Radiation Exposure Monitoring in PET/CT and Nuclear Medicine: Ensuring Safety and Compliance

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ABSTRACT

Background: With the increasing use of PET/CT and SPECT-CT imaging, monitoring occupational radiation exposure from high-energy radionuclides such as 18F-Fluorodeoxyglucose (FDG), Technetium-99m, and Iodine-131 has become essential.

Objective: This study evaluates radiation exposure levels across operational areas of a nuclear medicine facility over a 24-month period and assesses compliance with Bangladesh Atomic Energy Regulatory Authority and international safety standards established by the International Atomic Energy Agency and International Commission on Radiological Protection.

Methods: A longitudinal radiation survey was conducted from January 2024 to December 2025. Dose rates (µSv/h) were measured three times daily (08:00, 10:00, and 12:00) across the hot laboratory, patient environment, imaging rooms, and public areas using calibrated digital survey meters.

Results: Maximum unshielded dose rates reached up to 29.8 µSv/h in PET/CT areas, while shielding reduced exposure by approximately 60–70%. Public area dose rates remained below 1.0 µSv/h. Temporal variation was minimal across 477 working days. Estimated occupational exposure remained well below the 20 mSv/year limit.

Conclusion: The study confirms effective radiation protection practices, with all monitored values demonstrating compliance with international safety standards.

Keywords: Radiation exposure, PET/CT, SPECT-CT, occupational safety, shielding efficiency, ALARA principle.

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INTRODUCTION

Nuclear medicine has emerged as a vital component of the healthcare system in Bangladesh, playing a significant role in advancing diagnostic accuracy and therapeutic outcomes while emphasizing the ongoing need for skilled workforce development and infrastructural enhancement (1). The integration of hybrid imaging systems such as PET/CT and SPECT-CT has significantly improved disease detection, staging, and treatment monitoring, particularly in oncology. However, these advancements have also led to increased use of radioactive materials in clinical settings, raising concerns regarding occupational and environmental radiation exposure (2, 3). Unlike conventional imaging modalities, nuclear medicine procedures involve the administration of radiopharmaceuticals, making the patient a continuous source of radiation (3-5). As a result, healthcare workers, including physicians, technologists, nurses, and medical physicists, are exposed to ionizing radiation during multiple stages such as preparation, administration, imaging, and patient handling (4, 6, 7). The widespread use of high-energy radionuclides, particularly Fluorine-18 in PET/CT, has further intensified the need for strict radiation protection measures due to its higher photon energy and associated penetration capability (9, 10). Radiation protection in nuclear medicine is therefore a critical aspect of clinical practice, guided by fundamental principles such as time, distance, and shielding, along with the ALARA (As Low As Reasonably Achievable) concept (2). International organizations like the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP) have established dose limits and safety standards to minimize occupational exposure and protect both workers and the public (8). Effective implementation of these guidelines requires continuous monitoring of radiation levels, optimization of workflow, and appropriate shielding design, particularly in high-activity areas such as PET uptake rooms and hot laboratories (10, 14). Several studies have emphasized the importance of monitoring and controlling occupational radiation exposure in nuclear medicine facilities.

Previous research has shown that PET/CT procedures contribute significantly higher radiation doses to staff compared to conventional gamma camera imaging due to the higher energy of annihilation photons (3, 7, 14). Studies have also demonstrated that occupational doses in PET/CT environments remain within recommended limits when appropriate radiation protection practices are followed, although exposure varies depending on staff role and procedure type. Furthermore, optimization strategies such as shielding devices, remote handling techniques, and workflow adjustments have been shown to significantly reduce radiation exposure during critical tasks like patient positioning and radiopharmaceutical administration (6, 8). Despite these advancements, continuous long-term monitoring across different operational areas remains essential to ensure sustained compliance with safety standards (14, 15). In this context, the present study aims to evaluate radiation dose rates across multiple functional areas of a nuclear medicine facility over an extended period and to assess compliance with established radiation safety guidelines under routine clinical conditions.

METHODS

An observational study was conducted between January 2024 to December 2025, covering 477 working days, to assess the radiation exposure in a nuclear medicine facility like Institute of Nuclear Medicine and Allied Sciences (INMAS), Mohakhali, Dhaka. Radiation dose rates (µSv/h) were measured monthly using calibrated Geiger–Müller counter-based LUDLUM 3000 survey meter and ionization chambers, with all instruments undergoing annual calibration at a certified Secondary Standard Dosimetry Laboratory (SSDL) to ensure measurement accuracy within 10%. Occupational exposure was additionally monitored using chemiluminescent dosimeters (TLDs) worn by staff to evaluate cumulative dose relative to the 20 mSv annual limit.

Measurements were recorded at three fixed time points—08:00 A.M., 10:00 A.M., and 12:00 P.M.—to capture variations associated with Technetium-99m buildup, peak Fluorine-18 FDG activity, and post-injection decay, respectively. Data were collected from high-activity zones (hot laboratory, PET-CT, and SPECT-CT), controlled zones (therapy rooms), and public areas (reception, corridor, and under-stair locations). All readings were taken at a standardized distance of 1 meter from the source, along with corresponding measurements behind 5 mm lead shielding to evaluate attenuation efficiency. Data was analyzed using IBM SPSS Statistics (version 26.0) and Microsoft Excel 2019, with results expressed as mean values and ranges. Shielding effectiveness was calculated as percentage reduction, and findings were compared with established international radiation safety standards.

RESULTS

Radiation monitoring conducted over the 24-months study period demonstrated a consistent and predictable pattern of dose rate variation across different operational areas of the nuclear medicine facility.

Table 1: Average dose rates in hot laboratory in the year 2024 and 2025

Time	Fume Hood (µSv/h)	Background (µSv/h)	Interpretation
08:00 A.M.	6.9–7.1	2.9–3.1	Technetium buildup phase
10:00 A.M.	7.9–8.2	3.4–3.6	Peak activity (FDG + Tc overlap)
12:00 P.M.	6.3–6.4	2.7–2.9	Activity decay phase

In the hot laboratory, radiation levels showed a clear dependence on workflow timing and radionuclide handling. At 08:00 A.M., dose rates at the fume hood ranged between 6.9 and 7.1 µSv/h, while background levels remained within 2.9 to 3.1 µSv/h, corresponding to the peak accumulation of Technetium-99m following generator elution. The highest radiation levels were observed at 10:00 A.M., where fume hood values increased to 7.9–8.2 µSv/h and background levels to 3.4–3.6 µSv/h.

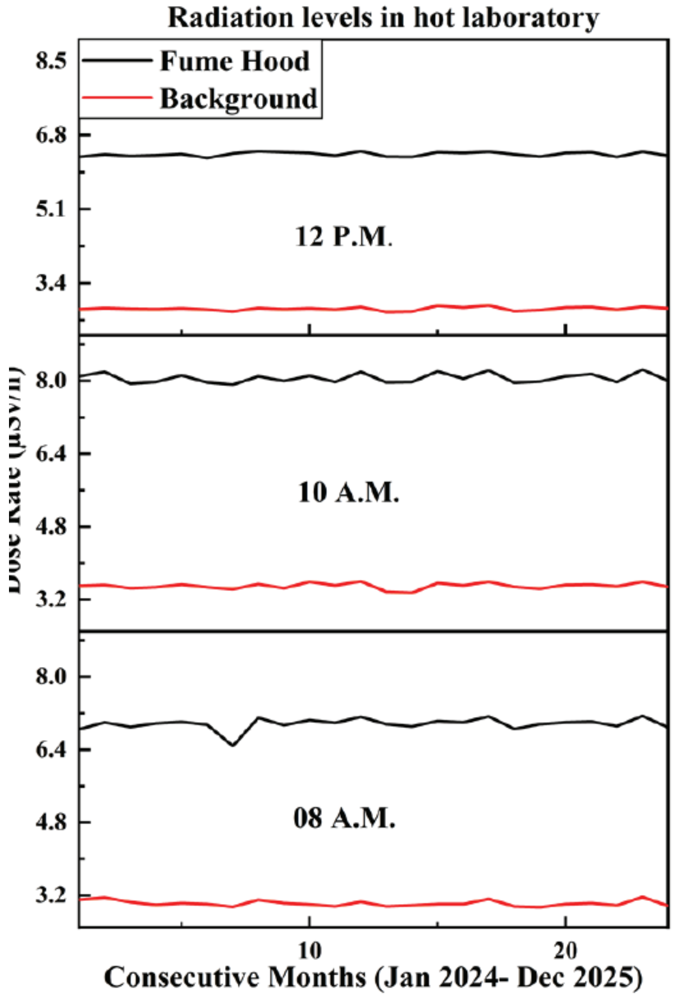

Figure 1: Time-dependent Variation of Radiation Levels in Hot Laboratory.

This peak coincides with the simultaneous presence of freshly eluted Technetium-99m and the arrival of Fluorine-18 FDG, resulting in increased photon emission. By 12:00 P.M., dose rates decreased to 6.3–6.4 µSv/h at the fume hood and 2.7–2.9 µSv/h in the background, reflecting radioactive decay and redistribution of activity from the laboratory to patient-related areas depicted in Figure 1.

In the SPECT-CT room, radiation levels measured at 1 meter from the patient ranged from 11.3 to 11.7 µSv/h at 10:00 A.M. and decreased to 7.8–8.2 µSv/h at 12:00 P.M. A substantial reduction in dose rate was observed behind lead shielding, where values dropped to 0.18–0.22 µSv/h at 10:00 A.M. and further to 0.08–0.12 µSv/h at 12:00 P.M., corresponding to an attenuation efficiency of approximately 98–99%. These findings indicate highly effective shielding against the lower-energy photons emitted by Technetium-99m, resulting in minimal radiation transmission beyond protected areas.

Table 2: SPECT-CT dose rates

Time	1 m from patient (µSv/h)	Behind Shield (µSv/h)	Reduction
10:00 A.M.	11.3–11.7	0.18–0.22	~98%
12:00 P.M.	7.8–8.2	0.08–0.12	~99%

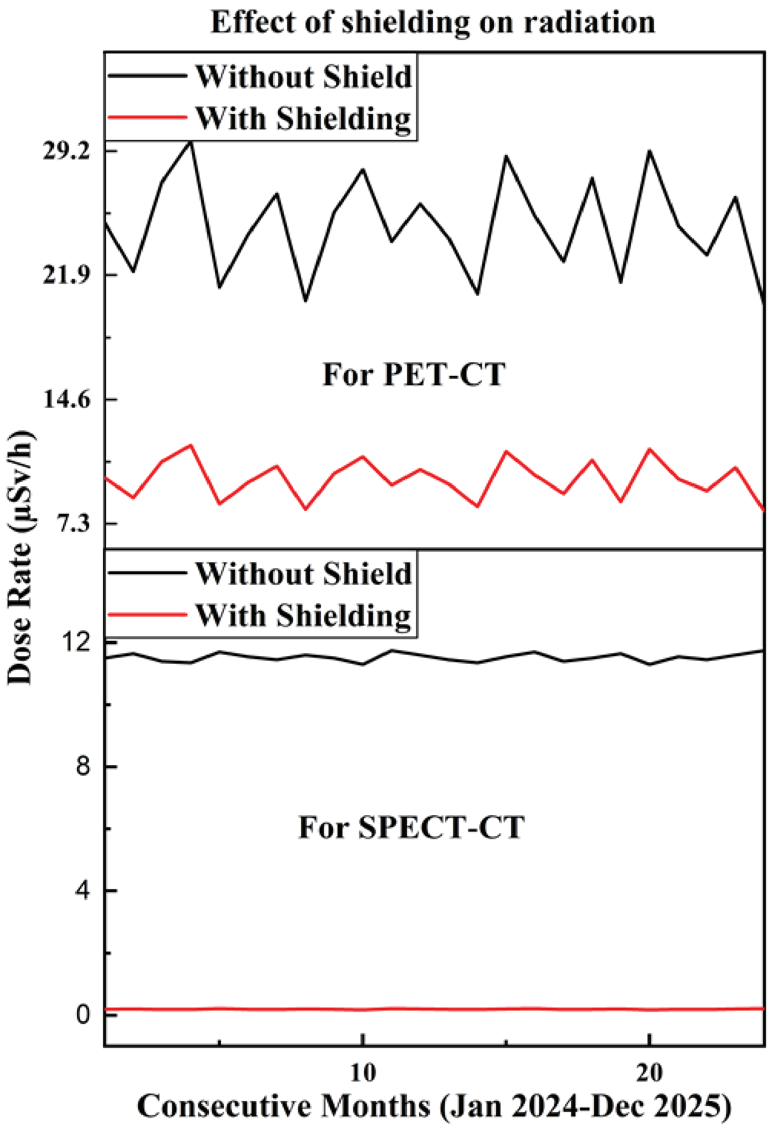

Figure 2: Effect of Lead Shielding on Radiation Dose Reduction.

In contrast, the PET-CT room exhibited significantly higher radiation levels. Dose rates at 1 meter from the patient ranged from 20.1 to 29.8 µSv/h at 10:00 A.M. and decreased to 9.60–14.2 µSv/h at 12:00 P.M. Following shielding, dose rates were reduced to 8.0–11.9 µSv/h at 10:00 A.M. and 4.52–6.62 µSv/h at 12:00 P.M., representing a reduction of approximately 60–65% is shown in Figure 2. The comparatively lower shielding efficiency observed in PET-CT is attributed to the higher photon energy (511 keV) associated with Fluorine-18, which has greater penetrating ability compared to Technetium-99m.

Table 3: PET-CT Dose Rates

Time	1 m from patient (µSv/h)	Behind Shield (µSv/h)	Reduction
10:00 A.M.	20.1–29.8	8.0–11.9	~60–65%
12:00 P.M.	9.60–14.2	4.52–6.62	~60–65%

Radiation levels measured in public and adjacent areas remained consistently low throughout the study period. The reception area recorded dose rates between 0.14 and 0.20 µSv/h, which are close to natural background levels and well within recommended limits for unrestricted areas. Similarly, the under-stair area showed values ranging from 0.16 to 0.24 µSv/h, indicating negligible radiation influence is shown in Figure 3.

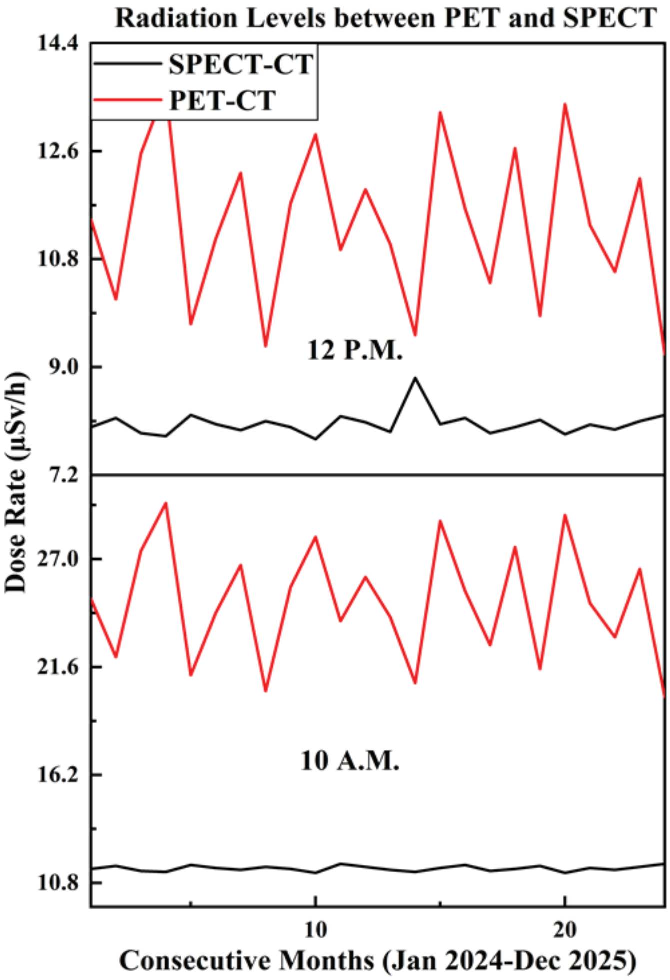

Figure 3: Dose rate comparison based on radiopharmaceuticals.

Corridor dose rates ranged from 0.75 to 0.99 µSv/h and remained within acceptable limits for supervised areas, where occupancy time is typically limited. In contrast, the therapy patient room door exhibited higher dose rates ranging from 6.0 to 8.9 µSv/h, confirming its classification as a controlled area requiring restricted access and appropriate radiation protection measures.

Table 4: Radiation Levels in Public and Adjacent Areas

Location	Dose Range (µSv/h)	Interpretation
Reception	0.14–0.20	Near background
Under the staircase	0.16–0.24	Safe
Corridor	0.75–0.99	Within public limit
Therapy Room Door	6.0–8.9	Controlled area

Over the entire monitoring period, covering 242 working days in 2024 and 235 days in 2025, radiation levels remained stable with no significant fluctuations or abnormal peaks. This consistency reflects effective radiation management practices, proper shielding design, and adherence to established safety protocols within the facility. A clear distinction in radiation characteristics was observed between SPECT and PET modalities, primarily due to differences in photon energy. Technetium-99m, emitting 140 keV photons, produced moderate radiation levels with highly effective shielding, whereas Fluorine-18, emitting 511 keV photons, resulted in higher ambient dose rates and comparatively lower shielding efficiency as shown in Figure 4 & 5.

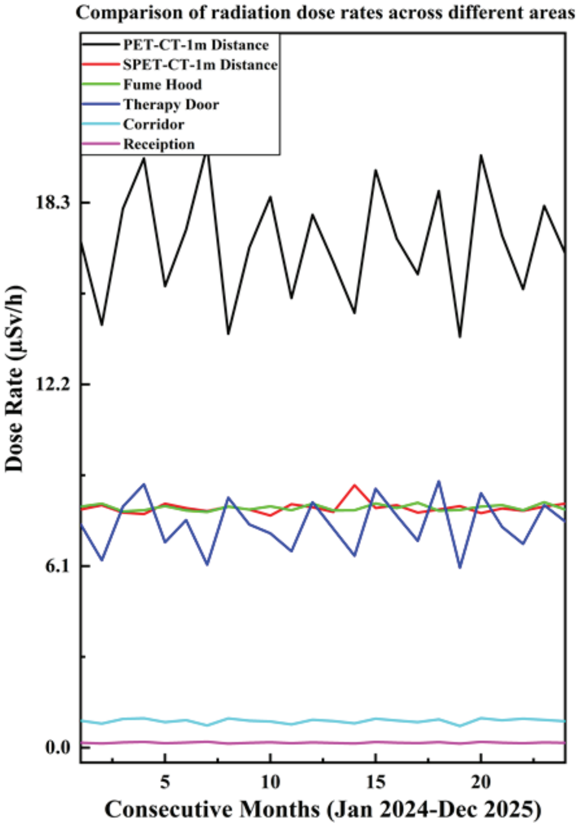

Figure 4: Comparison of radiation dose rates across different areas at peak activity time (10:00 A.M.).

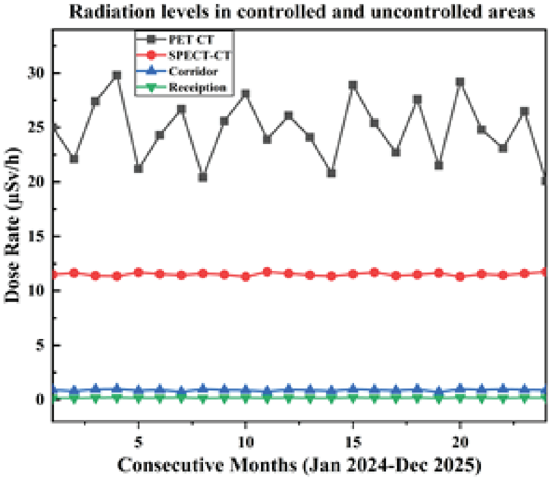

Figure 5: Radiation Levels in Controlled and Public Areas.

This difference is further supported by the higher specific gamma constant of Fluorine-18, which leads to significantly greater external dose rates for similar levels of activity. Measured dose rates at 1 meter from patients were consistently lower than theoretical estimates due to attenuation by the patient's body. For Technetium-99m, approximately 20–30% attenuation was observed, resulting in measured dose rates around 11–12 µSv/h, which aligns with adjusted theoretical expectations. Despite relatively high instantaneous dose rates in PET-CT areas, actual occupational exposure remains within safe limits because of limited exposure duration and adherence to radiation protection principles. Short-duration exposure scenarios indicate that cumulative doses to staff remain low, supporting the overall safety of routine clinical operations.

DISCUSSION

This study provides a comprehensive evaluation of radiation exposure patterns in a nuclear medicine facility over an extended period of 24 months. The findings demonstrate a consistent and well-controlled radiation environment, with dose distributions closely reflecting the clinical workflow and the physical characteristics of the radionuclides used. One of the most notable observations is the clear time-dependent variation in radiation levels within the hot laboratory. The elevated dose rates at 10:00 A.M. can be directly linked to the overlap of freshly eluted Technetium-99m and the arrival of Fluorine-18 FDG. This combination results in a temporary increase in photon flux, particularly due to the higher photon energy of Fluorine-18. As the day progresses, the decay of Fluorine-18, with its relatively short half-life, leads to a measurable reduction in ambient dose rates by 12:00 P.M. This pattern highlights the importance of workflow timing in radiation exposure and suggests that targeted protective measures during peak activity periods can significantly reduce occupational risk. The comparison between SPECT-CT and PET-CT further emphasizes the role of photon energy in radiation protection. The lower-energy photons emitted by Technetium-99m are effectively attenuated by standard lead shielding, resulting in a reduction of nearly 98–99% in measured dose rates behind protective barriers. In contrast, the higher-energy annihilation photons from Fluorine-18 exhibit greater penetration, leading to comparatively lower shielding efficiency in PET-CT areas. This difference underscores the need for enhanced shielding strategies and stricter exposure control protocols in PET-based facilities. Another important aspect observed in this study is the influence of patient attenuation on measured dose rates. In clinical settings, the human body acts as a natural attenuator, reducing the effective radiation emitted into the surrounding environment. The observed reduction of approximately 20–30% in measured dose rates for Technetium-99m aligns well with established theoretical expectations. This phenomenon explains why real-world measurements are often lower than calculated point-source values and reinforces the importance of considering clinical conditions when evaluating radiation exposure. Radiation levels in public and adjacent areas remained consistently low throughout the study period, indicating effective structural shielding and facility design. Dose rates in reception and under-stair areas were close to background levels, ensuring safety for nonoccupational individuals, including vulnerable populations. Corridor dose rates, although slightly higher, remained within acceptable limits due to low occupancy time and controlled movement of patients. The therapy patient room door, however, exhibited higher dose rates, confirming its classification as a controlled area and highlighting the need for restricted access and adherence to safety protocols in such zones. Despite relatively high instantaneous dose rates observed in PET-CT areas, particularly at 1 meter from the patient, actual occupational exposure is significantly lower due to limited exposure duration and adherence to radiation protection principles. Staff typically do not remain in close proximity to radioactive sources for extended periods, and practices such as maintaining distance, minimizing handling time, and using appropriate shielding effectively reduce cumulative dose. These findings support the continued application of the ALARA (As Low As Reasonably Achievable) principle in routine clinical operations. Overall, the stability of radiation levels over 477 working days reflects a well-optimized system of radiation safety management. The absence of abnormal fluctuations or unexpected peaks indicates that operational protocols, shielding design, and monitoring practices are functioning effectively. When compared with international benchmarks, the values observed fall within acceptable ranges, confirming compliance with established safety standards.

CONCLUSION

This study demonstrates that radiation exposure levels in the nuclear medicine facility are well controlled and consistent with international safety guidelines. Although higher dose rates were observed in PET-CT areas due to the use of high-energy radionuclides, effective shielding, optimized workflow, and adherence to radiation protection principles ensure that occupational exposure remains within recommended limits. Radiation levels in public areas were maintained near background levels, confirming the adequacy of structural shielding and facility design in protecting non-occupational individuals. The observed temporal variation in dose rates highlights the importance of workflow-based risk assessment and supports the implementation of targeted protective measures during peak activity periods. Continuous monitoring over an extended period provides strong evidence of sustained radiation safety compliance. Future improvements may focus on optimizing shielding in high-energy environments and reinforcing best practices such as maintaining distance and minimizing exposure time during peak operational hours. Overall, the findings confirm that the facility operates within safe radiological limits and maintains a high standard of radiation protection for both staff and the public.

LIMITATIONS OF THE STUDY

The study is limited by its reliance on area-based radiation measurements rather than individual personal dosimetry, which may not fully reflect actual occupational exposure. Measurements were taken at fixed time points and conducted in a single Centre, which may limit generalizability and fail to capture all temporal variations. Additionally, the lack of detailed workload correlation and advanced shielding analysis introduces some uncertainty in the precise estimation of radiation exposure and protection efficiency. Future studies incorporating personal dosimetry, multi-center data, and detailed workload analysis would help to overcome these limitations and provide a more comprehensive assessment.

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