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Paper

Radiation Protection among South African Diagnostic Radiographers—A Mixed Method Study

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***Abstract*—Worldwide, radiographers' radiation protection practices vary. In South Africa, evidence of diagnostic radiographers' suboptimal radiation protection practices has been reported, but the reasons for these practices and suggestions to improve practices were lacking. Therefore, this study explored radiation protection among South African diagnostic radiographers. This study used an explanatory, sequential, mixed-method approach. Data were collected in three phases. Phase I, the quantitative phase, used an online questionnaire and respondents from Phase I interested in participating in Phase II, the qualitative phase, were interviewed, yielding 13 in-depth semi-structured telephone interviews. In Phase III, eight radiography managers co-constructed change strategies to optimize radiation protection in South Africa in two focus group interviews. Radiation protection was suboptimal despite diagnostic radiographers having a good attitude, subjective norm and perceived behavioral control toward radiation protection and optimal radiation protection knowledge. Varying attitudes to radiation protection, lack of resources, and support from radiography management and healthcare teams contributed to suboptimal radiation protection practices. Radiography managers suggested increasing radiation protection awareness, ameliorating the diminished stature of the radiographer in the healthcare team, and increasing the availability of optimal quality resources. South African diagnostic radiographers' radiation protection knowledge was optimal, but the implementation of radiation protection varied and was influenced by multiple factors. A radiation protection culture supported by management is advocated to optimize radiation protection. However, ultimately radiation protection practices are incumbent on the individual radiographers' choice to practice radiation protection.**

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Key words: patient protection; radiation protection; radiography; x-ray imaging

INTRODUCTION

GIVEN THAT the linear no-threshold (LNT) model considers no dose of ionizing radiation as safe, the principles of radiation protection—justification, optimization, and dose limits—require compliance. The principle of justification states that altering exposure situations should do more good than harm, and benefits should outweigh the risks. The optimization principle considers societal and economic factors to keep any exposure situation as low as reasonably achievable. Patients are not subject to dose limits for medical exposure; however, there are occupational dose limits for radiographers (ICRP 1996, 2017).

Optimization of protection is applied at two levels: one level deals with optimizing design, selection, construction, and installation of equipment, and the other focuses on optimization during the daily working operation (ICRP 2007). Diagnostic radiographers (hereafter referred to as radiographers) ensure justification, optimization, and dose limits at the daily work operation level and are central to radiation protection. Radiographers are responsible for the radiation exposure and dose a patient receives. Apart from patient radiation protection, radiographers are responsible for protecting themselves, those in the radiation area, and the public (Ehrlich & Coakes, 2020). The LNT model asserts that there is no safe level of exposure to ionizing radiation (ICRP 2007); therefore, radiographers should endeavour to optimize and limit all x-ray exposures (Makanjee & Engel-Hills, 2018).

Worldwide, regulatory bodies, informed by international agencies, legislate radiography equipment quality programs and provide referral criteria, diagnostic imaging pathways, patient categories, and imaging protocols aligned to the

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International Commission of Radiation Protection (ICRP) recommendations and International Atomic Energy Agency (IAEA) regulations (AERB 2015; IAEA 2014; New Zealand Legislation, 2016; SA DOH 2015; ACR 2020; Government of Western Australia, 2021; ESR and EFRS 2019). However, despite the establishment of these radiation protection measures, there is still evidence of limited awareness and practice of radiation protection (WHO 2012; Faggioni et al. 2017; van der Merwe et al. 2017; Rose et al. 2018). Guidelines, legislation, and regulations establish practice standards and standards for accountability but do not guarantee optimization and evolution (Pronovost & Hudson, 2012), as evidenced by studies in California, England, Khuzestan-Iran, Iran, Ivory Coast, Northern Nigeria, and Togo, where radiographers' radiation protection practices were reported as poor (Okeji et al. 2010; Reagan & Slechta, 2010; Kouamé et al. 2012; Adambounou et al. 2015; Awosan et al. 2016; Karami et al. 2016; Talab et al. 2016; Hayre et al. 2018). Noncompliant radiation protection practice was evidenced in the study by Tarkiainen et al. (2020), where incidents of using the wrong protocols and imaging the wrong site and side of patients were reported. Exposure creep was observed in an ethnographic study when radiographers did not adjust exposure factors and selected exposure factors higher than necessary (Hayre, 2016). Similarly, 26% of examinations reviewed in the study by Farzanegan et al. (2020) used an exposure factor that was 1 mAs (milliangstrom second) greater than the acceptable value. In addition, a retrospective examination of 100 posteroanterior chest and 100 lateral lumbar spine x rays showed 7.1% exposure creep over the study time (Warren-Forward et al. 2007). Moreover, Martin's (2005) analysis of 606 radiology incidents revealed that 85% were overexposures of patients, and 80% of the overexposure was due to human or procedural error. Together the aforementioned studies reveal radiographers' noncompliance with radiation protection practices and evidence of exposure creep. Radiographers' limited radiation protection awareness and noncompliant radiation protection practices concurrent with exposure creep contribute to the ever-increasing global average effective dose from diagnostic radiology procedures (Marshall & Keene, 2007; Cole et al. 2014).

THE SOUTH AFRICAN CONTEXT

Radiographers in South Africa may be employed in the public or private sector or work in both sectors concurrently in any of the nine provinces of South Africa. Currently, radiographers constitute 1.2% of the public health workforce, with a national average of 5.94 radiographers per 100,000 population (SA DOH 2020). Western Cape has the most significant ratio of radiographers per 100,000 public sector population at 9.36, followed by the Eastern Cape at 6.55, Gauteng at 6.21, and Mpumalanga at 3.42 (SA DOH 2020).

The distribution of financial resources between the public and private sectors is inequitable; of the overall health expenditure, 50% goes toward financing the health care of 16% of the population via private medical aid, and the remaining 50% is provided by the government to support the health care needs of the remaining 83.5% of the population who cannot avoid private medical aid (SA DOH 2020). Consequently, radiology equipment and human resources vary between the sectors. Resource distribution in the public sector varies from well-resourced, particularly in central, tertiary, and regional hospitals, to under-resourced district and primary healthcare facilities (Kabongo et al. 2015; Makanjee & Engel-Hills, 2018). Some departments may only have one or multiple general x-ray rooms, fluoroscopy, computed tomography, magnetic resonance imaging, mobile x-rays, and theatre imaging services. Film-screen radiography is also still in use (Motiang & Chelule, 2017). These resource disparities may result in patients being dependent on whatever x-ray imaging facilities are available, exposing them to unnecessary ionizing radiation risks rather than imaging that exposes patients to the least amount of ionizing radiation (Makanjee & Engel-Hills, 2018). Using only the resources that were available was confirmed by a study analyzing radiological equipment in Western Cape, South Africa (van Zyl et al. 2021). Since access to computed tomography is limited in rural areas, general radiography is used. Besides equipment, human resources are also impacted, as evidenced by a shortage of radiographers and radiologists in South Africa (Thambura et al. 2014; Moodley, 2017; Makanjee & Engel-Hills, 2018). Consequently, not all radiology departments, whether private or public, may have a radiologist physically present or a radiologist reporting on x-ray examinations.

The National Department of Health is responsible for national health legislation, and each of the nine South African provinces is responsible for the provision of healthcare services in the respective province (SAG 2022). In addition, private healthcare is available. National regulations guiding healthcare in South Africa include the Hazardous Substances Act, 1973 (SAG 1973); the Department of Health Public Health Amendment Act, 1971 (SAG 1971); and the National Health Act 61 of 2003 (SAG 2003). Currently in South Africa, electromedical (x-ray) equipment falls under group III of the hazardous substances in the Hazardous Substance Act 15 of 1973 and is regulated by Regulation 1332 (SAG 1973). Licencing of medical x-ray equipment is dependent on the equipment meeting international and national legislation and guidelines. The Directorate of Radiation Control, as part of the South African Health Products Regulatory Authority (SAHPRA), issues the licences for x-ray equipment depending on its compliance with legislation and audits adherence to regulations periodically. The South African code of practice for users of medical x-ray equipment and requirements for licence holders with respect to quality-control tests for diagnostic x-ray imaging systems sets out conditions and recommendations for radiation safety associated with the use of medical diagnostic x-ray equipment in South Africa (SA DOH 2015, 2016).

In South Africa, radiographers may only practice if they are registered with the Health Professions Council of South Africa (HPCSA) and maintain registration through evidence of continuing professional development (CPD). Radiographers may only register with the HPCSA if they meet the educational requirements and clinical competencies. The HPCSA provides practice standards aligned to the scope and codes of practice for individual practitioners, professional bodies, and employers to guide ethical medical imaging services. The scope of practice standards benchmarks practice, behavior, and compliance criteria. Practice standards also guide education requirements and allow for the evaluation of the quality of practice (HPCSA 2020). Higher education institutions in South Africa that offer radiography education are guided by the HPCSA practice standards and are also bound by the qualification exit level outcomes standards as outlined by the South African Qualifications Authority (SAQA). Among the outcomes are the justification of practice, optimization of protection, dose limitation principles, radiation protection, and radiation safety awareness and practice (SAQA 2015).

The HPCSA's ethical guidelines for healthcare professionals include adherence to nonmaleficence and the moral imperative to follow the designated responsibilities of a qualified and licensed radiographer (HPCSA 2008). In radiography, nonmaleficence encompasses adhering to the legislation and guidelines prescribed by international and national regulatory bodies. Nonmaleficence and moral obligation are further highlighted in the Code of Practice for Users of Medical X-ray Equipment and the policy on the request for medical x-ray examinations. These documents outline the basic principles of radiation protection, justification of practice, optimization of protection, and radiographers' role in this regard (HPCSA 2014; SA DOH 2015).

Yet, despite the inclusion of the teaching and learning of principles and practices of radiation protection being mandated throughout South Africa within all radiography educational curricula offered by higher education institutions (SAQA 2015), there is testimony and evidence of radiological clinical practices in South Africa that are contrary to what has been taught (Herbst & Fick, 2012; van der Merwe et al. 2017). Modiba (2014) reported contrary clinical practice in Limpopo, SA; only 29% of radiographers in the study indicated using radiation protection on patients. In addition, Modiba (2014) reported that 65% of radiographers indicated that there was a safe dose of ionizing radiation, a belief that is in contrast with the LNT model wherein a safe radiation exposure (however small) does not exist (ICRP 2007). In their South African study, Lewis et al. (2019a) identified that a quarter of patients received more radiation exposure than was necessary to produce a diagnostic radiograph, and only half of the radiographers surveyed in their study had a correct understanding of exposure indicators (Lewis et al. 2019b). Moolman et al. (2020) reported even fewer radiographers; i. e., only 33% of radiographers in their study, knew the function of exposure indicators. The exposure indicator acts as a safeguard against overexposure in digital radiography since it indicates if the optimum exposure factors were used to acquire the x ray (Herrmann et al. 2012). A retrospective evaluation of 100 pre-processed neonatal chest x rays revealed that 77% were not collimated optimally (Essop et al. 2019). Even though these studies in South Africa highlight limited radiation protection awareness, noncompliant radiation protection practices, and exposure creep, the reasons for these behaviors remain largely unexplored. Therefore, this study undertook to explore radiation protection among South African radiographers.

MATERIALS AND METHODS

An explanatory, sequential, mixed-method approach was used to collect data in three phases. Phase I used a quantitative approach, and Phases II and III used a qualitative approach. Table 1 delineates the population, sample, respondents/participants, method of data collection, data analysis, reliability, validity, and trustworthiness for each of the phases.

In the first phase, quantitative data were collected using an online questionnaire based on the theory of planned behavior (Boyd, 2013), and invitations to participate in the study were shared on social media, at a radiography seminar, and through radiography departments. Respondents answered the questionnaire anonymously. Respondents to the questionnaire could opt to participate in further research at the end of the questionnaire, and 120 participants provided their details. After contacting the 120 participants, 27 agreed to participate in Phase II. Phase II explored the reasons for the results obtained from Phase I through individual in-depth telephone interviews until data saturation resulted in 13 interviews. In Phase III, radiography managers were interviewed virtually in two focus groups with four managers in each group to co-construct change ideas to implement and/or optimize radiation protection. The interviews were audio-recorded, transcribed verbatim, and underwent thematic analysis (Braun & Clarke, 2021).

The criteria of credibility, dependability, transferability, and confirmability (Lincoln and Guba 1985) were used to ensure the trustworthiness of the findings of Phases II and III. Informed consent was obtained from all participants, and all necessary permissions and ethical clearance were obtained (REC-01-28-2019). The detailed methodology and comprehensive results of each phase are provided in previous publications (Lewis et al 2022a, 2022b, 2022c). The aim of this paper is to provide an integrated analysis for data from all three phases.

RESULTS

The integrated findings from Phases I to III are depicted in Table 2.

Table 1. Phases one to three research methods.

Population 6,552 diagnostic radiographers	Sampling Purposive	Respondents and participants	Data collection	Data analysis	Reliability and validity/trustworthiness
Phase 1	Facebook Whatsapp radiography seminar and departments	417 (6.4% response rate)	Online questionnaire	Descriptive and inferential statistics Correlation analysis	Reliability: Cronbach's alpha Construct validity: Factor analysis Pilot study
Phase 2	27 respondents from Phase I agreed to participate in phase 2.	13 (representing eight provinces in South Africa)	In-depth interviews	Thematic analysis: Braun and Clarke (2021, 128–148): data familiarisation, coding, initial theme generation, theme development and review, refining, defining and naming themes and writing up.	Credibility: triangulating interview data, notes of the interviews and literature. Dependability and transferability: detailed description of the research methodology Confirmability: audit trail detailing data collection, analysis and interpretation together with reflexivity
Phase 3	Snowballing Radiography managers	8 (Participants' roles: 1 deputy director role, 3 assistant directors, remaining managing radiographers representing three of the nine provinces in South Africa)	2 focus group interviews		

The overall findings from the three phases surmised radiation protection in South Africa as suboptimal due to radiographers' attitudes, subjective norms, and perceived behavioral control. South African radiographers' attitudes toward radiation protection varied. In Phase I, radiographers believed radiation protection was good and beneficial but not as pleasing, worth the time, or rewarding. The likelihood and importance of the outcomes of radiation protection in terms of reducing harm, being a role model, and radiation protection being ethical or moral were rated highly. Therefore, according to the theory of planned behavior, overall radiographers' attitude toward radiation protection would be high or positive. However, in Phases II and III, radiographers' attitudes varied from positive to lackadaisical. The variation in radiographers' attitudes may be explained by the fact that on average, only half of respondents planned to use (making an effort) and intended to use radiation protection, while only 16.3% always used radiation protection in the past. In addition, only 15.8% of radiographers were observed using radiation protection.

Overall through all three phases, radiographers' definition and understanding of radiation protection aligned to radiation protection principles and legislation. In Phase I, the majority of respondents (296 or 71.2%) felt strongly that they were confident in their ability to perform radiation protection, yet non-compliance was rife. Some reasons for non-compliance included that radiographers were not recognized in the healthcare team, types of patients, patients' ionizing radiation literacy, resources, inadequate training, and lack of managerial support. To improve compliance, Phase II participants suggested changing mindsets, small practice changes, improving training, and emphasizing radiation protection in student training. In Phase III, radiography managers also suggested "re-engineering" radiation protection and improving training and radiography education.

Radiographers rated radiography managers, radiologists, their radiographer colleagues, patients and patients' families (in order of importance) as influencing their radiation protection behavior. In Phase II, trauma and challenging patients were seen as hindrances to optimal radiation protection. In addition, a patient's radiation protection literacy facilitated radiographers' radiation protection non-compliance. In Phase III, radiography managers thought that creating greater ionizing radiation awareness among healthcare workers, radiographers, patients, and the public and creating a patient dose register might ameliorate radiation protection compliance. In addition, a national patient dose register would allow patients access to their accumulated radiation dose coupled with improved ionizing radiation literacy, which may allow patients to make informed decisions.

DISCUSSION

The overall suboptimal radiation protection among South African radiographers is similar to radiographer radiation protection practices reported globally (Okeji et al. 2010;

Table 2. Integration of phases one, two and three findings.

Phase 1			Phase 2	Phase 3
Intention and past use (Likely)				
Plan to use radiation protection (RP)	51.6%		RP varied from compliant to non-compliant. Compliance was a personal choice. Changing mind sets small practice changes to improve RP compliance.	Need support to mitigate RP non-compliance. RP practices deficient.
Effort to use RP	52.3%			
Intend to use RP	49.3%			
Past use	16.3%			
Attitude direct: behavioral beliefs				
Good	72.2%		Lackadaisical attitude RP is a waste of time, a nuisance. Some RP important-positive attitude.	The lack of optimal RP was attributed to the diminished stature of the radiographer, ionizing radiation being an unseen harm and radiographers' attitude.
Pleasant	47%			
Beneficial	74.1%			
Rewarding	55.2%			
Worth the time	52.5%			
Attitude indirect: Subjective probability				
	Likelihood	*Importance*		
Reduce harm	76.2%	80.3%	Practicing RP depends on the individual radiographer and their diligence.	A national radiation dose registry. Ideal RP is ethical, consistent and conscious compliance.
A role model	70.5%	65.1%		
Doing something ethical or moral	82.2%	82.7%		
Takes longer to complete an exam	19.3%	20.9%		
Subjective norm: direct				
People important to me think I should use RP	51.1%		Greater RP compliance for paediatrics, pregnant and oncology patients. Influenced by their colleague's practice, the culture in the department	Radiographers not heard. Misunderstanding of their role as managers. RP practices deficient. Linking RP to organisation's objectives. Collaboration with different role players.
Radiographers use RP	15.8%			
Expected to use RP	72.7%			
Social pressure not to use RP	11%			
Important people want me to use RP	46.3%			
Subjective norm: indirect				
	Expectation	*Importance of approval*		
Patients	27.8%	43.5%	Patient knowledge of RP limited.	Ideal RP- Increase RP awareness - healthcare team, patient and public aware. Re-engineering RP: awareness, peer reviews, accountability, regular safety conversations.
Patients' family	32.5%	32%		
Radiographer co-worker	53.1%	31%	Influenced by their colleague's practice, the culture in the department and radiologists.	Accountability, frequently compliance monitoring, improving communication between hospital management, doctors, radiography managers and radiographers, different institutions
Radiography manager	69.5%	47%	Lack of support from radiology management	Radiography managers misunderstood their role as managers
Radiologist	55.8%	43.9%	Medical team did not value their opinion.	
Perceived behavioral control direct				
Confident	71.2%		RP principles and their application are well known.	RP was defined correctly. Ideal RP: Radiographers getting the respect
Entirely up to me	43.4%			
Beyond my control	23.1%			
Possible to use RP	67.7%			

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Table 2. *(Continued)*

Phase 1 Intention and past use (Likely)			Phase 2	Phase 3
Perceived behavioral control indirect				
	Likelihood	*Agreement*		
Rushed	10.1%	25.5%	Radiographer shortages, limited X-ray rooms, time spent locating RP equipment, being rushed trauma or challenging patients to complete exam results in non-compliance. Use of RP equipment varied Established protocols were not enforced Motivation in the form of rewards Not adequate training-failure to understand equipment optimally Influenced by the culture in the department	Ideal radiation well-resourced: equipment maintained, functioning optimally. A standardized national protocol on RP Frequent monitoring Radiographers empowered through education: latest technology, communication skills and patient care The "hidden curriculum" influenced by radiography managers perpetuated continued compliance deficiencies.
Trauma and challenging patients	44.6%	35.8%		
RP equipment NOT available	15.9%	33.3%		
RP equipment available	76.7%	77.6%		
Policies	63.1%	60.1%		
Reward	6.5%	28.8%		
Continuous education	30%	52.2%		
Safety culture	25.1%	57.9%		

Reagan & Slechta, 2010; Kouamé 2012; Adambounou et al. 2015; Awosan 2016; Karami et al. 2016; Talab et al. 2016; Hayre et al. 2018). Studies reveal that radiographers are setting exposures higher than necessary (Hayre, 2016; Lewis et al. 2019a; Farzanegan et al. 2020). Studies conducted in Yobe, Nigeria (Okeji et al. 2010), Khuzestan-Iran, Ahvaz-Iran (Farzanegan et al. 2020), Saudi Arabia (Karami et al. 2016), Australia (Alsleem et al. 2019), and South Africa (Essop et al. 2019) show evidence of poor collimation practices.

Consideration should also be given to the findings that only half of the Phase I respondents believed that radiation protection was rewarding, pleasant, and worth the time and that using radiation protection increased the time of the x-ray exam. Therefore, even though radiographers believe that radiation protection is moral and ethical, not appreciating it as rewarding, worth the time, and pleasant may hinder translating the belief into action or behavior. In addition, 71.4% of Phase I respondents agreed that whether or not they use radiation protection practices in x-ray examinations is entirely up to them, and 94.4% of Phase I respondents thought it possible to use radiation protection practices in x-ray examinations. Therefore, radiographers believe it is possible to use radiation protection, and it was entirely up to them to use it. Phase II participants shared the view that radiation protection is a personal choice. A number of studies are in alignment with this theory-practice divide. A study in Northern Nigeria indicates that although radiographers had a good knowledge of radiation protection, their radiation protection practices were poor (Awosan 2016). Similarly, Reagan and Slechta's (2010) California study found higher knowledge of radiation practices than compliance with practices. In contrast, a study conducted in Yobe, Nigeria, showed that radiographers had an overall high adherence to radiation protection practices (Yusuf et al. 2020). More than half the radiographers in a United Arab Emirates study showed good adherence to radiation protection practices (Abuzaid et al. 2019).

In Phase I, respondents rated patients' and their families' approval of using radiation protection as least important, yet participants in Phase II thought that patient radiation protection knowledge influenced radiation protection practices. Respondents in Phase I also indicated that patients' and their families' expectations of using radiation protection were low. Phase II showed that patients did not know about radiation—"they are illiterate"—and felt that radiographers would probably practice radiation protection if patients were more insistent. Patients not expecting radiographers to use radiation protection may be attributed to their lack of knowledge of ionizing radiation aligning to Phase II and III participants, who believe that South African patients have limited awareness of the hazards of ionizing radiation. Participants' beliefs of South African patients are confirmed in two South African studies (Modiba 2014; Mung'omba & Botha, 2012), where patients' knowledge of ionizing radiation was considered sparse.

In Phase I, 53.1% of respondents thought that their radiographer co-workers think they should use radiation protection, and only 25.1% of Phase I respondents indicated that promoting a safety culture is a regular and ongoing activity in their radiology department. To some extent, Phases I and II agree on the influence of colleagues' practices and culture. However, when considering that only 16% of Phase I respondents indicated using radiation protection in the past and only 15.8% of Phase I respondents indicated that their radiographer colleagues use radiation protection, the current radiation protection practices and culture might be considered to be suboptimal. In Phase I, respondents (65.1%) considered being a role model to other radiographers as extremely important, and 57.9% agreed that working in a department that promotes a safety culture makes it easier to use radiation protection practices. Similarly, Phase II and III participants indicate changes in the radiography department will ultimately shift the culture. Lohikoski et al. (2019) explain that workplace culture is the radiography department's identity, and the shared experience of radiographers would influence their behavior.

In Phase II, participants expressed a lack of support from radiology management as contributing to radiation protection practices and non-compliance to established radiation protection protocols. However, in Phase III, participants shared that radiography managers were not empowered. Therefore, radiography managers themselves require support to mitigate radiation protection non-compliance. Literature supports the current study's findings that healthcare managers find it challenging to confront doctors (Currie and Procter 2005; Carney, 2006). The International Radiation Protection Association (IRPA 2014) iterates that developing and sustaining a positive radiation protection culture requires strong leadership. Park and Yang (2021) suggest administrative support to optimize radiation protection. Since Phase I respondents' subjective norm was influenced most significantly by radiography managers, radiography managers leading the cultural shift would ensure buy-in from radiographers.

CONCLUSION

This mixed-method study explored radiation protection among South African radiographers, and the findings of the three phases were congruent in that although radiographers' radiation protection knowledge was optimum, their compliance was suboptimal. Radiographers' radiation protection compliance was influenced by the radiation protection culture. To optimize radiation protection, a culture that promotes radiation protection supported by the radiography manager and the organization is advocated. The availability of quality resources, support from management, and recognition of the radiographer as part of the healthcare team will create an environment that is conducive to compliance. Thereafter, radiation protection compliance on the part of radiographers hinges on the radiographer as an individual. Internalizing the ethical and moral obligation of radiation protection compliance may propel individual radiographer compliance.

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