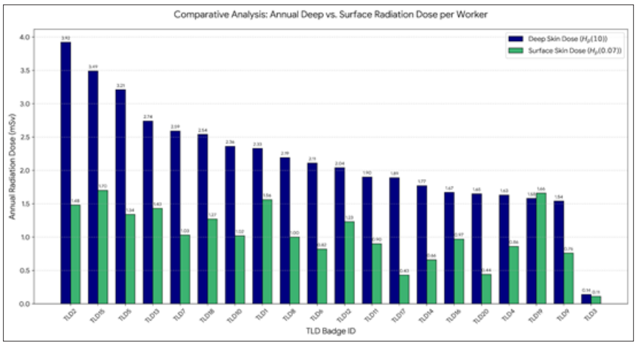


Figure 5: Comparative distribution of annual deep dose equivalent Hp(10) and shallow dose equivalent Hp(0.07) among occupationally exposed workers.

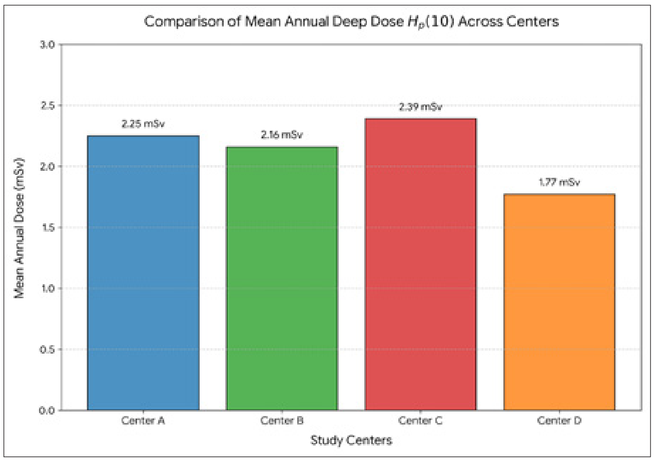


Figure 6: Comparison of mean annual occupational radiation doses among the four participating specialist hospitals in Northwestern Nigeria.

Findings

Environmental Radiation Safety

The environmental radiation assessment conducted across the four participating hospitals demonstrated that ambient radiation levels remained within internationally accepted background radiation limits. Mean background radiation measurements ranged from 0.10 to 0.11 μSv/h, values comparable to global natural background radiation levels reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2010). This finding indicates the absence of residual radioactive contamination within the diagnostic facilities and confirms that routine diagnostic radiology operations do not significantly elevate environmental radiation exposure.

Although radiation levels increased slightly during active radiographic examinations, the highest measured value was 0.148 μSv/h in the X-ray room at Rasheed Shekoni Federal University Teaching Hospital, Dutse. Measurements in adjacent control rooms and other occupied areas remained close to background levels. These findings indicate effective attenuation of scattered radiation by the existing structural shielding. Because ambient dose rate and occupational personal dose equivalent are different radiation-protection quantities, the environmental measurements were interpreted primarily as indicators of shielding performance rather than as direct estimates of annual occupational dose. Similar observations have been reported by Farai and Jibiri (2000), Engel-Hills (2008), and Wilson-Stewart et al. (2018), who showed that properly designed shielding barriers substantially reduce scattered radiation in adjacent occupied areas. The findings therefore suggest compliance with radiation protection requirements stipulated by the Nigerian Nuclear Regulatory Authority (NNRA, 2006) and the International Atomic Energy Agency (IAEA, 2014). The observed shielding efficiency is particularly important because it confirms that occupational exposures recorded in this study were attributable primarily to professional activities within diagnostic imaging environments rather than environmental leakage or structural deficiencies.

Occupational Exposure Patterns

The quarterly dose assessment revealed noticeable variations in occupational radiation exposure throughout the monitoring period. The mean quarterly Personal Dose Equivalent at 10 mm depth Hp(10) increased from 0.443 mSv in the first quarter to 0.965 mSv in the second quarter before declining to 0.354 mSv in the third quarter and rising moderately to 0.597 mSv in the fourth quarter.

The pronounced increase observed during the second quarter suggests a period of heightened radiological workload and increased utilization of diagnostic imaging services. Similar workload-dependent fluctuations in occupational exposure have been reported by Covens et al. (2007), Chida et al. (2013), and Hasford et al. (2019), who identified patient throughput, procedure complexity, and equipment utilization as major determinants of occupational dose accumulation.

The annual cumulative dose distribution further demonstrated that occupational exposures remained relatively low across all monitored personnel. The mean annual Hp(10) value of 2.359 mSv was substantially below the regulatory occupational dose limit of 20 mSv per year. Furthermore, the highest cumulative annual dose recorded in this study (3.92 mSv) represented less than one-fifth of the permissible regulatory limit.

These findings indicate that the participating hospitals maintain effective radiation protection practices and that occupational exposure remains adequately controlled despite fluctuations in clinical workload, consistent with observations reported by Obed et al. (2016) and Usman et al. (2020).

Determinants and Patterns of Occupational Dose

The observed quarterly variation suggests that occupational radiation exposure was influenced by operational factors associated with diagnostic workload. The highest mean Hp(10) occurred during the second quarter (0.914 mSv), followed by the fourth quarter (0.582 mSv), whereas the first and third quarters recorded lower mean values of 0.456 mSv and 0.336 mSv, respectively. This temporal pattern suggests that differences in patient throughput, procedure frequency, equipment utilization and staff involvement in radiation-producing procedures may have contributed to variations in occupational dose.

However, because workload indicators and procedural frequencies were not quantitatively modelled against individual dose measurements in the present study, these factors should be regarded as plausible contributors rather than statistically established determinants. The findings therefore provide an empirical basis for future studies incorporating workload metrics, procedure duration, modality-specific exposure and staff positioning into regression or other predictive models.

The observed variation among individual workers also suggests that occupational dose is influenced by differences in work assignment, positioning relative to the radiation field, duration of exposure, adherence to distance protocols and use of protective shielding. These factors should be considered in future dose-optimization programmes.

Implications for Predictive Occupational Exposure Assessment

The quarterly dose pattern provides an initial empirical basis for considering predictive approaches to occupational radiation protection. The observed increase in mean Hp(10) during the second quarter, followed by reductions in the third and fourth quarters, indicates that occupational exposure is not necessarily constant throughout the year.

Although the present study did not develop a formal regression or machine-learning prediction model, the observed temporal variation suggests that operational indicators such as patient throughput, procedure frequency, modality utilization, procedure duration and staff positioning could potentially be incorporated into future predictive models.

A predictive radiation-safety framework based on these measurable operational variables could enable healthcare institutions to identify periods of potentially increased occupational exposure and implement preventive measures before cumulative doses become excessive. Future studies should therefore integrate larger longitudinal datasets with quantitative workload indicators and appropriate statistical or machine-learning methods to develop and validate predictive models of occupational radiation exposure.

Comparison with Global Studies

The occupational doses recorded in this study are generally lower than values reported in many international investigations involving high-volume diagnostic and interventional radiology facilities.

Chida et al. (2013) reported occupational doses ranging between 3.4 and 7.8 mSv annually among interventional radiology personnel in Japan. Similarly, (Koike et al., 2021) observed elevated occupational exposures among staff participating in CT-guided interventional procedures, largely due to prolonged fluoroscopic beam usage.

In Switzerland, Chiriotti et al. (2021) reported annual occupational doses ranging from approximately 2.5 to 5.0 mSv among medical radiation workers during a ten-year monitoring period. Likewise, (Park et al., 2021) documented cumulative occupational exposure among diagnostic radiation workers in South Korea that exceeded the mean annual dose observed in the present study.

The lower exposure levels observed in Northwestern Nigeria may be attributable to the predominance of conventional diagnostic radiography, lower procedural complexity, reduced fluoroscopic utilization, and effective implementation of radiation protection measures.

Comparison with African Studies

The findings of this study are consistent with several occupational dosimetry investigations conducted across Africa.

Hasford et al. (2019) reported mean annual occupational doses of approximately 2.8 mSv among diagnostic radiology personnel in Ghana. Similarly, Akrobortu et al. (2015) found annual exposures ranging between 1.7 and 3.6 mSv among radiographers working in selected Ghanaian hospitals.

In Tanzania, Msaki et al. (2019) reported annual occupational doses generally below 5 mSv, while emphasizing the importance of continuous monitoring and radiation protection training. Arouna et al. (2022) also noted that occupational doses in African healthcare facilities remain relatively low when proper shielding and monitoring systems are implemented.

The close agreement between the present findings and those reported elsewhere in Africa suggests that occupational radiation protection programmes across the continent are increasingly effective and aligned with international recommendations.

The agreement observed across these African studies may reflect increasing adherence to IAEA radiation protection recommendations and improved personnel monitoring programmes throughout the continent (IAEA, 2018b).

Comparison with Nigerian Studies

The present findings are broadly consistent with previous Nigerian investigations of occupational radiation exposure. These findings support earlier evidence indicating that occupational radiation exposure among Nigerian radiology personnel generally remains below internationally recommended dose limits when routine personnel monitoring programmes are implemented (Jibiri & Emelue, 2008; Arogunjo et al., 2017).

Jibiri and Farai (2002) reported annual occupational doses ranging from 1.8 to 4.5 mSv among diagnostic radiology workers in selected Nigerian hospitals. Similarly, (Obed et al., 2016) observed annual exposures below 5 mSv among radiology personnel in tertiary healthcare facilities.

Usman et al. (2020) reported annual occupational doses of approximately 2.6 mSv among diagnostic radiology workers in Katsina State, a value closely comparable to the mean annual dose of 2.359 mSv observed in the present study. Umar et al. (2013) also reported occupational doses well below regulatory limits in Northern Nigerian radio diagnostic centres.

The consistency between the current findings and previous Nigerian studies reinforces the conclusion that occupational radiation exposure in diagnostic radiology departments remains relatively low and effectively controlled under existing radiation protection frameworks.

Radiation Protection Compliance

A major finding of this study is the high level of compliance with both national and international radiation protection standards. The mean annual deep dose equivalent of 2.359 mSv represents only 11.8% of the annual occupational dose limit of 20 mSv established by the International Commission on Radiological Protection (ICRP, 2007) and adopted by the Nigerian Nuclear Regulatory Authority (NNRA, 2006).

Even the highest individual cumulative dose recorded during the study (3.92 mSv) remained substantially below the regulatory threshold, corresponding to only 19.6% of the permissible annual limit. These findings clearly demonstrate that none of the monitored workers approached levels associated with significant occupational radiation risk.

The one-way ANOVA results ($F = 0.4616$, $p = 0.7126$) further confirmed that occupational exposure levels did not differ significantly among the four hospitals. This statistical uniformity suggests that radiation protection practices, dosimetry programmes, and operational safety procedures are being implemented consistently across the participating institutions.

The observed reduction in mean occupational dose during the third quarter provides additional evidence of successful implementation of the ALARA (As Low As Reasonably Achievable) principle, which remains the cornerstone of modern radiation protection practice (ICRP, 2007; NCRP, 2018).

Conclusion and Recommendations

Conclusion

This study assessed occupational radiation exposure levels among radiodiagnostic personnel in four specialist hospitals in Northwestern Nigeria using Thermoluminescent Dosimeter (TLD-100) technology over a twelve-month monitoring period. The study further evaluated environmental radiation conditions, determinants of occupational exposure, and the potential for predictive interpretation of future exposure risks based on observed operational trends.

The environmental radiation survey revealed ambient background radiation levels ranging from 0.10 to 0.11 µSv/h, which are consistent with internationally reported natural background radiation values. Radiation measurements obtained in control rooms and administrative areas remained at background levels even during active radiographic procedures, confirming the effectiveness of installed shielding structures and compliance with established radiation protection requirements.

The occupational dose assessment demonstrated that radiation exposures among monitored personnel remained low throughout the study period. The mean annual deep dose equivalent [Hp(10)] was 2.359 ± 0.929 mSv, while the maximum annual cumulative dose recorded was 3.92 mSv. These values are substantially below the annual occupational dose limit of 20 mSv recommended by the International Commission on Radiological Protection (ICRP, 2007) and adopted by the Nigerian Nuclear Regulatory Authority (NNRA, 2006).

Quarterly dose analysis revealed fluctuations in exposure levels, with the highest mean dose occurring during the second quarter. This observation indicates that occupational radiation exposure is strongly influenced by clinical workload, patient throughput, and procedural demands. The consistent finding that Hp(10) values exceeded Hp(0.07) values further demonstrated the effectiveness of personal protective equipment in attenuating superficial radiation exposure.

Statistical evaluation using one-way Analysis of Variance (ANOVA) showed no significant difference in occupational radiation exposure among the four hospitals ($F = 0.4616$, $p = 0.7126$) at $\alpha = 0.05$. This finding suggests a high degree of uniformity in radiation protection practices and safety standards across the participating institutions.

The study also demonstrated the value of integrating predictive exposure assessment into occupational radiation protection programmes. The observed relationship between workload intensity and dose accumulation suggests that future occupational exposure trends can be anticipated using operational indicators, thereby supporting proactive radiation safety management.

Overall, the findings confirm that radiodiagnostic personnel in the studied hospitals operate within a well-established radiation protection framework characterized by effective shielding, appropriate personnel monitoring, regulatory compliance, and adherence to the ALARA (As Low As Reasonably Achievable) principle (ICRP, 2007; IAEA, 2014).

Recommendations

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

1. Strengthening Continuous Personnel Monitoring: Routine occupational dose monitoring using TLDs should be sustained across all radiodiagnostic facilities to ensure early detection of exposure trends and continued compliance with regulatory standards.
2. Workload-Based Exposure Management: Healthcare facilities should integrate workload indicators into radiation protection programmes to identify periods of increased exposure risk and facilitate proactive dose optimization measures.
3. Periodic Radiation Protection Training: Regular refresher training on radiation safety principles, proper use of personal protective equipment, and interpretation of dosimetry reports should be conducted for all occupationally exposed workers.
4. Enhanced Monitoring in High-Volume Facilities: Facilities experiencing high patient throughput or increased utilization of advanced imaging modalities should consider more frequent dosimetric evaluations to improve exposure surveillance.
5. Strengthening Dosimeter Accountability Systems: Hospitals should establish formal dosimeter tracking and custody protocols to prevent loss of monitoring devices and ensure uninterrupted occupational dose records.
6. Promotion of Digital Imaging Technologies: Greater adoption of digital radiography systems should be encouraged as part of dose optimization strategies aimed at reducing radiation exposure to both patients and healthcare workers.
7. Development of Predictive Radiation Safety Models: Future studies should expand on the predictive framework established in this research by incorporating larger datasets, workload metrics, and machine-learning approaches to forecast occupational radiation exposure trends.
8. Multi-Centre National Studies: Further nationwide investigations involving a larger number of healthcare facilities and imaging modalities are recommended to establish a comprehensive national occupational radiation exposure database for Nigeria.

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