

A HIRARC Based Assessment of Occupational Health and Safety Risks in Hospital Radiology Units

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ABSTRACT

Introduction: Occupational health and safety (OHS) in hospital radiology units is critical due to the presence of multiple hazards, including ionizing radiation, chemical exposure, ergonomic strain, physical risks, and biological agents. Inadequate risk management may lead to adverse health outcomes for healthcare workers and compromise patient safety. Therefore, a systematic risk assessment approach is required to identify, evaluate, and control workplace hazards effectively.

Objectives: This study aims to assess occupational risks in a hospital radiology unit using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method.

Methods: This study employed a descriptive observational design using the HIRARC framework. Data were collected through direct observation and hazard identification across key radiology activities, including X-ray and CT scan procedures, contrast media administration, ultrasound examinations, MRI operations, general equipment handling, and patient management. Identified hazards were categorized into physical, chemical, biological, ergonomic, and safety risks. Risk levels were determined based on likelihood and severity, and appropriate control measures were proposed following the hierarchy of controls, including elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE).

Results: The findings revealed that radiology units are exposed to various levels of occupational risks. High-risk hazards were identified in ionizing radiation exposure during X-ray and CT scan procedures, while very high risks were associated with MRI-related hazards, particularly the projectile effect and interference with medical implants. Moderate to high risks were also observed in chemical exposure from contrast media, biological hazards from infectious patients, and ergonomic risks leading to musculoskeletal disorders. Existing and recommended control measures included radiation shielding, strict screening procedures, adherence to ALARA principles, use of PPE, ergonomic adjustments, and implementation of standard operating procedures (SOPs).

Conclusion: The HIRARC method proved effective in systematically identifying and evaluating occupational hazards in hospital radiology units. The study highlights the need for comprehensive risk control strategies, particularly for high and very high-risk activities, to ensure the safety of healthcare workers and patients. Strengthening engineering controls, administrative policies, and continuous staff training is essential to improve OHS performance in radiology departments.

Keywords: Hazard Identification; HIRARC; Occupational Health and Safety; Radiology Unit; Risk Assessment

INTRODUCTION

Occupational Health and Safety (OHS) is a fundamental component in healthcare systems to ensure the protection of workers, patients, and the overall quality of services. Hospitals are complex workplaces with a wide range of hazards, including physical, chemical, biological, and ergonomic risks that can lead to occupational injuries and diseases if not properly managed (Yuliani, I., Z. Zakiyuddin, M. Fadillah, J. Musnadi, 2025)(Ramadhan, M. R., 2025). Radiology units, in particular, represent high-risk environments due to the use of advanced diagnostic technologies such as X-ray, computed tomography (CT), and magnetic resonance imaging (MRI), which expose workers to ionizing radiation, strong magnetic fields, and contrast media. Exposure to ionizing radiation remains one of the most critical hazards in radiology departments, as prolonged or uncontrolled exposure may increase the risk of cancer and other long-term health effects. In addition, the use of contrast agents introduces chemical hazards, including allergic reactions and potential anaphylaxis in patients, while ergonomic factors such as repetitive movements and awkward postures contribute to musculoskeletal disorders among healthcare workers. Furthermore, biological risks from infectious patients and physical hazards such as electrical equipment and workplace layout also contribute to the overall risk burden in radiology settings.

Previous studies have highlighted that inadequate implementation of OHS management systems and risk assessment practices can lead to increased workplace accidents and unsafe conditions. The lack of systematic hazard identification and risk prioritization often results in ineffective control measures and low compliance with safety standards (Shofia, D., 2024),(Anwar, R. P., A. Kurniawan, Mulianti, 2024). Therefore, a structured and comprehensive approach is required to assess and manage occupational risks in healthcare environments. One of the widely used methods for occupational risk management is the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) approach. HIRARC provides a systematic framework to identify hazards, evaluate risk levels based on likelihood and severity, and determine appropriate control measures according to the hierarchy of controls. This method has been proven effective in various sectors, including construction, manufacturing, and industrial settings, in reducing workplace risks and improving safety performance (Pramesthi, S. A., R. Anwar, 2025),(Permana, M. A., B. Witjaksana, 2025).

Despite its widespread application in industrial sectors, the implementation of HIRARC in hospital radiology units remains limited, particularly in developing countries. Most existing studies focus on general hospital safety or non-healthcare industries, leaving a gap in evidence regarding comprehensive risk assessment in radiology departments. Considering the unique combination of radiation, chemical, ergonomic, and biological hazards, there is a need for a focused and systematic evaluation of risks in this unit. Therefore, this study aims to conduct a comprehensive assessment of occupational health and safety risks in hospital radiology units using the HIRARC method. The findings are expected to provide evidence-based recommendations for improving risk control strategies, enhancing workplace safety, and supporting the development of effective OHS management systems in healthcare facilities.

MATERIALS AND METHODS

This study employed a descriptive observational design to systematically assess occupational health and safety (OHS) risks in a hospital radiology unit using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) approach. This study was conducted in November 2025 in the radiology department of a private hospital in Kudus Regency, Indonesia. The study focused on key diagnostic and operational activities, including X-ray and computed tomography (CT) scan procedures, contrast media administration, ultrasound (USG) examinations, magnetic resonance imaging (MRI), general equipment operation, and patient care processes.

Data collection was carried out through direct observation, workplace inspection, and document review of standard operating procedures (SOPs) related to radiology services. Observations were conducted to identify potential hazards associated with each activity, including physical, chemical,

biological, ergonomic, and safety-related risks. In addition, informal discussions with healthcare workers were conducted to gain contextual understanding of work practices and potential risk exposure.

The HIRARC method was applied in three main stages. First, hazard identification was performed by systematically examining each work process to detect potential sources of harm. Second, risk assessment was conducted by evaluating the likelihood and severity of each identified hazard. The likelihood was assessed based on the frequency and probability of occurrence, while severity was determined by the potential impact on workers' health and safety. A risk matrix was then used to classify risk levels into categories such as low, moderate, high, and very high. Third, risk control measures were determined based on the hierarchy of controls, which includes elimination, substitution, engineering controls, administrative controls, and the use of personal protective equipment (PPE).

To ensure the validity of the findings, data triangulation was applied by comparing results from observations, document reviews, and field notes. The identified risks and proposed control measures were also reviewed in accordance with relevant occupational safety standards and best practices in healthcare settings. The results of the analysis were then presented in tabular form to provide a comprehensive overview of hazards, risk levels, and recommended control strategies in the radiology unit.

RESULTS

The application of the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method in the hospital radiology unit identified multiple occupational hazards across six main work activities. These hazards were categorized into physical, chemical, biological, ergonomic, and safety-related risks, with varying levels of severity ranging from moderate to very high. In diagnostic procedures involving X-ray and computed tomography (CT) scans, ionizing radiation was identified as a major hazard with a high-risk level. The potential impact includes chronic radiation exposure among radiographers and radiologists, which may lead to long-term health effects. The risk level was classified as high due to the frequent exposure and significant health consequences. Existing and recommended control measures included the implementation of radiation shielding (lead-lined walls and doors), strict adherence to the ALARA (As Low As Reasonably Achievable) principle, routine monitoring using personal dosimeters (TLD/film badges), and the use of personal protective equipment (PPE) such as lead aprons, thyroid shields, and lead goggles.

In procedures involving contrast media administration, chemical hazards were identified due to the use of iodine-based contrast agents. The associated risks ranged from moderate to high, particularly related to allergic reactions and potential anaphylaxis in patients. Risk control measures included strict pre-procedure screening of patient allergy history, availability of emergency response equipment (emergency kits), and regular staff training in managing adverse reactions, including code blue procedures. Ultrasound (USG) examinations primarily presented ergonomic risks associated with prolonged and repetitive working postures. These conditions contributed to moderate-level risks of musculoskeletal disorders (MSDs), particularly affecting the shoulders, neck, and wrists of healthcare workers. Control measures focused on ergonomic improvements, such as adjustable examination tables and operator chairs, as well as administrative controls including scheduled rest breaks and stretching exercises.

Magnetic resonance imaging (MRI) procedures posed the highest level of risk (very high), mainly due to the strong magnetic field. The most critical hazard identified was the "projectile effect," where ferromagnetic objects can be forcefully attracted to the MRI machine, potentially causing severe injury or equipment damage. Additionally, risks related to interference with implanted medical devices, such as pacemakers, were identified. Control measures included strict zoning systems (Zone III and IV restrictions), comprehensive screening protocols for both patients and staff, removal of all ferromagnetic objects, and intensive training on MRI safety procedures. General equipment operation across the radiology unit revealed physical and safety hazards, including the risk of slips, trips, and falls due to unmanaged cables and wet floors, as well as potential electrical hazards. These risks were

generally categorized as moderate. Control measures included proper cable management systems, installation of warning signs (e.g., wet floor signage), routine equipment maintenance, and availability of fire extinguishers in strategic locations.

Patient handling activities exposed healthcare workers to biological hazards, particularly the risk of healthcare-associated infections (HAIs) from contact with infectious patients. The risk level ranged from moderate to high depending on patient conditions. Control measures included strict implementation of standard precautions, use of appropriate PPE (e.g., masks and gloves), patient cohorting for infectious cases, and thorough disinfection procedures after examinations. Overall, the results indicate that the radiology unit is characterized by a combination of high and very high-risk hazards, particularly in radiation exposure and MRI procedures. Moderate risks were also prevalent in ergonomic, biological, and general safety aspects. The implementation of comprehensive control measures based on the hierarchy of controls was found to be essential in minimizing occupational risks and ensuring a safe working environment.

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Table 1. Hazard Identification, Risk Assessment, and Risk Control in Radiology Unit

No	Work Activity	Hazard Type	Identified Hazard	Risk Level	Potential Impact	Control Measures
1	X-ray & CT Scan	Physical (Ionizing Radiation)	Exposure to ionizing radiation	High	Chronic radiation exposure, cancer risk	Radiation shielding, ALARA principle, dosimeter monitoring, PPE (lead apron, thyroid shield)
2	Contrast Media Injection	Chemical	Iodine-based contrast agents	Moderate–High	Allergic reactions, anaphylaxis	Patient screening, emergency kit availability, staff training (code blue)
3	Ultrasound (USG)	Ergonomic	Repetitive and awkward posture	Moderate	Musculoskeletal disorders (MSDs)	Adjustable equipment, rest breaks, stretching programs
4	MRI Examination	Physical & Safety	Strong magnetic field (projectile effect)	Very High	Severe injury, equipment damage, implant interference	Zoning system (Zone III & IV), strict screening, removal of metal objects, staff training
5	General Equipment Operation	Physical & Safety	Loose cables, wet floors, electrical hazards	Moderate	Slips, falls, electric shock	Cable management, warning signs, routine maintenance, fire extinguishers
6	Patient Handling	Biological	Exposure to infectious patients	Moderate–High	Healthcare-associated infections (HAIs)	Standard precautions, PPE, patient cohorting, disinfection procedures

Following the tabulated results, it is evident that the highest risks were associated with MRI procedures (very high risk) and ionizing radiation exposure (high risk), while other activities such as contrast administration, patient handling, and ergonomic factors presented moderate to high risks. These findings highlight the need for strict implementation of control measures, particularly engineering and administrative controls, to reduce occupational hazards in radiology units.

DISCUSSION

The findings of this study indicate that hospital radiology units are characterized by a wide spectrum of occupational hazards, with ionizing radiation and MRI-related risks identified as the most critical. These results are consistent with previous studies emphasizing that radiology personnel are continuously exposed to radiation, which may lead to long-term health effects such as cancer and cataracts if not properly controlled (Rincón, G., Y. González, 2024b)(Shettigar, D., S. Sukumar, A. Pradhan, 2025a). The high-risk classification of radiation exposure in this study aligns with evidence showing that healthcare workers in radiology are regularly exposed to measurable radiation doses, even when safety protocols are implemented(Study, 2023).

Building on these findings, a deeper analysis highlights that occupational hazards in radiology units are not only related to the presence of ionizing radiation and MRI fields, but also to the complex interaction between exposure duration, cumulative dose, compliance behavior, and technological advancements in imaging modalities (Allam, S. M. E., M. M. A. Algany, 2024),(Beckert, Anna, Christopher Kloth, Angela Kretschmer, Bernd Schmitz, 2025).

First, although many studies report that occupational radiation doses are often maintained below recommended annual limits, chronic low-dose exposure remains a significant concern due to its cumulative biological effects (Yuan, J., D. Liu, 2024). Long-term monitoring studies demonstrate that even when exposure is within permissible thresholds, repeated exposure over years can contribute to stochastic effects such as carcinogenesis and lens opacities (Beckert, Anna, Christopher Kloth, Angela Kretschmer, Bernd Schmitz, 2025). This reinforces the concept that “safe limits” do not equate to “zero risk,” particularly for radiology staff involved in interventional procedures, where exposure intensity and frequency are higher (Allam, S. M. E., M. M. A. Algany, 2024).

Second, the increasing utilization of advanced imaging technologies has paradoxically contributed to higher occupational exposure. The rapid expansion of diagnostic and interventional radiology services has led to a proportional increase in radiation use, thereby elevating exposure risks among healthcare workers (Yuan, J., D. Liu, 2024). This trend suggests that technological progress, while beneficial for patient care, must be accompanied by stricter radiation protection strategies, continuous monitoring, and optimization of imaging protocols (Beckert, Anna, Christopher Kloth, Angela Kretschmer, Bernd Schmitz, 2025).

Third, behavioral and organizational factors play a crucial role in determining the actual level of occupational risk. Recent evidence indicates that inadequate knowledge, poor risk perception, and suboptimal compliance with radiation safety protocols remain prevalent among radiology personnel (Rincón, G., Y. González, 2024a). This gap between knowledge and practice can lead to unnecessary exposure, highlighting the importance of regular training, safety culture reinforcement, and institutional supervision(Allam, S. M. E., M. M. A. Algany, 2024).

In addition to ionizing radiation, MRI-related hazards represent a distinct but equally important risk category. Unlike radiation, MRI risks are associated with strong static magnetic fields, gradient fields, and radiofrequency exposure, which can induce physiological effects such as vertigo, nausea, and sensory disturbances in exposed workers(König, Alexander Marc, Antje Pöschke, 2025). Furthermore, the “projectile effect” and electromagnetic interactions with metallic objects introduce acute safety risks that require strict environmental control and adherence to zoning protocols(König, Alexander Marc, Antje Pöschke, 2025). Finally, these findings underscore the need for a comprehensive occupational health approach in radiology units that integrates technical protection (e.g., shielding, dosimeters), administrative controls (e.g., workload rotation, exposure monitoring), and behavioral interventions (e.g., training, awareness programs)(Rincón, G., Y. González, 2024a). The combination of these strategies is essential to minimize both immediate and long-term health risks, ensuring that the benefits of radiological services do not come at the expense of worker safety (Beckert, Anna, Christopher Kloth, Angela Kretschmer, Bernd Schmitz, 2025).

The implementation of radiation protection measures such as shielding, personal dosimeters, and adherence to the ALARA principle observed in this study reflects global best practices. However,

previous research indicates that compliance with radiation safety protocols is often inconsistent due to gaps in knowledge and awareness among healthcare workers (Allam, S. M. E., M. M. A. Algany, 2024), (Fataftah, J., R. Tayyem, S. Al-Dwairy, 2024). This suggests that, although control measures may be available, their effectiveness largely depends on continuous training and strict enforcement of safety regulations.

In addition to radiation hazards, this study identified MRI-related risks as having the highest risk level, particularly due to the projectile effect and interference with medical implants. These findings are supported by previous studies that highlight the unique and potentially severe hazards associated with strong magnetic fields in MRI environments, which require strict zoning systems and rigorous screening protocols (Razooqi, G. A., H. H. Abdul Ra'aoof, 2024). The very high-risk classification in this study underscores the importance of engineering controls and administrative procedures in preventing catastrophic incidents.

Chemical hazards related to contrast media administration were also found to pose moderate to high risks, particularly due to allergic reactions and anaphylaxis. This is consistent with existing literature that identifies contrast agents as a significant source of adverse reactions in radiological procedures, necessitating strict patient screening and emergency preparedness (Alshamrani, K. M., D. A. Alzahrani, Y. S. Alghamdi, 2024a). The presence of emergency response systems and trained personnel is therefore critical in mitigating these risks.

Ergonomic risks identified in ultrasound procedures, particularly musculoskeletal disorders (MSDs), are also widely reported in the literature. Radiology professionals frequently perform repetitive tasks in static or awkward postures, which can lead to chronic musculoskeletal problems if not addressed through ergonomic interventions (Shettigar, D., S. Sukumar, A. Pradhan, 2025b). The moderate risk level observed in this study suggests that, although these hazards are less immediately severe than radiation risks, they remain significant in terms of long-term occupational health.

Furthermore, biological hazards associated with patient handling highlight the ongoing risk of healthcare-associated infections (HAIs) in radiology units. This finding aligns with studies indicating that healthcare workers remain vulnerable to infectious diseases, particularly in high-contact environments, emphasizing the importance of standard precautions and infection control measures (Alshamrani, K. M., D. A. Alzahrani, Y. S. Alghamdi, 2024b).

The use of the HIRARC method in this study proved effective in systematically identifying hazards, assessing risk levels, and determining appropriate control measures. Similar findings have been reported in other sectors, where HIRARC has been shown to improve risk management and reduce workplace accidents through structured hazard identification and control strategies (Yuliani, I., Z. Zakiyuddin, M. Fadillah, J. Musnadi, 2025), (Shofia, D., 2024). The structured nature of HIRARC allows for prioritization of risks, particularly high and very high-risk hazards, which is essential in complex environments such as hospital radiology units.

Building on the effectiveness of the HIRARC method identified in this study, a more in-depth discussion reveals that its strength lies not only in systematic hazard identification, but also in its ability to integrate risk analysis with decision-making processes in occupational safety management systems.

First, the structured stages of HIRARC (hazard identification, risk assessment, and risk control) enable organizations to develop a proactive rather than reactive safety approach, where risks are anticipated before incidents occur (Purnomo, Dimas Aji, Harliwanti Prisilia, 2026). This proactive characteristic is particularly important in high-risk environments such as radiology units, where invisible hazards (e.g., radiation exposure) require early detection and continuous monitoring. Studies show that the application of HIRARC can map hazard sources comprehensively and link them directly to appropriate control strategies, thereby improving prevention effectiveness (Adetresna, Naufal, 2025). Furthermore, HIRARC facilitates risk stratification through the use of risk matrices, allowing organizations to categorize hazards into low, medium, high, and extreme levels. This prioritization is critical for resource allocation, ensuring that high-risk hazards receive immediate and more rigorous

control measures(Shofia, D., 2024). In complex healthcare settings, such prioritization supports management in focusing interventions on the most critical risks, such as radiation exposure and MRI-related hazards, rather than distributing resources evenly across all hazards.

In addition, recent studies emphasize that HIRARC contributes to reducing workplace accidents and improving safety performance by standardizing risk management procedures across different sectors(Hidayat, 2025). The method provides clear guidance for implementing the hierarchy of controls elimination, substitution, engineering controls, administrative controls, and personal protective equipment thus ensuring that risk mitigation measures are both systematic and effective(Sodik, Kumail Akhmad, 2025).

Another important aspect is the role of HIRARC in strengthening safety culture and worker awareness. By involving workers in hazard identification and risk assessment processes, the method promotes better understanding of workplace risks and encourages compliance with safety protocols(Prasetyo, Agung Joko, 2024). This participatory approach is particularly relevant in hospital environments, where multidisciplinary collaboration is essential to maintain safety standards.

Finally, the integration of HIRARC with other risk management tools (e.g., Bowtie analysis or safety management systems) enhances its analytical capability, allowing for a more comprehensive evaluation of cause effect relationships and control effectiveness(Purnomo, Dimas Aji, Harliwanti Prisilia, 2026). This integration supports continuous improvement in occupational safety practices, making HIRARC not only a tool for risk assessment but also a framework for sustainable safety management.

However, this study also highlights a critical gap between risk identification and implementation of control measures. While hazards can be systematically identified, effective risk reduction requires strong institutional commitment, continuous monitoring, and integration of OHS practices into daily operations. Previous studies have emphasized that organizational factors, including safety culture and management support, play a crucial role in the success of OHS programs (Razooqi, G. A., H. H. Abdul Ra'aoof, 2024).

Overall, the findings of this study reinforce the need for a comprehensive and integrated approach to occupational risk management in radiology units. Engineering controls, administrative policies, and the use of personal protective equipment must be implemented simultaneously to effectively reduce risks. In addition, continuous training and evaluation are essential to ensure that safety measures are consistently applied and updated in accordance with technological advancements and emerging risks.

CONCLUSION

This study demonstrates that the application of the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method is effective in systematically identifying and evaluating occupational health and safety risks in hospital radiology units. The findings reveal that radiology services are exposed to a wide range of hazards, with ionizing radiation and MRI-related risks categorized as high and very high, respectively, while chemical, ergonomic, biological, and general safety hazards fall within moderate to high risk levels.

The study highlights that the most critical risks require priority attention, particularly through the implementation of engineering controls such as radiation shielding and MRI zoning systems, supported by strict administrative measures, including standard operating procedures, routine monitoring, and continuous staff training. The integration of personal protective equipment (PPE) further strengthens the overall risk control strategy.

These results emphasize the importance of adopting a comprehensive and integrated OHS management approach in radiology units, where hazard identification, risk assessment, and control measures are continuously monitored and improved. Strengthening safety culture, ensuring compliance with established protocols, and enhancing worker awareness are essential to minimizing occupational risks and improving patient safety. In conclusion, the HIRARC method provides a practical and

structured framework for improving workplace safety in hospital radiology departments. Future studies are recommended to incorporate quantitative risk measurements and evaluate the effectiveness of implemented control measures over time to support evidence-based improvements in healthcare safety management.

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