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Assessment of Radiation Protection Practices among Healthcare Workers in High-Volume Radiology Departments

1Razan Awadh Bin Thafrah, 2Lama Olayan Alharbi, 3Ali Abdurhman Mohammd Alzarai, 4Abduallh Ali Ahmad Asiri, 5Bakheet Abdulrahman M Almukhalfi, 6Sarah Yahya Saif Shaker,

1Radiology Specialist, National Guard Hospital
2Radiology Specialist, National Guard Hospital
3Diagnostic Radiology Specialist, Wadi Tarj General Hospital
4Diagnostic Radiology Specialist, Al-Harjah General Hospital
5Radiological Technology, King Abdulaziz Medical City
6Radiological Technology, Al Harjah General Hospital

Abstract

High-volume radiology departments represent some of the busiest and most radiation-intense environments within modern healthcare systems. As imaging demand continues to expand—particularly in urban referral hospitals and tertiary care centers—concerns regarding occupational exposure among radiology personnel have increased. Healthcare workers in radiology, including radiologists, radiographers, technologists, nurses, and interventional teams, are exposed to varying levels of ionizing radiation depending on the nature of imaging modalities, procedural frequency, and workflow organization. This paper presents a comprehensive assessment of radiation protection practices among healthcare workers operating in high-volume radiology departments. It evaluates adherence to radiation safety principles, structural and personal protective measures, awareness levels, administrative controls, technological safeguards, and systemic challenges affecting compliance. The discussion synthesizes evidence from published literature and conceptual analysis to highlight gaps between recommended guidelines and real-world practice. The paper concludes with a set of strategic recommendations aimed at strengthening radiation safety culture, enhancing education, improving engineering controls, and integrating advanced monitoring technologies to reduce occupational exposure while maintaining high-quality imaging services.

1. Introduction

Radiological imaging has become indispensable to contemporary medical care, enabling early disease detection, more precise treatment planning, and minimally invasive therapeutic interventions. Modalities such as conventional radiography, computed tomography (CT), fluoroscopy, mammography, and hybrid imaging (PET/CT, SPECT/CT) rely on ionizing radiation to generate diagnostic information. As utilization of these modalities has increased, medical exposure has emerged as the largest source of man-made radiation for both patients and healthcare workers. High-volume radiology departments—commonly found in tertiary

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care centers, trauma hospitals, and cancer institutes—conduct large numbers of examinations and complex procedures on a daily basis. This intense workflow environment amplifies the risk of cumulative occupational exposure for radiology personnel.

Occupational exposure in radiology is characterized by repeated, low-dose exposure events, particularly in settings where staff spend long periods near active X-ray beams or radioactive sources, such as interventional radiology suites or CT-guided procedure rooms. Even when individual exposures remain below regulatory limits, cumulative doses over months and years may increase the risk of stochastic effects, including malignancy, and tissue reactions such as lens opacities. Recognizing these risks, international bodies including the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA), and national regulatory authorities have established detailed recommendations and standards for radiation protection in medical settings.

Despite the availability of clear guidance, numerous studies suggest that actual implementation of radiation protection practices is variable and often insufficient, particularly in high-workload environments. Time pressure, equipment constraints, insufficient training, and weak safety culture may lead to inconsistent use of personal protective equipment (PPE), suboptimal staff positioning, and inadequate monitoring of occupational dose. This paper aims to assess the key elements of radiation protection among healthcare workers in high-volume radiology departments, identify common deficiencies, and outline strategies for improvement based on current evidence and best-practice frameworks.

2. Radiation Exposure in Hospital Radiology Departments

2.1 Nature of Ionizing Radiation in Clinical Imaging

Ionizing radiation used in clinical imaging—primarily X-rays and gamma rays—has sufficient energy to eject electrons from atoms, producing ionization that can damage biological tissues. The resulting biological effects are classically categorized as stochastic and deterministic. Stochastic effects, such as radiation-induced cancer, have no threshold; rather, their probability increases with accumulated dose. Deterministic effects, including skin erythema or cataracts, have dose thresholds above which tissue reactions occur. In radiology, patient doses may be high during complex CT or interventional procedures, while staff are typically exposed to lower levels of scattered radiation over prolonged periods.

Radiation exposure arises from a spectrum of modalities. Conventional radiography generally involves relatively low doses but may be performed frequently. CT scanning delivers substantially higher doses per examination due to helical acquisition, multi-slice coverage, and the use of contrast-enhanced multiphase protocols. Fluoroscopy, especially in interventional radiology, entails continuous or pulsed X-ray beams used for real-time guidance, often for prolonged durations. Hybrid systems such as PET/CT and SPECT/CT

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combine ionizing radiation from radionuclides with CT, creating dual sources of exposure. In high-volume departments, the sheer number of procedures multiplies the potential for cumulative exposure among staff.

2.2 Patterns of Occupational Exposure

Occupational exposure in radiology departments is dominated by scattered radiation from patients and equipment during imaging procedures. Interventional radiologists, cardiologists, vascular surgeons, and technologists working in fluoroscopy-guided suites are among the most exposed healthcare workers. Staff who assist with patient positioning or remain in procedure rooms for long periods may receive higher doses than colleagues who operate equipment from protected control rooms. Nurses, anesthetists, and trainees who frequently enter procedure rooms without full awareness of risk may also accumulate appreciable doses over time.

In high-volume settings, extended operating hours, emergency procedures during nights and weekends, and high patient throughput can result in prolonged presence of staff in radiation areas. Without robust protection practices—including appropriate shielding, PPE, and adherence to time–distance–shielding principles—annual occupational dose limits may be approached or exceeded, particularly for the lens of the eye and hands. These realities underscore the importance of systematic assessment and continuous improvement of radiation protection measures in busy radiology departments.

3. Principles of Radiation Protection in Medical Imaging

Radiation protection in medical imaging is grounded in three fundamental principles: justification, optimization, and dose limitation. These principles, articulated by the ICRP and widely adopted by regulatory agencies, provide a conceptual framework for developing and evaluating safety protocols in clinical practice.

Justification requires that any medical exposure to ionizing radiation confer a net benefit to the patient. This implies that each imaging examination should be clinically warranted, based on sound indications, and selected over alternative modalities only when it is expected to meaningfully influence diagnosis or management. Inappropriate or redundant imaging violates this principle and unnecessarily increases radiation risk.

Optimization, expressed through the ALARA (As Low As Reasonably Achievable) concept, refers to keeping radiation doses as low as reasonably possible while still achieving the required diagnostic or therapeutic objective. Optimization involves protocol design, appropriate equipment settings, use of shielding, and staff training to ensure that image quality is sufficient but not excessive. In practice, optimization also applies to occupational exposure, requiring that staff dose be minimized through engineering controls, workflow design, and behavioral practices.

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Dose limitation applies primarily to occupational and public exposures, not to patients who require imaging for clinical reasons. Regulatory bodies define annual dose limits for whole body exposure, the lens of the eye, and extremities to prevent deterministic effects and limit stochastic risk. Radiology departments must monitor staff doses using personal dosimeters and ensure that work patterns and protective measures are adequate to keep exposures within prescribed limits.

4. Enhancing Patient Radiation Safety

4.1 Strengthening Justification Practices

Improving justification of imaging examinations is one of the most effective ways to reduce overall radiation burden. High-volume radiology departments often receive large numbers of imaging requests, some of which may be clinically unnecessary or could be replaced by non-ionizing modalities such as ultrasound or magnetic resonance imaging. Implementing structured referral criteria and clinical decision support systems can guide referring clinicians toward the most appropriate test. Integration of evidence-based guidelines into electronic ordering platforms helps prevent duplicate imaging, reduces the number of low-yield studies, and ensures that radiation-based examinations are reserved for scenarios where they are truly justified.

4.2 Optimization of Imaging Protocols

Once an examination is justified, attention shifts to optimization of imaging protocols. For CT, dose-reduction strategies include automated tube current modulation, patient-size–adapted tube voltage, iterative reconstruction techniques that permit lower-dose acquisition, and careful restriction of scan range and number of phases. For digital radiography, optimization involves selecting the lowest exposure parameters that yield diagnostically acceptable images, avoiding the phenomenon of dose creep that may occur when digital systems compensate for overexposure. In fluoroscopy and interventional radiology, dose can be substantially reduced through the use of pulsed fluoroscopy, low-dose modes, collimation, last-image hold, and minimization of fluoroscopy time.

4.3 Pediatric Radiation Safety

Pediatric patients are particularly vulnerable to radiation effects due to their greater tissue radiosensitivity and longer life expectancy, which provides a larger window for stochastic effects to manifest. High-volume centers that provide pediatric imaging must adopt dedicated protocols tailored to patient size and clinical indication. This includes adjusting exposure parameters based on weight or age, using child-specific CT dose indices, and favoring ultrasound or MRI whenever feasible. Staff must receive specific training on pediatric radiation issues, and parents should be informed about the rationale for imaging choices and the measures taken to protect their children.

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4.4 Patient Shielding and Communication

The role of patient shielding has been the subject of renewed debate, particularly in light of modern automatic exposure control systems. Nevertheless, selective shielding of organs such as the thyroid, breast, and eye lens remains beneficial in certain contexts, provided that shields are positioned correctly and do not interfere with exposure control or obscure diagnostic information. Effective communication with patients about radiation risks and benefits contributes to transparency and can reduce anxiety. Well-informed patients are more likely to cooperate during examinations, thereby reducing motion artifacts and the need for repeat imaging.

5. Enhancing Occupational Radiation Safety for Radiology Staff

5.1 Engineering Controls

Engineering controls provide the most reliable and sustainable means of protecting staff in high-volume radiology departments because they do not depend primarily on human behavior. Structural shielding, including lead-lined walls, shielded doors, and lead glass viewing windows, is designed on the basis of anticipated workloads, occupancy patterns, and source energies. Proper location of control rooms behind these barriers allows technologists and radiologists to operate equipment while remaining outside the primary and most intense scatter fields. In interventional suites, additional engineering controls such as ceiling-suspended lead screens, table-mounted skirts, and mobile barriers help shield operators and assisting staff from scattered radiation emerging from the patient.

Engineering design must be periodically reviewed, particularly in high-volume settings where workloads and procedure types may change over time. The introduction of new equipment, additional procedure rooms, or expanded hours of operation can alter dose distributions within a department. Routine radiation surveys performed by medical physicists are essential to verify that shielding remains adequate and to identify hot spots where additional controls may be required.

5.2 Personal Protective Equipment and Safe Work Practices

Personal protective equipment constitutes a critical supplementary layer of defense. Lead aprons, thyroid collars, lead glasses, and, where indicated, lead gloves reduce the dose received by radiosensitive organs during procedures conducted in radiation areas. However, PPE is only effective when it is readily available, in good condition, properly fitted, and consistently used. High-volume departments may struggle with damaged or aging aprons, insufficient numbers of protective garments, or inadequate storage systems that promote wear and tear. Routine inspection and replacement of PPE according to institutional policy and manufacturer recommendations are necessary to maintain its protective capability.

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Safe work practices complement PPE use. These include maximizing distance from the X-ray tube and patient whenever possible, standing on the detector side rather than the tube side of C-arm systems, minimizing fluoroscopy time, and avoiding placement of hands within the primary beam. Staff should be trained to position ceiling-suspended shields correctly and to utilize table skirts and mobile barriers effectively. In high-volume settings, reinforcing these behaviors through regular reminders, visual cues, and role modeling by senior staff contributes to safer routine practice.

5.3 Dosimetry and Exposure Monitoring

Occupational dosimetry is essential for quantifying staff exposure and ensuring compliance with dose limits. Personal dosimeters should be worn consistently by all staff who enter controlled radiation areas. For staff who wear lead aprons, dosimeters are typically placed at chest level outside the apron to provide a reasonable estimate of effective dose. In high-exposure roles, such as interventional radiology, additional dosimeters for the lens of the eye and extremities may be necessary to monitor localized doses. Data from dosimetry reports should be reviewed regularly by radiation protection officers or medical physicists, with special attention paid to individuals or roles with higher-than-average exposures.

Where available, real-time dosimetry systems provide immediate feedback on exposure during procedures, enabling staff to adjust their positioning and technique in response to elevated readings. Such systems are particularly valuable in high-volume departments, where cumulative effects of small procedural inefficiencies can become significant over time.

6. Administrative and Organizational Strategies

Technical measures alone cannot ensure effective radiation protection; administrative and organizational strategies are equally important, especially in high-volume radiology departments where operational pressures are intense. Hospital leadership must demonstrate visible commitment to radiation safety by allocating resources, supporting training programs, enforcing policies, and integrating safety metrics into quality management systems.

6.1 Radiation Safety Committees and Policies

A multidisciplinary radiation safety committee typically includes radiologists, medical physicists, radiographers, nursing representatives, and administrators. This committee oversees development and review of institutional radiation safety policies, monitors compliance with regulatory requirements, evaluates incident reports, and advises on procurement and installation of new equipment. Written policies should clearly define roles and responsibilities, specify standard operating procedures for each modality, and address issues such as management of pregnant workers, handling of high-dose procedures, and emergency response to radiation incidents.

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6.2 Education, Training, and Quality Assurance

Education and training are fundamental components of a strong safety culture. All staff who work in or near radiology departments should receive initial and periodic training on basic radiation physics, biological effects, protection principles, safe equipment operation, and relevant regulatory requirements. High-volume departments may benefit from combining traditional lectures with interactive workshops, simulation-based exercises, and case discussions centered on real incidents. Quality assurance programs that include regular equipment performance testing, protocol review, and dose audits help maintain technical standards and identify areas where additional training or process changes are needed.

7. Technological Innovations and Future Directions

Rapid technological developments offer new avenues for enhancing radiation protection. Artificial intelligence (AI) and machine learning algorithms are increasingly being applied to automatic protocol selection, exposure parameter optimization, and image reconstruction from lower-dose acquisitions. Dose-management software integrated with radiology information systems can track patient and staff doses across modalities, flag unusually high exposures, and generate benchmarking reports. Advanced detector technologies, including photon-counting CT, promise improved image quality at reduced doses, although their implementation remains concentrated in specialized centers.

In interventional radiology, robotic assistance and remote navigation systems can reduce the time operators spend near the patient and X-ray source. Improved ergonomic design of procedure rooms and user-friendly dose displays further support safer practice. However, adoption of new technologies must be accompanied by robust training and evaluation to ensure that they are used to their full protective potential rather than simply adding complexity to already busy workflows.

8. Discussion

Assessment of radiation protection practices in high-volume radiology departments reveals that safety performance is shaped by a dynamic interplay between technical infrastructure, staff knowledge and behavior, institutional culture, and external regulatory pressures. While many departments have implemented basic shielding and PPE provisions, gaps remain in consistent use, training frequency, protocol optimization, and systematic monitoring of occupational exposure. High workload, staffing shortages, and the perception that clinical throughput must take precedence over safety often undermine adherence to best practices.

Addressing these gaps requires a holistic approach that moves beyond individual responsibility and situates radiation safety within broader organizational quality and risk management systems. Engaging leadership, empowering staff to speak up about unsafe conditions, and embedding safety expectations into job descriptions and performance

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appraisals can help normalize protective behaviors. At the same time, investment in modern equipment, real-time dosimetry, and decision-support tools provides staff with the means to work more safely without sacrificing efficiency.

9. Conclusion

High-volume radiology departments are critical hubs within modern hospitals but also represent environments of elevated radiation risk for healthcare workers. Ensuring robust radiation protection practices is therefore essential for safeguarding occupational health while sustaining the benefits of advanced imaging. This paper has highlighted the key components of effective radiation protection, including adherence to justification and optimization principles, engineering controls, proper use of PPE, systematic dosimetry, administrative oversight, and continuous education. By integrating these elements within a strong safety culture and leveraging emerging technologies, hospitals can significantly reduce occupational exposure and promote sustainable, high-quality radiological services.

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