

Assessment and Data Analysis of X-ray and CT Room Shielding Efficiency

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Abstract: This study evaluated the shielding efficiency of X-ray and CT scanner rooms in governmental and private imaging clinics across Baghdad. Concerns have arisen that some private facilities may not fully comply with shielding requirements recommended by the National Council on Radiation Protection and Measurements (NCRP). The investigation aimed to assess compliance with international dose limits and identify potential safety deficiencies to protect patients, staff, and the public. Measurements of scattered and leakage radiation were conducted using a Geiger–Müller counter in both controlled and uncontrolled areas of multiple clinics. The results revealed that most governmental facilities maintained annual effective doses below NCRP limits, demonstrating adequate shielding performance and adherence to safety standards. However, several private clinics exhibited higher dose rates, particularly within CT-controlled zones and X-ray control rooms, where values reached or exceeded 0.25 mSv/year. In contrast, radiation levels in uncontrolled areas generally remained within safe limits. Overall, governmental clinics showed satisfactory compliance with radiation protection standards, whereas some private facilities displayed deficiencies in shielding effectiveness. These findings highlight the need for stricter regulatory oversight, periodic safety audits, and improved design protocols to ensure optimal radiation protection, particularly within the rapidly expanding private healthcare sector in Iraq.

1 INTRODUCTION

The rising application of X-rays and computed tomography (CT) scan equipment in medical diagnostics has transformed contemporary medical practice by facilitating the accurate imaging of internal organs and structures and contributing to effective diagnosis and treatment planning [1]. Nonetheless, the ionizing radiation used in these imaging techniques has the capability of creating health hazards for patients, healthcare professionals, and society in case of mismanagement [2]-[4]. Diagnostic imaging radiation shielding is a major element of diagnostic imaging safety. Radiation shielding is intended to reduce the unnecessary exposure to leakage radiation and scattered radiation and to comply with international safety standards, such as those of the International Commission on

Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) [5]-[7]. The ICRP and NCRP provide occupational as well as public limit conditions of exposure to X-rays. With regard to occupational exposure, the ICRP suggests an effective dose limit of 20 mSv per year averaged over 5 years (100 mSv in 5 years) with a maximum of 50 mSv in any 1 year. To the general population, the maximum is 1 mSv/year, but it can be exceeded in special cases when averaged over 5 years. The NCRP is quite in agreement with these guidelines by providing an occupational limit of 50 mSv annually. Both bodies pay great attention to the principle of maintaining the doses at the level of As Low As Reasonably Achievable (ALARA) in order to reduce unnecessary exposures and balance the practical advantages [5]-[7]. The rapid spread of private and public medical

imaging centers in Baghdad, Iraq, which has been accompanied by the introduction of X-ray and CT scanners, has raised alarm bells on the quality of radiation protection in diagnostic centers. In spite of the professional guidelines on the design of a shield, there is limited empirical data on the shielding performance of X-ray and CT scanner rooms in clinical practice, especially in the private imaging centers [8]. The main sources of occupational and public radiation exposure are leakage radiation of the X-ray tube housing and scattered radiation due to interactions between the primary beam and the tissues or surfaces in the room. Consequently, it is imperative to conduct a systematic evaluation of these radiation exposures to guarantee that shielding barriers meet the regulatory requirements and offer sufficient protection [9]. Literature precedents underline the necessity of the routine shielding assessment at diagnostic radiology centers. In other studies, conducted empirically, it has been demonstrated that inadequate protection can produce radiation above the allowable dose limits [10]-[12]. The depth of shielding and the quality of materials used in certain imaging centers located in Iraq are not in line with the international standards used; the shortcoming of such centers is that it leads to radiation leakage beyond the permissible range. A radiation safety report published by the IAEA in 2022 on Iraq revealed vulnerabilities in regulation and suggested that specific enhancements would be needed [8], [13]. However, few studies about the shielding efficiency of diagnostic imaging rooms were published, especially in urban areas like Baghdad. This gap in knowledge indicates the need for systematic surveys assessing the radiation safety practices and the identification of the areas that need remediation. This study evaluates the shielding efficiency of X-ray and CT scanner rooms in selected Baghdad clinics by measuring leakage and scattered radiation doses. It was performed to assess the compliance with global radiation safety standards and to determine the possible protection deficiencies. The previous literature studies are either limited by a disparate measurement technique or a limited facility type. To compensate for these shortcomings, the current research used standard protocols for the different categories of clinics and compared governmental and private organizations, thus producing findings that can apply to a wider range of users. The improvement of these shortcomings, in its turn, must contribute to the perfection of radiation protection practice and ensure the safety of both personnel and patients of the diagnostic imaging facilities in Baghdad.

2 EXPERIMENTAL

Study Design: The aim of this work was to evaluate the shielding efficiency of X-ray and CT scanner imaging rooms (private and governmental clinics) by measuring the effective dose resulting from scattered and leakage radiation in controlled and uncontrolled areas. In the controlled area where the X-ray machine operates, only authorized personnel, such as radiographers, enter the imaging area and must wear protective gear, like lead aprons. An uncontrolled area, such as a patient waiting room, allows both the patient and the visitor to stay unprotected. A cross-sectional survey will be conducted to encompass various clinics, e.g., private and governmental clinics, in Baghdad, Iraq.

2.1 Equipment

The radiation dose measurement was done using a portable, calibrated Geiger-Muller (GM) counter (INSPECTOR EXP, operating range: 0.01 to 1000 μ Sv; S.E. INTERNATIONAL, INC., USA). The instrument of choice was because of its proven reliability and high sensitivity in the detection of low-level radiation.

2.2 Imaging Centers

The current study recruited 9 diagnostic X-ray and CT scan facilities located in Baghdad. Five governmental (public) and four privately owned facilities were selected as the study sample and chosen randomly to cover a variety of shielding setups, operational procedures, and patients' numbers. In order to make the comparison fair, both sectors represented an equal proportion.

2.3 Measurement Protocol

Before data collection, clinical calibration of the generic monitoring (GM) counter used to conduct this investigation was done; calibration was confirmed by exposing the instrument to a traceable reference radiation source to ensure the accuracy of the measurement was maintained. Measurements using the radiation were undertaken at the routine daytime in the selected hospitals and clinics. A dosimeter affixed to a firm stand was placed 1 m higher than the floor and roughly parallel to the X-ray tube, as well as the standard CT table height. Before the activation of any imaging system, the baseline background doses were obtained. Measurements of radiation dose were then performed in both controlled and uncontrolled areas, taking into consideration standard clinical parameters (kVp and mAs) for each imaging

modality. For each measurement point, three consecutive readings were taken to overcome variations in source output or environmental factors. A 10-second stabilization was given to each reading interval, and sufficient separation time was given between two consecutive measurements. The average of the three readings was calculated and recorded as the final dose rate value for that location. This process was repeated consistently across all clinics to ensure reliable and comparable data. The measured dose rates ($\mu\text{Sv}/\text{hour}$) were later converted into annual effective doses (mSv/year) by standard conversion factors as given in the equation:

$$\text{Effective Dose (mSv/year)} = \text{Dose Rate } (\mu\text{Sv}/\text{hour}) \times \text{Exposure Time (hours/year)} \times \text{Occupancy Factor} \times 10^{-3}.$$

To explain the parameters in the above equation, dose rate was set to be the measured value in $\mu\text{Sv}/\text{hour}$, exposure time was set to be the estimated number of hours per year the area is occupied (e.g., 2,000 hours for full-time staff), occupancy factor is the fraction of time when the area was actually occupied (e.g., 1.0 for controlled areas, 0.25 for some uncontrolled areas, per NCRP Report No. 147), and 10^{-3} converts μSv to mSv [5], [6]. See Table 1. Data were then divided depending on the facility type (private and governmental) and imaging mode (X-ray and CT scanner). Measurement of dose was compared to international norms of safety, namely standards offered by ICRP and NCRP.

2.4 Statistical Analysis

Recorded data will be analyzed using descriptive and inferential statistics to evaluate the shielding efficiency of X-ray and CT scanner rooms in 9 clinics. The radiation dose measurements in controlled areas and uncontrolled areas will be summarized using descriptive statistics, including mean, standard deviation, and range. An independent

t-test will be used to compare the difference in dose of the clinics that are either privately owned or operated by the government. ANOVA will be applied to the evaluation of differences across imaging modalities. The Pearson correlation will be used to analyze the correlation between the parameters of shielding and the radiation exposure. As well, the ICRP and NCRP safety standards compliance will be checked with the help of a chi-square test, and the clinics will be divided into groups according to the compliance to the regulatory limits. A significance level of $p < 0.05$ will be set for all statistical tests. Results will be presented through tables and graphs for better interpretation.

3 RESULTS AND DISCUSSIONS

Measurements of the radiation dose were done in nine clinics of diagnostic imaging in Baghdad, including five governmental and four privately owned. These clinics had the conventional X-ray systems alongside CT scanner systems. Dose rates were measured both in the controlled (e.g., operator rooms) and non-controlled (e.g., waiting rooms) environments, and dose rates in micro-Sieverts per hour ($\mu\text{Sv}/\text{h}$) were recorded. These values were further applied in estimating the annual effective doses following the standard NCRP occupancy factors and exposure periods. Table 2 shows the average dose rates ($\mu\text{Sv}/\text{h}$) with their standard deviations (SD) in both CT-scanner and X-ray rooms for each clinic. The findings have demonstrated that CT-controlled areas typically exhibited higher dose rates compared to X-ray-controlled areas, and a similar result was noticed in uncontrolled areas. The readings in some clinics were near or even beyond international dose recommendations, particularly in clinics operating in the private sector.

Table 1: Typical occupancy factors and exposure time estimates (based on NCRP report No. 147).

Area Type	Occupancy Factor (T)	Estimated Exposure Time (hours/year)	Description
Controlled Area (e.g., control room)	1.0	2,000	Continuously occupied by trained personnel
Adjacent Office Area	1.0	2,000	Fully occupied office space next to imaging rooms
Corridors and Hallways	0.2	400	Occasionally occupied passageways
Patient Waiting Room	0.25	500	Frequently used by patients and visitors
Staff Break Room	0.25	500	Intermittently occupied by staff
Public Toilet	0.05	100	Rarely occupied by individuals
Outdoor Area or Parking Lot	0.01	20	Very infrequently occupied (e.g., public sidewalk or adjacent lot)

The current data indicates significant inter-clinical variation in annual effective dose levels, as shown in Figure 1. In controlled locations, CT-scanner rooms provided consistently high annual effective doses compared to conventional X-ray rooms; the controlled dose of CT-scanner was close to the upper safety limits suggested by international standards in some centers. Particularly, the most noticeable CT-controlled dose was 0.22 mSv/year at Al-Imam Ali Hospital, while in Private Clinic-4, the X-ray-controlled dose was an alarming 0.25 mSv/year, indicating serious shielding shortcomings. Most institutions, however, were within acceptable safety limits, and the annual effective dose in the uncontrolled areas was always below 0.01 mSv/year. These outcomes confirm that there is sufficient security in public areas, like waiting rooms. The increased rates in some private clinics, however, should be followed up by regulation and selective reinforcement of shielding. The colored bars in Figure 1 highlight the relative exposure contributions of CT and X-ray rooms in both controlled and uncontrolled areas, making it easier to distinguish areas that require regulatory attention. There was a higher consistency in the compliance across all modalities and all rooms that were checked in the governmental clinics. On the other hand, the dose data that was obtained in the private facilities showed a greater variation, and, in at least two facilities, the dose level was rather close to or even higher than the recommended limits of the ICRP and NCRP. Independent t-tests, which were applied to the measurements of dose with nine radiological facilities, showed that CT-scanner and X-ray exposure levels were statistically different across the board, regardless of the environment of detection ($p < 0.01$). One-way ANOVA analysis depicted that there was a significant variation across institutions (p

< 0.05), especially in the CT-scanner rooms. Seven of the nine surveyed clinics (77.8%) were within the recommended limits as outlined by ICRP and NCRP. In two of the clinics that were privately owned, however, the doses administered were higher than the permissible limits, which were predominantly in the CT-scanner-controlled rooms. These consequences indicate the need to conduct regular safety audits and regulatory inspections. Figure 2 presents average annual effective doses of CT and X-ray procedures in controlled and uncontrolled areas to further elucidate. The discrepancy between the institutions located in the public and private sectors. The graph also shows that governmental clinics tend to have more consistent and lower dose levels as compared to the privately run facilities, which have higher variability, particularly in CT-controlled rooms. The given visual data aligns with the previous statistical analysis. The relationship between technical factors kVp and mAs with dose rates measured was evaluated using Pearson correlation analysis, and the result showed a strong correlation ($r > 0.8$) between the variables.

The current study carried out a critical evaluation of the radiation shielding effectiveness in diagnostic imaging departments located in Baghdad, including both government-owned and privately owned medical institutions. The analysis shows a significant difference in the level of irradiation among the different categories of facilities, modalities of imaging, and spatial locations (controlled versus uncontrolled area). These results are of vital importance to compliance with international standards of radiation safety, especially those developed by ICRP and NCRP [3], [4]. As prior studies show repeatedly, dose rates in CT-scanner rooms are higher than in traditional X-ray examination rooms, in both controlled and uncontrolled regions.

Table 2: Average radiation dose rates ($\mu\text{Sv/h}$) \pm SD for each clinic.

Clinic	CT Controlled ($\mu\text{Sv/h}$)	CT Uncontrolled ($\mu\text{Sv/h}$)	X-ray Controlled ($\mu\text{Sv/h}$)	X-ray Uncontrolled ($\mu\text{Sv/h}$)
1) Radiation Institute	0.029 \pm 0.001	0.015 \pm 0.001	0.016 \pm 0.001	0.015 \pm 0.001
2) Al-Shaab Hospital	0.022 \pm 0.001	0.012 \pm 0.000	0.010 \pm 0.000	0.009 \pm 0.000
3) Al-Sadr Hospital	0.014 \pm 0.001	0.009 \pm 0.000	0.014 \pm 0.001	0.010 \pm 0.000
4) Special Nursing House	0.025 \pm 0.001	0.013 \pm 0.001	0.013 \pm 0.001	0.009 \pm 0.000
5) Al-Imam Ali Hospital	0.110 \pm 0.004	0.010 \pm 0.000	0.013 \pm 0.001	0.006 \pm 0.000
6) Private Clinic No. 1	0.018 \pm 0.001	0.008 \pm 0.000	0.010 \pm 0.000	0.007 \pm 0.000
7) Private Clinic No. 2	0.018 \pm 0.001	0.009 \pm 0.000	0.017 \pm 0.001	0.010 \pm 0.000
8) Private Clinic No. 3	0.028 \pm 0.001	0.021 \pm 0.001	0.016 \pm 0.001	0.009 \pm 0.000
9) Private Clinic No. 4	0.028 \pm 0.001	0.021 \pm 0.001	0.130 \pm 0.005	0.100 \pm 0.004

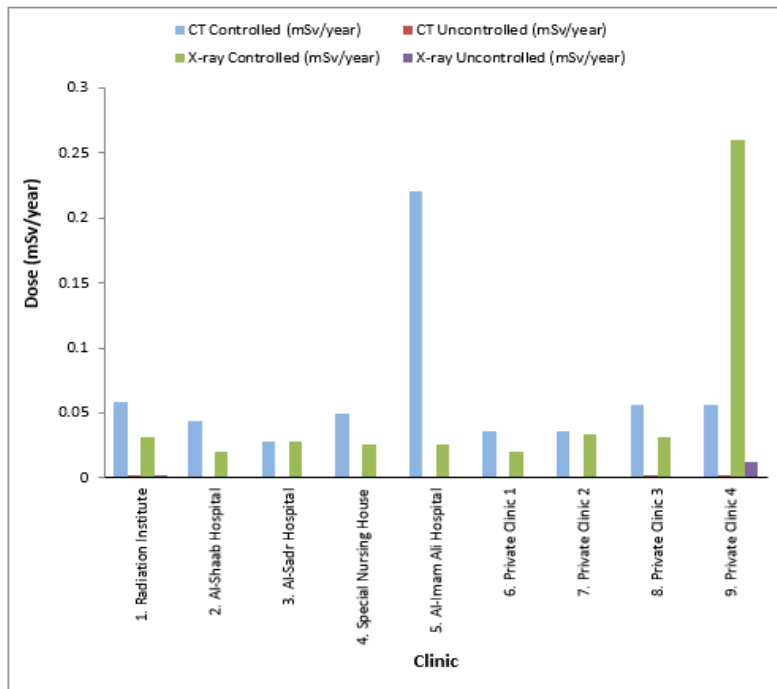


Figure 1: Comparison of annual effective dose (mSv/year) in controlled and uncontrolled areas across nine diagnostic clinics.

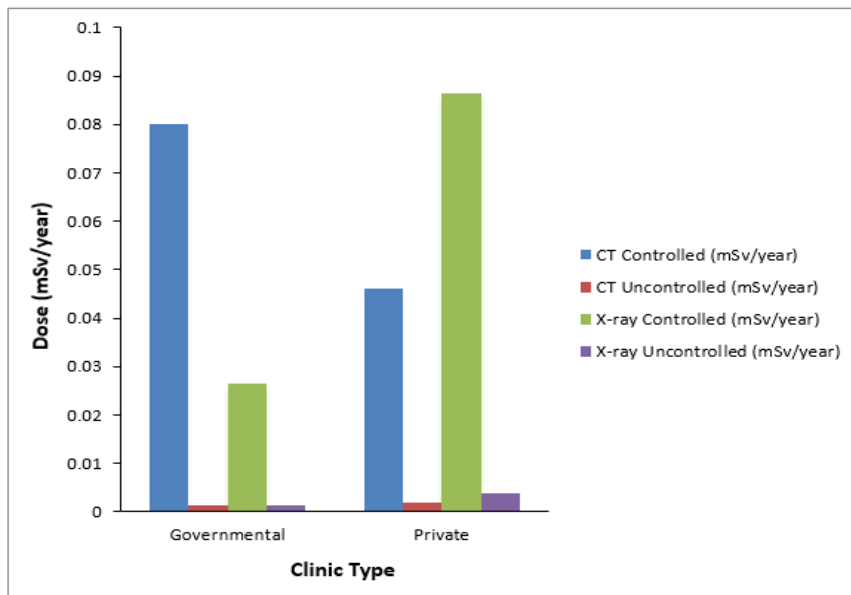


Figure 2: Comparison of average annual effective doses (mSv/year) in CT and x-ray controlled and uncontrolled areas between governmental and private clinics.

This result is consistent with the fact that CT technology provides significantly higher radiation doses due to the rotational and cross-sectional image nature that requires high tube currents and long exposure times [7], [14]-[16]. In spite of most of the reviewed clinics adhering to the statutorily defined

annual occupational exposure dose (50 mSv) and that of the population (1 mSv) limits, two privately owned facilities failed to do so. The related results, in particular, high exposure indices in multiple CT-controlled working areas and X-ray rooms, indicate the possible lack of shielding design or material

integrity. These results are an indication of the need to constantly monitor and carry out stringent quality-control measures to ensure proper safety levels in private clinics. The current research depicts a significant variation between the radiation dose released by the governmental facilities and the radiation dose recorded in the private clinics. The radiation levels were more stable and at lower doses in governmental institutions, and this could be attributed to their increased regulatory controls and uniformity of the infrastructure system. On the other hand, in the case of private clinics, the dose measurements were more varied, with some of them being over or close to the allowable levels. Such a trend is consistent with past experience in Iraq and other underdeveloped areas where regulation of the private sector is limited by financial and administrative capacity [6], [11], [17]. All these findings point to structural difficulties in radiation safety governance in the fast-growing healthcare sector in Iraq. The technical report of the IAEA in 2022 also highlights the importance of improving regulatory systems; the data proves that the dose variability is especially vulnerable when it comes to the private clinics due to financial, administrative, and training limitations [8]. Therefore, the regulatory systems must be improved soon, particularly in private clinics. The current research assesses the correlation between the parameters of exposure (kVp, mAs) and dose rate through statistical correlation analysis, indicating an intense positive correlation that supports the assumption that enhancing the technical settings is crucial for reducing the level of leakage and scatter radiation. These results are consistent with both theoretical predictions and earlier studies [7] and thus confirm the significance of optimal exposure procedures in daily clinical practice. Although the statistical significance of this correlation is clear, differences in shielding effectiveness seem to have an even stronger impact on the final dose levels. International best practices emphasize the use of the ALARA (As Low As Reasonably Achievable) principle, even in situations where measured doses are below regulatory limits. The existing findings indicate that a number of clinics, particularly those in the private sector, could use some extra shielding, such as thicker barriers, better shielding on the doors, or room design to minimize the spreading of radiation to the non-controlled zones [3], [5], [9]. The comparison of the current study with previous regional and global research shows that there is a pattern of radiation shielding inadequacy in fast-growing healthcare infrastructures. The 2022 IAEA technical report on

Iraq highlights these concerns and emphasizes the need for regular shielding audits and stronger inspection practices [6]. At the same time, more recent European surveys and consensus recommendations have observed a decreased focus on patient shielding and a simultaneous increase in the structural design as the most important protection [8], [9]. The current research, therefore, contributes empirical knowledge on radiation-safety practices in the diagnostic imaging industry of Baghdad and offers a practical foundation to health officials, regulatory organizations, and facility managers. Future studies ought to aim at expanding the sample size, adding real-time dosimetry to occupational staff, and studying the performance aspect of shielding materials to provide a more detailed picture of risk distribution.

4 CONCLUSIONS

This study assessed the shielding efficiency of X-ray and CT scanner rooms in governmental and private clinics across Baghdad to determine compliance with international radiation protection standards. The findings revealed that most governmental facilities maintained annual effective doses well below the limits recommended by the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological

Protection (ICRP), demonstrating satisfactory shielding performance and adherence to safety protocols. However, several private clinics exhibited higher dose rates, particularly in CT-controlled zones and X-ray control rooms, where values reached or exceeded 0.25 mSv/year, suggesting deficiencies in shielding design or material integrity. The significant variation in dose levels between public and private facilities highlights disparities in regulatory compliance and infrastructure quality. The strong positive correlation between exposure parameters (kVp, mAs) and radiation dose underscores the importance of optimizing technical settings alongside effective shielding to minimize radiation hazards. Overall, while public clinics generally conform to international safety standards, some private clinics demonstrate inadequate shielding and inconsistent safety practices. These findings emphasize the urgent need for stricter regulatory enforcement, regular inspection programs, and improved staff training in radiation protection to ensure a uniformly safe imaging environment for both healthcare workers and patients in Iraq's expanding medical imaging sector.

5 RECOMMENDATIONS

Based on the findings of this study, two main recommendations can be made: Firstly, increase regulation control, especially in those areas where the lack of shielding, as shown in this research, was detected, especially in private imaging facilities, and secondly, increase the frequency of inspection in order to counter such shortcomings. Likewise, the existing NCRP and ICRP shielding standards should be well followed in all clinics. In line with these endeavors should be a rigorous orientation of staff in radiation safety and exposure optimization in an attempt to maintain best-practice standards. Further, it is necessary that the continuous dose monitoring should be performed in the controlled and uncontrolled areas to maintain a safe environment. In the case of the private clinics, technical advice or financial incentives specifically aimed at the improvement of shielding infrastructure and the harmonization with international safety standards will probably be an effective tool for promoting such improvements.

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