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Exposure assessment of natural background ionizing radiation and its potential health effects in diagnostic radiology department

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Garba II,[1] Samaila B,[1] Maidamma B,[1] Rilwanu MD,[2] Jega AM[2]

[1]Department of Physics with electronics, Federal University Birnin Kebbi, Nigeria
[2]Department of Radiology, Federal Teaching Hospital Birnin Kebbi, Nigeria

Correspondence: Dr. B. Samaila, Department of Physics with electronics, Federal University Birnin Kebbi, Nigeria, Tel: +234 906 622 9957

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Abstract

Background: The back ground natural ionizing radiation is the biggest source of ionizing radiation exposure to humans. In diagnostic radiology environments, healthcare workers may experience additional exposure due to scattered radiation from imaging equipment. Continuous monitoring is therefore essential to ensure compliance with international radiation protection standards**.**

Objective: This study assessed ambient natural background ionizing radiation levels and associated excess lifetime cancer risk (ELCR) among healthcare workers in the Diagnostic Radiology Department of the Federal Teaching Hospital, Birnin Kebbi, Nigeria.

Methods: A cross-sectional observational study design was adopted. Ambient dose rates were measured using a calibrated Geiger–Müller survey meter at 1 m above floor level across computed tomography (CT), X-ray, fluoroscopy, and mammography buildings. Measurements were conducted under equipment "OFF" and operational conditions at predefined staff-occupied and patient-accessible locations. Annual effective dose (AED) was calculated using standard occupancy factors in accordance with recommendations of the International Commission on Radiological Protection and the United Nations Scientific Committee on the Effects of Atomic Radiation. ELCR was estimated using ICRP risk coefficients (0.05 Sv^{-1}).

Results: The CT unit recorded the highest mean ambient dose rate (0.20 μSv/h), corresponding to an annual effective dose of 1.41 mSv/year and ELCR of 4.93×10^{-3}. Non-CT areas (X-ray, fluoroscopy, and mammography units) showed a lower mean dose rate of 0.14 μSv/h, annual effective dose of 0.95 mSv/year, and ELCR of 3.32×10^{-3}. CT environments demonstrated a 43–49% increase in radiation dose compared with non-CT buildings, due to the fact that the CT complex was newly constructed. The highest localized readings were observed in CT preparation (0.34 μSv/h) and exposure rooms (0.30 μSv/h), while administrative and waiting areas recorded comparatively lower values (0.11–0.13 μSv/h). All estimated occupational doses remained below the recommended limit of 20 mSv/year averaged over five years as stipulated in ICRP Publication 103.

Conclusion: Although occupational exposures in the studied facility remain within internationally accepted limits, CT environments exhibit significantly elevated ambient radiation levels compared to other diagnostic units. Continuous environmental monitoring, periodic shielding assessment, and optimization of occupancy patterns are recommended to maintain exposures As Low as Reasonably Achievable (ALARA), consistent with guidelines of the International Atomic Energy Agency and the International Commission on Radiological Protection.

Keywords: natural background radiation, occupational exposure, computed tomography, annual effective dose, excess lifetime cancer risk, diagnostic radiology and radiation protection

Introduction

Natural background radiation (NBR) represents the largest contributor to human exposure to ionizing radiation and originates from cosmic rays, terrestrial radionuclides such as uranium and thorium, and naturally occurring radioactive gases like radon and its progeny.[1] The level of NBR varies widely across regions due to differences in altitude, geological composition, soil radioactivity, and construction materials, making localized assessment essential for understanding population and occupational exposure.[1,2]

Additional occupational exposure for healthcare professionals in diagnostic radiology settings comes from ambient background radiation in hospital settings as well as dispersed X-rays during imaging procedures. Evidence indicates that radiation levels vary greatly between facilities, departments, and job categories, despite the fact that patient and occupational doses have been greatly lowered by technological advancements and stringent radioactive protective measures.[3,4] Aging imaging equipment, irregular shielding, and poor dosimetry compliance can all increase occupational exposure over projected baseline values in many low- and middle-income settings.[5]

The annual occupational exposure limit is set at 20 mSv on average over five years, with no single year exceeding 50 mSv, according to international standards provided by the International Commission on Radiological Protection.[1] Despite these restrictions, new research indicates that employees in high-workload diagnostic facilities, especially those engaged in mobile radiography, fluoroscopy, and interventional procedures, may experience increased scatter exposures if protective controls are inadequate.[4,6] The significance of ongoing local monitoring is shown by this variability.

Research on the health effects of long-term low-dose exposure, which can result from cumulative NBR plus occupational scatter, is also ongoing. The long-term consequences of prolonged low-dose exposure are less certain because of statistical constraints and confounding factors, despite significant evidence for increased cancer risk at moderate to high levels.[1] However, radiation protection techniques continue to be based on the linear-no-threshold (LNT) paradigm, which emphasizes dosage reduction, optimization, and justification.

In order to lower avoidable exposures, recent occupational studies emphasize the necessity of strong institutional monitoring programs, region-specific radiation mapping, and proactive safety interventions.[3,7] In order to strengthen the evidence on occupational dose distributions and inform worldwide radiation protection regimes, international organizations have also advocated for more involvement in global surveys.[6] Evaluating occupational exposure to natural background radiation in radiology departments is crucial due to the growing use of diagnostic imaging technologies and the unequal distribution of radiological safety infrastructures across regions. These evaluations offer vital information on radiation levels at work, aid in identifying deficiencies in safety precautions, and support evidence-based regulations meant to shield radiology staff from possible long-term health hazards.

Materials and methods

Study design

In the Diagnostic Radiology Department of the Federal Teaching Hospital in Birnin Kebbi, Nigeria, this cross-sectional observational study evaluated occupational exposure to natural background radiation among medical staff and patients. The study included ambient environmental monitoring and estimation of potential long-term health implications, such as cancer risks.

Study area

The study was carried out at the Federal Teaching Hospital's Diagnostic Radiology Department in Birnin Kebbi, which is located in Kebbi State, Northwest Nigeria. General radiography rooms, fluoroscopy suites, a computed tomography (CT) unit, a mammography unit, control rooms, staff offices, and nearby hallways make up this department. Measurement mapping encompassed every location that was staff-occupied and clinically active.

Data collection

A Geiger-Müller GM-based radiation survey meter that had been calibrated was used to determine the ambient dose rate. Measurements were taken at predetermined sites reflecting staff working positions, patient areas, control consoles, and corridors. At a height of one meter above the ground, dose rate measurements (µSv/h) were taken. At each location, three repeat measurements were made and averaged.

Data analysis

Ambient dose calculations

According to ICRP, the radiation dosage parameter known as the "Effective Dose" considers the relative sensitivity of each irradiated organ as well as the absorbed dose received by each organ. According to Samaila et al.[8] and Samaila et al,[9] this protection level dosimetry quantity may be utilized as a rough indicator of the stochastic effect. Thus, for the population exposed to natural ionizing radiation, the annual effective dosage for both indoor and outdoor can be given as

$$IAEDR\ \left(mSv/yr\right) = Y\ \left(\mu Sv/hr\right) \times 8760\ \left(hr/yr\right) \times 0.8 \div 1000 \tag{1}$$

Where; Y and Z are the indoor and outdoor meter's readings while IAEDR is the indoor and annual effective dose rates respectively

Excess life cancer risks estimation

This relates to a specific level of exposure and the lifetime risk of acquiring cancer. It is shown as a number that indicates how many cancers are anticipated in a given number of individuals following exposure to a carcinogen at a specific dose. It's important to note that the chance of acquiring blood, prostate, or breast cancer increases in proportion to an increase in the ELCR. Equation[8–10] is used to calculate excess lifetime cancer risk (ELCR).

$$ELCR = AED \times DL \times RF \tag{2}$$

Where AEDE is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to 70 years) and RF is the Risk Factor (Sv-1), i.e., fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for the public. The cancer risks of individual organs were assessed using equation. The excess lifetime cancer risk is used in radiation protection assessment to predict the probability of an individual developing cancer over his lifetime due to low radiation dose exposure, if it will occur at all.[8,9]

Ethical considerations

The Federal Teaching Hospital's Research Ethics Committee in Birnin Kebbi granted ethical approval. The radiation safety officer at the hospital was informed of the exposure findings.

Results and discussion

Background ionizing radiation levels in CT buildings

The spatial distribution of natural background ionizing radiation throughout CT suite functional areas is shown in Table 1A. The overall mean dose rate of 0.20 µSv/hr, corresponding to an indoor annual effective dose of 1.41 mSv/y and an excess lifetime cancer risk of 4.93×10^{-3}, indicates that ambient radiation levels within CT environments are elevated relative to typical indoor hospital spaces without high-output imaging equipment. These values approach levels reported for high-occupancy diagnostic environments and call for systematic monitoring, even if they are still below the advised public exposure limit of 1 mSv/y for planned exposure situations when averaged over the general population.

Similar patterns have been documented in hospital-based radiation surveys in Nigeria and other developing nations, where indoor background dose rates in radiology departments were higher than those in clinical wards without imaging because of contributions from building materials and scattered radiation.[11,12] The observed dose distribution throughout the CT suite is in line with radiation protection frameworks developed by the International Atomic Energy Agency and the International Commission on Radiological Protection. These frameworks stress that diagnostic imaging facilities are controlled radiation environments that need regular area monitoring and shielding verification.

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Table 1A Natural background ionizing radiation in CT units

S/N	Measurement places	Mean dose rate (µSv/hr)	Indoor annual effective dose (mSv/y)	Excess life cancer risk
1	CT offices	0.11	0.77	2.70×10^{-3}
2	CT offices corridor	0.18	1.26	4.42×10^{-3}
3	CT seminar room	0.23	1.61	5.64×10^{-3}
4	CT patient waiting area	0.13	0.91	3.19×10^{-3}
5	CT patient reception	0.12	0.84	2.94×10^{-3}
6	CT preparation room	0.34	2.38	8.34×10^{-3}
7	CT control room	0.20	1.40	4.91×10^{-3}
8	CT machine exposure room	0.30	2.10	7.36×10^{-3}
9	CT reporting room	0.17	1.19	4.17×10^{-3}
10	CT ultrasound room	0.23	1.61	5.64×10^{-3}
	Mean	**0.20**	**1.41**	$\mathbf{4.93\times 10^{-3}}$

The most significant dose rates (0.34 µSv/hr and 0.30 µSv/hr, respectively) were obtained in the CT preparation room and the CT machine exposure room. These results equate to annual effective doses of 2.38 mSv/y and 2.10 mSv/y, respectively, with corresponding extra lifetime cancer risks of 8.34×10^{-3} and 7.36×10^{-3}. Their near closeness to the gantry and the prevalence of dispersed radiation during patient positioning and scanning are the reasons for these increased results. Similar results, showing the effects of scatter leakage and shielding flaws, have been documented in radiology departments in Nigeria, where CT rooms and immediate ancillary spaces showed noticeably higher ambient dose rates than administrative areas.[12]

According to surveys conducted internationally, rooms adjacent to CT exposure areas in diagnostic imaging suites in Asia and the Middle East also show increased background radiation, especially when architectural shielding is inadequate or when high patient throughput results in frequent beam-on time.[13] These findings highlight the significance of conducting regular shielding integrity evaluations, especially in the vicinity of shared walls, doors, and control room windows.

The CT control room had moderate background radiation levels (0.20 µSv/hr; 1.40 mSv/y), as did other operational areas including the CT lecture room and CT ultrasound room (0.23 µSv/hr; 1.61 mSv/y). Long-term staff presence in such rooms suggests that even modest increases in ambient dose rates may eventually result in non-trivial cumulative occupational exposure, even if these locations are not primary beam areas. Similar patterns of occupational exposure have been shown in multi-center investigations of diagnostic radiography facilities, where employees in reporting areas and control rooms amassed detectable background doses over long periods of time despite adhering to dose limits.[14]

The non-negligible excess lifetime cancer risk estimated for these public-access spaces highlights the significance of taking into account not only occupational exposure but also cumulative public exposure for patients and accompanying persons who may spend extended periods of time in waiting areas, especially in high-volume CT centers. In contrast, CT offices, patient reception, and patient waiting areas recorded comparatively lower dose rates (0.11–0.13 µSv/hr) and annual effective doses (0.77–0.91 mSv/hr).

The expected spatial attenuation of dispersed radiation from the CT source is reflected in the hierarchical pattern of dose distribution, which was highest in preparation and exposure rooms, intermediate in control and neighboring operational spaces, and lowest in offices and reception areas. The results show that CT suites are localized radiation environments with diverse dose fields, which is in line with both international and national reports from Nigeria. From the standpoint of radiation protection, our findings encourage the application of focused optimization techniques, such as regular area monitoring, recurring shielding audits, and workflow adjustments to reduce the number of employees and patients present in high-background areas. These steps are in line with global best practices promoted by the International Atomic Energy Agency and the International Commission on Radiological Protection, especially in hospital settings with limited resources where infrastructure limitations may impair shielding effectiveness.

Natural background ionizing radiation in x-ray, fluoroscopy, and mammography buildings (non-CT Areas)

Ambient exposures outside of the principal beam zones are nevertheless minimal and comparable to similar studies, according to the natural background ionizing radiation recorded in the radiology department's non-CT regions (Table 1B). With a mean dose rate of 0.14 µSv/hr, an annual effective dose of 0.95 mSv/year, and an excess lifetime cancer risk of 3.32×10^{-3}, it appears that natural environmental gamma radiation is the main cause of radiation exposure in waiting, control, and common areas, with operating equipment scatter radiation contributing very little. These results are consistent with earlier research conducted in diagnostic centers in West Africa. Background dose rates in southwest Nigeria varied from 0.137 to 0.183 µSv/hr, while non-exposure areas showed similar annual effective doses.[15]

Table 1B Natural Background Ionizing Radiation in X-ray, Fluoroscopy, and Mammography Units (Non-CT Areas)

S/N	**Measurement places**	**Mean dose rate (µSv/hr)**	**Indoor annual effective Dose (mSv/y)**	**Excess life cancer risk**
1	X-ray Patient Waiting Arena	0.12	0.84	2.94×10^{-3}
2	X-ray Reception Room	0.13	0.91	3.19×10^{-3}
3	X-ray Machine Exposure Room	0.12	0.84	2.94×10^{-3}
4	X-ray Machine Control Room	0.11	0.77	2.70×10^{-3}
5	X-ray Radiographers' Common Room	0.20	1.40	4.91×10^{-3}
6	Fluoroscopy control room	0.13	0.91	3.19×10^{-3}
7	Fluoroscopy exposure room	0.14	0.98	3.43×10^{-3}
8	Mammography control room	0.13	0.91	3.19×10^{-3}
9	Mammography exposure room	0.14	0.98	3.43×10^{-3}
	Mean	**0.14**	**0.95**	**3.32×10^{-3}**

Scatter radiation measurements in X-ray suites in Ghana revealed values ranging from 0.10 to 0.12 µSv/hr, indicating that shielded non-CT regions successfully preserve background levels similar to those of natural environmental radiation.[16] The present measurements fall within this range, indicating sufficient shielding and compliance with advised safety procedures. Due to its close proximity to operating imaging equipment, the radiographers' common room had the greatest exposure rate (0.20 µSv/hr) and yearly effective dose (1.40 mSv/y). Other investigations have shown similar spatial tendencies, with rooms nearer the main beam registering somewhat higher exposures than remote control or waiting areas.[17] Even in non-exposure zones, this observation emphasizes the significance of ongoing monitoring and optimal shielding.

The yearly effective exposure of 0.95 mSv/year is below the public dose limit of 1 mSv/year established by the International Commission on Radiological Protection[18] and the International Atomic Energy Agency.[19] There is little stochastic danger from long-term residence of these places, as evidenced by the accompanying extra lifetime cancer risk remaining low. Together, these findings show that background radiation is kept at acceptable levels in non-CT units through design and operation, which is in line with ALARA principles and earlier findings in comparable clinical and regional settings.

Percentage increase of CT over non-CT Buildings

Table 2 and Figure 1 present a comparison of CT and non-CT diagnostic regions and show that all measured radiation parameters are much higher in CT environments. In comparison to non-CT areas (0.14 µSv/hr), the mean dose rate in CT areas (0.20 µSv/hr) is 42.9% greater. In a similar vein, the excess lifetime cancer risk (4.93×10^{-3}) is 48.5% greater and the yearly effective dosage (1.41 mSv/year) is 48.4% higher than non-CT areas (0.95 mSv/year). These increases are a result of CT scanners' increased operational output, which generates high-resolution cross-sectional images by using numerous X-ray projections and greater tube currents. As a result, there is an increase in dispersed radiation, which raises ambient exposure levels in nearby CT areas.Similar observations have been reported in regional studies, where CT suites exhibited higher background radiation than X-ray or fluoroscopy rooms, though all measurements remained below occupational dose limits.[17,20]

Table 2 Percentage Increase of CT over Non-CT modalities

Parameter	**CT Mean**	**Non-CT Mean**	**% Increase (CT over non-CT modalities)**
Mean dose rate (µSv/hr)	0.20	0.14	**42.9%**
Annual effective dose (mSv/y)	1.41	0.95	**48.4%**
Excess life cancer risk	4.93E-03	3.32E-03	**48.5%**

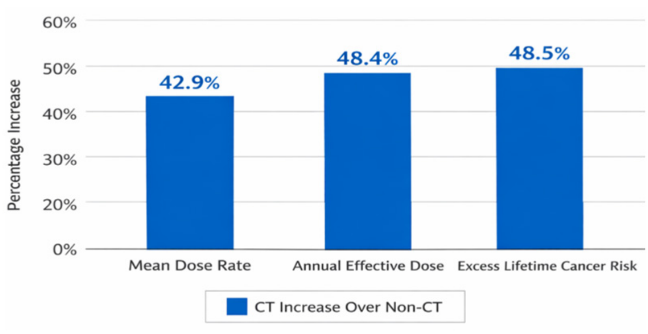

Figure 1 Percentage increase of CT over non-CT buildings.

There are consequences for workplace safety because to the higher radiation parameters in CT locations. The roughly 50% increase compared to non-CT zones emphasizes the significance of shielding, regulated access, and regular monitoring, even though observed doses are still below the suggested annual occupational limit of 20 mSv/year.[18] These results are consistent with the greater dosages that are naturally administered during CT scans from the standpoint of patient safety. The relative rise highlights the need for improved scan methods and protective measures for both patients and staff, even though the additional lifetime cancer risk is still minimal.[15,20]

The relative rise of CT versus non-CT modalities is clearly depicted in Figure 1, which successfully illustrates these proportional disparities. The consistent elevation across all metrics emphasizes how crucial it is to maintain exposure As Low as Reasonably Achievable (ALARA) even in controlled situations.

In general, compared to non-CT units, ambient radiation in CT diagnostic regions is around 43–49% higher across all studied

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metrics. These findings support regional and international research, demonstrating that even while background radiation levels are higher in CT locations, proper shielding and operational procedures keep exposures within safe public and occupational bounds.

Conclusion

This study shows that by modality and physical proximity to imaging equipment, natural background and scatter-associated radiation levels in diagnostic radiology situations differ considerably. Compared to X-ray, fluoroscopy, and mammography units, CT suites consistently showed higher ambient dose rates and related extra lifetime cancer risks, with an approximate 43–49% elevation across measured parameters. Calculated yearly effective doses remained far below the International Commission on Radiological Protection's recommended occupational limit of 20 mSv/year and below globally accepted safety levels despite this relative increase. However, under continuous occupancy assumptions, certain CT-associated sites came close to the 1 mSv/year public reference limit, underscoring the necessity of regular environmental audits, optimal staff rotation, and occupancy control. The spatial distribution pattern, which is lowest in administrative zones, middle in control areas, and highest in preparation and exposure rooms, proves the efficacy of structural shielding when used appropriately and confirms anticipated attenuation tendencies. However, the higher relative values in CT settings highlight the need for proactive radiation safety training, improved dosimetry compliance, and regular shielding verification. The results show that CT environments have relatively greater ambient radiation loads even while occupational exposures in the facility under study are still within guideline limits. According to the global radiation protection principles outlined by UNCEAR and the International Atomic Energy Agency, healthcare workers must be protected against potential long-term stochastic effects through ongoing monitoring, adherence to international protection standards, and infrastructure optimisation.

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None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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