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Article

Annual assessment of radiation exposure levels among radiology personnel at Usmanu Danfodiyo University Teaching Hospital, Sokoto, Nigeria

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ABSTRACT

The evaluation of occupational exposure to external ionizing radiation in diagnostic and therapeutic settings is crucial for understanding regulatory compliance and technological advancements. This research provides an analysis of occupational radiation exposure among radiology staff of Usman Danfodiyo University Teaching Hospital (UDUTH) in Sokoto, Nigeria, and compares the findings with relevant studies. A total of 30 radiology staff members participated, each identified by a TLD code instead of their names. Various parameters, including Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), Individual Distribution Ratio (NRE), Collective Dose Distribution Ratio (SRE), and Lifetime Probability of Cancer Risk (LFTR), were analyzed using SPSS version 21.0. The findings revealed that radiology workers had an AAED of 1.13 ± 0.51 mSv and an ACD of 33.90 ± 0.51 man mSv. The NRE and SRE indicated that 40.27% of the radiology staff received doses exceeding 1 mSv, while none exceeded 10 or 15 mSv. The LFTR for all medical radiation workers at UDUTH was less than 1 in a million, suggesting minimal lifetime cancer risk. Overall, the dose distribution trend indicates a shift towards lower exposure levels, highlighting the effectiveness of radiation protection protocols maintained by the majority of the staff.

1. Introduction

Ionizing radiation, including x-rays and gamma rays from radioactive materials, is electromagnetic and capable of penetrating matter, causing damage when absorbed. While these radiations have numerous beneficial applications, their misuse can be hazardous [1]. They can kill living cells or induce harmful changes in them, posing a significant risk to users. Those working with ionizing radiation must understand these risks and how they compare to everyday hazards, as well as how to mitigate them to safe levels. Operators of X-ray equipment and users of radioactive materials must be certified according to recognized standards and meet qualifications mandated by relevant Nigerian regulations. All operators should:

- Be familiar with the Nigeria Radiation Act, regulations, and license conditions.
- Understand the radiation hazards related to their work and their responsibility to protect themselves and others.
- Have comprehensive knowledge of their profession, safe working practices, and specialized techniques.
- Aim to minimize exposure through diligent use of appropriate techniques and procedures.
- Be at least 18 years old.

Female operators who suspect they are pregnant should inform their employer to ensure that their duties align with the accepted maximum radiation exposure guidelines during pregnancy [2]. X-rays function by traveling from the focal spot of the X-ray tube, casting shadows as they are blocked by objects. Unlike light, x-rays penetrate materials to varying degrees based on their generation and the material's properties. Bones appear in radiographic images because they absorb more X-rays than soft tissue. Lead and steel, which absorb X-rays more effectively, are used as protective barriers. X-rays emit in all directions from an energized X-ray tube, but the lead housing prevents escape in all directions except through the designated opening. The beam size, controlled by diaphragms, determines the visible area and the amount of scattered x-radiation produced, which poses a hazard if not properly blocked. The intensity of both primary and scattered X-rays decreases rapidly with distance from the source, similar to light intensity diminishing with distance [3]. X-rays are present only when the machine is on, and neither the operator nor the material becomes radioactive post-exposure. Gamma rays, however, are continuously emitted by radioactive materials and cannot be switched off. Their intensity and penetration depend on the radioisotope source. All individuals are exposed to background environmental radiation from cosmic rays, the air, and even within our bodies. Occupational radiation exposure adds to this background radiation, which varies geographically [4].

2. Literature review

2.1 Biological effects of radiation

X-rays and gamma rays are crucial in diagnostic and therapeutic medicine, industry, and research, inevitably exposing individuals to radiation. The challenge is to establish acceptable radiation exposure levels beyond natural background levels. The International Commission on Radiation Protection (ICRP) has long analyzed radiation effects on humans, periodically publishing recommended exposure limits [5]. These limits have been progressively lowered, not due to observed adverse effects at previous levels, but because it has been feasible to reduce exposure without significantly limiting radiation use in various fields. This principle, known as "As Low As Reasonably Achievable" (ALARA), applies to both patients and occupationally exposed personnel [6].

2.2 Effects of radiation on humans

A substantial amount of knowledge exists regarding the effects of radiation on humans, surpassing what is known about the impact of chemicals like insecticides and fungicides. The primary effects of the small amounts of radiation typically encountered by individuals using X-rays include genetic changes and cancer induction [7].

2.3 Personal exposure monitoring

Radiation exposure is monitored using badges that contain two tiny crystalline chips sensitive to very small amounts of radiation. These badges should be worn for a specified period, usually three months, before being returned for measurement. The results reflect the exposure received during this period [8]. To accurately measure individual exposure, the badge must be protected from radiation when not worn and should be worn next to the body during X-ray use. Without wearing the badge, it is impossible to determine an individual's radiation exposure accurately. Therefore, individuals must take responsibility for wearing their badges whenever there is a likelihood of X-ray exposure [9].

2.4 Medical utilization of ionizing radiation

The medical use of ionizing radiation, including procedures such as X-rays, fluoroscopy, mammography, and computed tomography, is the second-largest contributor to the global cumulative dose of ionizing radiation [10]. The increasing use of ionizing radiation for medical diagnostics has raised valid concerns [11]. Various levels of ionizing radiation exposure have been associated with potential biological risks, including radiation sickness, cellular damage, tissue and organ harm, cancers, and cataract development [1].

3. Methodology

Data for this study were collected from personnel working in the Radiology Department of Usman Danfodiyo University Teaching Hospital (UDUTH) in Sokoto, Nigeria. Anonymous records containing quarterly dosage measurements from this department, spanning the years 2019 to 2023, were obtained. The collected data documented medical radiation exposure doses, ensuring compliance with the regulations of the Health Research Ethics Board (HREB) by not disclosing the identities of the workers. Instead, each participant was assigned a unique TLD (Thermoluminescent Dosimeter) code to maintain anonymity. These depersonalized and coded records included details on quarterly whole-body and extremity doses for medical radiation workers. From these records, the cumulative annual dose was calculated using the method outlined by reference [7]. This approach aligns with established protocols in radiation safety research, ensuring the reliability and validity of the data. The use of anonymous TLD codes is a standard practice in radiation exposure monitoring, as noted by reference [12], to protect worker privacy while allowing for accurate dose assessment. By employing these standardized methodologies and ethical considerations, this study ensures the precise and confidential assessment of radiation exposure among radiology personnel at UDUTH, contributing valuable insights to the field of occupational health and safety.

$$D = \frac{H_T}{W_R} \tag{1}$$

Where D = Absorbed dose, H_T= Equivalent dose, W_R = Radiation weighting factor.

The calibration factor by reference [8] is defined as follows:

$$f_{calibration} = \frac{D_{ionization\ chamber\ (mGy)}}{TLD_{reading\ (n)}} \tag{2}$$

Absorbed dose due to irradiation is obtained after background subtraction using Equation 3:

$$D_{TLD} = D_{av} - BG \tag{3}$$

The absorbed dose is obtained for each TLD using Equation 4:

$$D(mGy) = \ f_{cal}\left(\frac{mGy}{nC}\right)\ X\ TLD_{reading}(nC) \tag{4}$$

For every individual measurement, the smallest detectable amount (referred to as MDL or minimum detection level) is 0.05 mSv within 3 months after accounting for the background. This MDL serves as a threshold for recording doses. Consequently, workers who have received doses lower than this MDL are classified as having not been exposed. The reader for Thermoluminescent Dosimeters (TLD) provides values for shallow dose equivalent (referred to as Skin dose) and deep dose equivalent (referred to as DDE), both of which are manually inputted into a Microsoft Excel spreadsheet. This input is then utilized to calculate the respective personnel dose equivalents, denoted as Hp(0.07) and Hp(10). The formulas for calculating Skin and deep doses are outlined in Equations 5 and 6, as detailed in the work by [8].

Skin dose: Hp(0.07) = [(1.2958Rskin) + 0.0097] Msv (5)

Deep dose: Hp(10)= [(1.3772Rdeep) + 0.0566]mSv (6)

Dose reporting was performed on a quarterly basis, and only those workers with doses exceeding a minimum detection level (MDL) of 0.05 mSv (exposed workers) after background subtraction will be considered. The workers with doses less than MDL are considered as non-exposed.

4. Data Analysis

This study used the average annual effective dose recommended by reference [2] to analyze individual doses for the stipulated period.

Absorbed dose (D): Energy imparted to matter from any type of radiation:

$$D = \frac{E}{m} \tag{7}$$

D: Absorbed dose
E: Energy absorbed by the body of mass (m).
Equivalent dose (H_T)
Accounts for biological effect per dose

$$H_T = W_R \times D \tag{8}$$

W_R: Radiation weighting factor.
Individual average annual effective dose is the risk-related parameter, taking the relative radio sensitivity of each organ or tissue into account.

$$E_i(Sv) = \sum_T W_T \times H_T \tag{9}$$

W_T: tissue weighing factor for organ T
H_T: equivalent dose received by organ or tissue T

5. Results and discussion

This study investigated the levels of occupational exposure to radiation among employees at Usmanu Danfodiyo University Sokoto Teaching Hospital, where ionizing radiation sources were utilized from 2019 to 2023. The report details the average effective dose on an annual basis for workers in the field of radiotherapy, and the findings are presented in this section. The results derived from Figure 1, detailing the experiences of 9 RD Radiographers over a five-year period, showcase the variability in Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk. Radiographers' AAED ranged from 0.40 to 2.80 mSv, while ACD ranged from 3.6 to 25.20 man mSv, with LFTR ranging from 0.0020 to 0.14 mil recorded by RT15 in 2019 and 20. Notably, RD15 was identified as being more exposed to radiation, suggesting potential lapses in adhering to radiation protection protocols. The recorded results surpassed those documented by reference [5], exceeded the 0.42 mSv recorded in India (1990-1994), and surpassed the 1.34 mSv world recommended dose (1990-1994).

The one-way ANOVA test revealed no statistical significance ($p < 0.05$). Analyzing the results indicated that approximately 80% of RD Radiographers received AAED exceeding 1 mSv, with 20% receiving lower than 1 mSv. None of the Radiographers received doses exceeding 5, 10, and 15 mSv, in accordance with reference [4] recommendations. The study demonstrated that the probability of cancer lifetime risks increased with the rise in dose. However, the risk of cancer induction at UDUTH for exposed workers was five times lower than the risk in Kuwait [3]. The results indicated that the 9 RD Radiographers monitored had induced cancer risks below 1 mil, underscoring an improvement in the radiation protection protocol at UDUTH. While acknowledging the potential risks associated with long-term exposure, the assessment suggested that building confidence among Radiographers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management. Furthermore, the information emphasized the linear relationship between the probability of LFTR and exposure time. If anyone gets overexposed, the risk of cancer induction can be minimized by reducing workload, reinforcing the importance of effective management strategies.

The results obtained from Figure 2, focusing on the experiences of 10 Residence Doctors over the study period, present insights into the Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk. The AAED ranged from 0.60 to 4.484 mSv, while ACD ranged from 6.0 to 48.40 man mSv. The probability of cancer lifetime risk ranged from 0.03 to 0.242 mil, with RD60 and RD61 in 2019 and 2023, respectively. Notably, RD61 was the only one on the seat in 2023, leading to the highest accumulation of doses. The recorded results surpassed those documented by [1], exceeded the 0.19 mSv recorded in Australia (1990-1994), and surpassed the 1.34 mSv world recommended dose (1990-1994), albeit remaining below the 20 mSv recommended by reference [10].

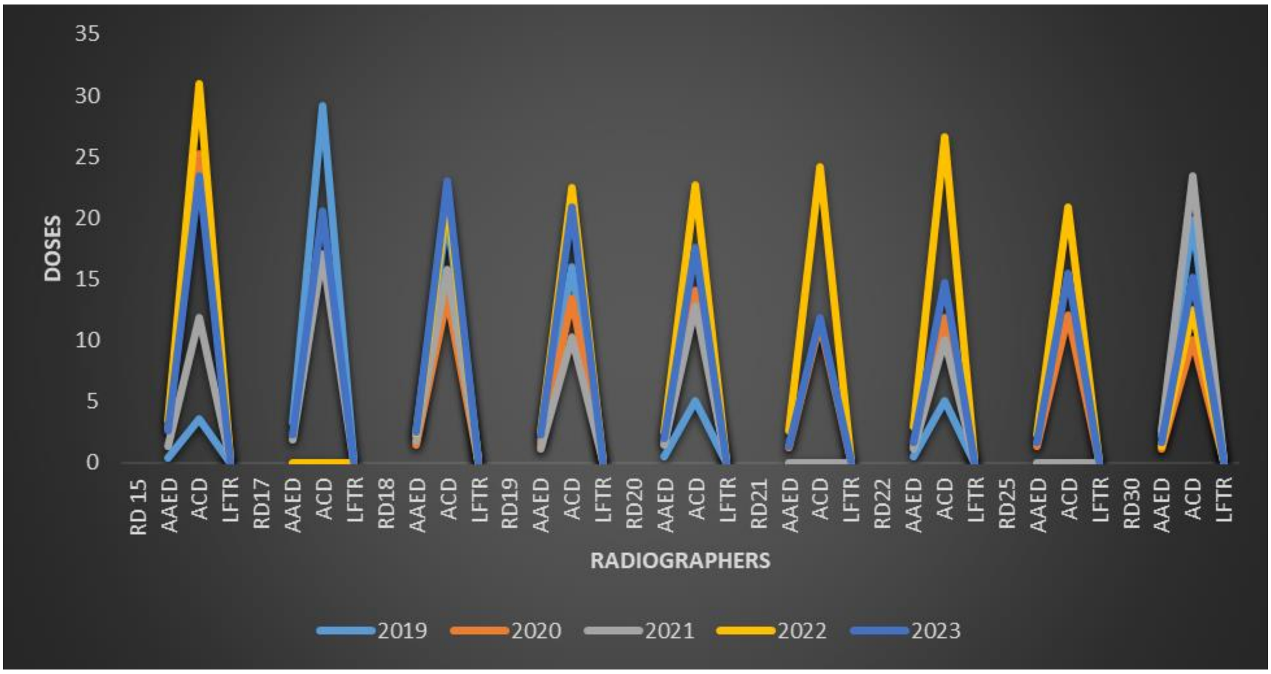

Figure 1. RD radiographers radiation doses

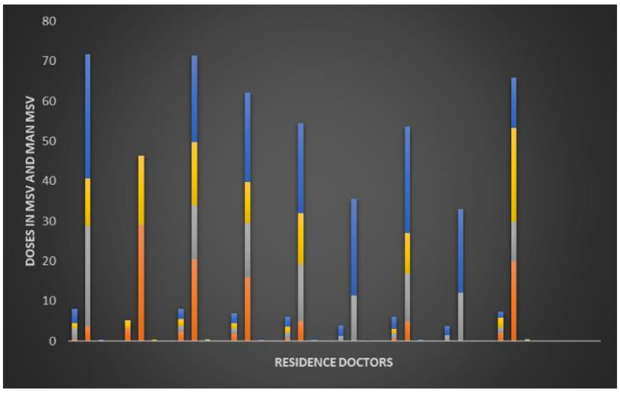

Figure 2. RD residence doctors' radiation doses

The one-way ANOVA test revealed no statistical significance for most pairwise comparisons, except for the comparisons of RD04 with RD61 ($p < 0.05$). In this comparison, RD04 received the lowest AAED, indicating low interaction with radiation. Analysis of the results showed that approximately 36% of Residence Doctors received AAED exceeding 1 mSv, with 64% receiving lower than 1 mSv. None of the Residence Doctors received doses exceeding 5, 10, and 15 mSv, aligning with reference [1] recommendations. The study demonstrated that the probability of cancer lifetime risks increased with the rise in dose. However, the risk of cancer induction at UDUTH for exposed workers was five times lower than the risk in Kuwait [3]. The results indicated that the 10 Residence Doctors monitored had induced cancer risks below 1 mil, highlighting an improvement in the radiation protection protocol at UDUTH. While acknowledging the potential risks associated with long-term exposure, the assessment suggested that building confidence among Residence Doctor workers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management. Additionally, the information underscored the linear relationship between the probability of LFTR and exposure time. If anyone gets overexposed, the risk of cancer induction can be minimized by reducing workload and emphasizing the importance of effective management strategies.

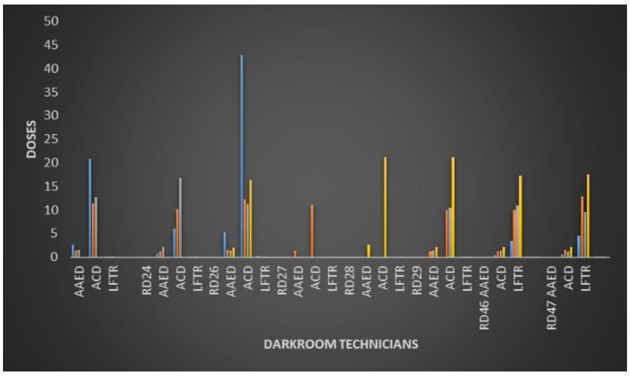

Figure 3. RD darkroom technicians' radiation doses

The findings from the assessment of 8 Darkroom Technicians over the study period (Figure 3), as presented in the results from the one-way ANOVA test, offer valuable insights into their Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk. The AAED ranged from 0.48 to 5.36 mSv, and ACD ranged from 3.84 to 42.88 man mSv. The probability of cancer risk ranged from 0.024 to 0.268 mil, with RD46 and RD26 in 2014, respectively. The recorded results surpassed those documented by reference [4], exceeded the 0.19 mSv recorded in Australia (1990-1994), and surpassed the 1.34 mSv world recommended dose (1990-1994), although remaining below the 20 mSv recommended by reference [1]. The one-way ANOVA test revealed no statistical significance for the pairwise comparisons ($p < 0.05$). Analysis of the results indicated that approximately 50% of Darkroom Technicians received AAED exceeding 1 mSv, with 45% receiving lower than 1 mSv. A small proportion, 5%, received doses exceeding 5 mSv, and none received doses exceeding 10 and 15 mSv, aligning with [3] recommendations.

The study demonstrated that the probability of cancer lifetime risks increased with the rise in dose. However, the risk of cancer induction at Usman Danfodiyo University Teaching Hospital Sokoto (UDUTH) for exposed workers was five times lower than the risk in Kuwait [11]. The results indicated that the 8 Darkroom Technicians monitored had induced cancer risks below 1 mil, highlighting an improvement in the radiation protection protocol at UDUTH. While acknowledging the potential risks associated with long-term exposure, the assessment suggested that building confidence among Darkroom Technicians workers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management. Additionally, the information underscored the linear relationship between the probability of LFTR and exposure time. If anyone gets overexposed, the risk of cancer induction can be minimized by reducing workload and emphasizing the importance of effective management strategies. The results obtained from the assessment of three RD Nurses, as presented in Figure 4, provide valuable insights into the Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk. Over the entire study period, the AAED ranged from 1.08 mSv in 2016 to 2.76 mSv in 2022, with ACD ranging from 3.24 to 8.228 man mSv and a probability of cancer lifetime risk ranging from 0.054 to 0.138 mil, recorded by RD39 and RD71 in 2021 and 2022, respectively. It is notable that RD71 recorded the highest doses.

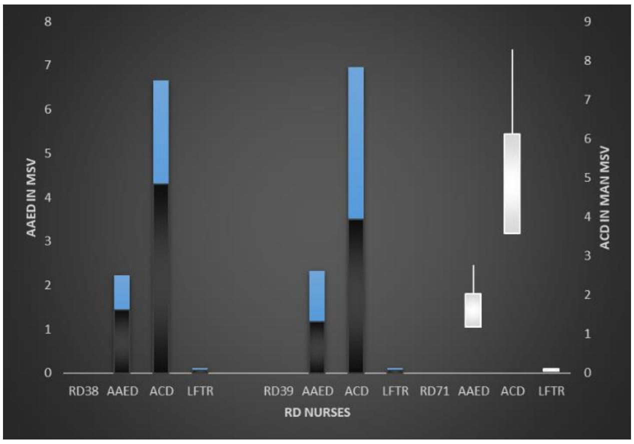

Figure 4. RD nurses' radiation doses

The results surpassed the 0.35 mSv recorded in Canada (1990-1994) but were lower than the 1.34 mSv and 20 mSv world records in 1990-1994, as well as the reference [1] recommendations. Fluctuations in the results may be attributed to an increase in workload or non-compliance with radiation protection protocols. The one-way ANOVA test revealed no statistical significance for the pairwise comparisons ($p < 0.05$). Analysis of the results indicated that approximately 66.67% of RD Nurses received AAED exceeding 1 mSv, with 33.33% receiving lower than 1 mSv, and none of the RD Nurses received doses exceeding 5, 10, and 15 mSv, aligning with reference [1] recommendations. The study demonstrated that the probability of cancer lifetime risks increased with the rise in dose. However, the risk of cancer induction at Usman Danfodiyo University Teaching Hospital Sokoto (UDUTH) for exposed workers was five times lower than the risk in Kuwait. The results indicated that the three RD Nurses monitored had induced cancer risks below 1 mil, highlighting an improvement in the radiation protection protocol at UDUTH. While acknowledging the potential risks associated with long-term exposure, the assessment suggested that building confidence among RD nurse workers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management. Additionally, the information underscored the linear relationship between the probability of LFTR and exposure time. If anyone gets overexposed, the risk of cancer induction can be minimized by reducing workload and emphasizing the importance of effective management strategies.

The presented results (Figure 5) highlight significant variations in Annual Average Effective Dose (AAED) among different groups, particularly between Radiographers (RG) and the combined group of Radiologists (DRT), Nurses (NUR), and Darkroom Technicians (DRK). Radiographers demonstrated the highest AAED, while Residence Doctors (RD) received the lowest. Additionally, the pair-wise comparisons between Radiographers and the combined group of Radiologists, Nurses, and Darkroom Technicians showed statistically significant differences.

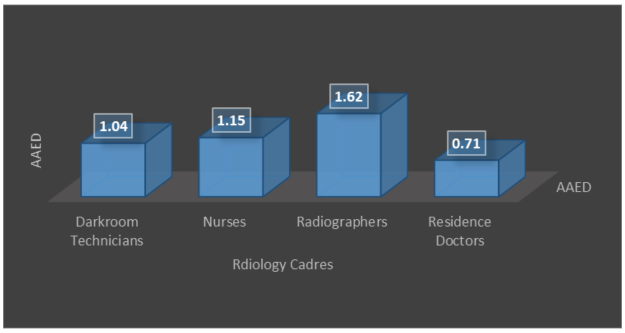

Figure 5. Comparisons of different cadres in the radiology department

5.1 Differences in AAED

Radiographers stand out as having the highest AAED among the groups, suggesting that their work tasks or exposure conditions contribute to elevated radiation doses. On the other hand, Residence Doctors, in contrast, received the lowest AAED.

5.2 Occupational practices

The observed differences may be linked to variations in occupational practices and tasks performed by different healthcare professionals. Radiographers who typically conduct diagnostic imaging procedures may encounter higher radiation levels due to their direct involvement in these processes.

5.3 Significant Pair-wise comparisons

The statistical significance in pair-wise comparisons between Radiographers and the combined group of Radiologists, Nurses, and Darkroom Technicians implies that there are substantial differences in radiation doses between these two sets of healthcare professionals. This could be influenced by the specific nature of their roles, procedures involved, or working conditions.

5.4 Risk assessment

The results obtained showed that none of the radiologists received a cancer risk exceeding the 1.0 million recommended by reference [1].

6. Conclusion

This study provides a comprehensive assessment of occupational radiation exposure among medical radiation workers at UDUTH. The dose limits, average doses, high-level exposure, and cancer risk test revealed the following:

Compliance with Dose Limits: All the radiology staff adhered to the national administrative dose limit of 20 mSv, ensuring no worker received excessive radiation exposure. This highlights the effectiveness of national regulations and commitment to worker safety.

Low Average Doses: While exceeding the 1 mSv threshold in some percentages, the average annual effective doses in the Radiology department (1.13 mSv) remained relatively low. This suggests proper implementation of radiation safety measures in most cases.

High-Level Exposure: Importantly, no worker across any department received annual doses exceeding 10, or 15 mSv, indicating the absence of serious exposure incidents. This further reinforces the overall picture of responsible radiation practices.

Minimal Cancer Risk: The estimated probability of cancer causation for all the medical workers was below the screening limit.

The study's findings suggest several areas for improvement and further research:

- Regular Calibration: To improve the accuracy of dosimetry measures, it is crucial to always calibrate the Harshaw 4500 manual TLD reader with a 137Cs beam exposure before each use. This ensures consistent and reliable dose assessments for workers.
- Upgrade Dosimetry Technology: Consider exploring the use of the Harshaw automatic TLD reader 8800/6600 model in future studies. This advanced technology offers higher precision and accuracy, potentially leading to more reliable data on radiation exposure.
- Comprehensive Risk Assessment Models: Develop or update existing models to simultaneously assess both Excess Relative Risk (ERR) and Excess Absolute Risk (EAR) of cancer based on radiation exposure. This

provides a more comprehensive picture of the potential long-term risks faced by workers.

- Expand Study Scope: Include occupational radiation exposure assessment for additional personnel within the hospital, such as porters, who might also encounter radiation during their work. Expanding the study scope provides a more holistic understanding of radiation safety within the medical facility.
- Workload Optimization: Implement measures to reduce the workload on radiation workers, such as, Radiotherapists, and Dental workers. Options include affordable time-scheduling practices to minimize fatigue and human error.
- Improved Cancer Detection Models: Develop or refine models that can detect cancer in any radiosensitive organ, not just those traditionally associated with radiation exposure. This ensures broader protection for workers' health.
- Optimal TLD Reading Timing: Considering the warm temperatures in Sokoto, ensure TLD reading is done within one month of badge collection to avoid potential fading of the dosimetry chips, which could lead to inaccurate dose readings.
- Staffing Considerations: To further reduce workload and improve efficiency within the department, consider allocating additional staff resources to support ongoing operations and ensure optimal safety practices.

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Ethical issue

The author is aware of and complies with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the corresponding author.

Conflict of interest

The author declares no potential conflict of interest.

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