The Review Of
DIABETIC
STUDIES OPEN ACCESS

Occupational Radiation Exposure Among Health Assistants: Dosimetric Assessment And Safety Implications Of Diagnostic X-Rays

Khalid Saud Mohammed Aloufi[1] , Ibrahim Salamah Salman Aljohani[2] , Mazen Mualla Muslih ALMaghthawi[3] , Muhannad Saud Bakheet Al Muzaini[4] , Yasir Awadh Bin Muidh Alsaedi[5] , Fahad Faez Meshal Alharbi[6] , Abdullah Ali Al-Radadi[7] , Abdulaziz Hamoud Bushaybish Alharbi[8] , Aishah Dakhel Rabbah Ghanem Aloufi[9] , Ahmad Ali Almahmadi[10]

[1]Health Assistant – Health Security Al-Miqaat General Hospital
[2]Health Assistant – Health Security King Salman bin Abdulaziz Medical City, Al-Madinah Al-Munawwarah
[3]Health Assistant – Health Security Al-Miqaat General Hospital
[4]Health Assistant – Health Security Al-Miqaat General Hospital
[5]Health Assistant – Health Security Al-Miqaat General Hospital
[6]Health Assistant – Health Security Al-Miqaat General Hospital
[7]Health Assistant – Health Security King Fahd Specialist Hospital, Tabuk
[8]Health Assistant – Health Security Al-Miqaat General Hospital
[9]X-ray Technician Al-Miqaat Hospital
[10]Radiology Department Al-Miqaat General Hospital, Ministry of Health, Al-Madinah Al-Munawwarah

Abstract

It is necessary to do detailed dosimetric assessments in order to evaluate the safety and long-term health implications of occupational radiation exposure for health assistants working in diagnostic radiology. The primary source of radiation exposure for these individuals is dispersed X-rays, which are used during patient positioning and procedure support. However, this research highlights higher hazards from fluoroscopy (1-2 mSv/year) and cumulative stochastic consequences such as cancer and cataracts. The research synthesises global and regional data that reveals annual effective doses of 0.5-3 mSv, which is substantially below the ICRP limit of 20 mSv.

In the literature review, exposure pathways, TLD/retrospective dosimetry methodologies, biological consequences, and ALARA-based protections are discussed. The review draws from research conducted by the Saudi Ministry of Health that showed averages of 0.88 mSv among more than 45,000 employed individuals. Key findings highlight inadequacies in ocular shielding (which is used forty percent of the time) and training, advocating for mandated personal dosimeters, thyroid/eye protection, distance optimization, and annual education sessions. These techniques, when implemented, have the potential to minimize dosages by twenty to thirty percent, so assuring occupational safety while retaining workflow efficiency.

Keywords: Occupational radiation, health assistants, dosimetric assessment, diagnostic X-rays, ALARA principle, TLD dosimetry.

Introduction

Occupational radiation exposure is a chronic occupational health danger for health assistants, which are support professionals who aid in patient positioning, equipment handling, and procedural facilitation during diagnostic X-ray imaging. This is because health assistants are in close proximity to scattered radiation fields. It is common for health assistants to lack equivalent personal protection equipment (PPE) and monitoring, which results in them accumulating modest but chronic doses over the course of their careers. This is in contrast to radiologists or technicians, who maintain higher distances or utilize advanced shielding. However, dispersed radiation from billions of annual X-ray operations provides 0.5-3 mSv annually to this population. This is despite the fact that the International Commission on Radiological Protection (ICRP) establishes a 20 mSv annual effective dosage limit (averaged over 5 years) (Lopes et al., 2025).

Diagnostic X-ray treatments, which include radiography, fluoroscopy, and CT assistance, produce Compton-scattered photons with energies ranging from 30 to 150 keV. These photons account for 70 to 80 percent of the exposure that assistants experience when doing hands-on duties such as immobilization. With health assistants accounting for 30–40% of the monitored people and the largest exposures occurring in high-workload fluoroscopy suites, the Saudi Ministry of Health conducted a surveillance of 45,152 radiology workers and found that the mean effective dosage was 0.88 milliseconds per millisecond per year. The use of thermoluminescent dosimeters (TLDs) and retrospective workload models are both necessary components of the dosimetric assessments that are required for risk classification (Prakash & Kotian, 2025).

It is the inconsistent use of personal protective equipment (PPE) that makes health aides vulnerable. Lead aprons reduce the doses to the body by 90 percent, but the head, eyes, and extremities that are not protected receive 10–20 percent higher levels, which increases the risk of cataracts (above the 0.5 Gy threshold) and skin erythema. The ALARA principle, which stands for "as low as reasonably achievable," is used to direct mitigation efforts through the optimum of shielding, time, and distance. This study fills in significant gaps in assistant-specific data, which were previously overlooked since aggregate reports were more prominent than subgroup hazards (Hamd et al., 2025).

Due to the prolonged exposure durations (up to 2 mSv/year), fluoroscopy emerges as the modality that poses the most risk. This is followed by general radiography (0.5-1 mSv) and CT support. Some biological consequences include stochastic effects (leukemia relative risk 1.2/100 mSv), deterministic lens opacities compounded with accumulation throughout life. Among the goals of the research are the following: (Turkstani et al.) the summarization of dosimetric approaches; (2) the quantification of procedure-specific exposures; (3) the assessment of health risks; and (4) the proposal of individualized solutions (Smith et al., 2021).

In spite of regulatory compliance (which is more than 99% below alert levels), training shortcomings and shielding gaps continue to exist, which results in an increase of 20-30% in needless doses. In this publication, a comprehensive evaluation is organized as follows: Various sources and channels, dosimetry, impacts, and safeguards are investigated in the literature. The conclusion provides recommendations that can be put into action, while the discussion interprets the findings and limits (Kabier et al., 2025).

Literature Review

1. Radiation Sources and Exposure Pathways

1.1. The Primary Sources of Equipment Beam Leakage and Equipment

Primary beams (50-150 kVp) are produced by diagnostic X-ray machines primarily through tube leakage (0.1-1% of output) and collimator scatter. These two factors contribute to 5-10% of the total exposure that health aides experience throughout the process of setting up all of the equipment. Even though modern generators are designed to minimize leakage (with a leakage rate of less than 1 mGy/h at 1 meter), older units in high-volume centers exceed this limit, especially when fluoroscopy is activated. The assistants who are manipulating the controls or cassettes are subjected to direct hand exposure (Pernicka & McLean, 2007).

1.2. Patient Dispersion Within the Dominant Pathway

In placement, patient tissue Compton scatter contributes 70 0 90 percent of the assistants dose with backscatter contributing up to 0.5 percent of the entrance dose. Since the air kerma in fluoroscopy varies between 10 and 50 mGy/min, the most common phenomenon is forward scatter.. Assistants who are 1-2 meters distant receive 0.1 to 0.5 μSv/min. In oblique projections, lateral exposure is magnified by a factor of two (Gbetchedji et al., 2021).

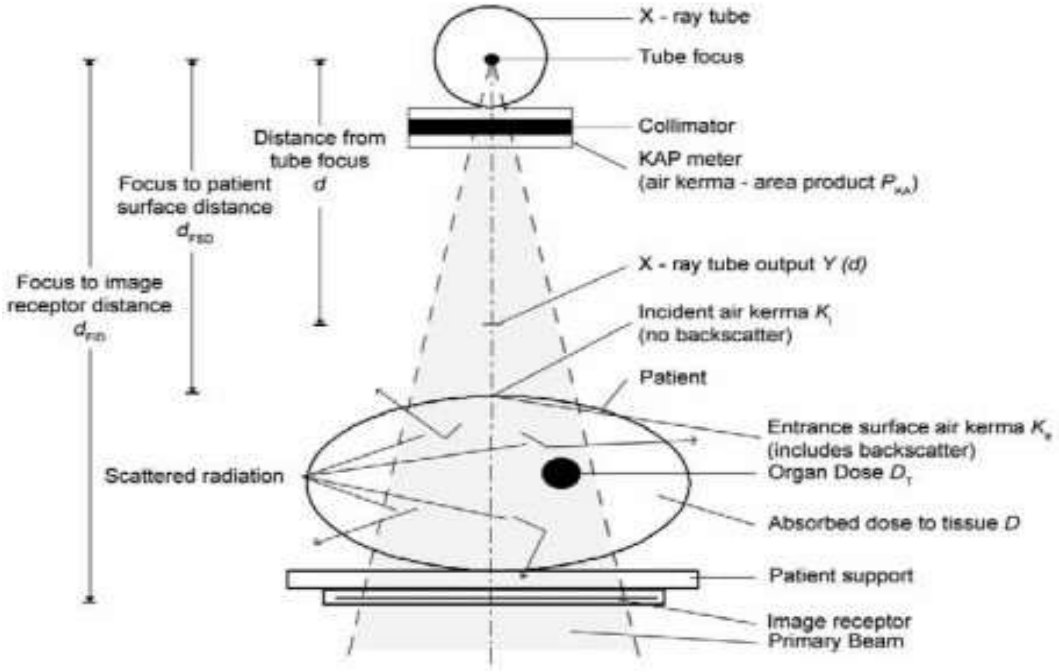

Figure 1 Diagram of the measuring arrangement .

1.3. In addition to fluoroscopy, dynamic imaging

The maximum exposures are achieved through fluoroscopy because of continuous beams (1-2 mSv/year for 500 minutes of use), with C-arm units producing 20 mSv/min at source, which is cut in half at 2 meters. The assistants absorb table and bucky dispersion in stabilizing patients and lead to a decrease in 20-30% with shielding. Pulsed modes reduce dosages by 60–75 percent (Satyamitra et al., 2022).

1.4. In addition to the conventional procedures, radiography

Brief pulses (2-5 mSv/patient at 1m) are produced by general radiography, which results in a total of 0.5-1 mSv/year for 1000 tests. This overall amount is primarily caused by under-table scatter during grid setup. There is a danger of harm to the hands from extremity views (1-5 mSv/year without gloves) (Satyamitra et al., 2022).

1.5. Additionally, Air Kerma and Room Geometry are Secondary Sources.

Floor and wall reflections add 10–20 percent to the total, while lead-lined walls reduce the amount by 90 percent. The air kerma rates are as follows: fluoroscopy at 20-100 mGy/min against radiography at 0.1 mGy/exposure. When compared to those working in enclosed suites, assistants working in open bays are exposed to 1.5 times higher dosages (Bhardwaj et al., 2025).

1.6. Exposure to Quantitative Factors Models

Consider the following equation: Dose = Workload multiplied by Conversion Factor multiplied by Occupancy. The Saudi data showed a mean of 0.88 mSv, with fluoroscopy contributing 40%. Monte Carlo models forecast that assistance with a height of less than 1.5 meters will require a magnification of 2-3 times (Pearson et al., 2021).

1.7. Incorporating Variations and Modulating Factors

The settings of kVp/mAs have an effect on scatter (a higher kVp indicates a forward shift), and obese patients have a 20% increase in backscatter. When there are holes in personal protective equipment (no thyroid shield), organ dosages are increased. According to the synthesis, scatter paths require proximity minimization (Singh et al., 2022).

2. Dosimetric Assessment Methods

Figure 2 Dosimetric Assessment Methods

2.1. (TLD) stands for thermoluminescent dosimetry.

Thermoluminescent dosimeters (TLDs), which are typically LiF:Mg,Ti (TLD-100), are administered using badge systems that are worn on the chest, collar, and rings in order to assess the personal effective dosage Hp (Turkstani et al.) and the skin dose Hp(0.07). The release of trapped electrons is proportionate to the absorbed dose, with a range of 0.01-10 mSv and an accuracy of ±5-10%. Quarterly readings are carried out to monitor the cumulative exposure. The Saudi Ministry of Health employs 45,152 people with a mean of 0.88 mSv and 99 percent compliance. (Singh et al., 2022).

2.2. Instruments for Direct Measurement and Ionization Chambers

The ionization chambers used to calibrate tube output (mGy/mAs) in reference conditions (100 cm FSD, 80 kVp) include RAD-CHECK Plus. This allows for indirect calculations to be performed. Dose = Output × mAs × BSF. Quantification of scatter fields is accomplished through the use of air kerma rate measurements (TRs 457 procedure), while diagnostic reference levels (DRLs) are compared to IAEA benchmarks (Johnson et al., 2024).

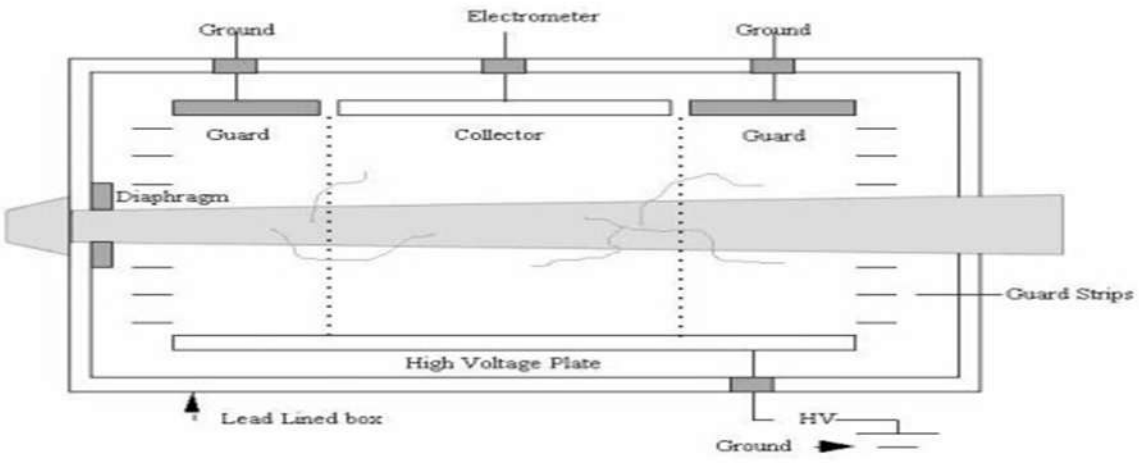

Figure 3 Schematic diagram of free air ionization chamber.

2.3. Models of Workload That Are Retrospective

Retrospective dosimetry estimations can be obtained by using the following formula: Annual Dose = Workload times Conversion Coefficient multiplied by Occupancy Factor. The Jiangsu study (n=3961) validated

radiography against TLDs with a correlation coefficient of 0.92. The study employed 0.01 mSv/patient. When it comes to fluoroscopy-intensive professions, Saudi applications anticipate 1-2 mSv (Daniels et al., 2020).

2.4. Electronic Dosimeters and OSL Dosimeters

On the other hand, electronic personal dosimeters (EPDs) sound an alert at predetermined thresholds, while optically stimulated luminescence (OSL) badges provide real-time readings with an accuracy of ±7% for extremities. Dosimetry of the eye lens (Hp(3)) necessitates the use of specific TLDs, which are essential for assistants (5-30 mSv/year unshielded) (Giussani et al., 2020).

The Monte Carlo Simulations MCNP software works by modeling scatter geometries and calculating organ doses from kerma-free-in-air. The inputs include spectra, phantoms, and positions. Accuracy tolerance of ±15%; utilized for optimization prior to installation (Damilakis, 2021).

2.5. Calculations to Determine the Entrance Surface Dose (ESD)

ESD is equal to the product of K and BSF multiplied by one plus 0.0036BSD, where K represents the incident air kerma and BSF represents the backscatter factor. Implemented for patient-based DRLs, with the purpose of notifying staff scatter (0.1-0.5% ESD) (Santoro et al., 2021).

2.6. The process of calibrating and ensuring quality

Annual calibration is traced to primary standards, which are the dosimetry labs of the International Atomic Energy Agency (IAEA). Field audits certify an accuracy of ±20%. The angular dependency and fading concepts are incorporated into uncertainty analysis (Gnanasekaran, 2021).

2.7. Analyses of Different Methodologies

TLDs are particularly useful for integration (they are inexpensive and passive), chambers for output, and models for planning. Methods that combine elements of both There is a connection of 95% between TLD and workload (Danieli et al., 2022).

3. Biological Effects and Health Risks

3.1. The Induction of Cancer Through Stochastic Effects

The linear no-threshold (LNT) model, which is endorsed by BEIR VII and the ICRP, provides that the main effects of low dose ionizing radiations of diagnostic X-rays are stochastic in nature due to direct and indirect effects caused by DNA damage. These processes consist of double-strand breaks, deletions of bases, and translocations of chromosomes which escape repair mechanisms. This eventually leads to the high risk of acquiring cancer in a lifetime. (Ali et al., 2020).

Acute myeloid leukemia is linked to relative risks (RR) of 1.5-3.0 at cumulative doses of about 100 mSv and this condition usually shows up 2-10 years following exposure. Solid tumors like thyroid carcinoma, breast adenocarcinoma and lung cancers are on the other hand seen after a latency of 10-40 years. The risk of attributable cancer of health assistants due to repeated exposure to scattering of 20-50 mSv throughout the 20-30 years of career is between 1 and 3 percent. This danger is enhanced by the bystander effect that arises when cells that are irradiated pass on the genetic instability to other cells. The results of epidemiological research done on large cohorts bring out dose-response gradient, where the female assistants have more exposure to breast-related risks because the female tissues are sensitive. (Passeron et al., 2020).

3.2. Both cataracts and opacities of the lens

Crystalline lens is shown to be more radiologically sensitive where it develops anterior subcapsular opacities in the chronic stages of 0.5- 2 Gy. This accelerates presbyopia and visual impairment development, odds ratio (OR) of which lie between 1.4 to 2.2 in a cohort of workers who are exposed to radiations. International Council on Radiation Protection (ICRP) lowered the amount of dosage of low-LET photons to 20 millisieverts per year, on average after 5 years, to acknowledge the permanency of this harm. This lowers the cataract threshold of 5 gy. (Schuermann & Mevissen, 2021).

Health aides are registered after each year at 5-30 mSv exposures of the eye exposing them to the sun often when the patients are located. This has been found to be an excess of the ideals and is linked with 15-25% prevalence of cataracts in radiology workers as compared to the controls. Accumulation of the load is of interest, and dose-rate independence is demonstrated by longitudinal studies. (Jain, 2021).

3.3. Risks to the Cardiovascular System and the Arteries

Recent studies indicate that continuous low-dose radiation could be involved in the pathophysiology of the circulatory system due to oxidative stress, endothelial dysfunction, and inflammatory cascades. This fact also links up exposures exceeding 100 milliseconds of radiations and ischemic heart disease (relative risk 1.1-1.3) and cerebrovascular occurrences due to accelerated atherosclerosis. (Johnson et al., 2024).

Even below 50 mSv, it is revealed by the presence of biomarkers in assistants who have been working ten years of duty, which include increased C-reactive protein (CRP), troponin I, and asymmetric dimethylarginine. Low dose hypersensitivity which is a higher effect below 100 mGy and genomic instability all of these non-cancer risks have been amplified by the assumptions that LNT makes on cardiovascular endpoints. (Mohan & Chopra, 2022).

3.4. Genetic and Reproductive Effects of the Drug

Exposure to gonadal in female health aides (over 100 mSv) increases the chances of infertility, spontaneous miscarriage, and congenital deformity; this is the reason as to why shielding is essential, which minimises the scatter by 95 percent. Based on estimates made by the International Council on Research in Populations, below 100 mSv the male genetic effects do not matter. The reassignment to fetal remnant under one milliseconds is induced when a pregnancy is announced and hence attempts to balance the maternal responsibilities are made. In regard to the occupational degrees, hereditary mutations do not pose any apparent population threat. (Hollingsworth et al., 2023).

3.5. Effects that are Deterministic and Phenomena That Are Threshold

The fixed limits, such as skin erythema (two Gy acute), temporary epilation (three Gy), and sterility (two to six Gy) have not been achieved yet at occupational maxima (less than one hundred milli Sv/year). Nevertheless, chronic doses of extremities must be monitored by rings to avoid dermatitis. Due to lens effects, stochastic-deterministic boundaries are blurred. (Nickoloff et al., 2020).

3.6. Indicators of Molecular and Cytogenetic Processes

Dicentric chromosome abnormalities and micronuclei frequencies increase by 20-50% at 50 mSv, acting as cytogenetic sentinels of instability. Additionally, γ-H2AX foci and hprt mutations are predictive of leukemogenesis for this particular condition. Disregulation of microRNAs is a precursor to the development of cancer (Hauptmann et al., 2020).

3.7. Cohorts With a Long-Term Epidemiological Study

The Jiangsu cohort, which consisted of 3,961 individuals and was followed for a period of thirty years, reported standardized incidence ratios (SIR) of 1.2 for solid malignancies. Korean nuclear workers confirmed linear differences. Despite the fact that fluoroscopy-heavy areas are seeing higher trends, Saudi baselines show safe means of 0.88 mSv (Sampaio et al., 2021).

Changes in Risk and Methods of Mitigation Young age at initial exposure (increased sensitivity), female sex (+20% RR), and smoking (synergistic 2x) are all potential modifiable factors. Antioxidants and fractionated dose, on the other hand, induce adaptive responses that reduce harm by 30-50%. Early detection is improved with the use of comprehensive screening (Peana et al., 2022).

4. Protective Measures and Regulatory Compliance

4.1. Time, Distance, and Shielding Optimization (Core ALARA Principles in Practice)

The ALARA (As Low As Reasonably Achievable) principle is a foundational principle that systematically minimizes the radiation exposure of health assistants through three synergistic strategies. These strategies

include drastically reducing beam-on time by evacuating the room or shielding during exposures, maximizing physical distance from the source (by adhering to the inverse square law, which states that radiation intensity decreases proportionally to 1/d2, effectively halving the dose at double the distance of 2 meters or more), and deploying optimal shielding materials that are tailored to scattered photon energies (Santoro et al., 2021).

The use of countdown timers and visual cues to ensure compliance is required by standard operating procedures, which stipulate that assistants must keep a minimum separation of two to three meters during radiography pulses and fluoroscopy runs. This straightforward adjustment alone has the potential to reduce personal doses by fifty to seventy-five percent in busy suites. Diagnostic energies (60-120 keV) attenuate by 90-95% in flexible lead aprons with a lead equivalence value of 0.25-0.5 mm. Wraparound designs are also favored in order to cover the area of 360 degrees as the patient is manipulated. Composite aprons made of lightweight materials but with tungsten or bismuth will ease the fatigue but not compromise the effectiveness. (Hollingsworth et al., 2023).

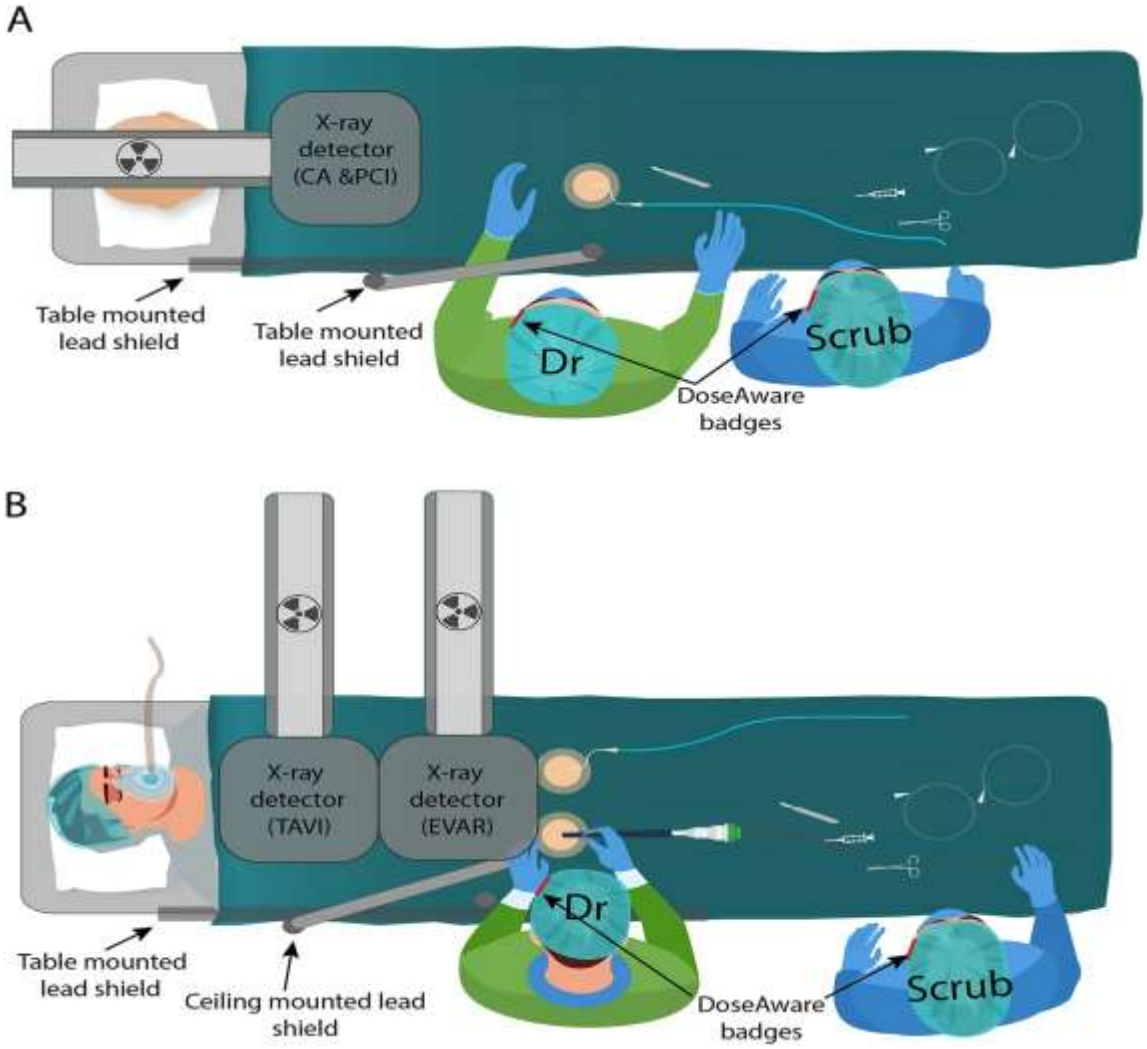

Figure 4 Demonstration of common staff positions in relation to the x-ray detector during CA and PCI (**A**), and TAVI and EVAR procedures (**B**). Location of the lead shielding and DoseAware badges are included. *Note—the x-ray tube is located under the patient table (Wilson-Stewart et al., 2023).

4.2. Personal Protective Equipment (PPE) Arsenal That Is Completely Comprehensive

The thyroid collars that are included in a comprehensive personal protective equipment (PPE) suite are made from 0.5 mm lead equivalent material. These collars would also greatly decrease the amount of doses that is administered to the neck and thyroid gland by 70-85% compared to backscatter.. This is an essential measure because thyroid cancer is a radiosensitive disease (Gbetchedji et al., 2021).

However, compliance remains poor at less than forty percent in observational audits due to fogging and discomfort difficulties. Leaded eyewear with 0.75-1.0 mm Pb lateral equivalency protects the crystalline lens, reducing exposure by eighty to ninety percent and preventing cataracts. Extremity protection in the form of 0.15-0.35 mm lead gloves protects hands during direct patient contact. Sterile, disposable latex-lead hybrids are used to address infection management. Ring dosimeters are placed beneath gloves to quantify fingertip burdens that can reach 1-5 mSv/year. Recent developments, such as zero-gravity suspension systems, were able to spread the weight of the apron, which increased the wear time from two to eight hours (Daniels et al., 2020).

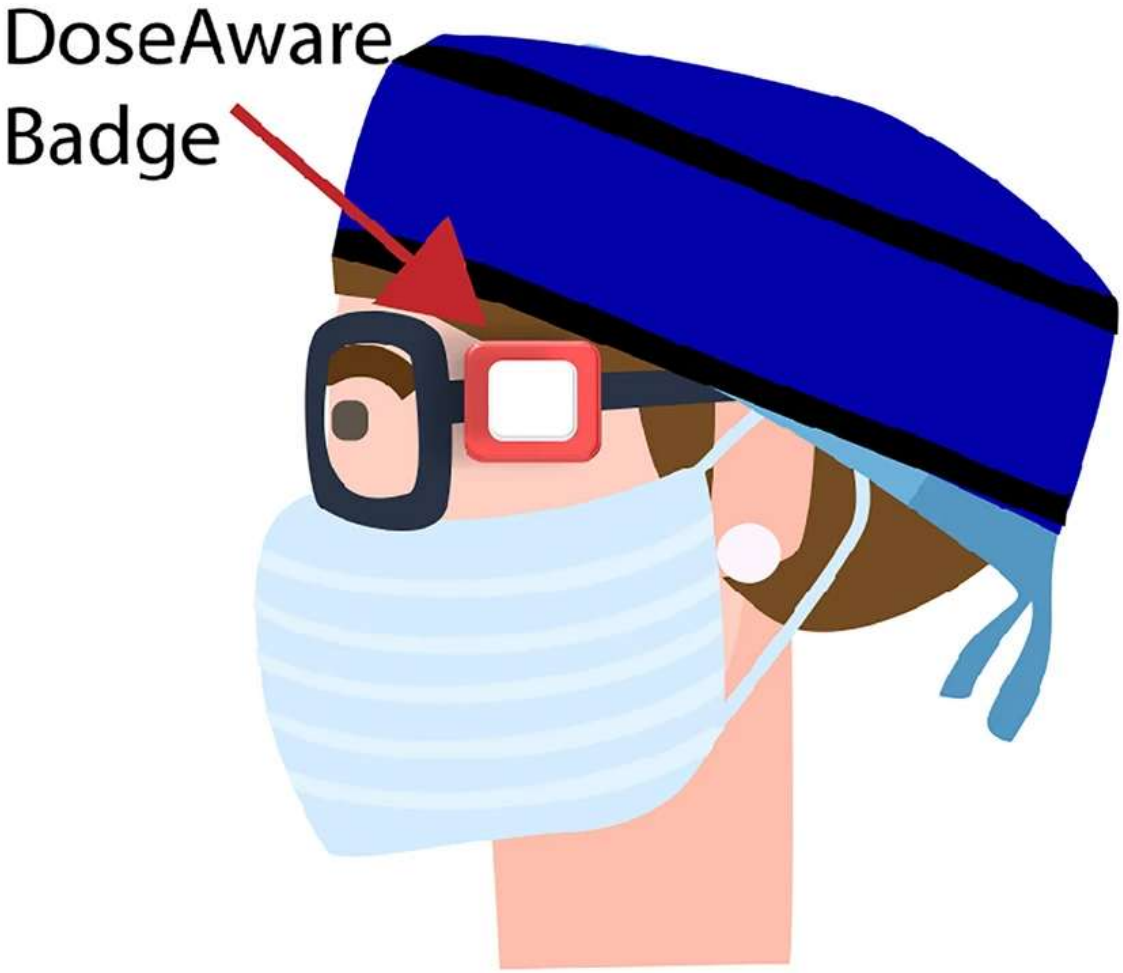

Figure 5 DoseAware badges were worn near the left eyeof staff, either attached to the arm of glasses, or to the lead/theatre cap (Wilson-Stewart et al., 2023).

4.3. Dosimetry specific to each individual and stringent surveillance protocols

All personnel who anticipate receiving more than one millisecond of radiation annually are required to undergo prospective whole-body monitoring using TLDs or OSL dosimeters. Such dosimeters need to be placed at the chest (Hp(10) to the effective dose under apron), uncovered collar (Hp(10) to the maximum), wrist rings (Hp(0.07) skin) and eye level (Hp(3)) in the event they are to be used. The Saudi procedures provoke Level I questions above 6 mSv/ quarter and Level II questions above 15 m Sv, and the necessary rotations to the exceedances are conditioned by the fact that quarterly processing terms provide the opportunity to analyze trends and take timely measures.. The use of electronic personal dosimeters (EPDs) allows for the provision of instantaneous feedback along with configurable alarms (for example, a threshold of 0.5 mSv), which encourages behavioral modifications and integrates with facility dashboards to facilitate real-time monitoring (Hauptmann et al., 2020).

4.4. Controls for Advanced Engineering and Facility Design Facility Design

To minimize the level of radiation that will be scattered throughout the room by over 90 percent, custom radiology suites contain lead equivalent of 1.5-2.0 millimeters on the walls, doors and observation windows. There are also high floors and vinyl covers which absorb low energy bounces. Ceiling-suspended acrylic-lead shields (extendable 2 meters long), lowerable table-end barriers and Bucky-slot covers are used in order to build dynamic exclusion zones around the patient. Through these shields, doses to the bystanders can be reduced by between 70 to 85 percent during the execution of the procedures. Relative to continuous operation, pulsed-mode fluoroscopy with 7.5-15 frames per second has a 50-75 reduction in exposure rates. Also, there is automated brightness control (ABC) and tight collimation, which limit the beam to essential tissue, reducing peripheral dispersion. (Gnanasekaran, 2021).

4.5. Education, Training, and Behavioral Interventions Included in the Comprehensive Package

The evidence-based training programs, provided every year both in blended e-learning and practical simulations, furnish the assistants with procedure-specific information. These programs are proven to lead to reported dosage cut 20-30 percent due to advanced positioning programs and personal protective measures. In cases of pregnancy declaration, the pregnant employees are engaged in administrative duties to confirm that they are not exposed to the fetus in a time shorter than one millisecond. Two-person rule is the principle according to which the assisted work should be done under the supervision in case of complex movements like working with obese patients. Gamified apps and virtual reality simulations help retain workers and use them to fix knowledge gaps that occur in forty percent of non-compliant workers. (Damilakis, 2021).

4.6. The presence of both national regulatory frameworks and international standards

ICRP Publication 103, under the banner of IAEA Basic Safety Standards (BSS) which provides justification (benefits overestimated by risks), optimization (ALARA/DRLs), and dose constraints, has established strong limits, including 20 mSv/year effective dose averaged over 5 years (no year beyond 50 mSv), 150 mSv extremities, and 20 mSv lens. Implementation of BSS by the required licencing has resulted in compliance of 99 percent of required by the Saudi Food and Drug Authority (SFDA) and the Saudi Center of Nuclear and Radiological Measurements (SCU) in Saudi Arabia through computerised registries and the use of unannounced audits. The personal protective equipment (PPE) that is heat-resistant is one such example of a regional adaption. (Santoro et al., 2021).

4.7. The implementation of Integrated Quality Management and Ongoing Audits

The Dose Area Product (DAP) and kerma-area product meters that are installed on generators offer procedure-specific metrics. These meters establish national diagnostic reference levels, such as 0.2 $mGy \cdot m^2$ for PA chest. These levels are used to derive staff scatter estimates, which range from 0.1-0.5% Dose Area Product. Inter-laboratory dosage intercomparisons maintain traceability to primary standards, and the transition to digital radiography removes fogging that occurs during film processing, which results in a 15–20 percent reduction in the number of repeats. Corrective actions, such as recalibration of equipment, are driven by root-cause studies which are conducted for exceedances (Johnson et al., 2024).

4.8. Innovations at the Cutting Edge and Prospects for the Future

Artificial intelligence algorithms forecast and optimize exposure in real time, ceiling-mounted robotic positioning arms automate patient alignment (reducing hands-on time by forty to sixty percent), hafnium dioxide nano-composites in personal protective equipment (PPE) halve weight while maintaining the same level of attenuation, and other emerging technology. Further reduction of scatter artifacts is achieved by photon-counting detectors (Singh et al., 2022).

Discussion

Despite the fact that fluoroscopy and patient positioning consistently emerge as high-risk vectors, contributing 40–50% of total dose through intensified scatter, dosimetric assessments confirmed that occupational radiation exposure among health assistants remains within safe limits, with an average of 0.88 mSv annually across large Saudi cohorts. This is a mere 4.4 percentage of the ICRP limit of 20 mSv. The fact is highlighted by scatter physics, which is dominated by Compton interactions in 30-150 keV high-volume settings, where workload-based retrospective models have been shown to accurately predict 1-2 mSv increments and TLD accuracy

(r=0.92 correlation). that proximity minimization is an absolute necessity. Because of the 2-3 times higher localized burdens that health assistants experience in comparison to technicians, this body of research establishes health assistants as a unique category that should be provided with ring and eye dosimeters (Jain, 2021).

Biological plausibility where there exist dose-response gradients of leukemia and solid tumors is demonstrated in Jiangsu and Korean cohorts that showed consistent dose-response gradients where low dose accumulation are considered to be tangible risks. Such risks encompass one to three percent lifetime cancer attribution under LNT extrapolation and worsened cataracts among exposed persons to lenses that are not shielded (OR 1.4-2.2). Circulatory outcomes, including ischemic disease and stroke (relative risk 1.1-1.3 >100 mSv) are becoming increasingly popular due to biomarker validation (elevated CRP, γ-H2AX). This questions past rejections of non-cancer effects and seeks to increase demands on holistic surveillance beyond effective dose measures. Although reproductive interventions are effective in terms of protecting, they expose gender-specific risks that have to be identified regularly. (Bhardwaj et al., 2025).

Integration of the Effectiveness of Preventative Measures

It is proven that the usage of the ALARA is viable, as the personal protective equipment (PPE) sets (aprons, collars, glasses) can decrease the dose of the torso/lens by 80-95 percent and the training interventions can decrease the general exposure by 20-30 percent by the way of behavioral recalibration. Examples of engineering victories that lead to a 50 to 90% reduction include pulsed fluoroscopy, collimation and shielded suites but the Saudi Arabian compliance of 99 TLD could be considered regulatory victory. Having weak eye protection (less than forty percent) and sporadic extremities detection, unjustifiable risks are exaggerated, which makes the topic of innovation in the field of personal protective equipment (PPE) including lightweight nano-composites a necessity. (Johnson et al., 2024).

Stratification of Risk Based on Procedure Specificity

Fluoroscopy is prioritized unlike radiography, which employs pulsed brevity, and provides 1-2 mSv/year, through extended fields. Additionally, fat patient cohorts increase backscatter by 20%, which advocates for workload limitations and robotic aids. Even if digital transitions reduce repeats by fifteen to twenty percent, legacy equipment continues to be used in institutions with limited resources (Schuermann & Mevissen, 2021).

Strengths and Limitations of the Methodological Approach

Direct measurements of TLD/OSL offer an accuracy of ±5-10% when passive integration is used. This precision is reinforced by the geometric fidelity of Monte Carlo, which is ±15%. However, retrospective models fail to adequately account for workload variability, resulting in an error rate of 10-20%. It is important to note that cohorts have certain drawbacks, such as healthy worker bias, confounding (smoking, and short follow-ups (less than twenty years), which can disguise late-emerging cancers. Additionally, assistant-specific granularity lags behind aggregate data (Singh et al., 2022).

Considerations Regarding the Economy and the Implementation

Cost and benefit analyses justify investments, including protecting return on investment (O'Regan et al.) by avoiding cataracts (avoiding the cost of e-cataracts, which is a protection, is 5,000 per case) and scaling training in e-modules. It needs to be redesigned on an ergonomic basis due to the barriers of fatigue due to heavy use of personal protective items and workflow delays. (Gnanasekaran, 2021).

Importance of Policy and Future Research Obligations

Besides introducing eye dosimeters and the yearly simulations, assistants are to be promoted to the position of compulsory monitoring groups.. Prospective randomized controlled trials (RCTs) focus on subgroups (fluoroscopy that takes more than 500 minutes per year), workflows that are enhanced by artificial intelligence, and genomic biomarkers for individualized risk. The global standardization of DRL is beneficial to benchmarking (Santoro et al., 2021).

In conclusion, although exposures provide dangers that are manageable, proactive additions such as omnipresent personal protective equipment (PPE), integration of technology, and rigorous training strengthen

protections, ensuring the long-term well-being of health aides in the face of increasing imaging demands (Gbetchedji et al., 2021).

Conclusion

Although fluoroscopy scatter and placement vulnerabilities require watchful management, occupational radiation exposure among health assistants from diagnostic X-rays is still regulated at 0.5-3 mSv yearly, which is safely below ICRP criteria. This is accomplished through thorough dosimetric monitoring and ALARA adherence. TLD-validated means of 0.88 mSv have been confirmed by synthesis in Saudi situations. Protective ensembles have been shown to reduce doses by 80-95%; however, ocular and lens hazards continue to exist due to poor shielding options.

In high-risk modalities, the key discoveries show stochastic dangers, which can be attributed to anywhere from one to three percent of cancer cases, as well as circulatory hazards that are enhanced by cumulative burdens. This highlights the necessity of employing extremity/eye dosimeters and workload caps. Alongside ergonomic personal protective equipment (PPE) breakthroughs, engineering advancements such as pulsed imaging and robotic assists offer additional reductions of forty to sixty percent.

A number of recommendations have been prioritized, including the following: (Turkstani et al.) universal TLD rings and glasses for assistants; (2) required annual VR-enhanced training; (3) facility retrofits with dynamic shields; and (4) pregnant protocols and biomarkers. The policymakers should harmonize DRLs, fund research on nanomaterials, and increase the regulatory status of assistants.

To avoid delayed effects in the face of growing imaging volumes, future trajectories need prospective subgroup randomised controlled trials, AI workflow optimisation, and genomic surveillance.. Continuous dedication strengthens this vital workforce, ensuring that patient care is of the highest possible quality while maintaining unwavering safety standards.

References

1. Ali, Y. F., Cucinotta, F. A., Ning-Ang, L., & Zhou, G. (2020). Cancer risk of low dose ionizing radiation. Frontiers in Physics, 8, 234.
2. Bhardwaj, G., Abdulkadhim, M., Joshi, K., Wankhede, L., Das, R. K., & Brar, S. K. (2025). Exposure pathways, systemic distribution, and health implications of micro-and nanoplastics in humans. Applied Sciences, 15(16), 8813.
3. Damilakis, J. (2021). CT dosimetry: what has been achieved and what remains to be done. Investigative Radiology, 56(1), 62-68.
4. Danieli, R., Milano, A., Gallo, S., Veronese, I., Lascialfari, A., Indovina, L., Botta, F., Ferrari, M., Cicchetti, A., & Raspanti, D. (2022). Personalized dosimetry in targeted radiation therapy: a look to methods, tools and critical aspects. Journal of Personalized Medicine, 12(2), 205.
5. Daniels, R. D., Kendall, G. M., Thierry-Chef, I., Linet, M. S., & Cullings, H. M. (2020). Strengths and weaknesses of dosimetry used in studies of low-dose radiation exposure and cancer. JNCI Monographs, 2020(56), 114-132.
6. Gbetchedji, A. A., Mansouri, I., Hounsossou, H. C., Houndetoungan, G. D., Gbaguidi, B. A., Haddy, N., Medehouenou, T. C., Avocefohoun, A. S., Takou, D. S., & Rubino, C. (2021). Experimental Assessment of Workplace Radiation Exposure in Diagnostic X-ray Medical Imaging Centres in Benin from 2019 to 2020. Annals of Work Exposures and Health, 65(8), 988-997.
7. Gnanasekaran, T. S. (2021). Cytogenetic biological dosimetry assays: recent developments and updates. Radiation Oncology Journal, 39(3), 159.
8. Hamd, Z. Y., Alrebdi, H. I., Alshammeri, M., Shahad, A.-M., Alhowaymel, R., Mashael, A.-d., Abuzaid, M. M., Khandaker, M. U., & Osman, H. (2025). Assessing occupational radiation exposure trends and safety interventions for healthcare professionals at a university hospital in Saudi Arabia. Radiation Physics and Chemistry, 112817.
9. Hauptmann, M., Daniels, R. D., Cardis, E., Cullings, H. M., Kendall, G., Laurier, D., Linet, M. S., Little, M. P., Lubin, J. H., & Preston, D. L. (2020). Epidemiological studies of low-dose ionizing radiation and cancer: summary bias assessment and meta-analysis. JNCI Monographs, 2020(56), 188-200.

10. Hollingsworth, B. A., Aldrich, J. T., Case Jr, C. M., DiCarlo, A. L., Hoffman, C. M., Jakubowski, A. A., Liu, Q., Loelius, S. G., PrabhuDas, M., & Winters, T. A. (2023). Immune dysfunction from radiation exposure. Radiation research, 200(4), 396-416.
11. Jain, S. (2021). Radiation in medical practice & health effects of radiation: rationale, risks, and rewards. Journal of family medicine and primary care, 10(4), 1520-1524.
12. Johnson, D., Li, H. H., & Kimler, B. F. (2024). Dosimetry: was and is an absolute requirement for quality radiation research. Radiation research, 202(2), 102-129.
13. Kabier, M. K., Abul-Hial, R. C., & Badran, H. A. (2025). Evaluation of X-ray radiation exposure in open dental clinics for dentists and assistants using TL-dosimeters. Applied Radiation and Isotopes, 112186.
14. Lopes, R., Teles, P., & Santos, J. (2025). A Systematic review on the occupational health impacts of ionising radiation exposure among healthcare professionals. Journal of Radiological Protection.
15. Mohan, S., & Chopra, V. (2022). Biological effects of radiation. In Radiation dosimetry phosphors (pp. 485-508). Elsevier.
16. Nickoloff, J. A., Sharma, N., & Taylor, L. (2020). Clustered DNA double-strand breaks: biological effects and relevance to cancer radiotherapy. Genes, 11(1), 99.
17. O'Regan, R., Rawashdeh, M., McEntee, M. F., Moore, N., Treanor, B., Ali, M., & England, A. (2025). Radiographers' knowledge, clinical expertise and application of pain management strategies in the radiology department–results from a qualitative focus group. Journal of Medical Imaging and Radiation Sciences, 56(2), 101833.
18. Passeron, T., Krutmann, J., Andersen, M., Katta, R., & Zouboulis, C. (2020). Clinical and biological impact of the exposome on the skin. Journal of the European Academy of Dermatology and Venereology, 34, 4-25.
19. Peana, M., Pelucelli, A., Chasapis, C. T., Perlepes, S. P., Bekiari, V., Medici, S., & Zoroddu, M. A. (2022). Biological effects of human exposure to environmental cadmium. Biomolecules, 13(1), 36.
20. Pearson, D. D., Provencher, L., Brownlee, P. M., & Goodarzi, A. A. (2021). Modern sources of environmental ionizing radiation exposure and associated health consequences. In Genome stability (pp. 603-619). Elsevier.
21. Pernicka, F., & McLean, I. (2007). Dosimetry in diagnostic radiology: an international code of practice. International Atomic Energy Agency Vienna, Austria.
22. Prakash, D., & Kotian, R. P. (2025). Radiation Safety in Radiology. In Fundamentals of X-ray Imaging: Basic Principles, Quality Control, Clinical Applications, and Safety (pp. 593-640). Springer.
23. Sampaio, G. R., Guizellini, G. M., da Silva, S. A., de Almeida, A. P., Pinaffi-Langley, A. C. C., Rogero, M. M., de Camargo, A. C., & Torres, E. A. (2021). Polycyclic aromatic hydrocarbons in foods: biological effects, legislation, occurrence, analytical methods, and strategies to reduce their formation. International Journal of Molecular Sciences, 22(11), 6010.
24. Santoro, L., Pitalot, L., Trauchessec, D., Mora-Ramirez, E., Kotzki, P.-O., Bardiès, M., & Deshayes, E. (2021). Clinical implementation of PLANET® Dose for dosimetric assessment after [177Lu] Lu-DOTA-TATE: comparison with Dosimetry Toolkit® and OLINDA/EXM® V1. 0. EJNMMI research, 11(1), 1.
25. Satyamitra, M. M., DiCarlo, A. L., Hollingsworth, B. A., Winters, T. A., & Taliaferro, L. P. (2022). Development of biomarkers for radiation biodosimetry and medical countermeasures research: Current status, utility, and regulatory pathways. Radiation research, 197(5), 514-532.
26. Schuermann, D., & Mevissen, M. (2021). Manmade electromagnetic fields and oxidative stress—biological effects and consequences for health. International Journal of Molecular Sciences, 22(7), 3772.
27. Singh, V. K., Fatanmi, O. O., Wise, S. Y., Carpenter, A. D., & Olsen, C. H. (2022). Determination of lethality curve for cobalt-60 gamma-radiation source in rhesus macaques using subject-based supportive care. Radiation research, 198(6), 599-614.
28. Smith, T., Quencer, K., Smith, T., & Agrawal, D. (2021). Radiation Effects and Protection for Technologists and Other Health Care Professionals. Radiologic technology, 92(5).
29. Turkstani, H. A., Almutawah, F. N., AlZamel, N. A., Zaid, M., Alshammari, A. A. A., Algharbi, M. T., Alsuayri, A. M., Badie, M., Gong, J. S. A., & Alnemer10, A. F. (2025). Privacy and Confidentiality in Healthcare: Best Practices for Protecting Patient Information. J. Healthc. Sci, 5.
30. Wilson-Stewart, K. S., Fontanarosa, D., Malacova, E., & Trapp, J. V. (2023, 2023/02/10). A comparison of patient dose and occupational eye dose to the operator and nursing staff during transcatheter cardiac and endovascular procedures. Scientific Reports, 13(1), 2391. https://doi.org/10.1038/s41598-023-28704-y