Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 01 June 2026
Revised 17 July 2026
Accepted 29 July 2026

Natural Resources for Human Health 2026, Vol. 6 (13s): 143–154

KEYWORDS:
Human factors; qualitative study; radiation safety; radiographers; unsafe behavior

Causes And Contributing Factors of Unsafe Radiation Safety Behavior Among Radiographers in Hospital Radiology Installations: A Qualitative Study

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ABSTRACT: Radiographers occupy a critical position in protecting themselves, patients, and colleagues from the hazards of ionizing radiation, yet unsafe radiation-related behavior persists in clinical practice. Existing literature has documented radiographers' knowledge, attitudes, and isolated barriers to specific protective behaviors, but has relied predominantly on single-round, questionnaire-based designs, leaving the underlying root causes and their interaction with contributing organizational factors insufficiently explored, particularly within Indonesian hospital settings. This study aimed to identify the root causes and contributing factors of unsafe radiation-related behavior among radiographers using a qualitative exploratory design. Five participants, comprising one head of the radiology room, one radiation protection officer, and three radiographers, were recruited through purposive sampling from two hospital radiology installations in Sleman and Bantul, Special Region of Yogyakarta. Data were collected through in-depth interviews and structured behavioral observation, and analyzed thematically. Findings identified root causes centered on procedural knowledge deficits, personal dosimeter non-adherence, incomplete door closure, and inconsistent hazard communication, as well as contributing factors related to infrastructure, supervision, peer influence, workload, and management commitment. These findings converged consistently across participants occupying different organizational roles, reinforcing their credibility as systemic rather than isolated concerns. Findings were synthesized within the Software-Hardware-Environment-Liveware (SHELL) human factors framework, indicating that unsafe behavior arises from interactions among procedural, physical, environmental, and interpersonal domains rather than from a single determinant. This study offers a preliminary premise for hospital radiology management to design domain-specific, rather than knowledge-only, occupational safety interventions in comparable hospital settings.

1. INTRODUCTION

Occupational safety in radiology installations is a critical concern, given the risks associated with radiation exposure and the complexity of the medical equipment involved. The implementation of radiation protection protocols, including the use of radiation shielding, safe distancing, and minimization of exposure time, aims to protect both patients and healthcare workers (Aljamal et al., 2025). Continued innovation in protective equipment and dose-monitoring technology supports safer practice(Zeinali-Rafsanjani et al., 2017); however, the effectiveness of these tools ultimately depends on a variable that is far more difficult to control: the safe behavior of radiographers themselves.

Empirical evidence points to a persistent gap between awareness and practice. Wadood et al. (2025) found that only 48.6% of radiology staff understood how to protect themselves from radiation exposure, while Al-Mousa et al. (2024) reported that most practitioners were unaware of the X-ray tube voltage of the machines they operated. Other studies have documented inconsistent use of personal protective equipment (Shungube & Khoza, 2024), as well as an association between inadequate training and radiation exposure-limit violations among vascular staff (Bhinder et al., 2023). Leadership factors (Chau, 2024), team safety culture (Korsah et al., 2025) and workload (Derdowski & Mathisen, 2023), have likewise been identified as contributors to unsafe behaviour across various radiology contexts.

Although a growing body of literature addresses radiation protection behaviour among healthcare workers, a recent scoping review protocol characterises this literature as exhibiting considerable methodological heterogeneity and explicitly calls for mapping remaining research gaps (Liu et al., 2024). Notably, even studies that identify as qualitative in this field have typically relied on a single round of open-ended, survey-based questions rather than on in-depth, triangulated data collection (Christensen et al., 2024).

Within Indonesia specifically, existing research on radiation safety compliance has remained predominantly quantitative and single-method. Almas et al. (2023) examined radiology staff across facilities in East Kalimantan using a structured questionnaire built on the *Man–Money–Method–Material–Machine* framework, identifying standard-operating-procedure availability as a significant correlate of safety management implementation, but relying entirely on self-reported questionnaire data rather than direct interview or field observation.

Regionally, a qualitative exploratory study of radiographers in Eswatini reached data saturation through in-depth interviewing, identified attitudinal and normative barriers to compliance, and reported a broadly comparable compliance pattern noted by Ridzwan et al. (2023), illustrating triangulated, in-depth qualitative methods are more common outside Southeast Asia. In Indonesia and nearby areas, research mainly relies on single-method questionnaires, with less focus on understanding how unsafe behavior actually develops and persists. Instead, the emphasis is often on identifying factors that are correlated with unsafe behavior, rather than exploring the underlying processes.

Consequently, while barriers to specific protective behaviors have been documented both globally and within Indonesia, comparatively little is known about how these barriers interact as a system to produce and sustain unsafe behavior over time, particularly within Indonesian hospital radiology installations.

In tracing this underlying problem, it is useful to draw on the established distinction in root-cause-analysis and human-factors literature between active, individual-level failures and latent, systemic conditions (Reason, 2000). In this study, a root cause is a core lack of knowledge about radiation safety that leads to unsafe behaviour. A contributing factor is systemic conditions like infrastructure, leadership, peer support, workload, and management that reinforce or normalize unsafe practices without directly causing them. This distinction is important because lacking clarity could lead safety efforts to target the wrong problem level.

This study contributes methodologically, conceptually, and contextually. It triangulates interviews with behavioral observation across two hospital sites, moving beyond the single-method questionnaires common in Indonesian and regional studies. Conceptually, findings are organized within a systems-based interpretive framework, identifying procedural, physical, environmental, and interpersonal sources of unsafe behavior instead of listing correlates. This form of qualitative inquiry remains rare in Indonesian and Southeast Asian radiation safety research. The study aims to identify root causes and factors of unsafe behavior among radiographers and how these interact as an integrated system, rather than as isolated determinants.

2. MATERIALS AND METHODS

2.1 Study Design

This study employed a qualitative design informed by an interpretive paradigm, which assumes that the meaning of safe and unsafe behavior is socially constructed through radiographers' lived experience, interaction, and workplace context (Hannes et al., 2022). An exploratory approach was selected because the root causes of unsafe radiation-related behavior among radiographers remain insufficiently examined in the context of Indonesian hospital radiology installations, warranting a design that allows meaning to emerge inductively from participants' own accounts rather than testing a predetermined hypothesis (Creswell & Poth, 2018).

This study was conducted in the radiology installations of Panti Nugroho Hospital, Sleman (Type D) and PKU Muhammadiyah Hospital, Bantul (Type C), Special Region of Yogyakarta, as part of the doctoral research protocol (Ethical Approval Ref. No. KE/FK/0942/EC/2024). Data collection took place over two sequential stages: a structured behavioral observation stage followed by an in-depth interview stage conducted after the observation findings had been reviewed, allowing the interview guide to probe directly into the behavioral patterns already documented in the field.

2.2 Sample Collection

Participants were recruited using a purposive sampling technique from Panti Nugroho Hospital, Sleman, and PKU Muhammadiyah Hospital, Bantul. Inclusion criteria were: (1) currently serving as a head of the radiology room, a radiation protection officer, or a radiographer directly performing radiographic procedures; (2) actively employed at the study site; and (3) willing to participate voluntarily after signing a written informed consent form, consistent with the Informed Consent Form (version 02, 2024) approved under Ref. No. KE/FK/0942/EC/2024. Exclusion criteria included being on leave during the data collection period or declining audio recording during the interview. Five participants were included: one head of the radiology room, one radiation protection officer, and three practicing radiographers. This sample size was determined based on the principle of thematic saturation, whereby data collection was concluded once additional interviews no longer generated new codes or categories (Hennink & Kaiser, 2022).

2.3 Data Collection

The interview guide was developed as part of the approved doctoral research protocol and was structured around seven domains: (1) safe work procedures, (2) facilities and environmental conditions supporting occupational safety and health (K3) in radiology, (3) management commitment, (4) worker involvement in safety, (5) communication, (6) occupational safety and health (K3) behavior, and (7) recommendations for improving K3 behavior. The guide was developed after the structured observation stage had been completed, so that questions under domains 1, 5, and 6 could directly probe the behavioural patterns already documented during observation.

Data were collected through two methods: structured behavioural observation and semi-structured interviews. Observation focused on 19 safety-behaviour indicators, recorded across two periods at each hospital. Interviews used a guide covering seven domains: safe work procedures, infrastructure, management, worker involvement, communication, occupational safety, and future practice recommendations. Participants provided informed consent before each interview, with the interviewer explaining the purpose of audio recording and confidentiality, which was maintained in accordance with the guide. Each interview session lasted approximately 30–45 minutes.

Because one participant held a supervisory role (head of the radiology room) relative to the other participants, interviews were conducted individually and confidentially, and the head of the room was not present during, nor given access to, the individual responses of the radiographers under their supervision. Participants were also informed prior to the interview that their responses would not be shared with their direct supervisor and that declining to answer any question would not affect their employment status.

2.4 Analytical Methods

Data were analyzed using thematic analysis following (Braun & Clarke, 2023) six-phase framework, supported by NVivo 12: transcription, familiarization, open coding, categorization, and synthesis into themes. Initial coding was performed independently by two research team members (APU and AHD) to strengthen investigator triangulation; discrepancies were resolved through consensus, following (A'la et al., 2026).

2.5 Trustworthiness

Trustworthiness followed Lincoln and Guba's (1985) four criteria. Credibility was strengthened through methodological triangulation (interviews combined with behavioral observation) and source triangulation (participants across three organizational roles), following Korstjens & Moser (2018) and further supported by member checking of preliminary themes with participants. Dependability and confirmability were maintained through an audit trail comprising the interview guide, observation checklists, transcripts, and NVivo coding records (A'la et al., 2026). Transferability was addressed through detailed description of the setting, participants, and sampling procedure.

3. RESULTS AND DISCUSSION

3.1 Preliminary Analysis

Five participants took part in this study: one head of the radiology room, one radiation protection officer, and three practicing radiographers, drawn from two hospital radiology installations in Sleman and Bantul, Special Region of Yogyakarta (Table 1). All participants had direct experience with radiographic procedures and radiation safety practice; however, the specific number and type of examinations handled by each participant was not systematically recorded.

Table 1. Participant characteristics

No	Participant Code	Age	Background Education	Sex	Hospital	Years of Experience
1	Informant 1	32	Bachelor of Applied Radiology	Male	Hospital B, Bantul	9
2	Informant 2	44	Bachelor of Applied Radiology	Female	Hospital A, Sleman	19
3	Informant 3	38	Bachelor of Applied Radiology	Male	Hospital A, Sleman	14
4	Informant 4	42	Bachelor of Applied Radiology	Female	Hospital B, Bantul	17
5	Informant 5	51	Bachelor of Applied Radiology	Male	Hospital B, Bantul	27

3.2 Theme and Categories

Through iterative open coding, categorization, and thematic synthesis, the data were classified into nine categories and two overarching themes (Table 2).

Table 2. Category and theme

Category	Theme
Knowledge of safe work procedures	Root Causes of Unsafe Behavior
Non-adherence to personal dosimeter (TLD) use	
Incomplete closure of examination-room doors	
Inconsistent hazard communication to patients	
Infrastructure availability	Contributing Factors to Unsafe Behavior
Leadership supervision	
Co-worker concern	
Workload	
Management commitment	

The iceberg metaphor in Figure 1 is used here as an illustrative heuristic, commonly invoked in occupational safety and incident-reporting communication to depict the disproportionate relationship between visible events and the far larger set of underlying systemic conditions that produce them (in the tradition of Heinrich's accident triangle), rather than as a formally tested theoretical model in its own right. The substantive analytic distinction underlying the two-layer structure is grounded directly in Reason's (2000) framework, which differentiates active failures, unsafe acts committed by individuals at the operational "sharp end" of a system, from latent conditions, the more distal, often invisible organizational, managerial, and design deficiencies that create the circumstances under which active failures occur. This distinction, already introduced in the Background section of this manuscript, justifies placing Theme 1 (individual-level unsafe behaviors) above the waterline and Theme 2 (organizational-level conditions) below it, rather than treating the nine categories as a flat, undifferentiated list.

Within each layer, category grouping also follows Sudiarno et al. (2025), the absence of a disseminated SOP reflects a Software-domain deficiency; incomplete door closure and infrastructure gaps reflect Hardware-domain deficiencies; workload pressure reflects an Environment-domain condition; and TLD non-adherence, leadership supervision, co-worker norms, and management commitment each reflect Liveware or Liveware–Liveware interface conditions.

Figure 1. The iceberg model of unsafe radiation behavior among radiographers, illustrating the distinction between visible behavior-level root causes (Theme 1, above) and latent organization-level contributing factors (Theme 2, below), consistent with Reason's (2000) active failure–latent condition distinction. (Visualization by Biorender)

Theme 1: Root Causes of Unsafe Behavior

a. Knowledge of safe work procedures

The results revealed that participants were unable to describe the safe work procedures for the radiology installation in detail. No standard operating procedure (SOP) on occupational safety and health had been formally disseminated to radiographers; instead, general, non-written procedures were relied upon.

Table 3. Knowledge of Safe Work Procedures

Category	Subtheme/Code	Representative Quote
Knowledge of safe work procedures	No written SOP disseminated	"*There should be an SOP about the safety of working for the Radiographer, and then there is PPE about the safety of the Radiographer in the workplace.*" (Informant 4)
	Reliance on informal, minimal practice	"*For safe work, it would be better for us to use personal protective equipment. In my own hospital, there is only an apron; the second one is that we use kV mA according to such a procedure.*" (Informant 5)

Notably, the deficit is not confined to the frontline: the head of the room; the individual formally positioned to enforce procedural compliance; describes an equally minimal, non-standardized practice ("only an apron"). This indicates the gap is not a matter of individual radiographers' unwillingness to learn, but the absence of an institutional artifact (a formally written and circulated SOP) that could be learned from in the first place. Reframed this way, the finding shifts from an individual competency problem to a documentation and governance failure; a distinction with direct implications for what kind of intervention would actually close the gap

b. Non-adherence to personal dosimeter (TLD) use

Reluctance to use TLDs converges on two distinct, mutually reinforcing psychological pathways rather than a single explanation.

Table 4. Non-Adherence to TLD Use

Category	Subtheme/Code	Representative Quote
TLD non-adherence	Outcome-based reasoning ("use vs. non-use makes no difference")	"*There are still people who forget the use of TLDs, and some are not very aware, important or not. Use and not use, the result is always the same.*" (Informant 1)
	Habitual lapse under time pressure	"*I don't know. Maybe lazy. Even though it has also been provided, maybe friends are in a hurry, because there are many patients.*" (Informant 2)
	Social conformity to peer non-use	"*In the beginning, I used to use TLDs a lot, but seeing others not using them, I finally joined in.*" (Informant 3)
	Passive non-use despite availability	"*I also don't know, even though it has been provided in the back, just install it. But many people still don't use it.*" (Informant 3)

Two distinct mechanisms are visible here, not one. The first is outcome-based reasoning: a belief that dose readings do not change regardless of use, which removes the perceived value of the behavior at the individual level. The second is social conformity: an individual who was initially compliant abandoned the behavior after observing non-compliant peers, independent of any belief about dose outcomes. These two pathways converge on the same behavioral result but originate from different psychological processes, one cognitive-evaluative, one normative-social, which matters because a knowledge-correction intervention would address only the first pathway, leaving the second (peer-driven) pathway untouched. It is also worth noting that Informant 2 volunteered, unprompted, that compliance became "more orderly" specifically during the period of direct research observation, a detail that signals a possible gap between directly observed and habitual behavior.

c. Incomplete closure of examination-room doors

Unlike the two categories above, this pattern originates from a hardware failure rather than a knowledge or attitudinal gap, and it produces a cascading, not merely localized, safety consequence.

Table 5. Incomplete Door Closure

Category	Subtheme/Code	Representative Quote
Incomplete door closure	Mechanical failure (weight, handle, rail)	"*The sliding door has two obstacles. The first is the door handle. Sometimes it hasn't been a month since it was broken because the lead is heavy, and the rails are at risk of plummeting... Finally, it was opened only for entry.*" (Informant 1)
	Behavioral workaround (physical shielding substitution)	"*The door that the operator is on, it is indeed a bit heavy... so we just hid it to the east or west, it does not fit in front of the operator's door.*" (Informant 2)
	Secondary breach by third parties	"*Friends, when working with patients, the door is not locked, so often the ER nurses open it.*" (Informant 5)

The consequence here is layered, not singular. At the primary level, the radiographer compensates for the broken door by relocating behind a protective wall, an improvised but at least self-protective adaptation. At a secondary level, however, the same unresolved defect allows ER nurses to enter mid-examination, meaning the hardware failure extends occupational radiation risk to personnel who were never part of the original safety assessment for that room. This distinguishes the door-closure finding from the TLD finding: the radiographer's adaptive response partially mitigates their exposure, but does nothing to prevent exposure to a third party who is unaware that the examination is in progress.

d. Inconsistent communication of radiation hazards to patients

This category rests on a thinner evidentiary base than the three above, a limitation worth stating plainly rather than implying broader support than the data provide.

Table 6. Inconsistent Hazard Communication

Category	Subtheme/Code	Representative Quote
Hazard communication	Reactive, patient-initiated disclosure only	"*Yes, usually if someone asks... or if a pregnant woman is informed.*" (Informant 4)

This finding extends the knowledge-deficit thread from category (a) in a specific direction: communication is contingent on the patient's initiative or a narrow triggering condition (pregnancy), rather than a default, institutionalized step in every examination. This frames the problem as a policy gap (no standard script or requirement for hazard disclosure) rather than purely a training gap, radiographers are evidently capable of explaining the hazard when prompted, so the deficiency lies in when and to whom disclosure is triggered, not in an inability to communicate it at all.

Theme 2: Contributing Factors to Unsafe Behavior

a. Infrastructure availability

Table 7. Infrastructure Availability

Category	Subtheme/Code	Representative Quote
Infrastructure availability	Incomplete PPE stock, unrepaired hardware	"*If it's the infrastructure facilities, in addition to personal protective equipment, we have other equipment constraints, such as damaged door facilities that have not been repaired, causing the inspection to tend not to be closed.*" (Informant 1)
	Inspection/storage standard not met	"*The infrastructure is not complete. For gonad and thyroid shields, there has also been no inspection. The PPE for storage is not up to standard.*" (Informant 5)

This category is not merely co-occurring with category (c); it is causally upstream of it. The Hardware-domain deficiency identified here manifests directly as the Theme-1 behavioral pattern of incomplete door closure, the same broken door mentioned by Informant 1 in category (c) is again named here as an infrastructure gap. This cross-reference matters methodologically: a flat, tree-based coding structure that lists "root causes" and "contributing factors" as parallel, side-by-side branches understates how directly one produces the other in this case.

b. Leadership supervision

Unlike categories (a) and (i), where quotes from both frontline and supervisory participants converge on a shared account, the leadership-supervision category surfaces exclusively through the perspective of radiographers describing supervision from below; no directly corroborating or countervailing statement from the head of the room or the radiation protection officer appears within this specific category. This asymmetry does not necessarily mean the perception is inaccurate, but it does mean the finding should be read as an account of supervision as experienced by those being supervised, rather than a triangulated organizational fact.

Table 8. Leadership Supervision

Category	Subtheme/Code	Representative Quote
Leadership supervision	Supervision perceived as absent, delegated	"*From the leadership of the Hospital, it seems that it has never, ma'am. But from here, if the one who checks the radiation is the PPR and the medical physicist.*" (Informant 3)
	Reporting burden shifted to workers	"*If it is from the leadership, it is rare. To go to radiology, we must actively report to the leadership.*" (Informant 4)

Read together, these two quotes describe a reactive rather than proactive supervisory model: oversight exists only insofar as radiographers themselves initiate contact with leadership, and routine technical checks are effectively outsourced to the radiation protection officer and medical physicist rather than performed directly by hospital leadership. This is a more precise characterization than "leadership supervision is low", the finding is not an absence of oversight structures altogether, but a shift of responsibility away from hospital leadership and onto either the worker or a technical specialist.

c. Co-worker concern

Table 9. Co-worker Concern

Category	Subtheme/Code	Representative Quote
Co-worker concern	Peer non-reinforcement of safe practice	"*In the beginning, I used to use TLDs a lot, but seeing others not using them, I finally joined in.*" (Informant 3)
	Individualized rather than collective safety orientation	"*...In my opinion, it is very lacking in reminding and giving advice; there is still individual work at all.*" (Informant 5)

Informant 3's quote here is the same one cited under category (b), and this dual placement is analytically informative rather than redundant. It shows that a single reported episode operates simultaneously at two levels: as an individual act of non-adherence (Theme 1) and as evidence of an absent peer-accountability norm (Theme 2). Rather than treating this as an accidental duplication in the coding process, it should be read as direct evidence that the root cause and contributing factor are not always separate events, in this instance, they are two descriptions of the same episode viewed from different analytic perspectives.

d. Workload

Table 10. Workload

Category	Subtheme/Code	Representative Quote
Workload	Compromise in technical precision	"*There are many patients here, so the work has to be fast, so sometimes the irradiation field is not regulated according to the object.*" (Informant 4)
	Compromise in protective measures	"*A lot of queues... makes us have to quickly serve patients, so that sometimes we are not given protection.*" (Informant 5)

These two quotes reveal that time pressure does not uniformly compromise safety, it produces two distinct types of trade-off, depending on which task is compressed. In one case, precision suffers (the collimation field is not properly matched to the object); in the other, protection is entirely foregone (patients are not given shielding). This distinction matters for intervention design: reducing patient volume or improving scheduling efficiency would plausibly address the precision trade-off, but the protection trade-off may instead require a hard procedural rule that cannot be skipped, regardless of queue length.

e. Management commitment

Table 11. Management Commitment

Category	Subtheme/Code	Representative Quote
Management commitment	Infrequent, non-routine safety socialization	"*There is an Occupational Safety and Health socialization from the hospital, which is carried out once a year, or not necessarily. Radiology itself has been, but not been, routine*." (Informant 5)
	Routine equipment-related commitment	"*Calibration has been routine per year. In the past, it was only during the licensing process by LPFK*." (Informant 2)
	Routine maintenance commitment	"*From the management's side, they facilitate routine maintenance, so every 3 months there is routine maintenance of the technique*." (Informant 4)

Reading these three quotes together shows that management commitment is domain-selective rather than uniformly weak. Equipment-related obligations (calibration and maintenance), are reported as genuinely routine and institutionalized. What is inconsistent is specifically radiology-targeted safety socialization and training. This is a more precise and useful finding for hospital management than a blanket "low management commitment" label, because it identifies exactly which domain of commitment needs strengthening (behavioral/educational) rather than implying that all forms of management support are lacking, which the equipment data directly contradict.

The findings indicate that unsafe radiation safety behavior among radiographers stems from an interaction between root causes centered on procedural knowledge and individual compliance (Theme 1) and contributing factors rooted in the surrounding organizational system (Theme 2), rather than from either category in isolation.

3.4 Discussion

Rather than treating the root causes and contributing factors identified in this study as an unordered list, the findings can be organised using the Software–Hardware–Environment–Liveware (SHELL) human factors framework, in which safety-relevant behaviour is understood as emerging from the fit, or mismatch, between an individual operator and four surrounding domains, written procedures and training (Software), physical equipment and infrastructure (Hardware), the working environment and workload (Environment), and interpersonal relationships, including peers and supervisors (Liveware) (Sudiarno et al., 2025).

The absence of a formally disseminated SOP reflects a Software-domain deficiency, whereas the damaged examination-room door reflects a Hardware-domain deficiency. This distinction carries analytic weight: a recent qualitative study of Swedish radiographers similarly found that patient-safety-supporting behavior depended on both standardized procedural guidance and adequate technical equipment as separate, non-substitutable conditions, the presence of one did not compensate for the absence of the other (Wallin et al., 2023). The present findings extend this observation to occupational (rather than patient) safety, radiographers in this study did not treat the missing SOP and the broken door as equivalent problems, and their coping responses differed accordingly, improvising a physical workaround for the door, but showing no equivalent adaptive strategy for the missing procedural knowledge (López et al., 2018). This suggests that Hardware-domain failures may prompt situational compensation, whereas Software-domain failures are more likely to produce a durable, uncorrected behavioural gap.

The finding that one radiographer began neglecting TLD use after observing colleagues do the same aligns with recent evidence that leadership modelling and peer behaviour are key determinants of protective-equipment compliance in healthcare settings, sometimes outweighing an individual's own risk knowledge (Barratt & Gilbert, 2024). This is a Liveware–Liveware interface effect in SHELL terms: the deficiency does not originate with any single individual but in the interaction between individuals. Comparable findings among healthcare workers more broadly indicate that PPE compliance is shaped jointly by individual knowledge, workload pressure, and organisational/peer climate rather than by knowledge alone (George et al., 2023), reinforcing that the TLD non-compliance identified in this study is unlikely to be resolved through knowledge-focused training in isolation.

An additional pattern evident in the supplementary observation dataset (Supplementary Table S2) is that behavioral compliance varied more between the two hospital sites than within either site: nine of nineteen indicators showed variation at PKU Muhammadiyah Bantul, compared to comparatively little variation at Panti Nugroho Sleman. This asymmetry is consistent with the qualitative finding that participants described infrastructure and management-commitment gaps as site-specific conditions rather than a uniform problem across both hospitals, since facility-level conditions, rather than a single, hospital-wide determinant, would be expected to produce exactly this kind of differential pattern. This supplementary observation therefore reinforces, at a descriptive level, the qualitative argument that unsafe behavior is shaped by local organizational conditions, without requiring any assumption about what distinguishes the two observation periods themselves.

Consistent with the setting description provided in the Method section, these findings are most directly transferable to radiology installations of comparable scale and staffing in Indonesian district-level hospitals, where similar constraints on SOP dissemination, equipment maintenance budgets, and supervisory staffing are plausible. Transferability to tertiary academic hospitals or high-resource settings, where dedicated radiation safety departments and dedicated maintenance budgets are more likely to exist, should not be assumed without further comparative research.

Beyond the methodological limitations already addressed, two interpretive limitations are relevant to how these findings should be read. First, because one participant held a supervisory role over the others, some residual social desirability effect cannot be fully excluded despite the safeguards described in the Method section. Second, the qualitative data represent a single interview time point per participant and therefore cannot establish whether the root causes identified were stable features of the unit or reflected conditions specific to the period in which the data were collected.

Taken together, the research suggests that a single, generic safety-training intervention is unlikely to address all the root causes and contributing factors identified in this study at once. Instead, the SHELL-based reading of these findings points to the need for parallel, domain-specific actions: formal SOP development and dissemination (Software), scheduled equipment and infrastructure repair with a defined timeline (Hardware), and structured peer-accountability mechanisms rather than awareness campaigns alone (Liveware), since awareness-based approaches, as shown above, appear to reach some behaviors but not others.

4. CONCLUSION

This study found that unsafe radiation safety behavior among radiographers arises not from a single determinant but from the interaction of procedural knowledge deficits and systemic organizational conditions, consistent with the Software-Hardware-Environment-Liveware (SHELL) human factors framework. Root causes centered on the absence of a formally disseminated SOP, non-adherence to personal dosimeter use, incomplete door closure, and inconsistent hazard communication, while contributing factors reflected infrastructure limitations, inadequate supervision, peer influence, workload, and limited management commitment. These findings were reported consistently across participants occupying different organizational roles, indicating that they represent genuine systemic conditions rather than isolated frontline grievances.

For hospital radiology management, these findings suggest that a single, generic safety-training intervention is unlikely to address the full range of identified root causes and contributing factors. Parallel, domain-specific actions are recommended instead: formal development and dissemination of a written SOP (Software domain), a scheduled timeline for equipment and infrastructure repair (Hardware domain), and structured peer-accountability mechanisms rather than one-off awareness campaigns (Liveware domain). For allied health education, these findings underscore the importance of embedding occupational radiation safety as a distinct competency area rather than assuming that general safety training transfers uniformly across behaviors. For future research, studies employing larger, more geographically diverse samples, along with longitudinal designs that track behavioral change over time, are needed to test the transferability of the SHELL-based interpretation proposed here beyond the two hospital sites examined.

ACKNOWLEDGEMENTS

The authors acknowledge the Doctoral Study Program in Medical and Health Sciences, Faculty of Medicine, Public Health and Nursing, Universitas Gadjah Mada, for the academic support provided during this research.

AUTHOR CONTRIBUTIONS

Asih Puji Utami: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing.

Adi Heru Sutomo: Supervision, Validation, Writing – Review & Editing.

Agus Surono: Supervision, Validation, Writing – Review & Editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS STATEMENT

This study received ethical approval from the Medical and Health Research Ethics Committee (MHREC), Faculty of Medicine, Public Health and Nursing, Universitas Gadjah Mada, Dr. Sardjito General Hospital (Ref. No. KE/FK/0942/EC/2024, approved 28 June 2024). Written informed consent was obtained from all participants using the approved Informed Consent Form (version 02, 2024) prior to data collection, following a full explanation of the study's aims, procedures, potential risks, and the voluntary nature of participation. To protect participant confidentiality given the supervisory relationship among informants, individual responses were not disclosed to the head of the radiology room, and participants were informed that declining to answer any question would not affect their employment status.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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