

UNIVERSITY OF BAHRAIN

College of Science



**Environment and Sustainable
Development Program**

Assessment of Radiation Safety Measures in the Radiology Work Environment at the Public Health Centers in Bahrain

A Thesis submitted in Partial Fulfillment of the Requirements for the Master
Degree in Environment and Sustainable Development

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Abstract

Radiation safety is crucial in radiology due to the potential harm from ionizing radiation. By adhering to established safety protocols, radiology departments can protect patients, radiology, and other healthcare professionals from the effects of ionizing radiation, contributing to sustainable development goals. This study aims to assess radiation safety measures and practices in seven Bahrain health centers. The study adopted a descriptive cross-sectional design combining the quantitative method (ambient radiation dose measurements) and qualitative (staff surveys) method, and both were conducted from March 7th to March 21st, 2022. The study's findings revealed a high level of awareness at 83.3% (n= 41) among participants regarding the importance and impact of regulations on radiation safety. In comparison, 60.2% (n= 29) demonstrated a positive response toward the availability of resources and the application of regulations. Most participants, 93.9% (n= 46), demonstrated awareness and a positive attitude towards practicing radiation safety. The availability of resources varied between centers, with a noticeable lack of radiation protection officers and Quality Control (QC) testing among the centers studied. In general, radiation leaks were minimal in all centers, and the estimated occupational exposures were well below permissible limits, ranging from 0.52 - 1.04 mSv/year to 1.3 - 1.82 mSv/year for deep and shallow doses, respectively. Bahrain health centers have good radiation safety practices. All readings were consistent with those of the International Commission on Radiological Protection (ICRP), which established adequate public and occupational dose limits of 1 mSv/yr. and 20 mSv/yr., respectively. However, improvements are needed in resource availability, personnel, QC testing, safety protocols, and staff training. The limitations present in this research are the small sample size and the absence of a radiation safety officer.

Keywords: Radiology, Radiation Safety, Sustainable Development, Bahrain Health Centers.

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Dedication

This study is dedicated to.

My loving parents and family are the unwavering pillars of my strength and support.

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LIST OF ABBREVIATIONS

AAS	Awareness Availability Score
ACR	American College of Radiology
ALARA	As Low as Reasonably Achievable
ARS	Acute Radiation Syndrome
ATTS	Attitude Score
CT	Computerized Tomography
DNA	Deoxyribonucleic acid
DRL	Dose Reference Level
EGA	Environmental Governance Agency
EPC	Environmental Protection Committee
EPTS	Environmental Protection Technical Secretariat
HC	Health Center
HPS	Health Physics Society
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
KAP	Knowledge-Attitude-Practice
KS	Knowledge Score
LiF	Lithium fluoride

mSv	Millisievert
MoH	Ministry of Health
NCRP	National Council on Radiation Protection
NHRA	National Health Regulatory Authority
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration Agency
PS	Practice Score
QA	Quality Assurance
QC	Quality Control
RPD	Radiation Protection Directorate
RSO	Radiation Safety Officer
SD	Standard Deviation
SDGs	Sustainable Development Goals
SMC	Salmaniya Medical Complex
SPSS	Statistical Package for Social Sciences
TLD	Thermoluminescent Dosimeter
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UOB	University of Bahrain
WHO	World Health Organization

Chapter I

Introduction

1.1 Introduction

Sustainable development balances economic growth, progress, social equality, and environmental protection. Ensuring radiation safety plays a role in achieving sustainable development by guaranteeing that radiation used in healthcare is secure for patients, staff, and the environment (International Atomic Energy Agency, 2019 "Radiation Protection and Safety of Radiation Sources; International Basic Safety Standards").

Organizations constantly strive for sustainability and aim to achieve long-term prosperity and success by considering the planet, profit, and people; this suggests that organizations could only be considered sustainable when they do prioritize their resources' safety, health, and well-being of their workforces. Medical institutions are no exception to this principle. Molamohamadi, Z., & Ismail, N. (2014) highlights the interconnectedness between two concepts: safety, health, and environment on the one hand and sustainable development on the other. Because these concepts are founded upon the same principles, it is crucial to approach both thoughtfully.

Ionizing radiation exists in our environment either naturally or through artificial sources. According to reports 92 - 95 from the National Council on Radiation Protection (NCRP), ionizing radiation in therapeutic procedures has brought advancements in modern medicine while becoming an integral part of medical practices (NCRP, report 92 – 95, 1987).

The various sources of diagnostic ionizing radiation the general population is exposed to include diagnostic X-rays, detector computerized tomography (CT) imaging, dental radiography, interventional angiography,

and fluoroscopy. Radiography and CT procedures alone account for 90% and 50% of medical radiation exposure, respectively (Sullivan et al., 2010; Hricak et al., 2011; Mettler et al., 2020).

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports over the decades and years have highlighted the outstanding increase in the use of ionizing radiation in examinations worldwide, starting in 2000 with an elevation of approximately 2.1 billion examinations conducted annually, representing a 10% increase compared to rates between 1991 and 1995 (UNSCEAR, 2000), reaching 4.2 billion examinations over the years 2009-2018 (Mettler et al., 2020); showcasing the surge in using radiation for medical and therapeutic purposes.

Moreover, The European Commission Radiation Protection (ECRP) reports No. 154 and 180 revealed that European collective dose encountered an average increase of 23%, which resulted from a growing tendency to undergo high-dose examinations

such as computed tomography (CT) and interventional examinations, even though plain radiography and fluoroscopy examinations witness a reduction in frequency (Masjedi et al., 2020). These figures illustrate the growing reliance on ionizing radiation in healthcare. However, concerns are associated with medical diagnostic imaging using ionizing radiation despite its benefits in diagnosis and treatment. These concerns primarily revolve around side effects that can impact patients, healthcare providers, and workers within radiology environments (Ghazi et al., 2009; Dianati et al., 2014; Tsapaki, 2017). It is no secret that radiation can cause harm to humans.

Scientifically speaking, the impact and potential harm caused by ionizing radiation depend on factors such as the dose, frequency, and duration of examinations. Generally, if the doses delivered during these examinations are much higher than the permissible dose index and applied over a prolonged period, they could affect human health negatively (Desouky and Zhou, 2015). Considering the numbers and statistics on ionized radiation's role in modern medical diagnosis and treatment, the International Commission on Radiological Protection (ICRP) strongly emphasizes that patients receive low doses and carefully consider their exposure levels (Vaño et al., 2016).

In recent years, considerable attention has been drawn to monitoring radiation doses received by patients and radiology staff in radiology departments. Occupational radiation monitoring ensures protection measures (Nassef and Kansara, 2017). Relevant literature has stressed the importance of radiation monitoring within controlled radiology work environments to identify radiation levels and leakage sources; this helps assess the facility's radiation protection integrity over time and enables quality control reports for actions with optimization goals in mind. Therefore, it is crucial to prioritize the application of radiation protection principles in these domains. To ensure the safety and well-being of radiology staff and patients, we must optimize radiation protection measures and continuously monitor individual dose exposure to keep it minimal (Oluwafisoye et al., 2009; Salama et al., 2016).

1.2 Research Problem:

As a developing country, Bahrain prioritizes advancing health and

medical services provided to all citizens and non-citizens at governmental medical complexes and health centers, ensuring access and proximity to these high-quality health services. Recent years have exhibited tremendous development in diagnostic radiology departments in Bahrain as various newer and up-to-date imaging modalities and equipment have been introduced and operated in most governmental radiation departments.

Besides, over the years, there has been a noticeable increase in the frequency of radiological procedures performed at radiology departments. This significant incline in both aspects does reflect a positive image of the health service systems in the kingdom; however, it does raise a concern that the probable lack of compliance with the safety measures may induce radiation hazards to the workers and the public (Abuzaid et al., 2019; Rahman et al., 2020; Erkan et al., 2019; Qahtani et al., 2022). Various scientific studies and reports have stressed the adverse stochastic and deterministic effects of ionizing radiation on the human body, which necessitate the implementation of radiation safety and protection measures and quantifying the radiation exposure for patients and radiology staff at periodic intervals to ensure that these doses are within the recommended limits and do not exceed them.

To sum up, no previous research has been related to assessing radiology departments' work environments regarding safety measures in Bahrain's governmental public health centers. Hence, there is a need to investigate whether these safety measures comply with national and international standards and assess the awareness, attitude, and compliance level of radiology staff with these measures. Therefore, this study should be considered to assess the radiology departments' safety measures in public governmental health centers in Bahrain, which is expected to provide

helpful information and recommendations for decision-makers and stakeholders as a foundation to plan for safe practices associated with radiology services.

1.3 Research Significance

In all healthcare environments, workers are often exposed to harmful substances and radiation in general and in radiology departments, as radiation equipment, materials, and hazards surround the workers. Therefore, hospitals must have policies, guidelines, and procedures to monitor, control, and minimize risks for radiology workers. In addition, these procedures can only be successful and achieve the desired objectives if existing Quality Assurance (QA) programs incorporate systemic radiation protection guidelines under the supervision of a radiation protection officer, in addition to assuring the radiology workers are aware of and committed to radiation safety practices. Failure to maintain the required procedures and guidelines, lack of awareness, or low compliance levels will only lead to inevitable and unnecessary exposure to health hazards.

A study by Zervides et al (2019) regarding the levels of knowledge in radiation protection indicates the importance of educating radiology workers about the requirements of radiation protection legislation and how this new knowledge can be linked with practice to keep staff safe, in addition to it the importance of reviewing the adherence levels toward radiation safety policies and measures, with considering the required amendments when it was found that these were not being followed. Furthermore, the study emphasizes the educational programs that can possibly increase understanding and awareness.

The significance of this study arises from the following facts:

- Ionizing radiation from sources like X-rays, radon gas, and nuclear power holds potential harm. At high doses, it can directly damage DNA in human cells, leading to mutations that increase the risk of cancer. This risk depends on factors like the type and amount of radiation, individual susceptibility, and exposure time. Though most everyday exposure levels are minimal, understanding these risks empowers practitioners to make informed decisions. Proper regulations, safety measures, and individual awareness can minimize potential harm while reaping the benefits of medical procedures that utilize radiation for diagnosis and treatment.
- No previous research is available about radiology services work environment and radiation protection safety measures in diagnostic radiology departments at governmental public health centers in Bahrain.
- Due to the exponential use of ionized radiation for diagnostic and therapeutic purposes on the one hand and the realized potential hazardous effects of ionized radiation on humans and the environment, global concern about ionizing radiation protection is rising.
- This study will provide a foundational assessment of the adequacy level of radiation safety measures in the radiology department's work environments, where the results can be used to develop action plans and strategies to enhance radiation safety measures and practices.
- The results of this study will ultimately boost the implementation of scientific approaches that should be followed to preserve life sustainability and achieve sustainable development goals through protection against ionizing radiation hazards.

1.4 Aim of the Study

To evaluate the radiology department's radiation safety measures in selected health centers, identify areas for improvement, and formulate recommendations following the regularity standards.

1.5 Research Questions:

- (1) Are the current radiation safety measures in the health centers' radiology departments consistent with the standards?
- (2) What is the level of knowledge and compliance with radiation safety measures among the radiology staff?
- (3) Are the radiation safety measures and compliance consistent among the health centers' radiology departments?

1.6 Research Objectives:

Objective (1): To evaluate the status of radiation safety measures in selected health centers' radiology departments in Bahrain.

Objective (2): To determine the level of knowledge and compliance with the radiation safety measures among the radiology staff in these health centers.

Objective (3): To check and compare the consistency of radiation safety measures among these selected radiology departments.

Objective (4): To formulate recommendations for improving the radiology work environment based on the obtained results.

1.7 Research Hypotheses

Null Hypothesis:

The setup and application of radiation safety measures in the radiology departments of the selected health centers in Bahrain are sufficient and up to the established recommended standards.

Alternative Hypothesis:

The setup and application of radiation safety measures in the radiology departments of the selected health centers in Bahrain are insufficient and need improvement to fulfill the established recommended standards.

Chapter II

Literature Review

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of radiation safety in radiology departments and its link to sustainable development goals. The chapter also covers the development of Bahrain's environmental policy, besides highlighting the importance and contribution of ionizing radiation to medical imaging services, the effects of ionizing radiation, and the radiology department's safety measures according to the nationally and internationally recommended guidelines. Figure (2.1) presents the radiation safety and protection aspects covered in the literature review. It guides the research process by discussing and examining the factors affecting the application and adaptation of radiation safety in the radiology department.

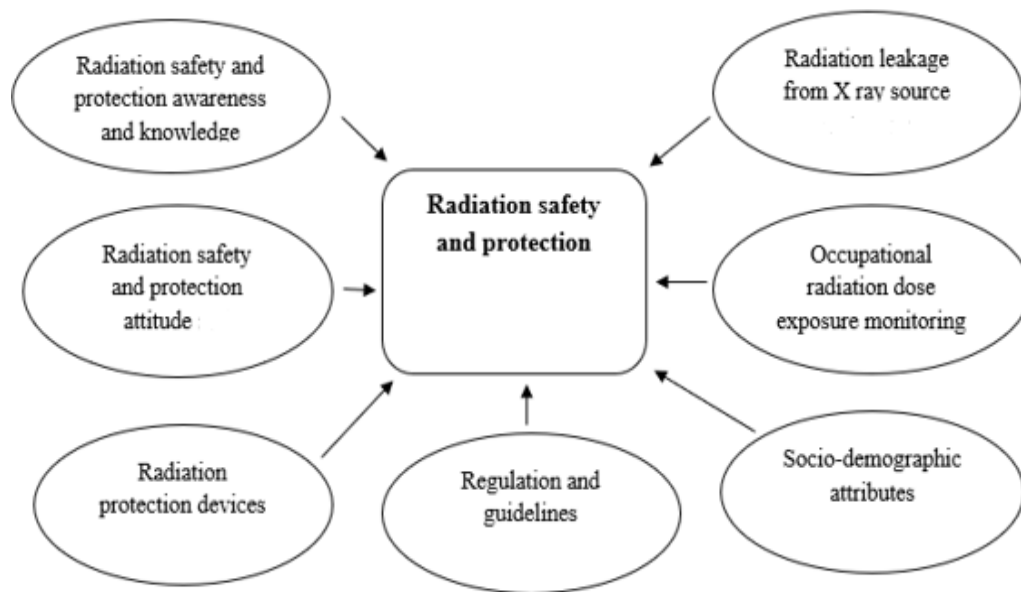


Figure (2.1): Study Conceptual framework (devised by the researcher, 2022)

2.2 Radiation Safety and Sustainable Development

Occupational health plays a role in development by promoting better health outcomes, boosting productivity, ensuring social equity, and preserving the environment. Investing in health is vital for achieving the Development Goals (SDGs) and creating a healthier, fairer, and more sustainable future for everyone. According to the World Health Organization (WHO) (2019), occupational health is a factor in development as it influences both social and health aspects of achieving the SDGs. It contributes to:

- **Preventing mental harm:** By minimizing work-related injuries, illnesses, and fatalities, interventions in occupational health help reduce the loss of human potential and resources; this contributes to SDG 3 (promoting health and well-being) and SDG 8 (advancing decent work and economic growth).
- **Boosting productivity:** Creating healthy and safe work environments nurtures a workforce, which leads to increased output. This aligns with SDG 8 (promoting work and economic growth).
- **Promoting social equity:** Occupational health interventions can address disparities in health outcomes among groups. By doing so, they contribute to SDG 10 (reducing inequalities).
- **Sustainability:** Implementing health practices that promote resource efficiency and reduce pollution can contribute to achieving SDG 13 (climate action) and SDG 12 (responsible consumption and production).

Radiology imaging services have impacted healthcare, offering tools for diagnosis and treatment. However, this advanced technology also carries risks, particularly when it comes to healthcare professionals' exposure to

ionizing radiation in the radiology work environment. Extensive research has been conducted to examine the effectiveness of safety measures in minimizing these risks and safeguarding the well-being of healthcare professionals from the effects of ionizing radiation. This chapter presents an analysis of the literature exploring critical aspects related to radiation safety measures by reviewing previous studies that have examined various strategies and the challenges associated with their requirements and implementation.

Many studies prove the interrelationship between radiation safety and sustainable development. Myint et al. (2019) concluded that protection against the effects of ionizing radiation promotes a sustainable environment by achieving well-being and health. This concept was agreed upon by Oliveira et al. (2019) in their study, which highlighted the interrelationship between safety and health and their impact on achieving sustainable development. Figure 2.2 represents the relationship between occupational safety, health, the environment, and sustainable development.

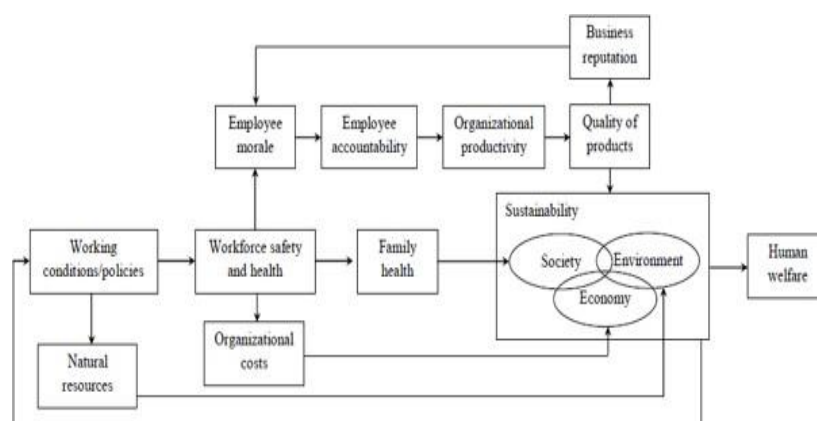


Figure (2.2): The relationship between occupational safety and sustainable development (Molamohamadi, Z., & Ismail, N. (2014)).

2.3 Ionizing Radiation - An Overview

2.3.1 Nature and Sources

Ionizing radiation is a form of energy that possesses the strength to strip electrons from atoms or molecules, resulting in the formation of charged particles known as ions. This process, called ionization, occurs when the radiation interacts with substances such as air, water, and living tissue. The impact of ionizing radiation can be beneficial or harmful depending on factors such as the type of radiation, the level of exposure, and an individual's sensitivity (UNSCEAR, 2018).

There are two sources of ionizing radiation: natural and artificial. Natural sources encompass radon gas in soil, cosmic rays originating from space, and radioactive isotopes found in rocks and minerals. On the other hand, artificial sources include procedures, nuclear power plants, and industrial applications (Barceló et al., 2021). Radioactive decay is the emission of energy from ionizing radiation, which can be classified into alpha particles, beta particles, and gamma rays.

Alpha particles (α) are composed of two protons and two neutrons originating from the atom's nucleus and possess a positive charge. The decay of the heaviest radioactive elements, including polonium, radium, and uranium, produces alpha particles. Despite their high energy, alpha particles are immobile. They cannot travel very far from the atom due to their tremendous mass, which means they expend energy over short distances. Alpha particles are considered penetrating; they can be halted by something as thin as a paper or skin. Beta particles (β), which have a negative electrical charge and are small and rapidly moving, are emitted from the

nucleus of an atom during radioactive decay. The emission of these particles occurs from specific unstable atoms, including carbon-14, hydrogen-3 (tritium), and strontium-90 (Dunlap, 2023).

Beta particles are more permeable than alpha particles, but their widely spaced ionizations render them less damaging to living tissue and DNA. It can travel several millimeters of tissue (Hall & Giaccia, 2020). Apart from alpha and beta particles, there are also gamma rays and X-rays, which belong to the category of radiation that also has properties. Among these types, gamma rays exhibit a higher penetration level than others.

Gamma rays (γ) are energy packets called photons that are weightless. Unlike alpha and beta particles, gamma rays are energy only. Gamma rays are high-energy counterparts to visible light. Radioactive decay emits gamma rays and alpha or beta particles. Gamma radiation harms the entire body. They can easily penetrate skin and clothing barriers that block alpha and beta particles and even penetrate several inches of lead or several feet of concrete. Gamma rays can completely pass through the body, causing tissue and DNA ionizations (Chen et al., 2021).

Unlike beta rays, x-rays can completely pass through the human body and have less energy in comparison to gamma rays, making them the perfect tool for diagnostic medical imaging. It is worth mentioning that medical imaging by X-ray is considered the single largest source of synthetic (artificial) radiation exposure in the world (Ramachandran, 2011).

Despite the risks involved, ionizing radiation plays a role in various medical imaging procedures, such as X-rays, CT scans, and nuclear medicine. It enables doctors to diagnose and treat diseases without radiation

therapy to combat cancer cells (Brenner & Hall, 2021). Additionally, it finds applications in industries like food irradiation to preserve freshness and eliminate bacteria to ensure food safety. Moreover, it is used in radiography to inspect welds and other materials for defects (IAEA, 2021). Furthermore, ionizing radiation is a research tool that allows scientists to study material properties and develop new technologies (NRC, 2019).

2.3.2 Ionizing radiation exposure categories

Ionizing radiation exposure to the individual has been categorized by the ICRP into three main types, as follows:

- **Occupational exposure:** It describes all radiation exposure to workers subsequently due to their job environment. ICRP limits occupational exposure to reasonable ionizing radiation exposure in a controlled and responsible manner. The organization is responsible for ensuring employees' protection against any probable causes of harm.
- **Public exposure** covers every kind of public radiation exposure, excluding occupational and medical exposure. Natural sources are the major contributors to the public's exposure, while a minority is caused by artificial radiation. Interestingly, exposure of the fetus of a pregnant worker in a radiation-induced environment is considered public exposure.
- **Medical exposure** refers to radiation exposure to patients during diagnostic, interventional, and therapeutic examinations and procedures. Moreover, it involves volunteers helping to support and comfort patients and volunteers in biomedical research. Each area of medical exposure requires a certain level of exposure that differs from the others and the

applied exposures are intentional for the sake of the patient (ICRP, 2007; Wrixon, 2008; Do, 2016)

2.3.3 Health Effects of Ionizing Radiation

Exposure to ionizing radiation can present health risks as it can potentially harm cells. The impact of ionizing radiation on tissues and cells depends on factors, including the type, energy, radiation dose, and the irradiated cells' characteristics. Regarding energy-ionizing radiation, cell damage is likely due to its ability to remove multiple electrons from atoms. This process creates free radicals with unpaired electrons that can harm the DNA molecule. According to the National Research Council (NRC, 2019), these harmful effects can be categorized into stochastic effects, each with characteristics and implications. Deterministic effects are characterized by a threshold dose of radiation exposure below which no observable effects occur. However, once this threshold is surpassed, the severity of the effects increases with radiation doses. This relationship between severity and dose is well-established and predictable, allowing for the establishment of limits to prevent effects from occurring (Mettler & Snyder, 2021).

Some of the impacts that can occur due to radiation exposure include a condition called acute radiation syndrome (ARS). Symptoms like nausea, vomiting, and diarrhea characterize ARS. Additionally, some radiation burns resemble skin burns but take longer to develop. Usually, these effects become noticeable after exposure to radiation levels within a few hours up to days. They are more likely to occur in tissues with rapid cell turnover rates, such as the gastrointestinal tract and bone marrow (Hall, 2019). Many studies prove that deterministic effects could occur in radiology practice. A study

conducted by Prokop and Shrimpton (2018) reviewed the literature on the deterministic effects of ionizing radiation in pediatric radiology and found that children are more susceptible to these effects than adults. The authors concluded that radiologists should minimize radiation exposure in pediatric patients by using the lowest possible radiation dose and shielding when appropriate. Another source of deterministic effects is fluoroscopy-guided interventions, where patients undergoing these procedures are at risk of radiation-induced skin reactions, cataracts, and other deterministic effects, concluding the necessity to justify the need for the requested radiographic examination and to optimize the entailed procedure to minimize patient exposure (Zanzonico & P. B et al., 2019).

A study by Kubo (2018) reviewed the literature on the effects of occupational exposure to ionizing radiation on health and found that radiology workers are at risk for various deterministic effects, including radiation-induced skin reactions, cataracts, and other adverse effects. The authors concluded that radiology workers should minimize their radiation exposure by using personal protective equipment and following radiation safety procedures. Another study by Kim S. et al. (2020) developed a risk assessment model to estimate the risk of deterministic effects of ionizing radiation on radiology workers. The authors found that the risk of these effects increases with the duration of exposure and the cumulative dose of radiation received. Furthermore, a retrospective study of radiology workers by Huang Y. et al. (2019) found they are at risk for radiation-induced skin reactions, cataracts, and other deterministic effects. All authors concluded that employers should implement radiation safety programs to protect workers from these adverse effects.

In contrast to deterministic effects, stochastic effects, also known as random effects, do not exhibit a threshold dose. Instead, the probability of a stochastic effect occurring increases with increasing radiation dose, but the severity of the effect is dose-independent. Even low-dose radiation exposure carries a small but non-zero risk of stochastic effects. The most prominent example of a stochastic effect is cancer. Ionizing radiation can damage DNA, potentially leading to genetic mutations that can initiate the development of cancer. The probability of cancer induction increases with radiation dose, but the severity of the cancer, once developed, is not directly related to the dose received (Vatansever & Dikmen, 2020). Other stochastic effects include hereditary effects, which involve transmitting radiation-induced genetic damage to offspring, cataracts, and a clouding of the eye's lens. These effects typically manifest years or decades after radiation exposure, making it more challenging to establish a direct cause-and-effect relationship (Hope et al., 2019).

Many studies prove that ionizing radiation can cause various health problems in patients and radiology workers. The risk of these health problems increases with increasing levels of radiation exposure. A systematic meta-analysis review study carried out by Preston (2018) found that radiologists are at increased risk of certain types of cancer, including leukemia, lymphoma, and thyroid cancer. The risk of cancer is higher with higher levels of radiation exposure. Another pooled analysis of 13 studies conducted by Smith et al. (2019) proved that medical imaging professionals have an increased risk of developing lung cancer. The risk of lung cancer for professionals exposed to higher levels of radiation is higher. In addition, a significant study by Preston et al. (2018) found that children of radiographers have an increased risk of developing childhood cancer. The

risk of childhood cancer is higher for children of radiographers exposed to higher levels of radiation.

The consistent findings of these studies suggest that there is a real risk of health problems associated with unnecessary radiation exposure. Gonzalez et al. (2004) investigated 100,000 radiographers in the UK for 30 years, finding a statistically significant increase in mortality from circulatory diseases and cancer among those with higher radiation exposure. Another study by Rajaraman et al. (2016) conducted a comprehensive study on cancer risks among radiologic technologists working in fluoroscopy and interventional angiography units in the US over the period 1994-2008 had revealed an increased risk of brain cancer, melanoma, and breast cancer in comparison with other technologists who never worked in such units. In addition, a study by Pearce et al. (2012) dealing with the long-term follow-up of over 70,000 radiologists and radiographers in the UK for 40 years found a statistically significant increase in mortality from leukemia and other cancers among those with higher radiation exposure. Furthermore, a meta-analysis of eleven studies explored by Li et al. (2013) found a statistically significant increase in the risk of cataracts among radiologic technologists as well, and another survey by Li et al. (2016) found a statistically significant increase in the risk of cognitive decline among workers exposed to ionizing radiation.

In conclusion, ionizing radiation poses a dual threat to human health, manifesting in deterministic and stochastic effects. Deterministic effects exhibit a threshold dose and increase in severity with increasing radiation dose and typically manifest within hours or days. In contrast, stochastic effects have no threshold dose and increase in probability with increasing

radiation dose, and the effects may not appear for years or decades. The risk of deterministic and stochastic effects increases with increasing radiation exposure; for that, it is essential to reduce radiation exposure to as low a level as reasonably achievable (ALARA) to protect patients and workers from the harmful effects of radiation. Table 2.1 summarizes the deterministic and stochastic effects of ionizing radiation.

Table (2.1): Biological Effects of Ionizing Radiation (Tatsuzaki, T., 2013).

Characteristics of effects	Occurring time	Object	Effects on organs
Deterministic	Acute effects	Somatic effects	• Skin damage • Cataracts • Damage to the reproductive system. • Damage to the forming system. • Damage to the digestive system. • Damage to the central nervous system. • Damage to the immunization system
Stochastic	Latent effects	Genetic effects	• Hereditary effects • Cancer

2.4 Principles of Radiation Protection

Radiation protection is the group of measures and procedures to protect individuals against the potential harm of ionizing radiation. When applied to radiology services, the concern is related to patients undergoing radiology procedures and the radiology staff who perform these procedures, and the hazard may extend to the public and the environment. The ICRP is the international regularity and reference body that establishes and encourages the elaboration of the main principles of radiation protection.

The ICRP 103 report (ICRP, 2007) recommends three principles for radiology radiation protection. (1) Justification relates to the idea that all procedures must benefit the patient to justify radiation exposure. (2) Optimization deals with keeping radiation doses as low as possible while achieving the desired image quality supporting diagnostic purposes. (3) dose limitation must be considered by following the recommended dose reference levels.

In diagnostic radiology, radiation exposure during imaging depends on the patient's age, gender, and the type of radiology examination (Vilar-Palop et al., 2018). Therefore, it is essential to optimize radiation doses by justifying the imaging procedures by the referring physicians and defining and applying the imaging technique by the radiology workers; in addition, it is essential to establish dose reference levels (DRLs) to serve as a standard value for dose reduction. Furthermore, quality assurance programs and adequate training for radiology staff also contribute to reducing medical radiation doses. Abuzaid et al. (2021) prove the importance of establishing DRL in any given radiology service based on the approved national and international guidelines; these DRL values are considered the backbone of enhancing the radiation dose reduction efforts and serve as a benchmark for optimizing the radiation dose of the various radiology procedures while keeping the desired diagnostic image quality that supports providing the diagnostic information to diagnose the suspected pathology or abnormality. Table 2.2 highlights the DRLs recommended for standard radiology procedures according to the published values of the IAEA (2021).

Table (2.2): DRL for the common radiology procedures (IAEA, 2013).

Radiology Procedure	Dose Reference Level (DRL)
Chest PA/AP	0.05 mSv
Abdomen AP	0.07 mSv
Extremities AP/LAT	0.02 mSv
Barium Esophagram	0.25 mSv
Upper Gastrointestinal (UGI) Series	0.5 mSv
Barium Enema (BE)	0.75 mSv
Intravenous Urography (IVU)	0.5 mSv

2.5 Radiation Dose Limits in Diagnostic Radiology

The limits of radiation dosage in radiology play a role in ensuring patient safety. These limits aim to balance the benefits of imaging with the risks associated with radiation exposure. The International Commission on Radiological Protection (ICRP) is responsible for establishing internationally recommended dose limits based on scientific evidence regarding radiation exposure and its health effects. It is the responsibility of healthcare providers and regulatory bodies to comply with these limits and implement measures for radiation protection. Healthcare providers can optimize the use of radiology while minimizing the risk of ionizing radiation by following guidelines provided by experts such as Kim et al. (2020), Mettler et al. 2022), and Pearce et al. (2012).

Given the reliance on ionizing radiation within diagnostic and therapeutic medicine practices, the ICRP has suggested that patients should be exposed to low doses whenever possible while accounting for their exposures. To

protect patients undergoing radiology procedures; the ICRP has set dose limits. These limits are based on the ALARA principle, which focuses on minimizing radiation exposure while maintaining accuracy.

According to a report from the ICRP in 2017, members of the public should not exceed a dose limit of one millisievert (1 mSv). However, there is some flexibility as a threshold of five millisieverts (5 mSv) is permitted if the average dose, over five years, remains below one millisievert (1 mSv). The specified limit pertains to the dose, which considers the radiation exposure to the entire body, considering that different organs and tissues have varying sensitivities to radiation.

Medical professionals working in radiology, such as radiologists, technologists, and nurses, are classified as exposed individuals and subjected to stricter dose limits than the public. The International Commission on Radiological Protection (ICRP) and the Nuclear Regulatory Commission (NRC) have established an effective dose of 20 mSv per year averaged over five consecutive years, with no year exceeding 50 mSv. This limit ensures that these workers do not accumulate levels of radiation exposure throughout their careers. In addition, there are also specific limits on how much radiology workers can be exposed to in their organs and tissues. As per the guidelines provided in NCRP Report No. 160 2016, e.g., the limits for equivalent doses to the eye lens and the skin are set at 20 and 50 mSv per year, respectively. In contrast, patient dose limits were established to safeguard tissues from harm caused by radiation exposure.

2.6 The Role of Governments, Regulatory Bodies, and Facilities in Radiation Safety

Various international organizations, such as The International Atomic Energy (IAEA), the International Commission on Radiological Protection (ICRP), and the International Commission on Radiation Units and Measurements (ICRU), have established standards and guidelines for ensuring radiation safety. These standards serve as a framework for governments and regulatory bodies to develop national radiation safety programs. Some significant international documents in this regard include the International Basic Safety Standards (BSS) for Protection against Ionizing Radiation and the Safety of Radiation Sources. This document, issued by the IAEA, offers guidance on radiation protection principles, dose limits, and safety requirements for different radiation sources and activities. The ICRP publishes recommendations covering aspects of radiation protection, including dose limits, risk assessment methodologies, and optimization principles. Also, reports from the ICRU guide radiation dosimetry and measurements to ensure a consistent assessment of radiation exposure.

To effectively ensure radiation safety, enforcing and maintaining collaboration among governments, regulatory bodies, and facilities is very important. The involvement and Responsibilities of these entities in this process can be classified as follows (IAEA and ICRP):

2.6.1 The Role and Responsibilities of Governments

In collaborating and benchmarking with international organizations, governments have the responsibility of establishing a framework for radiation safety by enacting legislation and regulations that align with

standards and best practices for radiation safety include and are not limited to providing funds, assigning authority with authority to effectively administer and enforce radiation safety regulations, licensing monitoring, monitoring radiation dose limits, following up on implementing radiation protection programs, and managing risk and emergencies.

2.6.2 The Role and Responsibilities of Regulatory Bodies

Regulatory bodies are responsible for issuing licenses and providing authorizations to facilities that use ionizing radiation sources, ensuring they meet all requirements, in addition to monitoring radiation levels in the environment to assess risks and identify trends, conducting inspections and audits of facilities to ensure compliance with regulations and identify any potential safety concerns; furthermore, they investigate possible incidents, take action to prevent future occurrences and conduct and support research to enhance the practice of radiation safety.

2.6.3 The Role and Responsibilities of Facilities

Facilities utilizing radiation sources must safeguard the well-being of their staff, the environment, and the public. This could be achieved in coordination with the regular bodies and by complying with the established standards. Developing and implementing a program for radiation safety that covers all aspects, including training, monitoring exposure levels, implementing shielding measures, and establishing emergency procedures, is the backbone of the process, with an emphasis on appointing a Radiation Safety Officer (RSO) who possesses relevant expertise to oversee the implementation of the radiation safety program and facilitate regularly monitoring radiation levels along with keeping records of radiation

exposure. In addition, each facility is responsible for practicing emergency response strategies to handle accidents involving the release of radiation.

2.7 Bahrain's Environmental Policy

2.7.1 Evolution

Initiatives (1980- 1996): Bahrain took strides towards safeguarding the environment in 1980 when it established the Environmental Protection Committee (EPC) and the Environmental Protection Technical Secretariat (EPTS) through Amiri Decree No. 7. These organizations operated as the country's bodies responsible for environmental affairs functioning from 1980 to 1996.

Environmental Governance Agency (1996–2012): A significant milestone in Bahrain's environmental policy framework was reached with the introduction of Amiri Decree Law No. 21 in 1996. This decree brought forth the Law on the Environment. The Environmental Governance Agency (EGA) was established as the authority entrusted with environmental protection and sustainable development.

Public Commission for Marine Resources, Environment, and Wildlife Conservation (2002): To fortify its commitment to protection, Bahrain formed the Public Commission for Marine Resources, Environment, and Wildlife Conservation in 2002. This commission was set up following the establishment of the Environmental Protection Committee (ERC) and Environmental Protection Technical Secretariat (EPTS) through Amiri Decree No. 7 in 1980.

Supreme Council for Environmental Affairs (2012–Present): In 2012, Bahrain established the Supreme Council for the Environment (SCE) through a decree to be the authority responsible for safeguarding the environment (SCE, n.d.). The SCEs' primary role is to ensure the preservation and sustainable use of resources for future generations while taking comprehensive measures for environmental protection (SCE, n.d.).

2.7.2 Key Principles of Bahrain's Environmental Policy

1. Precautionary Principle: This principle underscores the importance of taking action to prevent harm even when there may be uncertainties about its whole extent (SCE, n.d.).

2. Polluter Pays Principle: According to this principle, those responsible for polluting activities should bear the costs associated with damage (SCE, n.d.).

3. Sustainability Concept: fabricate an approach between development and environmental conservation; this principle aims to ensure long-term sustainability (SCE, n.d.).

4. Shared Responsibility: Recognizing that individuals, businesses, and governments all do share responsibility in protecting the environment and collaborative efforts are required to achieve desired development (SCE, n.d.).

2.7.3 Radiation Safety Regulations in the Kingdom of Bahrain

In the Kingdom of Bahrain, the Ministry of Health (MoH) works closely with the Radiation Protection Directorate (RPD) in the Supreme Council for Environment (SCE), which is responsible for radiation safety, by implementing radiation safety regulations besides providing training,

educational, and technical advice on radiation safety. All radiology facilities should fulfill the specified safety requirements to practice and provide the service to the public.

Healthcare organizations in Bahrain must comply with safety requirements mandated by the Supreme Council for the Environment (SCE) to protect radiation users and preserve their well-being (SCE, n.d.). These requirements encompass the following elements:-

- 1. Licensing:** When installing radiation-emitting equipment and dealing with materials, it is essential to conduct quality control check-ups, provide radiation safety and protection training, establish guidelines for these practices, regularly monitor compliance, and carry out radiation dosimetry (SCE, n.d.).
- 2. Import/Export Authorization:** It is necessary to obtain authorization to import or export materials and devices that emit radiation (SCE, n.d.).
- 3. Environmental Radiation Monitoring:** It is crucial to assess background radiation dose rates through radiation monitoring (SCE, n.d.).
- 4. Emergency Response:** There should be designated emergency response agencies to handle nuclear emergencies effectively (SCE, n.d.).
- 5. National Radiation Monitoring Network:** The operation and maintenance of the National Environmental Radiation Monitoring Network should collaborate with authorities by monitoring unusual readings and providing technical support for their restoration (SCE, n.d.).

2.8 Radiology Department Radiation Safety Measures

2.8.1 Safety Measures: Radiology Department Design.

Designing X-ray departments should follow evidence-based design and must be devised, revised, and carried out by a team of architects, engineers, management representatives, radiation safety advisors, radiologists, physicians, and chief radiation technologists. Many factors should be considered when planning a radiology department. The location and layout of x-ray rooms must be considered from a radiation protection perspective. The surroundings of the room, entrances, and waiting areas should promote accessibility and productivity and ensure health and well-being for individuals in the different areas inside and outside the imaging rooms by providing radiation protection, considering the standard radiation safety requirements (Tessler et al., 2021).

According to the NCRP (2004), Report No. 147, an X-ray room typically measures 6 meters by 4 meters by 3 meters with a wall thickness of about 2 mm of lead in all directions. The thickness of lead required may vary depending on factors like protecting doors and other wall openings. Additionally, windows should be positioned at 1.6 meters above floor level to prevent scattered radiation from passing through them into areas. Furthermore, when placing shields around the control panel within the X-ray room, special attention should be paid to ensure that direct and scattered radiation from any area where X-ray procedures are performed does not pass around the edges of the control panel.

2.8.2 Safety Measures: Quality Assurance (QA) Program

QA assurance programs are essential for any given service; they help

ensure the quality of the product or service. In radiology, a QA program aims to improve patient care by promoting accurate and timely diagnostic services, controlling unnecessary radiation exposure, and managing maintenance services (American College of Radiology [ACR], n.d.).

The concept of quality in the healthcare system is complex and has been explored by researchers who rely on different variables and attributes depending on their specific focus (Sower et al., 2001). Researchers have differing opinions on the dimensionality of healthcare quality (Choi et al., 2005; Sower et al., 2001), resulting in classifications of dimension components based on their insights and experiences within particular contexts. However, selecting dimensions and criteria to define quality significantly impacts the approaches and methods used to assess healthcare services (Schembri & Sandberg 2011). Despite variations, there are overlapping attributes that are commonly identified. For example, some researchers have categorized service excellence into quality and functional quality (Fiala, 2012). In a study conducted by Bowers & Kiefe (2002, p. 123) to assess quality concerns in healthcare, they identified two elements of quality: the quality and the delivery of healthcare services. Piligrimienė et al. (2011) explored differences between healthcare providers, shareholders, and patients on their perception of quality, showcasing the complexity of the process. Furthermore, quality in the healthcare context can be assessed based on the accuracy and procedures provided and the patient care received (Rubin, 2011); this concept was emphasized by Mosadeghrad (2012) in his study, mentioning that quality in the healthcare system is determined by the accuracy of diagnosis and adherence to practices (procedures) and how services are delivered to patients, concluding that patients primarily rely on factors like facilities, cleanliness, safety, and

the attitudes of healthcare providers.

Quality control (QC) testing is part of the QA program and is crucial in ensuring the safety and accuracy of radiology department services. It involves testing the equipment's performance, image quality, dosimetry, and safety. It helps to identify and correct technical problems before they can affect patient care (Khawaja & McNulty, 2017). Radiology departments can control errors, reduce risks, enhance patient care, and improve the overall outcome of the service by applying a comprehensive radiology QC program consistent with the established regulatory guidelines (Vano et al., 2019).

An initial step for planning a safe radiology environment is to assign a QA committee in charge of planning and to apply radiation protection guidelines, monitoring staff's practices per these guidelines, and taking corrective action for all radiology activities. Figure 2.3 presents the fundamental elements and cycle of QA (IAEA, 2009).

Many studies have proven that an organized QA program is pivotal in enhancing patient care, optimizing radiation safety, and improving image quality. According to Maheshwari et al. (2021), medical imaging departments today have increasingly focused on overall performance to achieve the desired radiation safety and quality of service to their patients. Other studies by Beigelman et al. (2018) and Kim et al. (2020) emphasized the impact of implementing a structured radiology QA program in achieving the desired patient safety and image quality, concluding that QA programs are crucial for maintaining compliance, safeguarding radiology staff and patient well-being, adopting a culture of radiation safety within radiology departments, and improving image quality. By implementing comprehensive QA measures, radiology departments can effectively

manage radiation risks, improve patient care, and uphold the highest standards of medical imaging services.

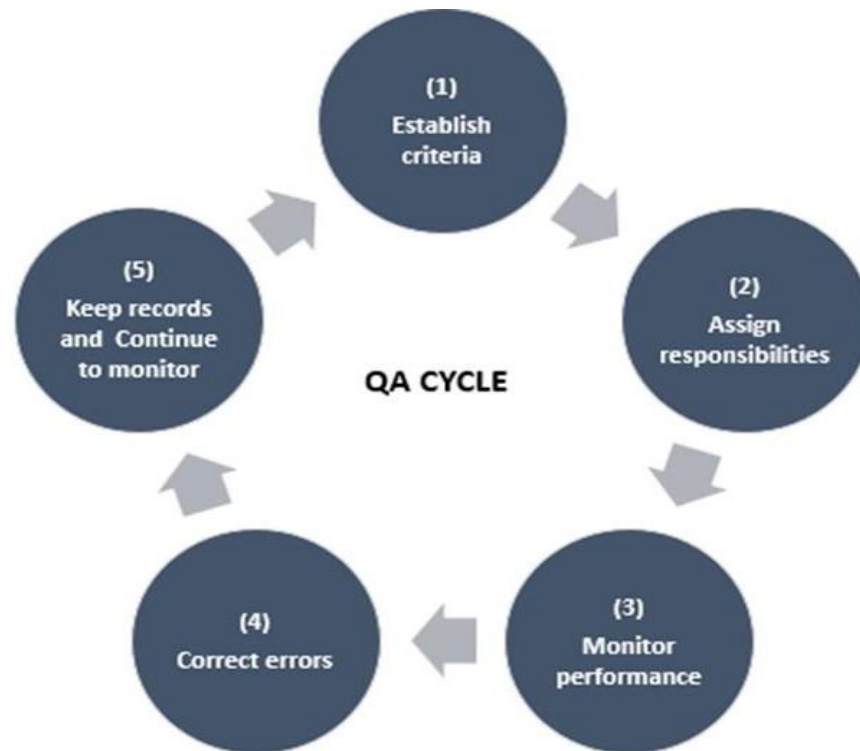


Figure (2.3): QA Program Elements and Cycle (Adapted by the researcher according to the IAEA). (2009) (Radiology QA guidelines).

2.8.3 Safety Measures: radiation safety devices, personnel, and policies

Radiology departments prioritize safety by ensuring the availability of Personal Protective Equipment (PPE) made specifically for radiation protection. These essential devices and gadgets include lead gloves, gonad shields, lead aprons, thyroid shields, lead barriers, and lead glasses. It is crucial to consider their utilization to achieve protection for patients, staff members, and other personnel involved. Establishing procedures and criteria for using these devices helps minimize unnecessary exposure to

ionizing radiation. A case study conducted by El Khatib et al. (2021) demonstrates that the absence of a radiation protection program, which guides radiology staff practices and is monitored by a designated radiation protection officer, increases exposure risks for staff and patients. These findings align with studies conducted by Khan (2022). Moreover, El Feky et al. (2019) confirmed the positive impact of such safety programs on reducing radiation exposure for patients and radiology staff. Other important aspects to consider when it comes to policies and procedures include:

- 1. Training on radiation safety:** It is essential for all personnel working in the radiology department to undergo radiation safety training. This training should cover information about the risks associated with radiation exposure techniques to minimize exposure and the use of protective equipment (such as lead aprons, gloves, and thyroid shields).
- 2. Promoting a culture of radiation safety:** It is vital to foster a culture within the radiology department; everyone should be fully and always committed to these safety protocols.
- 3. Monitoring radiation exposure:** Individuals exposed to radiation should wear dosimeters that measure their level of exposure. Regularly review and analyze dosimetry data to ensure exposures are as low as reasonably achievable (ALARA).
- 4. Reporting incidents:** Any incidents related to radiation safety must be promptly reported and thoroughly investigated. This proactive approach helps identify any weaknesses in the program. Enables appropriate actions for improvement.

Attaining the highest compliance level to all these safety measures

requires the presence of radiation safety personnel or a Radiation Safety Officer (RSO), who is responsible for monitoring and reporting all protection activities and incidents to minimize the potential hazards of ionizing radiation used in radiology departments (EU-OSHA, 2023).

2.8.4 Safety Measures: Compliance with Radiation Safety by

Staff The framework of Knowledge-Attitude-Practice (KAP)

The KAP is essential in health behavior change; this theory is based on the phenomenon change of human behavior through three successive processes: the acquisition of knowledge, the generation of attitude, and the formation of behavior (Al-Qahtani et al., 2022). This model (Figure. 2-5) is considered rational in health education. Therefore, the KAP theory and model should be adopted to guide the development and improvement of compliance with safety measures in radiology departments (Jadoon et al., 2021).

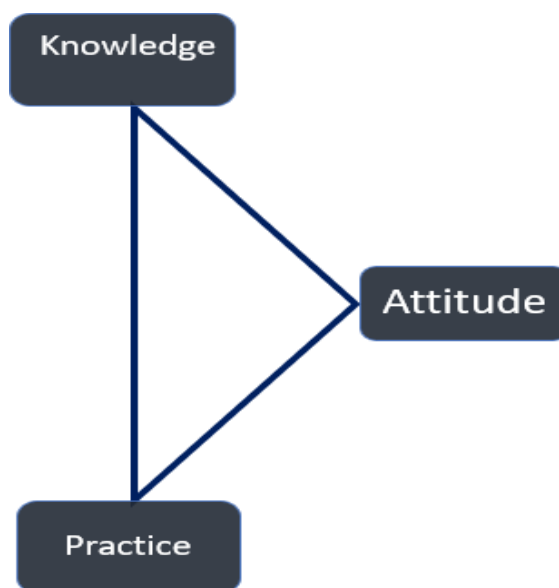


Figure (2.4): The KAP Model shows that practice is directly proportional to attitude and knowledge while attitude is shaped by knowledge (Figure adapted from SPRING (2023)).

The knowledge, attitude, and compliance level of radiology workers toward radiation protection directly affects the total dose rate exposed by radiology personnel and patients undergoing radiology procedures (Mojiri & Moghimbeigi, 2011). Ahmed et al. (2015) proved a direct association between the radiology workers' attitude toward compliance with safety measures and their radiation safety knowledge and awareness level; they concluded that without a high awareness level and compliance with radiation safety measures, radiation safety practices would be affected, leading to potential health hazards. Furthermore, other medical staff, especially the clinicians' knowledge about the health effects of ionizing radiation and the importance of justifying the radiology request and providing adequate clinical information is vital in minimizing radiation hazards. Gacega et al. (2015) carried out a study in a tertiary hospital in Rwanda regarding medical staff knowledge about ionizing radiation; this study revealed a lack of basic knowledge of ionizing radiation and its health effects in the majority of those involved in the study, which impacts negatively on their attitude and practice.

The negative contribution of clinicians toward medical radiation safety comes through failure to select the suitable diagnostic tool to support diagnosing diseases or failure to provide clear clinical information through the proper filling of the radiology request forms. A study conducted by Patel et al. (2023) revealed that one-third of requested radiological exams are somewhat inappropriate and unnecessary; he concluded the importance of a monitoring mechanism to evaluate the physician's request appropriateness and conduct training for those who fail to follow the proper requesting.

2.8.5 Hierarchy of control and prioritized safety measures

Many factors contribute to controlling and minimizing occupational radiation exposure hazards. The concerned organizations worldwide adopted a hierarchy of control and prioritized many control measures to reduce risk and support workplace safety (OSHA, 2023). These measures are shown in Figure 2.5 and categorized according to their effectiveness, from utmost to minimum, as follows:

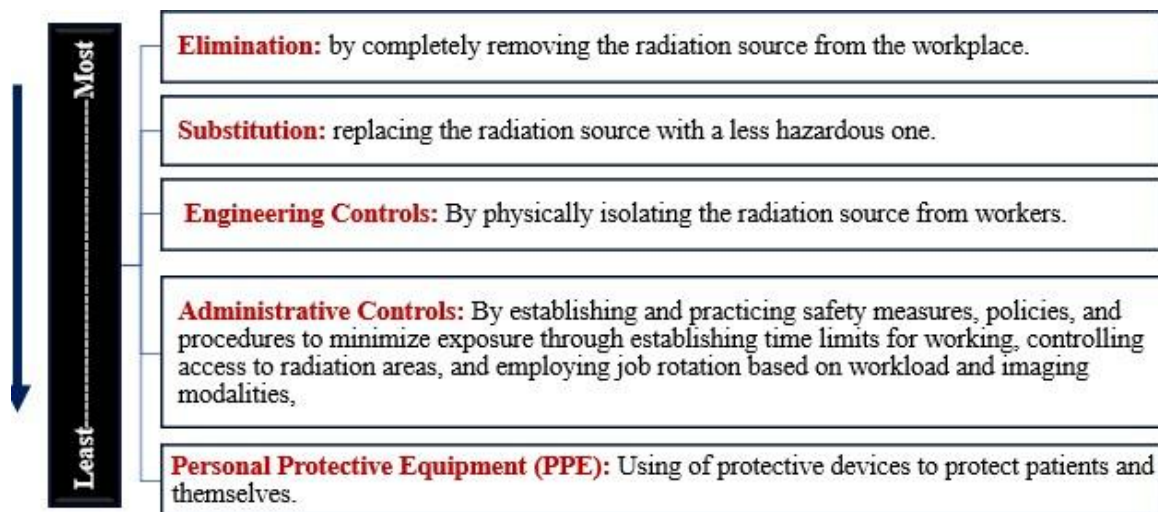


Figure (2.5): Hierarchy of Control Measures to reduce Radiation Risk According to their Effectiveness, from Utmost to Minimum (OSHA, 2023).

The radiology services are tied to the possibility of exposing patients undergoing radiology procedures to unnecessary radiation doses besides affecting the cumulative occupational exposure to medical radiation workers. For that, radiology workers must comply with radiation protection guidelines by practicing and applying the principles of radiation protection by adopting the ALARA concept, which emphasizes minimizing time for radiology procedures, maximizing distance from the radiation source, and applying

proper shielding for additional protection for themselves and patients (Safety Guide Series No. SSG-46, IAEA, 2018). Utilizing personal protective equipment in radiology departments is considered the least effective control in the hierarchy; therefore, it should be combined with administrative controls for better compliance to reduce occupational radiation risks, ensuring that the ALARA principle is constantly practiced in the workplace and that radiation dose monitoring is conducted regularly (ICRP Pub- 60, 1991).

To conclude, many studies conducted in some X-ray facilities in Africa, Asia, and the Middle East revealed that most facilities did not align with radiology safety measures. A study in India by Sharma et al. (2020) reported that only 54% of X-ray facilities in rural India complied with radiation protection regulations. The study revealed missing shielding devices and a lack of personnel training as significant issues. Another study conducted in China by Li et al. (2019) found that 37% of X-ray facilities in dental clinics do not follow radiation safety standards. They conclude malpractices are related to poor radiation shielding and a lack of dosimetry monitoring. In Saudi Arabia, Al-Qahtani et al. (2022) found in their study that 29% of X-ray facilities had inadequate radiation safety protocols. The study recognized the lack of proper staff training and personal protective equipment. Furthermore, in African Nigeria, a study by Oladipo et al. (2018) stated that 42% of X-ray facilities in Nigeria lacked essential radiation safety equipment and had inadequate staff training. These unusual findings reflect the importance of conducting this study to ensure the safe and effective use of radiology services by adhering to the safety standards for any radiology facility.

Chapter III

Material and Methods

MATERIALS AND METHODS

This chapter presents the methodological framework utilized to evaluate the status of radiation safety measures in the radiology departments at healthcare centers in the Kingdom of Bahrain. The chapter identifies the research design, the study population, the inclusion and exclusion criteria, the sampling size, the data collection procedure, measurement, analysis tools, and the ethical considerations for conducting this study.

3.1 Study Design

This study was carried out using a descriptive cross-sectional design. It includes qualitative surveys to assess the awareness, attitudes, and practices of radiation safety measures among the radiology personnel, as well as a quantitative cross-sectional method to obtain data on dosimetry measurements to enhance the validity of assessing the radiation safety measures in the radiology work environment in health centers in the Kingdom of Bahrain.

3.2 Study Settings

The survey part of this study includes all radiological staff in all radiology departments in public health centers under the Ministry of Health (MoH) umbrella in the Kingdom of Bahrain. In contrast, the radiation leakage experimental part of the study was conducted in the radiology departments of the following government.

(1)HCs: Al-Nuaim HC, (2) Al-Kuwait HC, (3) Hamad Kanoo HC, (4) Mohammed Jasim Kanoo HC, (5) Yousif. Rahman Engineer HC, (6) Shaikh

Jaber Al-Sabah HC, and (7) Budaiya HC. The selection of these health centers was based on their high workload according to the National Health Regulatory Authority (NHRA) statistics, as they serve heavily populated areas, while some centers were not included because of the minimal workload on the one hand and the dysfunctionality of some radiography units on the other.

3.3 Population

The total number of primary public health centers with radiology units in the Kingdom of Bahrain is 22, distributed among the Northern, Southern, Capital, and Al-Muharraq governances. The population of this study comprised all radiology workers practicing in the health centers in the Kingdom of Bahrain. The target population is all licensed radiographers and radiologic technologists currently working at radiology departments in governmental public health centers in Bahrain, with 54 radiological staff working under the umbrella of the MoH.

3.4 Study Inclusion and Exclusion Criteria:

This study's inclusion and exclusion criteria were developed according to the study objectives, participants' feasibility, the tools used for data collection, and ethical considerations. Subjects included in the study are with the following inclusion and exclusion criteria:

3.4.1 Inclusion criteria:

1. All radiology-licensed workers practice at the public health centers in Bahrain under the MoH.

2. The seven selected MoH, public health centers for the radiation leak survey

3.4.2 Exclusion criteria:

1. Radiology workers in governmental and private hospitals.
2. Private hospitals and medical clinics.
3. Non-radiological technical staff and patients.

3.5 Study Sample Size

Convenience sampling was utilized to identify the sample size out of 54 population members who are radiology workers licensed and practicing in health centers. The study subjects were a convenience sampling of radiology workers who fulfilled the inclusion criteria. The sample size was calculated by using an online calculator (Figure 3.1), assigning a confidence level of 95% and a significance level of 5% ($p\text{-value} \leq 0.05$). The calculated sample size was (48) out of the (54) overall population.

Sample Size Calculator

Find Out The Sample Size

This calculator computes the minimum number of necessary samples to meet the desired statistical constraints.

Result

Sample size: 48

This means 48 or more measurements/surveys are needed to have a confidence level of 95% that the real value is within $\pm 5\%$ of the measured/surveyed value.

Confidence Level: ?	95%	
Margin of Error: ?	5%	
Population Proportion: ?	50%	Use 50% if not sure
Population Size: ?	54	Leave blank if unlimited population size.
Calculate Clear		

Figure (3.1): Sample size calculation test (Calculated and retrieved from <https://www.calculator.net/sample-size-calculator.html>)

3.6 Measurement Tools

To achieve the research's aim and objective, two questionnaires with different sections were used as tools to collect the required data. The surveys were presented to the targeted population in English language. The content validity of these questionnaires was carried out, and a pilot study was done with five staff radiographers. Moreover, the reliability was conducted utilizing two chief radiographers who independently recorded their observations using the questionnaires. Furthermore, the study measures radiation leaks in the health centers specified in the inclusion criteria. The specifications of these measurement tools are as follows:-

3.6.1 Tool one: Radiology Staff Survey

This survey includes structured questions for radiology staff. It includes five sections (Appendix 2).

Section (I) covers the socio-demographic information of the participants.

Section (II) covers the knowledge about the impact of regulations on radiation safety. The responses for each item in this section are Yes, No, or I Don't Know.

Section (III) covers the availability of radiation safety devices, personnel, and policies. The responses for each item in this section are available, unavailable, or I don't know.

Section (IV) covers the assessment of radiation safety practice level. The responses for each item are regular, occasionally, if a problem exists or I do not know.

Section (V) covers the attitude toward radiation safety practices among radiology staff. The responses for each item are regular, occasionally, if applicable, or not at all.

3.6.2 Tool two: Visual Inspection Assessment Survey

This survey includes an inspection checklist with two sections (Appendix 1).

Section (I) covers the availability of radiation safety protective devices, personnel, and policies. The responses for each item in this section of the observation checklist are available or unavailable.

Section (II) covers the construction and protection requirements of the radiology imaging rooms. The responses for each item in this section of the observation checklist are Yes or No.

3.6.3 Tool Three: Radiation Leak Measurement

This tool measures the possible radiation leaks in seven selected health centers, specifically, Mohammed Kanoo, Budaiya, Hamad Kanoo, Al-Nuaim, Al-Kuwait, Yousif Engineer, and Sh. Jaber Al-Sabah Health Center. The measurement involves four specific locations in each selected center: at the control panel station, the wall behind the chest standing bucky, at direct contact with the glass protective, and behind the waiting area main door window. The equipment for radiation leak measurement includes calibrated thermo-luminescence dosimeters and digital instant dosimeters to ensure that the possible leaks are within the internationally recommended level.

3.7 Data Collection Procedures

3.7.1 Study surveys.

The visual inspection survey of this study was conducted on-site. In contrast, the radiology workers survey was constructed using Google Forms, which supports a user-friendly nature in developing and designing surveys. WhatsApp was chosen as the application of choice for distributing the survey's link due to its ease and proven effectiveness in sharing information in social and academic interactions (Khatun & Al-Dhlan, 2017; Ahad & Lim, 2014). An introductory paragraph informed the participants before starting the survey that anonymity is assured and secured, and the results would be used only for a scientific study and possible future scientific publication; they were conditioned to give their approval before going through the answering surveys.

3.7.2 Radiation Exposure Leaks

Instant radiation exposure leaks were measured in specific radiology departments at selected governmental public health centers in Bahrain. These centers were selected based on the considerable workload intensity compared to other centers. At every radiology unit, radiation leakage was measured using the Geiger Counter Nuclear Radiation Detector model KB6011. This counter detects ionizing radiation by utilizing a specialized gas-filled tube. This tube contains a central electrode surrounded by a lower-voltage outer electrode, all encased in a sealed container. When ionizing radiation enters the tube, it interacts with the gas atoms, knocking out electrons and creating charged ions. These ions, attracted to the electrodes,

create a brief electrical current pulse. Each detected ionizing particle triggers a single current pulse, generating the characteristic clicking sound associated with Geiger counters. The KB6011 measures the frequency of these pulses, translating them into a radiation dose rate displayed on its screen. Think of it like a tiny particle counter, with each click representing an individual radiation event, ultimately painting a picture of the overall radiation environment.

KB6011 is characterized by high sensitivity and accurate measurement and widely applied in the environment where existing ionizing radiation is used for radiation dose supervision was used to check the possible leaks in the targeted locations. The measurement involves four specific locations: at the control panel station, the wall behind the chest standing bucky, at direct contact with the glass protective, and behind the waiting area main door window.

Moreover, the ambient radiation doses were measured using calibrated Lithium fluoride (LiF) Thermoluminescent Dosimeters (TLDs) type to accumulate doses and measure the average exposure level at the control panel station where the radiological staff stood while exposing the patients.

Thermoelement dosimeters (TLDs) act as tiny radiation detectives, storing absorbed ionizing radiation as trapped electrons in their crystal lattice. These electrons are released when heated, producing a burst of light proportional to the radiation dose received. This light is measured by a specialized reader, generating an electrical signal converted into a dose reading. Imagine the TLD crystal like a piggy bank for radiation energy, accumulating deposits with exposure. Heating is the key, unlocking the stored energy and converting it into measurable light. The higher the

radiation dose, the more "coins" are released, resulting in a brighter "flash" and a higher dose reading.

The background radiation was accounted for by placing unexposed TLDs in a shielded location and subtracting their readings from the exposed TLDs. The exact location was determined by questioning the workers and through personal observation by the researcher himself. The TLDs were kept for two consecutive weeks, from 7th March to 21st March 2022. The TLD readings and interpretation were attained with the aid of a medical physics expert at Salmaniya Medical Complex (SMC).

3.8 Statistical Analysis

The data collected from answered surveys and the recorded radiation exposure were analyzed using Statistical Package for Social Sciences (SPSS) (version 26.0). In the primary radiology workers survey, which contains four main parts, the responses to the questions under these parts were rated as correct/positive and were given 1 point, while incorrect/negative responses were given 0. If the responses were rated partially correct, a half point (0.5) was given. The participant's score under each part is the sum of their points across all the questions in the part. For example, the knowledge part contains 11 questions, so the knowledge score for a particular participant may range between 0 and 11 out of 11. The scores were better converted to a 100% scale for more straightforward interpretation and comparability. These scores can be averaged for the whole sample or specific groups within the sample. The four scores will be abbreviated as follows: Knowledge Score (KS), Awareness about the Availability Score (AAS), Attitude Score (ATT), and Practice Score (PS). Analyzing the demographic variables and the

response to the survey questions is attained using the frequency distribution and point statistics (like mean, SD, and median) to summarize the scores and support the statistical testing.

3.9 Ethical Considerations:

The scientific research committee and the university council approved conducting this study after fulfilling the requirements under approval No (244/2021) (Appendix 3), in addition to official permission, which was obtained from the Ministry of Health (Appendix 4). Moreover, the purpose of this study was explained to the participants, along with their rights of anonymity, confidentiality, and withdrawal from the study at any time, and informed consents were signed and collected from the participants willing to participate (Appendix 5). Moreover, the researcher confirmed to the participants that the privacy and performance of the collected data would not affect their jobs or annual evaluations.

Chapter IV

Results

RESULTS

This chapter presents the study results in four parts: (I) Presents the Socio-demographic Characteristics of the Participants, (II) Displays the primary survey's data analysis, (III) Sums up the radiation dose measurements measures as specified in the methodology, and (IV): summarize the hypotheses testing.

Part I: Participants' Socio-demographic Data

Table (4.1): Participant Socio-demographic Characteristic

Item	Value	n (%)
Gender	Female	45 (91.8%)
	Male	4 (8.2%)
Age in Years	21 – 29	17 (34.7%)
	30 – 39	24 (48.9%)
	40 – 49	7 (14.3%)
	50<	1 (2%)
Occupation	Radiographer	33 (67.3%)
	Radiologic Technologist	16 (32.7%)
Academic qualification	Associate degree (AD)	33 (67.3%)
	Bachelor's Degree (B.Sc.)	16 (32.7%)
Years of experience	1 – 4	14 (28.6%)
	5 – 10	10 (20.4%)
	11 – 15	8 (16.3%)
	> 15	17(34.7%)

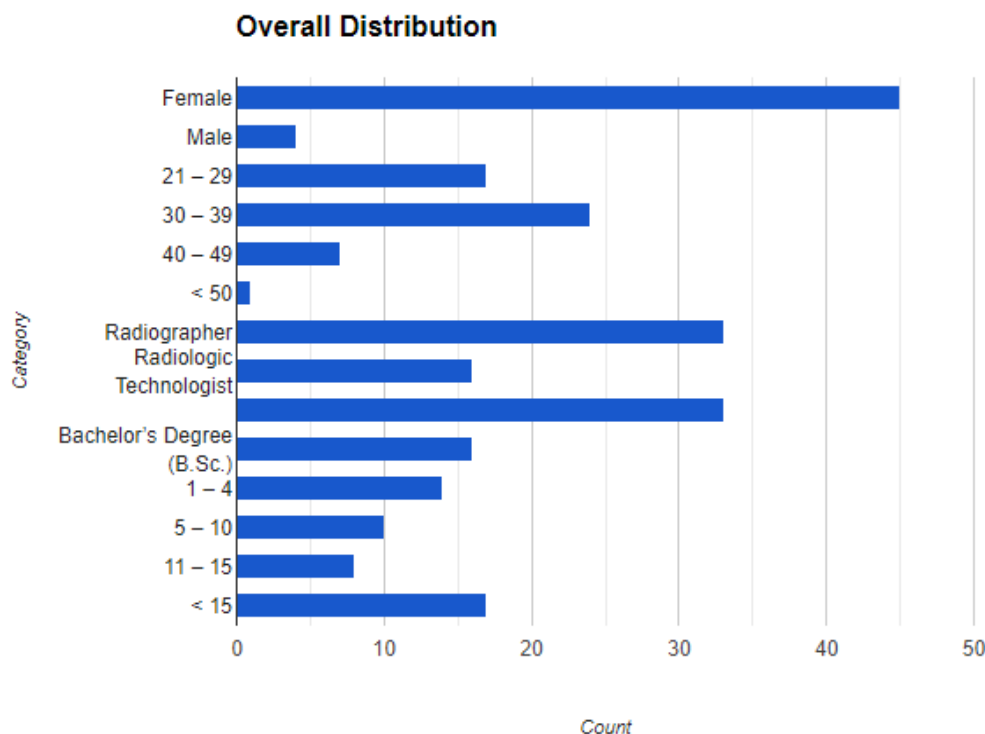


Figure (4.1): Participant Socio-demographic Characteristic

As shown in Table 4.1 and illustrated in Figure 4.1, the largest groups of participants were individuals between the ages of 21 and 29, accounting for 34.7% (n=17), followed by those 30 to 39, making up 48.9% (n=24). Together, these two age groups represented 83.6% of all participants. When it comes to qualifications and job titles, most participants (67.3%) held an Associate Degree and worked as radiographers (n=33), while the remaining (32.8%) possessed a bachelor's degree and worked as radiologic technologists (n=16). Regarding job tenure and experience, the highest % of staff revealed more than 15 years of working experience at 34.7% (n=17). Around 28.6% (n=14) had one to four years of experience, while 20.4% (n=10) had accumulated five to ten years in their roles.

Part II: Main Survey's Data Analysis

(A) Availability of radiation safety devices and policies

Table (4.2): Participants' perspectives on the availability of radiation safety devices and policies

Items	Available	Not available	I don't know
Gonad lead shields	49 (100%)		
Lead aprons	49 (100%)		
Lead barriers	26 (53.1%)	18 (36.7%)	4 (8.2%)
Thyroid shields	5 (10.2%)	42 (85.7%)	2 (4.1%)
Breast shields	8 (16.3%)	39 (79.6%)	2 (4.1%)
Eye goggles shields		48 (98.0%)	1 (2.0%)
Lead gloves		48 (98.0%)	1 (2.0%)
Radiation room caution indicator lights	46 (93.9%)	1 (2.0%)	2 (4.1%)
Clear radiation safety policies and copies of the radiation survey report	32 (65.3%)	4 (8.2%)	13 (26.5%)

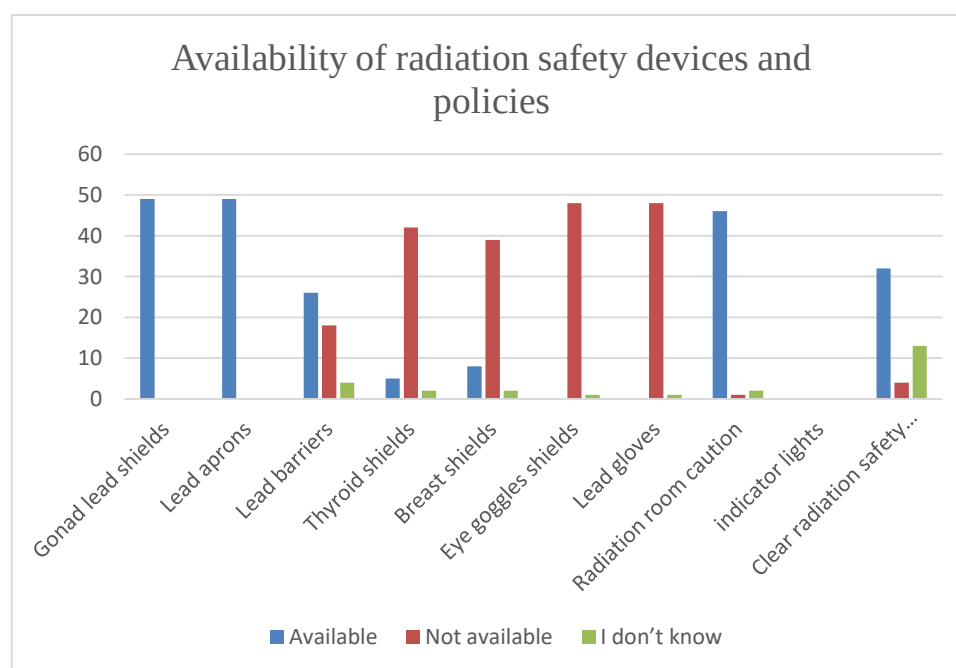


Figure (4.2): Participants' perspectives on the availability of radiation safety devices and policies

Table 4.2 and Figure 4.2 display the Participants' perspectives on the availability of radiation safety devices and policies. All participants (100%) agree with the availability of gonad lead aprons, whole body vest lead aprons, eye goggles shields, and lead gloves. In comparison, 71% of participants report that thyroid lead shields are available in their radiology departments, while 76% agree with their availability for the caution indicator lights in the imaging room.

(B) Awareness of Radiation Safety Regulations

Table (4.3): Participants' Awareness of Radiation Safety Regulations

Question	Yes	No	I don't know
Do you think certifying a radiology department will enhance safety and safety culture?	46 (93.9%)		3 (6.1%)
Do you think the radiology department staff should meet the qualifications and experience to improve radiation safety?	49 (100%)		
Do you think assigning responsibility for radiation safety at the management level in each center contribute to safety?	39 (79.6%)	7 (14.3%)	3 (6.1%)
Do you think that it is required that each health care center should appoint/access radiation safety experts to monitor and improve levels of radiation safety?	34 (69.4%)	13(26.5%)	2 (4.1%)
Does the radiation safety regulation motivate you/your department to estimate and compare patient doses with reference levels?	30 (61.2%)	11 (22.5%)	8 (16.3%)
Do you think that consideration should be given to patient doses when identifying specifications for purchasing new equipment?	47 (95.9%)	2 (4.1%)	
Do you think the requirements to perform regular QC tests on radiological equipment affect your practice?	34 (69.4%)	10 (20.4%)	5 (10.2%)
Do you think the regulatory requirement to optimize patient doses and keep records of patient doses influences radiation safety?	43 (87.8%)		6 (12.2%)
Do you think regulatory requirements should be strictly applied to have written protocols for radiological procedures?	45 (91.9%)	3 (6.1%)	1 (2%)

Do you think a system for quickly obtaining information about the number of radiological procedures a patient has undertaken will improve safety?	42 (85.7%)	5 (10.2%)	2 (4.1%)
Do you believe your radiology center aligns with the radiation safety requirements?	41 (83.7%)	5 (10.2%)	3 (6.1%)

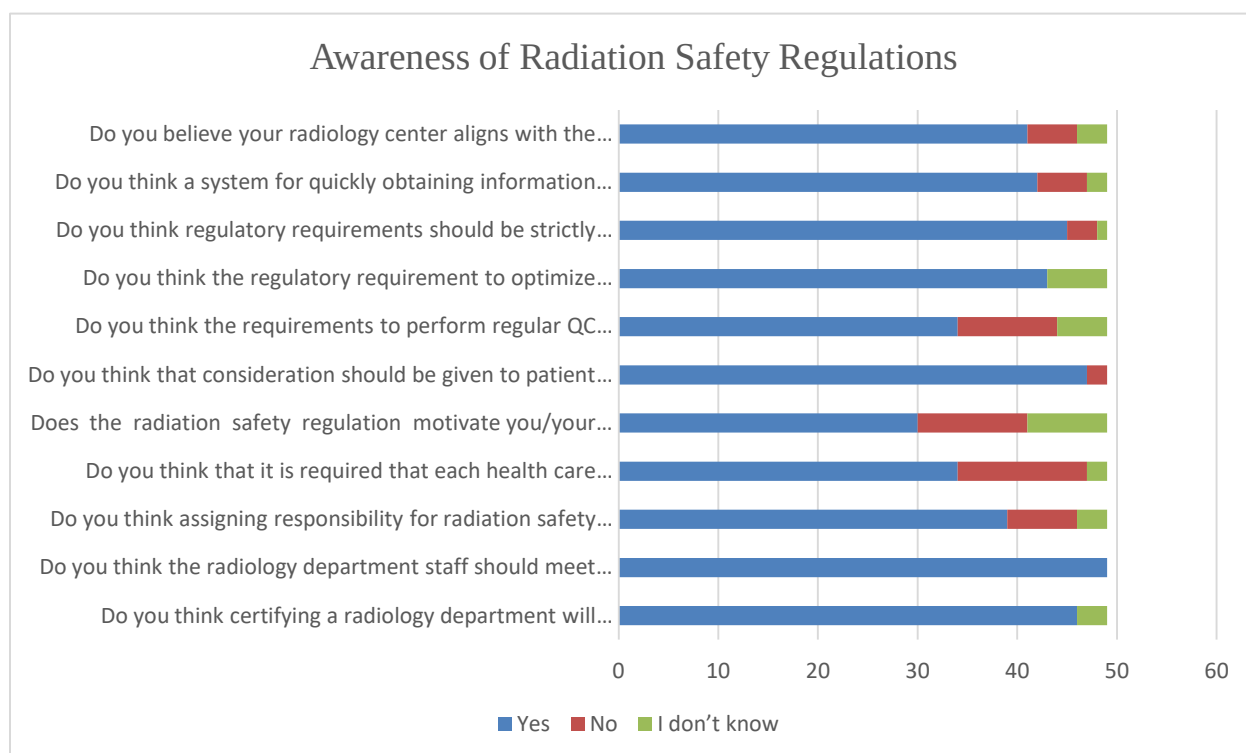


Figure (4.3): Participants' Awareness of Radiation Safety Regulations

Participants' perspectives regarding the importance and impact of regulations on radiology radiation safety demonstrated a high level of awareness, with an average cumulative awareness level of 83.3%, and 84% of participants believed their radiology centers aligned with radiation safety requirements. The key findings of these results, as illustrated in Table 4.3 and Figure 4.3, are as follows:

- 93.9% of participants were aware of the positive impact of implementing regulatory guidelines on radiation safety and safety culture.

- 100% of participants recognized the importance of having good academic qualifications and working experience in enhancing radiation safety culture.
- 80% of participants agreed on the importance of assigning responsibility for radiation safety, while 69% agreed that appointing a radiation safety expert would improve radiation safety.
- 69% of participants agreed that regular Quality Control (QC) tests will affect their practice.
- 88% of participants agreed that regulatory requirements to optimize patient doses and keep records of patient doses would influence radiation safety, and radiology departments must have written protocols for radiological procedures and should be strictly applied.
- 86% of participants agreed that an advanced and efficient system that retrieves and obtains all patient health information would influence safety.
- 69% of participants agreed that appointing a radiation safety expert would improve radiation safety.

(C) Practice of Radiation Safety Measures

Table (4.4): Participants' Feedback on the Application of Safety Measures

Survey questions	Survey responses n (%)*			
	Regularly	Occasionally	If a problem Exists	Not at all
How often is a review of the radiological protocols in your health care center?	6 (12.24%)	6 (12.24%)	27 (55.1%)	10 (20.4%)
How often are patient exposures compared with DRL or exposure in other centers?	7 (14.28%)	9 (18.36%)	6 (12.24%)	7 (55.1%)
Are quality control checks on x-ray imaging equipment performed?	9 (18.36%)	7 (14.28%)	27 (55.1%)	6 (12.24%)

How often do you perform reject analysis on radiographic images?	22 (44.8%)	21 (42.85%)	6 (12.24%)	0 (0%)
How often are medical physicists/RAD protection experts involved in your practice to assure safety?	8 (16.32%)	11 (22.45%)	14 (28.57%)	16 (32.65%)
How often do you use personal dosimeters and keep track of your doses?	44 (89.8%)	4 (8.16%)	1 (2%)	0 (0%)
How often is radiation leakage testing performed in your department?	2 (4.08%)	3 (6.12%)	31 (63.26%)	13 (26.5%)
How often do you receive training courses in r receive radiation protection?	21 (42.8%)	18 (36.73%)	5 (10.2%)	5 (10.2%)
How often do you use the personal radiation device when on duty?	45 (91.8%)	2 (4.08%)	0 (0%)	2 (4.08%)
How often do you receive updated safety measurements from the safety officers?	27 (55.1%)	6 (12.24%)	4 (8.16%)	12 (24.4%)
How often do you track your radiation monitoring device readings?	42 (85.7%)	5 (10.2%)	1 (2%)	1 (2%)

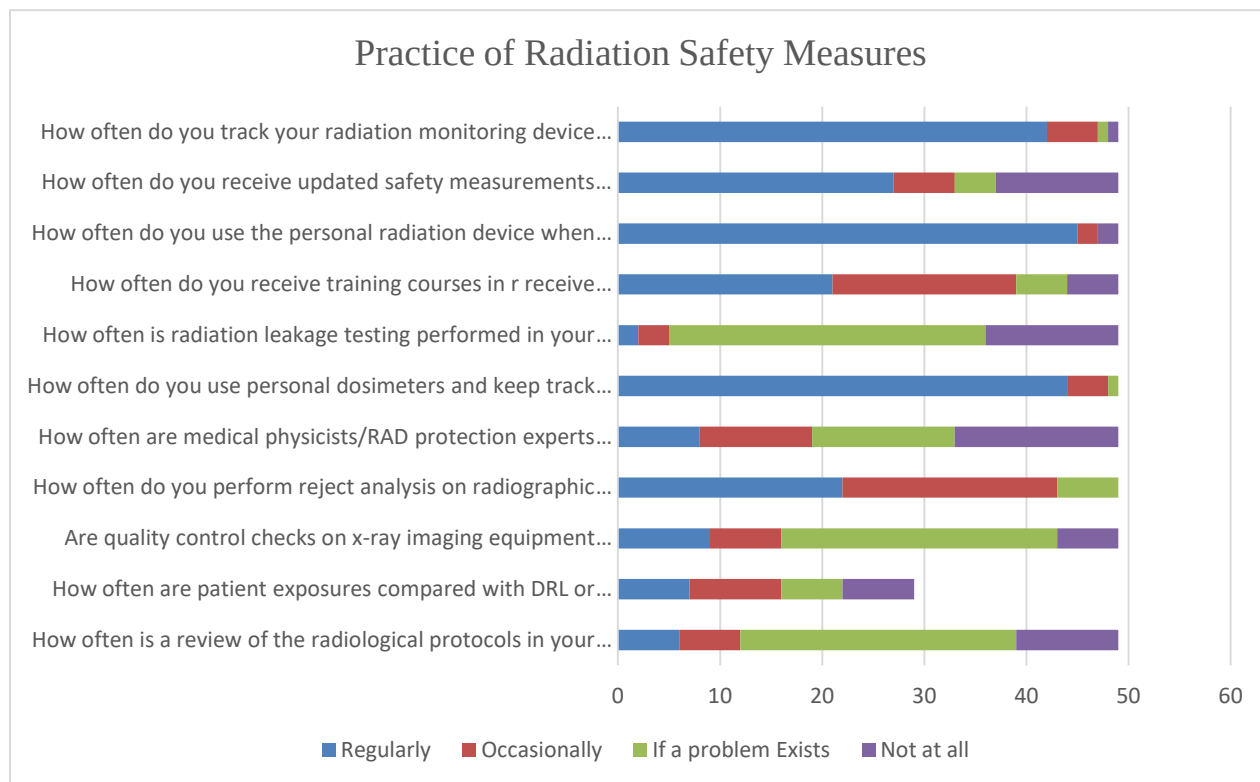


Figure (4.4): Participants' Feedback on the Application of Safety Measures

The survey results shown in Table 4.4 and Figure 4.4 revealed a mixed level of attitude and awareness of the application of radiation safety among radiological staff. While most respondents (83.3%) showed high awareness and attitude toward radiation safety, the participants' overall perspectives toward applying these regulations were relatively low (60.2%). These areas include:

- 55% of respondents believe such revisions only occur when a problem exists, and 20% have no idea if such revisions ever occur.
- (55%) do not know the procedures for revising patients' exposures Compared to local and international dose reference levels
- 55% of respondents stated that QC tests are only done when a problem exists rather than being conducted regularly.

The respondents' commitment towards attending radiation safety training courses and workshops is relatively low (60%); however, areas where respondents' commitment towards safety measures was positive include:

- 87.74% of respondents reported performing rejected analysis on bad-quality radiographic images at least occasionally.
- 89.79% track their personal dose readings and reports.
- 91.83% of respondents regularly wear personal dosimeters.
- 85.71% of respondents track receiving reports on their radiation monitoring device readings regularly or occasionally.

(D) Attitude toward Practicing Radiation Safety Measures

The survey results in Table 4.5 displayed participants' good practices and adherence to the radiation protection measures.

Table (4.5): Participants' Attitude toward Radiation Safety Measures.

Survey questions	Survey responses n (%)*			
	Regularly	Occasionally	If applicable	Not at all
Do you explain the radiology exam instructions to the patient before the exam?	41 (83.7%)	2 (4.1%)	6 (12.2%)	0
Do you check the patient ID, take the patient history, and match it before exposure?	49 (100%)	0	0	0
Do you explain the radiology procedure to the patient before starting it?	45 (91.8%)	1 (2%)	3 (6.2%)	0
Do you apply lead shielding for protection when imaging patients?	49 (100%)	0	0	0

Do you instruct the accompanying relatives or health care personnel to evacuate the X-ray room before commencing the procedure?	49 (100%)	0	0	0
Do you wear the suitable protective lead apron when you perform x-ray procedures?	33 (67.3%)	0	13 (26.5%)	3 (6.2%)
Do you close the imaging room and control area doors before starting the x-ray procedure?	40 (81.7%)	8 (16.3%)	1 (2%)	0
Do you follow the safe distance parameters when operating the X-ray systems?	46 (93.9%)	2 (4.1%)	1 (2%)	0
Do you apply protection to the patient's relative whenever needed to restrain or accompany the patient during the X-ray procedure?	49 (100%)	0	0	0

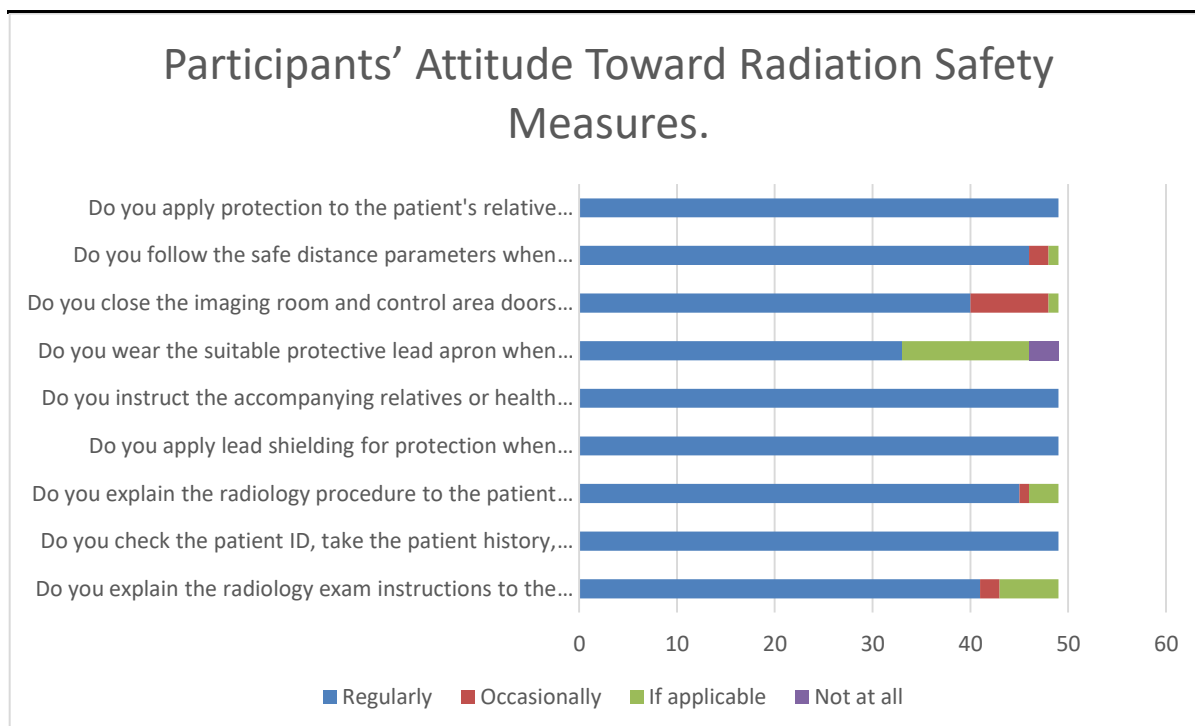


Figure (4.5): Participants' Attitude toward Radiation Safety Measures.

Key findings

- 100% of respondents always check the patient's ID, take the patient's history, and crossmatch it with the doctor's clinical indication input at the X-ray request.
- 100% of respondents always apply lead shielding protection to the patient's relatives/s whenever needed, instruct the accompanying relatives and healthcare workers to evacuate the X-ray room before commencing the procedure, and apply lead shielding for protection during the examination period.
- 91.8% of respondents briefly explained the radiology procedure to the patient before starting the procedure.
- 93.9% of respondents follow the safe distance parameters when operating the X-ray system.
- 97.9% of respondents always close the radiography main door and the control area's door before starting the procedure.
- 93.9% of respondents wear a suitable protective lead apron when performing X-ray procedures.

(E) Visual Inspection: Availability of Safety Devices, Personnel, and Safety Policies

The results of the visual inspection concerning the availability of radiation safety resources in the radiology departments are shown in Table 4.6. The observations were translated into percentages to measure the availability of radiation safety resources.

Table (4.6): Visual Inspection of the Availability of Radiation Safety Devices,

Personnel, and Policies

Items	Al Nuaim	Al Kuwait	Hamad Kanoo	Mohammed Kanoo	Yousif Engineer	Sh. Jaber Al Sabah	Budaiya
Gonads lead shield	✓	✓	✓	✓	✓	✓	✓
Lead apron	✓	✓	✓	✓	✓	✓	✓
Thyroid lead shield	✓	×	×	×	×	×	×
Lead barrier	✓	×	✓	✓	×	×	×
Breast shield	×	×	×	×	×	×	×
Lead hanging curtain	✓	×	×	×	×	×	×
Eye goggles shield	×	×	×	×	×	×	×
Lead gloves	×	×	×	×	×	×	×
Radiation caution indicator lights	✓	✓	✓	✓	✓	✓	✓
Assigned radiation safety officer	✓	×	×	×	×	×	×
Radiation safety policies and copies of the radiation survey report	×	×	✓	×	×	✓	×

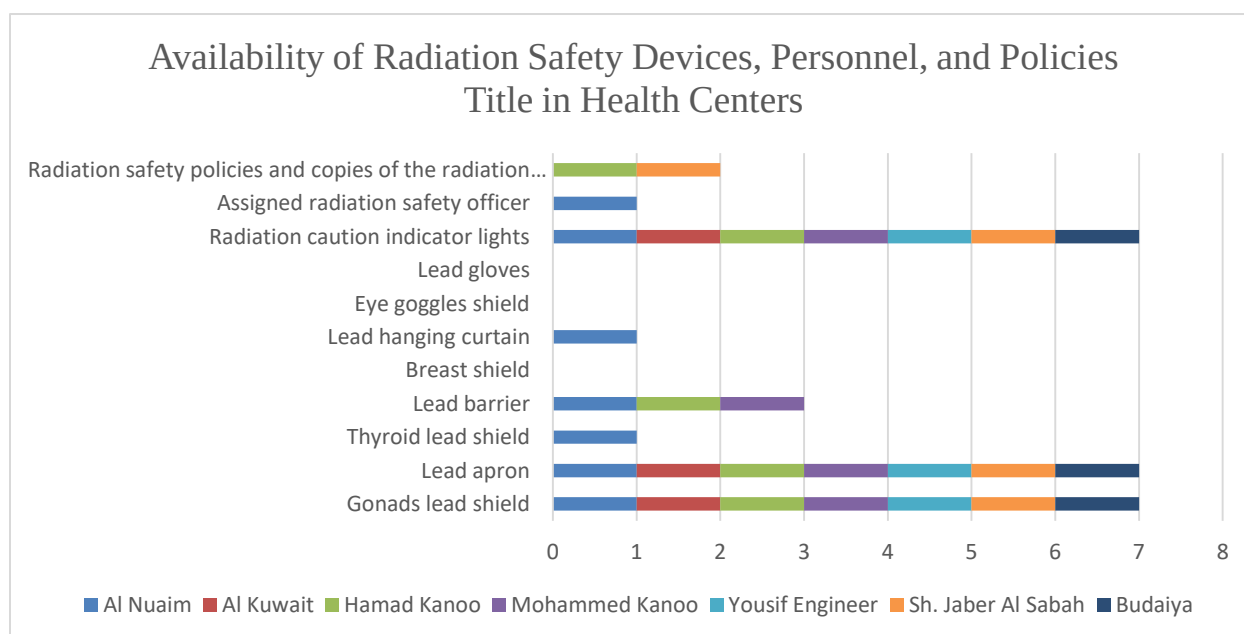


Figure (4.6): Visual Inspection of the Availability of Radiation Safety Devices, Personnel, and Policies

Results key findings:-

Personal Protective Equipment (PPE)

- Gonad lead shields and lead aprons are 100% available at all HCs.
- Thyroid shields, breast shields, eye goggles, and lead gloves are all absent in all radiography rooms at these HCs.
- Wall-fixed lead barrier extensions were provided at Al-Nuaim, Hamad Kanoo, and Mohammed Jasim Kanoo HCs.
- Lead-hanging curtains are absent in all radiography rooms except for Al-Nuaim HC.

Radiation Safety Personnel and Policies

- Clear radiation safety policies were found at Hamad Kanoo and Sh. Jaber Al-Sabah only.
- An assigned radiation safety officer can only be found in Al-Nuaim HC.
- Quality control tests are not conducted at any of the HC radiology departments.

(F) Visual inspection of radiology room design and equipment

The visual inspection findings to assess the design and equipment of the radiography rooms at the selected HCs in Bahrain are shown in Table 4.7 and reveal the following key findings:

Room Design

- All radiography rooms are adequately sized and well-protected with structural shielding.
- The number of entry doors is kept to a minimum.
- Glass windows are at least 2 meters above the floor level.

- Placing the table, chest standing wall, generator, and control panel is convenient and safe.
- The X-ray unit is ideally located.
- All doors are provided with visible controlled area warning signs and live radiation exposure warning signs.

Equipment status

- All X-ray machines are specifically designed for general radiography.
- All X-ray machines have basic adjustable diaphragms and proper exposure-centering light beams.
- Beam absorbers are provided behind the chest, standing bucky at all radiography rooms.

Table (4.7): Visual Inspection Results of Radiology Room.

Items	Al Nuaim	Al Kuwait	Hamad Kanoo	Moh. Kanoo	Yousif Engineer	Sh. Jaber Al Sabah	Budaiya
Is the X-ray room of adequate size, and well-protected?	✓	✓	✓	✓	✓	✓	✓
Are doors protected, and are all windows at least 2 meters above the outside ground level?	✓	✓	✓	✓	✓	✓	✓
Is the layout of equipment convenient and consistent with mechanical and electrical safety?	✓	✓	✓	✓	✓	✓	✓
Is a warning sign provided outside and signs light up when the X-ray tube is energized?	✓	✓	✓	×	✓	×	✓
Has the control panel sufficient protection in the form of a lead-lined cubicle having lead glass windows giving a clear view of the room?	✓	✓	✓	✓	×	✓	✓

Is the main X-ray beam usually directed away from the doors, the patient waiting room, and the control panel?	✓	✓	✓	✓	✓	✓	✓
Is a beam absorber provided behind the chest stand?	✓	✓	✓	✓	✓	✓	✓
Are adjustable diaphragms or a complete set of cones provided to define the X-ray beam?	✓	✓	✓	✓	✓	✓	✓
Are the grids displayed in good condition?	✓	✓	✓	✓	×	✓	×

Non-Conformities

- Two non-functional caution lights were found at Mohammed Jasim Kanoo and Sh. Jaber Al-Sabah Healthcare Centers.
- The control panel at Al-Kuwait HC has a small window glass embedded at the staff's main door, giving slight visual difficulty while standing at the control panel during the exposure time.
- The overall quality of X-ray images was inadequate and somewhat suboptimal at the Yousif Engineer and Budaiya centers.
- Overall, the design and equipment of the radiography rooms at HCs in Bahrain are generally good. However, some non-conformities need to be addressed.

Part (3): Radiation Leakage Measurements

(A) Radiation leakage measurements (M. Jasim Kanoo HC)

Tables 4.8 and 4.9 present the instant dose and TLD readings within the radiography room at Mohammed Jasim Kanoo Health Center, respectively.

Table (4.8): TLD Readings at the Control Panel (Mohamed Jasim Kanoo HC).

Health Center	Deep	Shallow	Unit
Moh'd Jassim Kanoo	0.02	0.06	mSv/2 weeks
	0.52	1.56	mSv/y

Table (4.9): Instant Dose Readings (Mohamed J. Kanoo HC.).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading ($\mu\text{Sv/procedure}$)
Chest	Standing Chest wall	Direct contact with the glass window	0.02
Ankle	On table		0.04
Chest	Standing Chest wall		0.10
Chest	Standing Chest wall	At the control panel	0.18
Foot	On table		0.08
Chest	Standing Chest wall		0.31
Ankle	On table	Behind the main door/waiting area	0.11
Foot	On table		0.10
Chest	Standing Chest wall	The wall behind the standing Bucky	0.09
Abdomen	On table		0.13

Key Findings

I. Thermo-luminescent Dosimeters Readings and Findings:

- The TLD readings were obtained at the control panel's area in Mohammed Jasim Kanoo HC to assess the occupational radiation exposure of radiological staff. The deep and shallow dose equivalent readings were 0.02 and 0.06 mSv/2 weeks, respectively. When converted to annual dose equivalents, these values were 0.52 and 1.56 mSv/y, respectively.

II. Instant Dosimeter Reading Findings:

- The highest dose was measured in the control panel's area.
- The dose rate detected at the direct glass window reflects well on its protection factor.

- The chest X-ray was lower in reading compared to the foot X-ray despite the big difference in exposure factors of both procedures.
- Readings were detected behind the main door and the wall behind the chest stand. However, all readings are deemed insignificant.

(B) Radiation Leakage Measurements (Budaiya HC)

Table (4.10): TLD Readings at the Control Panel (Budaiya HC.).

Health Center	Deep	Shallow	Unit
Budaiya	0.04	0.07	mSv/2 weeks
	1.04	1.82	mSv/y

Table (4.11): The Instant Dose Readings (Budaiya HC.).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading (μ Sv/procedure)
Chest	Standing Chest wall	The wall behind the standing Bucky	0.13
Lumber	On table		0.12
Hand	On table	Direct contact with the glass window	0.07
Nasal bone	On table		0.07
Chest	Standing Chest wall		0.09
Hand	On table	At the control panel	0.11
Chest	Standing Chest wall		0.16
Nasal bone	Standing Chest wall	Behind the main door/waiting area	0.07
Chest	Standing Chest wall		0.15
Chest	Standing Chest wall		0.11

Tables 4.10 and 4.11, respectively, present the Instant dose and TLD readings within the radiography room at Budaiya Health Center and reveal the following key findings:-

I. Thermoluminescent Dosimeters Readings and Findings:

- TLD readings at the control panel showed deep and shallow dose equivalents of 0.04 mSv/2 weeks and 0.07 mSv/2 weeks, respectively. Annual dose estimates were calculated to be 1.04 mSv for deep and 1.82 μ Sv for shallow doses. While the deep dose estimate was double that of Mohammed Jasim Kanoo HC, all radiation dose measurements remained well below the permissible limits for occupational radiation exposure.

II. Instant Dosimeter Reading Findings:

- Radiation leakage in the radiography unit is minimal, with the lowest readings measured at direct contact with the control panel's protective glass window (0.08 μ Sv).
- Readings were also comparable behind the standing bucky wall for chest and lumbar x-rays (0.13 μ Sv and 0.12 μ Sv, respectively).
- Higher readings are also considered below the acceptable limit of 0.2 μ Sv were observed behind the waiting area's main door (0.11 μ Sv) and at the control panel (0.16 μ Sv), likely due to their distance from the X-ray tube.
- Radiographic procedures with lower exposure factors, such as wrist and nasal bone X-rays, resulted in correspondingly lower radiation dose readings (0.05 μ Sv and 0.07 μ Sv, respectively).

(C) Radiation Leakage Measurements (Hamad Kanoo HC)

Table (4.12): TLD Readings at the Control Panel (Hamad Kanoo HC.).

Health Center	Deep	Shallow	Unit
Hamad Kanoo	0.01	0.05	mSv/2 weeks
	0.26	1.3	mSv/y

Table (4.13): The Instant Dose Readings (Hamad Kanoo HC.).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading ($\mu\text{Sv}/\text{procedure}$)
Chest	Standing Chest wall	Direct contact with the glass window	0.06
Tibia and Fibula	On table		0.09
Foot	On table		0.06
Chest	Standing Chest wall	At the control panel	0.13
Calcaneum	On table		0.20
Hand and Wrist			0.10
Thoracic Spine	On table	The wall behind the standing Bucky	0.05
Chest	Standing Chest wall		0.07
Chest	Standing Chest wall	Behind the main door/waiting area	0.15
Calcaneum	On table		0.11
Foot	On table		0.16

Tables 4.12 and 4.13, respectively, present the instant dose and TLD readings within the radiography room at Hamad Kanoo Health Center and reveal the following key findings:-

I. Thermoluminescent Dosimeters Readings and Findings:

- The results of the TLD readings at the control panel area of the radiography unit showed minimal radiation exposure, with deep and shallow dose equivalents of 0.01 mSv/2 weeks and 0.05 mSv/2 weeks, respectively. These values correspond to annual estimated doses of 0.23 mSv/y for deep and 1.3 $\mu\text{Sv}/\text{y}$ for shallow doses.

II. Instant Dosimeters Readings and Findings:

- Radiation leakage in the radiography unit is minimal, with the lowest readings measured at direct contact with the control panel's protective glass window (0.06 μSv).
- Lead lining protection in the radiography unit is effective in minimizing radiation exposure, as evidenced by the low readings obtained for extremities imaging (0.09 μSv and 0.06 μSv) and chest x-rays (0.06 μSv and 0.05 μSv).
- Readings behind the patients' waiting area's main door (0.14 μSv) and at the control panel (0.14 μSv)
- These findings indicate occupational radiation exposure levels are well below permissible limits, which should not exceed 0.2 μSv .

(D) Radiation Leakage Measurements (Al-Nuaim HC)

Tables 4.14 and 4.15 present the TLD and Instant dose readings within the radiography room at Al-Nuaim Health Center.

Table (4.14): TLD Readings at the Control Panel (Al-Nuaim HC).

Health Center	Deep	Shallow	Unit
Al-Nuaim	M	0.02	mSv/2 weeks
	M	0.52	mSv/y

Table (4.15): The Instant Dose Readings (Al-Nuaim HC).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading (μSv/procedure)
Chest	Standing Chest wall	Direct contact with the glass window	0.06
Thumb	On table		0.09
Knee	On table		0.08
Chest	Standing Chest wall		0.08
Chest	Standing Chest wall	The wall behind the standing Bucky	0.05
Calcaneum	On table		0.09
Foot	On table		0.08
Hand	Standing Chest wall		0.04
Chest	Standing Chest wall	At the control panel	0.19
Lumbar spine	On table		0.13
Knee	On table		0.11
Chest	Standing Chest wall		0.13

Key findings:-**I. Thermoluminescent Dosimeters Readings and Findings:**

- The results of TLD revealed minimal radiation exposure, with a deep dose equivalent of either too low to be measured or approximately one millirem (mrem) during the monitoring period. The shallow dose equivalent was measured at 0.02 mSv/2 weeks, corresponding to an estimated annual dose

of 0.52 mSv/year. These findings suggest that the radiography unit at the healthcare center is operating safely and effectively, with minimal risk of radiation exposure to staff and patients.

II. Instant Dosimeters Readings and Findings:

- Minimal, with the lowest readings measured at direct contact with the protective glass window (0.0775 μ Sv).
- Lead lining protection in the radiography unit effectively minimizes radiation exposure, as evidenced by the low readings for various radiographic procedures.
- Relatively high readings but within limits were observed behind the patient's entry door (0.19 μ Sv) and the wall behind the chest stand wall (0.17 μ Sv) during chest x-rays when using the standing bucky.
- These reported dose values prove that radiation exposure levels remain below permissible limits.

(E) Radiation Leakage Measurements (Al-Kuwait HC)

Tables 4.16 and 4.17 present the TLD instant and dose readings within the radiography room at Al-Kuwait Health Center, respectively.

Table (4.16): TLD Readings at the Control Panel (Al-Kuwait HC.).

Health Center	Deep	Shallow	Unit
Al-Kuwait	M	0.02	mSv/2 weeks
	M	0.52	mSv/y

Table (4.17): The Instant Dose Readings (Al-Kuwait HC.).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading ($\mu\text{Sv/procedure}$)
Chest	Standing Chest wall	Direct contact with the glass window	0.15
Tibia and Fibula	On table		0.10
1st Toe	On table		0.07
Chest	Standing Chest wall	The wall behind the standing Bucky	0.22
Lumbar Spine	On table		0.14
Wrist	On table	At the control panel	0.09
Lumbar Spine	On table		0.14
Chest	Standing Chest wall		0.20
Thoracic Spine	On table	Behind the main door/waiting area	0.10
Chest	Standing Chest wall		0.10
Chest	Standing Chest wall	Direct contact with the glass window	0.15

Key findings:-**I. Thermoluminescent Dosimeters Readings and Findings:**

- The TLD readings measured at the control panel were precisely the same as Al-Nuaim's, suggesting that the control panel is a good location. Deep dose readings during the monitoring period were either too low to be measured or approximately one millirem (mrem), a very low radiation dose and well below the recommended dose limit. Shallow dose was measured at 0.02

mSv/2 weeks, estimated at 0.52 mSv/year, displaying a low radiation dose and well below the recommended annual dose limit. The two methods of radiation dose readings prove reassuring and indicate that radiological staff are not being exposed to high radiation levels.

II. Instant Dosimeters Readings and Findings:

- Radiation leakage is minimal, with the lowest readings measured directly with the protective glass window (0.0775 μ Sv).
- Lead lining protection effectively minimizes radiation exposure, as evidenced by the low readings for various radiographic procedures.
- Occupational radiation exposure levels, even at the locations with higher readings, remain well below permissible limits.

(F) Radiation leakage measurements (Yousif Engineer HC)

Tables 4.18 and 4.19 present the Instant dose and TLD readings within the Yousif Engineer Health Center radiography room.

Table (4.18): TLD Readings at the Control Panel (Yousif Engineer HC.).

Health Center	Deep	Shallow	Unit
Yousif Engineer	M	0.03	mSv/2 weeks
	M	0.53	mSv/y

Table (4.19): The Instant Dose Readings (Yousif Engineer HC.).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading ($\mu\text{Sv/procedure}$)
Hand	On table	Direct contact with the glass window	0.03
Knee	On table		0.05
Chest	Standing Chest wall	At the control panel	0.13
Cervical Spine	Standing Chest wall		0.06
Foot	On table		0.10
Cervical Spine	Standing Chest wall	Behind the main door/waiting area	0.10
Hand	On table		0.07
Foot	On table		0.11
Chest	Standing Chest wall	The wall behind the standing Bucky	0.06
Knee	On table		0.11
Hand	On table	Direct contact with the glass window	0.03

Key findings:**I. Thermoluminescent Dosimeters Readings and Findings:**

- TLD readings measured at the control panel area revealed Deep dose reading was either too low to be measured or approximately one millirem (mrem), while a slightly higher shallow dose equivalent was measured at 0.03 mSv/2 weeks, estimated at 0.53 mSv/year. These findings are similar to the readings

observed in Al-Nuaim HC and Al-Kuwait and suggest that the radiography unit at the healthcare center is operating safely and effectively, with minimal risk of radiation exposure to staff and patients.

II. Instant Dosimeters Readings and Findings:

- The highest readings were measured at the control panel, with an average of 0.0967 μSv .
- Lower readings were measured behind the waiting area's main door and the wall behind the chest stand wall, with an average of 0.096 μSv .
- The average radiation dose was 0.04 μSv at direct contact with the glass window.
- The average radiation dose reading behind the waiting area's main door is 0.096 μSv .
- The average radiation dose reading during chest and spine X-ray procedures is 0.08 μSv .

(G) Radiation leakage measurements (Sh. Jaber Al-Sabah HC)

Tables 4.20 and 4.21 present the TLD and Instant dose readings within the radiography room at Sh. Jaber Al-Sabah Health Center.

Table (4.20): TLD Readings at the Control Panel (Sh. Jaber Al-Sabah HC.).

Health Center	Deep	Shallow	Unit
Sh. Jaber Al-Sabah	M	0.02	mSv/2 weeks
	M	0.52	mSv/y

Table (4.21): The Instant Dose Readings (Sh. Jaber Al-Sabah HC.).

X-ray procedure	X-ray tube location	Measurement location	Instant radiation dosimeter reading ($\mu\text{Sv/procedure}$)
Chest	Standing Chest wall	Direct contact with the glass window	0.05
Elbow	On table		0.04
Chest	On table	At the control panel	0.02
Chest	Standing Chest wall		0.08
Chest	On table		0.03
Chest	Standing Chest wall	The wall behind the standing Bucky	0.11
Finger	On table		0.02
Wrist	On table	Behind the main door/waiting area	0.01
Chest	Standing Chest wall		0.07
Chest	On table		0.02
Chest	Standing Chest wall	Direct contact with the glass window	0.05

Key findings:**I. Thermoluminescent Dosimeters Reading Findings:**

- TLD readings measured at the control panel area were identical to those measured at Al-Nuaim HC and Al-Kuwait HC. The deep dose readings had registered readings that were either too low to be measured or approximately one millirem (mrem). The shallow dose was measured at 0.02 mSv/2 weeks, estimated at 0.52 mSv/year, which is low and well below the recommended.

annual dose limit, suggesting that the control panel is well-designed and adequately protected.

II. Instant Dosimeters Readings and Findings:

- Average radiation dose reading at direct contact with the protective glass window: 0.045 μSv .
- The average radiation dose reading at the control panel station for pediatric chest X-rays over the table is 0.025 μSv while measuring 0.08 μSv for adult chest X-rays in the erect position.
- Average radiation dose reading at the wall behind the chest wall for exposures taken at the chest stand wall: 0.11 μSv and 0.02 μSv for exposures taken over the table:
- Average radiation dose reading at the waiting area's main door for exposures at the chest stand wall: 0.07 μSv .

Part (IV): Hypotheses Testing

This study aims to evaluate the radiology department's radiation safety measures in selected health centers, identify the areas for improvement, and formulate recommendations following the regularity standards, starting with assessing the radiological staff's awareness of radiation protection working in healthcare radiology departments in Bahrain. This objective was further investigated based on three main fields involved with working in such a diagnostic radiologic environment, including radiological staff's knowledge, attitude, and practices toward applying radiation safety and protection policies. The current study also involves assessing the radiation safety measures, setups, and recording of overall detectable ionized radiation in the working environment.

during actual radiographic examinations, cross-examining the results against the permissible dose rate and comparing it with the ICRP recommendations. Two hypotheses were set to answer the research questions and formulated in null and alternative forms in tune with the present study.

The null hypothesis states that The setup and application of radiation safety measures in the radiology departments of the selected health centers in Bahrain are sufficient and up to the established recommended standards. At the same time, the **alternative predicts that** the setup and application of radiation safety measures in the radiology departments of the selected health centers in Bahrain are insufficient and need improvement to fulfill the established recommended standards.

5.7.1 Results and Decision of Hypothesis Testing:

As for hypothesis testing, researchers usually choose between the One-Sample t-test, which belongs to the family of parametric statistics, and the Wilcoxon Signed Ranks (WSR) test, which belongs to the family of non-parametric, and the decision depends on the “normality” of our data. For normality testing, The Shapiro-Wilk test was used to assess normality, with the additional support of histograms to overcome potential p-value inflation due to small sample size.". It was concluded that the data of all listed variables are not typical. Therefore, a non-parametric (WSR) test will be used for hypothesis testing. Moreover, hypotheses that concern the study sample's awareness, attitude, and practice attributes, as well as percentage statistics, were used to summarize the scores and support statistical testing. Hypothesis testing was used to determine whether the observed results were statistically significant.

This is because we have established that our data are not normally distributed, meaning they might contain some extreme values (very high or very low) that could bias the mean; however, the median in these cases is much more robust. Based on median selection, the Wilcoxon Signed-Rank (WSR) test will be used to answer the research hypotheses.

The results of this study present mixed findings regarding the setup and application of radiation safety measures in the selected health centers. While there is high awareness of regulations and satisfactory adherence to certain practices, there are also discrepancies in the application of some other safety measures, such as the presence of equipment and non-compliance with policies. For dose measurements, as shown in Tables 4.22 and 4.23, although the overall results suggest that radiation exposure levels for staff are generally low and within acceptable limits, there are some variations in instant dose readings at specific locations. However, some areas require improvement.

Table (4.22): Significance of Instant Dose Measurements

Mean	SD	Median	H ₀	H ₀ Testing	H _a	H _a Testing	Remark
0.86	0.47	0.83	Median > 0	0.000*	Median > 4	1.000	Significant

Table (4.23): Significance of TLD Dose Measurements

Sample Type	Mean	SD	Median	H ₀	H ₀ Testing	H _a	H _a Testing	Remark
Deep	0.26	0.40	0.00	Median > 0	0.054	Median > 4	0.992	Significant
Shallow	0.93	0.61	0.52	Median > 0	0.009*	Median > 4	0.991	Significant

Based on the obtained evidence and analysis of results, the null hypothesis of this study cannot be fully supported; this is because while some aspects of safety measures are adequate, others require improvement. The lack of some equipment and practice variations support the alternative hypothesis that the setup and application of radiation safety measures in the investigated radiology department are inadequate in some areas and require improvement to comply with the recommended standards.

Chapter V

Discussion

DISCUSSION

This chapter discusses the thesis results and provides an interpretation of these findings besides concluding and summarizing the main points of the discussion by endorsing the significance of the thesis research. Furthermore, the chapter will also discuss the study limitations and directions for future research on the same topic.

5.1 Participants' Socio-demographic Data

The number of females involved in this study aligns with the composition of the Bahrainis' labor forces in the health sector. Records of NHRA on lists of licensed allied health professionals at radiology departments at the Ministry of Health, governmental hospitals, and private health sector hospitals and clinics showcased that most workers were females (NHRA, 2022). As for age groups, our results indicate that the radiological staff population in HC is young, which was consistent and fits the overall feature observed in respondents' years of experience. These findings draw special attention to investigating the pregnancy policy for radiology female workers among these centers, as radiation exposure during pregnancy can pose severe risks to the developing fetus.

5.2 Awareness of the availability of radiation safety devices, personnel, and policies

As stated by Morgan, J. P., & Konrath, G. (2021), radiation safety measures are a critical aspect of radiology practice, as radiological workers are exposed to ionizing radiation, which can pose health risks if not adequately managed, one of the critical factors that contribute to effective radiation safety practices is the availability of adequate radiation personal protective equipment (PPE) and written guidelines. Most participants in this study

(94.4%) reported that radiation protective devices, such as lead aprons, thyroid shields, and eye goggles, were available in their radiology departments. However, some items, such as breast shields, were less readily available, with only 44.4% of participants reporting their availability. Participants also reported high awareness of written radiation safety guidelines, with 98.9% indicating they were available in their departments. These guidelines covered various topics, including radiation safety principles, equipment operation, and emergency procedures. These findings suggest that radiology departments in the studied health centers in Bahrain have good radiation protective equipment availability and written radiation safety guidelines; this is a positive finding, as it suggests that radiological staff have the resources to protect themselves from the harmful effects of ionizing radiation. However, there are some areas where improvement could be made. For example, the availability of some PPE items, such as breast shields, could be improved. Additionally, the researcher's observation that Quality Control (QC) tests were not being conducted regularly suggests that it requires special consideration as an essential element in radiation safety.

5.3 Awareness of Radiation Safety Regulations

The results of radiation safety awareness levels among radiological workers in healthcare centers revealed that most participants had an excellent general awareness level regarding radiation safety; this is likely due to the compulsory Continuing Medical Education (CME) system in place in Bahrain by NHRA, which requires all licensed health workers to undergo regular workshops related to their job description and practice. However, there are still some areas for improvement to maintain awareness levels. For example, one-third of participants were unaware that the RSO is

responsible for monitoring and improving radiation safety at the workplace. Additionally, 41% of participants were unaware of the impact of radiation regulations on motivating radiology workers to estimate patients' doses and compare these doses with the recommended dose reference levels. The feedback also highlights the importance of having a written radiation regulatory requirement that is easily accessible on estimating patient dose and applying radiation safety in any given situation. Therefore, improving radiology workers' knowledge about radiation safety as part of the KAP model should be adopted to guide the development and improvement of compliance with safety measures in radiology departments.

5.4 Practice of Radiation Safety Measures

Radiation safety measures practices among Radiology Staff indicate that most staff adhere to radiation safety regulations and practices at a commendable level where over 90% consistently demonstrate optimum practices in applying radiation safety measures; these findings are consistent with those of Adejumo et al. (2012), who investigated radiation safety practices among radiological workers in southwest Nigeria and revealed a high level of adherence to radiation safety regulations, attributing to the strict enforcement of national radiation protection guidelines and aligns with the principles of Sustainable Development Goal (SDG) 3, which emphasizes promoting healthy lives and well-being for all ages. However, the obtained results also identified areas for improvement related to discussing X-ray requests; the radiology request form is proved by the American College of Radiology (ACR, 2023) as a crucial tool to facilitate communication between the referring physician and the radiology staff, providing essential information to guide the X-ray examination and interpretation of results supporting the appropriate and safe use of X-rays

for diagnostic purposes without unnecessary radiation exposure. The results also revealed inconsistency in the use of lead aprons among participants, where some regularly wore lead aprons, while others only did so when directly exposed to radiation; this should be considered by emphasizing adhering to the guidelines.

Providing training and refresher courses to radiological staff on radiation safety regulations, procedures, and the importance of consistent adherence, as well as emphasizing the importance of effective patient communication, including discussing X-ray requests, providing detailed instructions, and addressing patient outcomes in addition to conducting regular audits of radiation safety practices and providing constructive feedback to radiological staff to identify areas for improvement and maintain high standards will prompt better safety outcomes.

5.5 Visual Inspection of Safety Measures & Requirements

5.5.1 Availability of Safety Devices, Personnel, and Safety Policies

The availability of personal protective equipment (PPE) in the observed radiology departments is concerning and proved by the feedback obtained from the participants' survey regarding the availability of radiation safety devices, personnel, and policies. The visual inspection revealed that while gonad lead shields and lead aprons are universally available, essential items like thyroid shields, breast shields, eye goggles, and lead gloves are absent. In addition, the availability of wall-fixed lead barrier extensions and lead hanging curtains is inconsistent across the HCs. While some HCs have these safety features, others lack them entirely. This inconsistency creates inconsistencies in radiation safety among the HCs. Furthermore, the results displayed a lack of assigned radiation safety officers (RSOs) in most HCs, besides the absence of regular equipment QC testing, highlighting a critical

gap in radiation safety management. The lack of some PPE is a significant safety concern, as it leaves radiological staff vulnerable to unnecessary radiation exposure; furthermore, QC testing and transparent policies with dedicated RSOs are essential for ensuring that radiation safety practices are implemented and maintained effectively (Poenaru & Badulescu, 2020).

5.5.2 Visual inspection of radiology room design and equipment

Ensuring the safety of patients, radiology workers, and the public is crucial when designing and shielding a radiography room. International organizations, like IAEA, WHO, and ILO, have emphasized the importance of having rooms with a size of 24 square meters. The visual inspection of the radiology rooms to assess compliance with safety standards regarding the design, components, and layout of the seven selected healthcare centers (HCs); this study's findings are consistent with a study of three radiology centers in Southeast Nigeria by Nkubli et al., (2017) published in the *Journal of Global Radiology*, where the X-ray rooms adhered to the recommended dimensions in compliance with the recommendations of the "Safety Code for Medical Diagnostic X-ray Equipment and Installations" manual issued by the Atomic Energy Regulatory Board (Board, 2001).

Furthermore, in line with the recommendations of Emi-Reynolds et al. (2012) and Esfahani and Cheraghi (2021), the presence of functioning caution lights and warning signs at all radio-diagnostic centers was checked. However, two caution lights were found to be out of order. The researcher notified the radiological staff at these radiology departments to report this issue and resolve it promptly. Unfortunately, despite previous requests for maintenance, no action has been taken. In addition, Al-Kuwait HC lacked a lead glass window, except for a small window on the door, resulting in a very narrow field of view for the radiological worker. It is

advisable to either install a larger glass window or extend an exposure cable near the main door to observe the patient's well-being, positioning, and compliance with instructions during the exam. Furthermore, suboptimal image quality was observed at Yousif Engineer and Budaiya HCs. This was attributed to conventional X-ray film radiography rather than digital radiography, which is employed in the other centers. Conventional X-ray films often degrade over time due to dirt accumulation and physical damage, and to address this issue, it is required that the facilities switch to Computed Radiography (CR) or Digital Radiography (DR), which offer additional technical advantages and safe practice (Ozcete et al., 2015).

To sum up, all these obtained findings suggest a generally positive relationship between knowledge, attitude, and practice. High levels of knowledge translated into positive attitudes towards safety measures. However, inconsistencies in practice highlight the need for further efforts to bridge the gap between knowledge and action. These results were proved by the overall visual inspection, which confirmed that the radiation safety integrity of all general X-ray radiography rooms is adequate and compliant with radiation safety regulations; furthermore, these findings were also evident by Al-Ghamdi et al. (2016) in a study that investigated the knowledge, attitude, and practice of radiation safety measures among 380 radiographers in various hospitals across Saudi Arabia. The study confirmed the interrelation between the knowledge, attitude, and practice of radiographers towards complying with the safety measures, besides highlighting the need for beset interventions, including refresher courses and improved access to resources, to bridge the gap between knowledge and practice and ensure optimal radiation safety in the radiology service

environment. However, the inconsistencies and remarks observed in this study should be considered to rectify any irregularities and ensure a safe and sustainable radio-diagnostic working environment for healthcare personnel and the public.

5.6 Radiation Leakage Measurements

Radiology departments utilize ionizing radiation, offering invaluable support for medical care in diagnosing diseases. However, the inherent risks of ionizing radiation exposure necessitate careful protection measures for staff and patients through regular measurements of radiation leaks to ensure optimal safety and prevent potential harm. Several factors can contribute to radiation leaks in radiology departments. The causes of these leaks include structural deficiencies in imaging rooms, equipment malfunctioning, and inadequate operational procedures (Zankl et al., 2019)

Many studies have investigated the impact of regular leak testing on radiation safety in radiology departments. It proved that measuring radiation leaks in radiology departments is one of the critical components of any given radiation safety program. They conclude that providing quantitative data on radiation levels and leak measurements will enable monitoring for leaks, identifying their sources, and implementing corrective measures by optimizing shielding, implementing additional safety measures, and prioritizing interventions that will end with better staff and patient safety and overall outcomes (Bari et al., 2015; Zira et al., 2020; Ovwasa et al., 2023).

Based on the radiation dosimeter measurements in this study, which was conducted at selected healthcare centers (HCs) in Bahrain, there appears to be minimal radiation leakage. These measurements are below the reference threshold established by the International Commission on Radiological

Protection (ICRP) in 2007.

This observation aligns with the radiation regulations set by the ICRP, which restricts the effective dose for occupational personnel to 20 mSv and imposes a restricted effective dose of 100 mSv over five years (Valentin, 2007; Wrixon, 2008).

The observed variations in measured doses during X-ray examinations in this study (ranging from 0.02 μ Sv to 0.31 μ Sv per procedure) are justifiable by the room layout, positioning, and angulation of the X-ray tube, patient body characteristics, type of examination exposure factors, and workload. Various studies have demonstrated the influence of these factors on background ambient radiation levels. For example, Wang et al. (2020) investigated how room layouts in radiology departments impact scattered radiation levels. Their findings highlighted that room size, wall material, and equipment placement significantly affect scattered radiation levels. Similarly, Dudfield et al. (2023) examined how X-ray beam angulations during chest radiography contribute to variations in scattered radiation levels. They concluded that proper tube positioning is crucial in minimizing radiation and dose-optimization. Additionally, a comprehensive article by Choi et al. (2019) delves into the impact of a patient's body structure on scattered radiation. It concludes that larger body sizes require exposure factors that increase radiation scatter.

Moreover, Kim et al. (2019) researched strategies to optimize exposure factors in radiography, focusing on adjusting how to minimize scatter while preserving image quality. Furthermore, Kumar et al. (2020) conducted a study demonstrating increased background radiation levels due to workload. Hence, it is crucial to consider these factors' influence on background radiation in radiology to optimize radiation safety practices and ensure the well-being of patients and staff.

To sum up, the result findings of radiation leakage in most cases across all investigated health centers in the HCs involved in this study were minimal. Generally, low radiation leak readings are evidence of this, confirmed throughout the facilities. Instant readings, both deep and shallow dose equivalent estimates, were consistently low, falling within acceptable limits and well below permissible levels. However, the overall results are positive areas for improvement as part of the continuous improvement plan to enhance radiology safety measures further and optimize patient and staff protection need to be considered. The essential elements for continuous safety improvement, as stated by Smith et al. (2018), include equipment maintenance, staff awareness and training, infrastructure monitoring, regular testing, data analysis, reporting, and record keeping. All these elements will help maintain a proactive approach to radiation safety to ensure a safe environment for staff and patients while providing high-quality diagnostic and treatment services.

Chapter VI

Conclusion, Limitations and Recommendations

CONCLUSION, Limitations, and Recommendations

6.1 Limitation:

This study is considered a foundation for conducting further research toward consistently assessing and improving radiology department safety measures with the sustainable development goals of safeguarding health and ensuring well-being. The researcher faced the challenge of a small sample size, which limited the study to radiology technologist staff. The study was also limited by the absence of radiation safety officers (RSO) in the investigated health centers to help in identifying and addressing radiation safety risks because testing of some safety measures requires specialized knowledge and expertise; this factor forced the researcher to cover certain safety measure areas with incomplete assessments of the areas that require RSO, such as tracking and comparing the patients and staff doses as well as checking the imaging equipment performance because the lack of regular QC testing can lead to undetected equipment malfunctions that might increase radiation exposure to patients and staff. The study is also associated with limited related or relevant literature at the local level and includes only seven health centers out of twenty-two because of the time limit.

6.2 Conclusion:

This study provides crucial data about radiation safety measures in the radiology department environment in selected health centers in Bahrain. The findings reveal a moderate correlation between the participants' perceptions of radiation safety resource availability and the actual availability of these resources. However, there are some notable discrepancies suggesting a need for efforts to maintain the shortage of some safety requirements, specifically the lack of QC equipment and testing protocols, the shortage of radiation

safety officers to monitor and support radiation safety practices, and the need for continuous training and updates on radiation safety for the radiology staff to improve the outcome.

Concerning the radiation leakage measurements, the findings of this study provide valuable information about the safety status of the tested radiology departments at the seven health centers regarding possible radiation leaks in the radiology-controlled areas. The measured doses revealed values below the accepted limit, indicating safe practice. However, the report could be strengthened by including a larger sample size, a more extended timeframe for TLD measurements, and a more detailed analysis and comparison of the results between all health centers in the Kingdom of Bahrain.

Based on these findings, the investigated radiology departments in the selected health centers were supported by radiological workers who are aware of and committed to radiation safety measures and practices. The tested health centers were equipped with the necessary safety measures. However, there is still room for improvement in the application of safety measures, particularly by emphasizing the appointment of radiation safety experts in these health centers, reviewing and publishing safety measures to staff, and establishing regular QC testing besides emphasizing staff outcome-based training. Filling these gaps and closing the loop in the required radiology safety measures isn't just a technical matter; it's a vital step toward achieving a more sustainable and equitable future, and by prioritizing radiation safety, we safeguard health, ensure well-being, promote responsible practices, and ultimately contribute to a thriving and sustainable world.

6.3 Recommendations:

Based on the current study's findings, the following recommendations are suggested to ensure effective radiology safety measures.

1. Appoint a dedicated Radiation Safety Officer (RSO) in each health center with expertise in radiation safety principles and regulations to conduct QC testing, ensure equipment performance, monitor patients' and staff's radiation doses, and address radiation safety risks. Limited expertise in radiation safety in radiology departments can lead to overlooked hazards and ineffective safety measures.
2. Review and regularly update the written policies and procedures to reflect best practices and regulatory changes while considering all aspects of radiation safety, including equipment operation, patient care, dose management, incident reporting, and emergency response.
3. Improve plans of providing ongoing training and education for all staff involved in radiological procedures, covering topics such as radiation safety principles, patient communication, and care, the concept of DRL, radiation protection techniques, equipment operation, and emergency response procedures with documentation of all training activities and maintaining records.
4. Improve the system for monitoring patient and staff radiation doses to identify trends and areas for improvement., besides overlooking and improving the dose optimization strategies.
5. Conduct further comprehensive studies concerning radiology departments' safety measures to include other healthcare centers and hospitals in Bahrain while considering the current study findings, limitations, and recommendations.

Chapter VII

Summary

SUMMARY

Radiation safety practices contribute to the sustainable development program by contributing to health and well-being by controlling exposure to ionizing radiation associated with radiology services. This Master's degree graduation thesis, entitled "Assessment of Radiation Safety Measures in the Radiology Work Environment at selected Public Health Centers in Bahrain," aimed to evaluate the radiology departments' radiation safety measures in selected health centers to identify areas for improvement and formulate recommendations as per the regularity standards.

The importance of this study arises from the idea that there is no previous similar study assessing radiology departments' work environment regarding safety measures in Bahrain. Hence, there is a need to investigate whether these safety measures comply with national and international standards and assess the awareness, attitude, and compliance level of radiology staff with these measures. The study displayed the status of radiation safety practices in the radiology department in selected healthcare centers and highlighted the areas for improvement and suggestions for further studies in this critical area of research; the study incorporates qualitative surveys to assess the awareness, attitudes, and practices of radiation safety measures among the radiology personnel, as well as a quantitative cross-sectional method to obtain data on dosimetry measurements to enhance the validity of assessing the radiation safety measures in the radiology work environment in health centers in Bahrain. The study results showed a statistically significant level of setup, awareness, and practices of radiation safety measures; however, areas for improvement were identified, and specific recommendations were formulated as a foundation for further comprehensive studies in Bahrain.

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Appendices

Appendix I

Visual Inspection Surveys

VISUAL INSPECTION SURVEY

Public Health Centers: _____

Radiology equipment available:

Section I: Availability of Radiation Safety Devices, Personnel, and Policies

Gonadal lead shields:

Available Not Available

Lead aprons:

Available Not Available

Lead barriers:

Available Not Available

Thyroid shields:

Available Not Available

Breast shields:

Available Not Available

Lead hanging curtain:

Available Not Available

Eye goggles shields:

Available Not Available

Lead gloves:

Available Not Available

Assigned Radiation Protection Officer:

Available Not Available

Safety instructions and restrictions for the safe operation of the X-ray equipment

Available Not Available

Section II: The Construction/ Protection Requirements of the Radiology Room(s)

Is the X-ray room adequate, and are the walls, floors, and ceiling protected?

Yes **No**

Are doors protected, and are all windows at least 2 meters above the outside ground level?

Yes **No**

Is the layout of equipment convenient and consistent with mechanical and electrical safety?

Yes **No**

Is a warning sign provided outside each door, and do all the signs light up when the X-ray tube is energized? (This should be tested by switching on the machine).

Yes **No**

Has the control panel sufficient protection in the form of a lead-lined cubicle having lead glass windows giving a clear view of the rest of the room?

Yes **No**

Is the main beam of X-rays usually directed away from the doors, the patient waiting room, and the control panel?

Yes **No**

Is a beam absorber provided behind the chest stand?

Yes **No**

Are adjustable diaphragms or a complete set of cones provided to define the X-ray beam?

Yes **No**

Are the grids used and in good condition? (A test exposure should reveal this).

Yes **No**

Appendix-II

Radiology Staff Surveys

RADIOLOGY STAFF SURVEY

Public Health Centers: _____

Dear participant :

- You are invited to participate in answering this survey, which is part of a thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Environmental Health in the Environment and Sustainable Development Master program at the University of Bahrain.
- Please note that all participants will remain anonymous, and their answers will be kept confidential and used for research purposes only.
- No impending risks or discomforts are involved in this survey; this study's results might be published later.
- You can accept or decline participation in this study or withdraw from it at any stage, regardless of your participatory decision, that will not affect you or your job.
- By choosing (YES, I Agree), you declare that you have read the above-stated information while you still have the right to withdraw at any stage of the survey.

YES, I Do Agree ☐ NO, I do not Agree. ☐

Section I: Socio-demographic information

1) Gender :

- a) Male
- b) Female

2) Age:

- a) 21-29
- b) 30-39
- c) 40-49
- d) +50

3) Occupation:

- a) Radiologist
- b) Radiologic Technologist
- c) Radiographer

4) Academic qualification:

- a) PhD
- b) M.Sc.
- c) B.Sc.
- d) Associate degree (AD)

5) Years of experience:

- a) 1-4
- b) 5-10
- c) 11-15
- d) +15

6) Place of Works, please specify _____

Section II: Impact of regulations on radiation safety

- Do you think certifying a radiology department will enhance safety and safety culture?
Yes No I Don't know.

- Do you think the radiology department staff should meet the qualifications and experience to improve radiation safety?
Yes No I Don't know.
- Do you think Assigning responsibility for radiation safety at the management level in each center will contribute to safety?
Yes No I Don't know.
- Do you think that it is required that each health care center should appoint/access radiation safety experts to monitor and improve levels of radiation safety?
Yes No I Don't know.
- Is the radiation safety regulation motivating you /your department to estimate patient doses and compare them with reference levels?
Yes No I Don't know.
- Do you think that consideration should be given to patient doses when identifying specifications for purchasing new equipment?
Yes No I Don't know.
- Do you think the requirements to perform regular QC tests on radiological equipment will affect your practice?
Yes No I Don't know.
- Do you think the regulatory requirement to optimize patient doses and keep records of patient doses influences radiation safety?
Yes No I Don't know.
- Do you think regulatory requirements should be strictly applied to have written protocols for radiological procedures?
Yes No I Don't know.
- Do you think a system for quickly obtaining information about the number of radiological procedures a patient has undertaken will improve safety?
Yes No I Don't know.
- Do you believe your radiology center aligns with the radiation safety requirements?
Yes No I Don't know.

Section III: Availability of radiation safety devices, personnel, and policies

- **Gonadal lead shields:**
Available Not Available I do not know.
- **Lead aprons:**
Available Not Available I do not know.
- **Lead barriers:**
Available Not Available I do not know.
- **Thyroid shields:**
Available Not Available I do not know.

- **Breast shields:**

Available	Not Available	I do not know.
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- **Radiation caution indication lights:**

Available	Not Available	I do not know.
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- **Lead hanging curtain:**

Available	Not Available	I do not know.
-----------	---------------	----------------

- **Eye goggles shields:**

Available	Not Available	I do not know.
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- **Lead gloves:**

Available	Not Available	I do not know.
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- **Assigned Radiation Protection Officer:**

Available	Not Available	I do not know.
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- **Clear radiation safety policies and copies of the radiation survey report**

Available	Not Available	I do not know.
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Section IV: Assessment of Radiation Safety Practice Level

- **How often is a review of your health care center's radiological procedures' protocols?**

Regularly	Occasionally	If a problem exists,	I do not know.
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- **How often are patients' exposures in your health care center compared with diagnostic reference levels or exposure in other centers?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **Are quality control checks on x-ray imaging equipment performed?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **How often is the reject analysis on bad-quality radiographic images performed?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **How often is a medical physicist/RAD protection expert involved in your practice to assure safety?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **How often do you use a personal dosimeter and keep track of your doses?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **How often is radiation leakage possible in your radiology department?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **How often do you participate in/receive training courses in radiation protection?**

Regularly	Occasionally	If a problem exists,	I do not know.
-----------	--------------	----------------------	----------------

- **How often do you use the personal radiation monitoring device when on duty?**
Regularly Occasionally If a problem exists, I do not know.
- **How often do you receive the updated measurements that should be taken into consideration by the safety officers?**
Regularly Occasionally If a problem exists, I do not know.
- **How often do you receive a detailed report on your radiation monitoring device readings?**
Regularly Occasionally If a problem exists, I do not know.

Section V: Attitude of Radiology Staff Toward Radiation Safety Practices:

- **Do you explain the radiological examination instructions to the patient before the exam?**
Regularly Occasionally If Applicable Not at all
- **Do you check the patient ID, take the patient history, and match it with the requested procedure before exposure?**
Regularly Occasionally If Applicable Not at all
- **Do you explain the radiology procedure to the patient before starting the procedure?**
Regularly Occasionally If Applicable Not at all
- **Do you apply lead shielding for protection when imaging patients?**
Regularly Occasionally If Applicable Not at all
- **Do you instruct the accompanying relatives or health care personnel to evacuate the X-ray room before commencing the procedure?**
Regularly Occasionally If Applicable Not at all
- **Do you wear a suitable protective lead apron when you perform x-ray procedures?**
Regularly Occasionally If Applicable Not at all
- **Do you close the imaging room and control area doors before starting the x-ray procedure?**
Regularly Occasionally If Applicable Not at all
- **Do you follow the safe distance parameters when operating the X-ray systems?**
Regularly Occasionally If Applicable Not at all
- **Do you apply protection to the patient's relative whenever needed to restrain or accompany the patient during the X-ray procedure?**
Regularly Occasionally If Applicable Not at all

Appendix-III

UOB Proposal Approval

الرسالة: م ع د / 3820/430
التاريخ: 13 يونيو 2021

الفاضل الأستاذ الدكتور محمد مصطفى محمد الحلو المحترم

عميد كلية العلوم

تحية طيبة وبعد،
قإنه وبناء على ما ورد في المادة (45) من نظام الدراسات العليا بجامعة البحرين، وبعد إطلاع
عمادة الدراسات العليا على خطابكم والوثائق المرفقة به بشأن تعيين مشرف وإقرار خطة أطروحة،
وموافقة مجلس الجامعة بقرار رقم (2021/244) بتاريخ 9 يونيو 2021،

نفيدكم علماً بأنه قد تمت الموافقة على عنوان الأطروحة والخطة المقدمة وتعيين

المشرف وذلك حسب الآتي:

بيانات الطالب:			
الاسم:	علي جعفر أحمد رستم	الرقم الجامعي:	20190189
الكلية:	العلوم	القسم الأكاديمي:	-
البرنامج:	ماجستير في البيئة والتنمية المستدامة		
عنوان الأطروحة	Assessment of radiation safety measures in the radiology work environment at the public health centers in Bahrain		
المعتمد:			
بيانات المشرف المعتمد:			
اسم	د. عصام الدين محمد	الرتبة العلمية:	استاذ مساعد
المشرف الحالي:	العلوم الصحية	القسم الأكاديمي:	العلوم الصحية
الكلية:	العلوم الصحية	القسم الأكاديمي:	المساعدة

* مستوفي لشروط المادة (44/ب) من نظام الدراسات العليا بجامعة البحرين.

وتفضلوا بقبول فائق التقدير والاحترام

دكتور محمد رضا فاكر
عميد الدراسات العليا والبحث العلمي

لمحة منه:

- ☒ عمادة القبول والتسجيل.
- ☒ لجنة الدراسات العليا بكلية العلوم.
- ☒ رئيس قسم العلوم الصحية المساعدة.

Appendix-IV

Participant Consent Form



Written Informed Consent Form

Title of Study:

Assessment of Radiation Safety Measures in the Radiology Work Environment at the Public Health Centers in Bahrain

Principal Investigator:

Ali Jaafar Ahmed Rustam (Email: 20190189@uob.edu.bh) Tel: (66376337)

Purpose of the Study:

This study aims to investigate the radiation safety measures in the radiation work environment in selected public health centers in the Kingdom of Bahrain to identify the status of these measures and the level of practice among radiology workers.

Procedures:

If you agree to participate in this study, you must complete the survey, including various questions about the subject.

Risks and Benefits:

There are no known risks associated with participating in this study. The potential benefits of participating in this study are that you will contribute to helping evaluate the status of radiology departments' safety measures in the selected health centers as a foundation for improvement plans for better staff and patient safety and overall radiology service outcomes.

Alternatives

You are not required to participate in this study. If you choose not to participate, there will be no adverse consequences.

Confidentiality:

All the data in this study will be kept confidential. Your name and other identifying information will not be used in any reports or publications.

Consent:

I have read and understood the information provided in this consent form. I agree to participate in this study.

[Signature of participant] _____ [Signature of investigator] _____ .Date: _____

Additional Information:

- You may withdraw from this study at any time without penalty.
- You have the right to ask questions about the study at any time.
- You have the right to be informed of the results of this study if you wish.
- Please contact the principal investigator if you have any questions about this study.

Thank you for considering participating in this study.

Appendix-V

MoH Approval



Date :	20 th December 2021
Proposal Title:	Assessment of radiation safety measures in the radiology work environment at the public health centers in Bahrain
Type of Study	Research
Name of Researcher submitting proposal:	Ali Jaafar Ahmed Sultan Yusuf Rustam

Reviewer's recommendation:

Accept	☒
Request modifications	☐
Reject	☐

Reviewer's Comments:

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Committee's recommendation:

Thank you for the efforts. Best of luck.

Signature: Head of the Research Committee Primary Health Care	Dr. Reham Ahmed Al-Garf 
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Signature: Core team Member	Dr. Adel Al-Sayyad 
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Appendix-VI

**Cover page, Abstract and
Summary in Arabic**

خلاصة الدراسة

السلامة الإشعاعية أمر بالغ الأهمية في مجال الأشعة بسبب احتمال وقوع ضرر من الإشعاع المؤين. وبانضمامها إلى بروتوكولات السلامة المعمول بها، يمكن لإدارات علم الأشعة أن تحمي المرضى وعلم الأشعة وغيرهم من المهنيين العاملين في مجال الرعاية الصحية من آثار الإشعاع المؤين. تهدف هذه الدراسة لإنشاء تقييماً لتدابير وممارسات السلامة الإشعاعية في سبعة مراكز صحية مختارة في مملكة البحرين. جمعت الدراسة بين الأساليب الكمية (قياسات تسرب الإشعاع) والأساليب النوعية (الدراسات الاستقصائية للموظفين) كمنهجية للبحث، وقد تم جمع البيانات في الفترة من 7 من مارس حتى 21 من مارس من العام 2022. كشفت نتائج هذه الدراسة عن مستوى عالٍ من الوعي (ن=41 ، 83.3 %) بين المشاركين فيما يتعلق بأهمية وأثر الأنظمة المتعلقة بالسلامة الإشعاعية، في حين أظهر 60.2 % استجابة إيجابية إزاء توافر الموارد وتطبيق اللوائح. وأبدى معظم المشاركين (ن=46 ، 93.9 %) وعياً وموقفاً إيجابياً تجاه ممارسة الوقاية من الإشعاع بينما تتفاوت الموارد المتاحة بين المراكز، مع وجود نقص ملحوظ في موظفي الحماية من الإشعاع واختبارات مراقبة الجودة فيما بين المراكز التي شملتها الدراسة. وبصفة عامة، كانت تسربات الإشعاعات في الحد الأدنى في جميع المراكز، وكانت حالات التعرض المهني المقدرة أقل بكثير من الحدود المسموح بها، حيث تراوحت بين 0.52-1.04 ملّي سيفرت/السنة إلى 1.3-1.82 ملّي سيفرت/السنة للعمق والضحلة على التوالي. لدى المراكز الصحية التي تمت دراستها في البحرين ممارسات جيدة في مجال السلامة الإشعاعية. تمت مقارنة جميع القراءات بحدود الجرعة العامة والمهنية الفعالة التي حددتها اللجنة الدولية للحماية من الإشعاع (ICRP) وهي 1 ملي سيفرت/عام و20 ملي سيفرت/عام على التوالي. بيد أنه يلزم إدخال تحسينات على توافر الموارد، والموظفين، واختبارات مراقبة الجودة، وبروتوكولات السلامة، وتدريب الموظفين. من القيود في الدراسة هي حجم العينة الصغير وعدم تواجد مسؤول السلامة الإشعاعية.

الكلمات الرئيسية: الأشعة، الإشعاع، البيئة، السلامة، التنمية المستدامة، المراكز الصحية

جامعة البحرين

كلية العلوم



برنامج التنمية المستدامة

تقييم تدابير السلامة من الإشعاع في بيئة عمل الأشعة في بمراكز الصحة العامة في البحرين

في إطار الاستيفاء الجزئي لمتطلبات الحصول على درجة ماجستير العلوم
في البيئة والتنمية المستدامة

تقديم

علي جعفر رستم

الرقم الجامعي: 20190189

إشراف

د. عصام الدين محمد

(أستاذ مساعد)

جامعة البحرين

مملكة البحرين

ديسمبر 2023