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Assessing the Risks to Nuclear Safety: Case Study of Institutional Transformation and Governance Challenges in Indonesia's Research Agency Reform

Yarianto Sugeng Budi Susilo[1], Muhammad Budi Setiawan[2], Djarot Sulistio Wisnubroto[3], Rr. Arum Puni Rijanti[4]*, Suparman[5], Ferly Hermana[6], Totti Tjiptosumirat[7], Anik Purwaningsih[8], Jaja Sukmana[9], Riyan Mahendra Saputra[10], Dini Anggraeni[11], Nugraha Luhur[12], Kurnia Setiawan Widana[13]

Abstract

This study explores the restructuring of Indonesia's National Nuclear Energy Agency into the National Research and Innovation Agency, merging it with non-nuclear bodies. Using surveys, interviews, and field surveys, the research finds weakened nuclear sector leadership, poor safety protocol enforcement, and institutional conflicts that compromise nuclear safety. The integration risks diluting specialized expertise in favor of broad innovation agendas. The Indonesian case highlights the dangers of bureaucratic consolidation in high-risk organization. The study offers policy recommendations to strengthen nuclear safety governance through better institutional design, leadership accountability, and safety-oriented organizational culture in public high-risk research institutions.

Keywords: *Institutional Restructuring · Nuclear Safety · High Reliability Organizations · institutional isomorphism · Public Sector Reform*

Introduction

The institutional restructuring of specialized public organizations into broader, cross-sectoral entities has become a common feature of contemporary public sector reform, particularly in developing countries aiming to streamline governance and enhance

[1] Research Center for Nuclear Reactor Technology, National Research and Innovation Agency, Indonesia
[2] Research Center for Nuclear Reactor Technology, National Research and Innovation Agency, Indonesia
[3] Research Center for Nuclear Material and Radioactive Waste Technology, National Research and Innovation Agency, Indonesia
[4] Directorate of Policy Formulation of Research, Technology and Innovation, National Research and Innovation Agency, Indonesia: Email: rrar001@brin.go.id
[5] Directorate of Environmental, Maritime, Natural Resources, and Nuclear Policy, National Research and Innovation Agency, Indonesia
[6] Research Center for Nuclear Beam Analysis Technology, National Research and Innovation Agency, Indonesia
[7] Research Center for Radiation Process Technology, National Research and Innovation Agency, Indonesia
[8] Research Center for Nuclear Reactor Technology, National Research and Innovation Agency, Indonesia
[9] Research Center for Nuclear Reactor Technology, National Research and Innovation Agency, Indonesia
[10] Directorate of Policy Formulation of Research, Technology and Innovation, National Research and Innovation Agency, Indonesia
[11] Directorate of Policy Formulation of Research, Technology and Innovation, National Research and Innovation Agency, Indonesia
[12] Directorate for Nuclear Facility Management, Deputy for Research and Innovation Infrastructure, National Research and Innovation Agency. Indonesia
[13] Research Center for Nuclear Material and Radioactive Waste Technology, National Research and Innovation Agency, Indonesia

innovation capacity. In Indonesia, this trend was exemplified by the integration of the National Nuclear Energy Agency (BATAN) into the newly established National Research and Innovation Agency (BRIN) in 2021. This consolidation merged one nuclear-specialized agency with four non-nuclear institutions under a unified organizational structure, marking a significant departure from the traditional model of sector-specific expertise and safety-focused governance.

BATAN, established in 1958, had long functioned as a dedicated nuclear research institution with a strong emphasis on safety culture and compliance with international standards (BATAN, 2018). It operated multiple high-risk facilities, including three nuclear reactors, fuel fabrication installations, radioactive waste management systems, and radiopharmaceutical production units. Its safety performance was historically robust, supported by a well-defined institutional identity, leadership commitment, and a vertically integrated management system.

However, the integration into BRIN introduced new challenges for nuclear safety governance. The shift toward a generalized research organization diluted the prominence of nuclear-specific priorities within the broader institutional framework. Organizational restructuring altered key dimensions of governance, including vision and mission alignment, leadership roles, personnel relationships, and the implementation of safety protocols. These changes raise critical questions about how institutional transformation affects the sustainability of safety culture and leadership accountability in high-reliability public organizations.

This study interrogates the extent to which institutional restructuring erodes top management's commitment to nuclear safety priorities, disrupts safety management systems, and weakens the implementation of a coherent safety culture, issues central to the literature on High Reliability Organizations (HROs), Institutional Theory, and Public Sector Reform. Drawing on survey data, interviews, and field assessments, we analyse the implications of merging a risk-intensive nuclear organization into a large, multi-purpose public research institution.

Our findings contribute to the understanding of how institutional design shapes risk governance in complex public organizations, particularly in contexts where sector-specific expertise is subsumed into broader bureaucratic structures. The Indonesian case offers unique insights into the tensions between administrative efficiency and operational safety in high-stakes environments, and serves as a cautionary example for other developing nations considering similar reforms.

Literature Review

The integration of specialized nuclear organizations into broader research institutions represents a significant institutional transformation with potential implications for safety governance in high-reliability environments. Drawing on the theoretical frameworks of Institutional Theory, HROs, and Organizational Learning, this study examines how such transformations affect leadership commitment, safety culture, and operational effectiveness in public sector organizations managing high-risk technologies.

Institutional Theory and Isomorphic Pressures

Institutional Theory provides a useful lens to understand how external pressures shape

organizational structures and practices (DiMaggio & Powell, 1983). The restructuring of BATAN into BRIN reflects mimetic isomorphism, where organizations adopt structural forms perceived as legitimate or efficient within a policy field. However, this process may dilute domain-specific expertise and weaken the embeddedness of nuclear safety priorities within the new institutional framework.

This phenomenon has been observed in other contexts where technical specialization was subsumed under broader administrative models. For example, Trajano highlights that Southeast Asian countries often struggle to maintain strong nuclear safety cultures due to weak institutionalization and fragmented oversight. In contrast, Northeast Asian nations like Japan, China, and South Korea have institutionalized nuclear safety through dedicated regulatory bodies and continuous learning systems following major incidents such as Fukushima (Imperial Trajano, 2019).

Greer and Trump had already reminded that adaptive regulation for new organizations allows management to become more stringent if new evidence reveals previously unknown negative consequences (Greer & Trump, 2019). Within high-risk organizations, such as those in the nuclear energy sector, organizational adaptation may have either positive or negative implications for nuclear safety. When decision-makers lack a background or culture rooted in nuclear safety, the policies they implement may lead to adverse outcomes for nuclear safety.

High Reliability Organizations (HROs)

Organizations operating in high-risk environments, such as nuclear facilities, are expected to exhibit characteristics of High Reliability Organizations (Weick & Sutcliffe, 2007). These include preoccupation with failure, sensitivity to operations, deference to expertise, commitment to resilience, and reluctance to oversimplify complex systems. However, the integration of BATAN into BRIN introduced structural simplifications that may conflict with these principles.

For instance, the consolidation of six nuclear facilities under one directorate with limited autonomy raises concerns about span of control, accountability, and responsiveness, key dimensions of effective HRO management. This echoes findings from Hammond et al., who found statistically significant correlations between strong safety culture and improved KPIs related to incident reporting, problem classification, and emergency preparedness (Hammond et al., 2023).

Organizational Learning and Safety Culture

Safety culture plays a central role in sustaining nuclear safety over time. Alshehri emphasize that safety culture is shaped by individual, managerial, and environmental factors and must be continuously reinforced through training, feedback mechanisms, and leadership behavior (Alshehri et al., 2023). However, recent changes at BRIN have led to the discontinuation of regular safety culture workshops, internal audits, and accreditation processes, activities that were previously integral to BATAN's safety system.

This erosion mirrors patterns observed in other contexts where institutional reforms disrupted established safety practices. For example, Ghosh and Apostolakis argue that hidden deficiencies, such as declining employee competence and reduced awareness of safety risks, can accumulate over time and eventually trigger serious accidents if not addressed proactively (Ghosh & Apostolakis, 2005).

Comparative Institutional Responses

Internationally, several countries have undertaken institutional reforms involving nuclear organizations. In Japan, post-Fukushima reforms led to the creation of an independent Nuclear Regulation Authority (NRA), separating regulatory functions from research and development activities. Similarly, China maintains a vertically integrated nuclear safety framework through its National Nuclear Safety Administration (Mu et al., 2015). These examples highlight the importance of maintaining clear lines of accountability and functional separation between research, operations, and regulation, principles that appear to be weakened in BRIN's current structure.

Research Gap and Contribution

While previous studies have examined nuclear safety culture and institutional change separately, few have explored how the merger of specialized nuclear agencies into large, multi-purpose institutions affects long-term safety outcomes. This study fills this gap by analyzing the case of Indonesia's BRIN reform through the lenses of Institutional Theory, HROs, and Organizational Learning. It contributes to the literature on public sector reform by illustrating how generic institutional models may undermine domain-specific safety governance in high-risk settings.

Linking to IAEA Safety Principles: A Focused Lens

Among the ten fundamental safety principles outlined by the International Atomic Energy Agency (IAEA, 2006), this study focuses on four that are most directly affected by institutional restructuring, as shown in Table 1.

Table 1 Selected IAEA Safety Principles relevant to institutional restructuring

Principles	Description	Link to institutional restructuring
1	Responsibility for safety must lie with the highest level of leadership	Weakened due to diluted accountability under BRIN; ultimate responsibility lies with top leadership but implementation is fragmented across units.
3	Leadership and management must prioritize safety in all operations.	Leadership lacks nuclear-specific understanding, weakening the prioritization of nuclear safety.
8	Preventive measures and accident mitigation must be systematically applied.	Maintenance delays increase accident risk; aging infrastructure requires strong preventive measures.
9	Emergency preparedness and response must be continuously maintained.	Decline in regular drills and coordination reduces readiness for nuclear emergencies.

These four principles serve as a benchmark to evaluate how the integration of BATAN into BRIN has influenced nuclear safety governance, particularly in terms of leadership commitment, organizational structure, and safety culture implementation.

Linking Institutional Change to Nuclear Safety: A Theoretical Framework

This study draws on three complementary theoretical perspectives: Institutional Theory, HROs, and Organizational Learning, to examine how institutional restructuring affects nuclear safety governance in high-risk public organizations. These frameworks collectively offer a robust analytical lens to explore the interplay between structural change, leadership

dynamics, and safety culture erosion in Indonesia's National Research and Innovation Agency (BRIN).

Institutional Theory and Isomorphic Pressures

Institutional Theory provides a critical lens for understanding how formal structures in public organizations are shaped by external pressures, norms, and legitimacy-seeking behaviors (DiMaggio & Powell, 1983). It explains how organizations adopt practices not necessarily because of efficiency, but due to perceived legitimacy or peer influence, which DiMaggio and Powell call isomorphic pressures, including mimetic, coercive, and normative mechanisms.

The integration of BATAN into BRIN reflects mimetic isomorphism, where an organization adopts structural forms seen as legitimate within a policy field, in this case, the model of a large, multidisciplinary research institution. However, this shift risks diluting sector-specific expertise and weakening embedded nuclear safety priorities. While the merger aimed to enhance innovation and administrative efficiency, it inadvertently compromised domain-specific accountability and leadership clarity, key elements for maintaining safety in high-reliability contexts.

This phenomenon resonates with Trajano's observation that Southeast Asian countries often struggle to institutionalize nuclear safety cultures due to fragmented oversight and weak organizational identity. In contrast, Northeast Asian nations like Japan and China have maintained strong nuclear safety institutions through vertical integration and regulatory separation, a lesson that remains unheeded in Indonesia's current structure (Imperial Trajano, 2019).

High Reliability Organizations (HROs)

Organizations operating in hazardous environments, such as nuclear facilities, are expected to exhibit characteristics of HROs, which maintain exceptional safety records despite operating under conditions of complexity and uncertainty (Weick & Sutcliffe, 2007). HROs are defined by five core principles: (a) a preoccupation with failure, (b) reluctance to simplify interpretations, (c) sensitivity to operations, (d) commitment to resilience, and (e) deference to expertise.

The transformation of BATAN into BRIN introduced organizational simplification, which contradicts these foundational HRO principles. For example, the consolidation of six nuclear facilities under one directorate has raised concerns about span of control, responsiveness, and operational sensitivity, particularly when managing aging infrastructure. Moreover, the lack of dedicated nuclear leadership erodes the deference to expertise necessary for effective risk mitigation. By applying the HRO framework, this study evaluates how BRIN's structural design aligns, or fails to align, with the attributes of high-reliability systems. Our findings suggest that the current configuration may compromise the ability to detect early warning signs of safety degradation, especially amid personnel turnover and weakened internal audits.

Organizational Learning and Cultural Erosion

Organizational Learning Theory emphasizes the importance of continuous learning and adaptive capacity in complex environments (Argyris & Schön, 1997). In nuclear safety contexts, organizational learning involves detecting errors, institutionalizing corrective

actions, and reinforcing a shared commitment to safety.

The transition from BATAN to BRIN disrupted long-standing routines and feedback mechanisms vital to sustaining safety culture. Regular safety workshops, internal audits, and ISO accreditation processes, once integral to BATAN's learning system, have been reduced or eliminated. This disruption threatens the development of what Alshehri term a "learning organization," where individual, managerial, and environmental factors converge to reinforce safety at all levels (Alshehri et al., 2023).

The erosion of learning mechanisms mirrors patterns observed in other institutional reforms. Ghosh and Apostolakis argue that hidden deficiencies, such as declining employee competence and reduced awareness of safety risks, can accumulate over time and eventually trigger serious accidents if not addressed proactively (Ghosh & Apostolakis, 2005).

Integrating Theory and Context

These three frameworks collectively provide a multi-dimensional foundation for analyzing institutional restructuring in Indonesia by explaining the rationale behind organizational structures through Institutional Theory, assessing their implications for safety reliability through HRO principles, and evaluating their effects on knowledge retention and cultural continuity through Organizational Learning.

Together, they reveal how BRIN's structural isomorphism may weaken its capacity to function as a high-reliability organization, particularly when facing long-term challenges such as aging infrastructure and workforce regeneration.

Research Contribution

This study contributes to the literature by demonstrating how institutional isomorphism in the public sector can conflict with the requirements of high-reliability governance. Unlike previous studies that treat nuclear safety primarily as a technical issue, we show how organizational form and institutional pressures shape safety outcomes in public agencies. Furthermore, our analysis highlights the tension between bureaucratic rationalization and safety culture preservation, a concern increasingly relevant for developing countries pursuing science and technology reforms without adequate safeguards for high-risk functions.

Research Objectives

This study aims to contribute to the understanding of how institutional restructuring in high-risk public organizations affects nuclear safety governance, particularly in the context of developing countries undergoing science and technology reforms. By focusing on Indonesia's integration of BATAN into the multidisciplinary National Research and Innovation Agency (BRIN), we seek to address the following research question:

"To what extent does institutional restructuring dilute sectoral leadership and affect safety culture in high-reliability public organizations?"

Specifically, this study has three interrelated objectives as follows:

Theoretical Objective

To advance the literature on institutional change and high reliability governance by

analyzing how mimetic isomorphism, driven by bureaucratic consolidation, affects the embeddedness of nuclear safety priorities in a large, generalized public research institution.

Practical Objective
To provide actionable policy recommendations for strengthening nuclear safety performance in BRIN, with particular emphasis on leadership commitment, organizational structure clarity, alignment of the safety management system, and the institutionalization of a safety culture.

Comparative Objective
To situate Indonesia's case within a broader global context by comparing its post-merger challenges with institutional reforms in Northeast Asian countries (e.g., Japan, China, South Korea), where nuclear safety remains a central institutional priority despite structural changes.

By achieving these objectives, this study offers insights into how generic institutional models may undermine domain-specific expertise and safety accountability in high-risk settings and provides guidance for policymakers seeking to balance administrative efficiency with operational safety in large-scale public organizations.

This study contributes to the literature on public sector reform and high-reliability governance by illustrating how institutional isomorphism can erode safety culture and leadership clarity in high-risk contexts, offering lessons not only for Indonesia but also for other developing nations pursuing integrated research models.

Critical Institutional Challenges in Nuclear Safety Governance

The integration of BATAN into the broader National Research and Innovation Agency (BRIN) has introduced several critical challenges for nuclear safety governance in a high-reliability public organization. Drawing on survey data, interviews, and field observations, this study identifies four key institutional and operational issues that threaten the continuity of effective nuclear safety management under the new organizational structure.

Aging Infrastructure and Management Gaps
Most of BRIN's nuclear facilities, including research reactors and radioactive waste treatment installations, have been operating for several decades. The GA Siwabessy Reactor (30 MW), Triga 2000 Bandung, and Kartini Reactor are now over 30–60 years old, requiring specialized maintenance and aging management strategies. However, the current isomorphic organizational structure lacks dedicated oversight mechanisms to prioritize aging-related risks. Under mimetic isomorphism, BRIN has adopted a generic research model that treats nuclear facilities as one among many technical assets, rather than high-risk infrastructures requiring specific lifecycle management.

This issue aligns with findings from Hammond, who demonstrate that weak institutional prioritization of aging infrastructure can significantly degrade safety performance indicators (Hammond et al., 2023). In BRIN's case, the lack of clear accountability lines further exacerbates the challenge of implementing timely preventive maintenance or upgrades.

Paradigm Shift in Nuclear Safety Culture
The transition from a nuclear-specific agency to a multidisciplinary research institution has altered the fundamental understanding of nuclear safety within BRIN. Prior to the merger,

BATAN maintained a vertically integrated safety culture where nuclear expertise was embedded at all levels. Post-merger, not all leaders and staff under BRIN possess the same level of appreciation for nuclear safety principles, leading to a dilution of safety priorities in favor of innovation goals.

This phenomenon reflects Trajano's observation that Southeast Asian countries often struggle to institutionalize nuclear safety due to fragmented oversight and cultural shifts following structural reforms (Imperial Trajano, 2019). In contrast, Northeast Asian nations like Japan and China have reinforced nuclear safety through vertical specialization and continuous training, practices that have diminished under BRIN's current configuration.

Partial Adoption of Safety Management Systems

Despite the existence of formal safety policies inherited from BATAN, the safety management system has not been fully internalized by BRIN as an organization-wide priority. Interviews reveal that while technical standards remain in place, there is limited top-down commitment to enforcing them across all units. This partial adoption undermines the principle of "safety as a core value" (IAEA, 2006), particularly when nuclear activities are managed alongside non-nuclear operations.

The erosion of systemic safety practices, such as regular audits, ISO accreditation, and safety culture workshops, has weakened BRIN's capacity to function as an HRO. Without strong enforcement of safety protocols, hidden deficiencies may accumulate, increasing the risk of latent failures (Ghosh & Apostolakis, 2005).

Human Resource Sustainability and Knowledge Erosion

One of the most pressing long-term concerns is the sustainability of human resources with nuclear safety competencies. While many current employees retain knowledge from the BATAN era, future workforce regeneration may lead to significant gaps in safety awareness and technical expertise. This concern is exacerbated by the absence of a centralized nuclear education and training unit within BRIN, a role previously fulfilled by BATAN's dedicated center.

Without targeted interventions to preserve and transmit safety knowledge, BRIN risks experiencing what Argyris and Schön describe as a breakdown in organizational learning. The loss of experiential safety knowledge could compromise resilience and responsiveness to emerging threats, especially in complex, high-risk environments (Argyris & Schön, 1997).

Structural and Cultural Challenges in an Open Platform Model

BRIN's strategic vision emphasizes openness and collaboration, positioning its nuclear facilities as shared platforms for domestic and international researchers. While this approach fosters innovation, it also introduces new safety risks, particularly when interacting with personnel unfamiliar with nuclear safety norms.

The open platform concept, outlined in BRIN's Strategic Plan (2022–2024), demands robust safety induction programs and consistent reinforcement of safety values across diverse user groups (BRIN Regulation No. 6 Year 2023 Regarding Strategic Planning of BRIN Year 2022-2024, 2023). Yet, our findings show that such programs have been reduced or eliminated since the merger. Without deliberate efforts to embed safety culture across all

levels of the organization, the open-platform model may inadvertently undermine safety reliability.

These institutional changes raise critical questions about how generic organizational models interact with domain-specific safety requirements. They also highlight the need for adaptive regulation and policy reform to ensure that high-reliability functions are preserved amid bureaucratic consolidation.

METHODOLOGY

This study employs an exploratory case study approach (Robert K. Yin, 2014), focusing intently on the complex institutional transformation of Indonesia's nuclear safety governance following the merger of BATAN into BRIN. This approach is particularly suited to our research question, 'To what extent does institutional restructuring dilute sectoral leadership and affect safety culture in high-reliability public organizations?', as it allows for an in-depth investigation of a contemporary phenomenon within its real-world context, where the boundaries between phenomenon and context are not clearly evident. Given the inherent complexity of organizational change within a high-risk sector and the multifaceted nature of safety governance, a mixed-methods design was strategically employed.

This approach not only captures quantitative perceptions regarding key aspects of nuclear safety management, such as leadership commitment and safety culture implementation, but also provides rich qualitative insights into the underlying reasons, dynamics, and lived experiences of these changes. Specifically, quantitative data from surveys identified observable trends and patterns in staff perceptions across the organization. Complementary qualitative data from semi-structured interviews and field observations then allowed for a deeper exploration of *why* these trends emerged and *how* they manifested in daily operations, thereby explaining decision-making delays, institutional clarity issues, and resource allocation challenges. This comprehensive combination of data sources provides a more robust and nuanced understanding of the restructuring's impact on nuclear safety than either method could achieve independently.

Our methodological design is further guided by a modified framework for evaluating management change, as depicted in Fig.1. This model emphasizes that organizational transformation, including shifts in vision, mission, and management structures, directly impacts the implementation of safety principles and overall nuclear safety performance (Wahlström et al., 2005). Following this framework, our research commenced by identifying the *Change of Organization* and *Change of Management* within BRIN, which set the stage for potential impacts on nuclear safety. To assess these impacts and the resulting *Challenges to Safety Improvement*, we performed comprehensive *Data Collection.* This stage involved the distribution of structured questionnaires to gather quantitative perceptions on leadership commitment, role clarity, aging management, and emergency preparedness. Concurrently, semi-structured interviews were conducted to elicit qualitative insights into decision-making processes, institutional clarity, safety culture, and resource allocation. Additionally, field observations and document analysis at the Radioactive Waste Treatment Installation (RWTI) provided real-time understanding of safety practices and institutional interactions.

The collected data then informed the generation of *Recommendations to Fulfill Safety Requirements*, aimed at strengthening institutional frameworks. Furthermore, the model highlights 'Organizational Learning and Strengthening', which is crucial for continuous improvement in high-reliability environments (Handoyo, 2012). Our analysis, therefore, not only

evaluates the current state but also seeks to provide insights for developing future 'Strategies and Plan Action' and fostering a culture of 'Lesson Learnt' within BRIN, thereby contributing to sustainable nuclear safety performance.

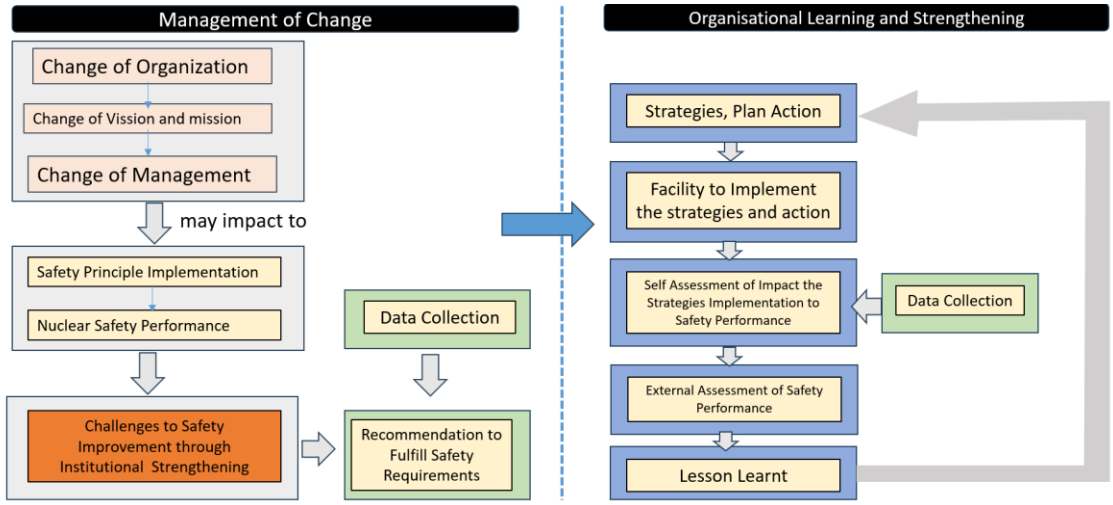

Fig. 1 General overview of the safety evaluation model due to organizational change

Data Collection

Data was collected using three primary methods as follows.

Questionnaire

Structured questionnaires were distributed to 177 staff across six nuclear facilities managed by BRIN. The target population for the survey comprised all employees within the nuclear-related units of BRIN, specifically the Nuclear Energy Research Organization, the Directorate of Nuclear Facilities Management (DNFM), and the Directorate of Laboratory Management, totaling approximately 1,100 employees at the time of data collection. A stratified random sampling technique was employed to ensure representation from these distinct organizational units. The sample aimed to include approximately 16% of the total employees from these units, proportionally. This approach ensured that perceptions from various operational and management levels directly involved with nuclear facilities were captured.

The questionnaire items were meticulously designed based on selected IAEA safety principles (Principles 1, 3, 8, and 9), which directly address responsibility for safety, leadership commitment, accident prevention, and emergency preparedness – all critical aspects impacted by the institutional restructuring. To ensure the content validity of the instrument, initial drafts were rigorously reviewed by three former high-ranking BATAN safety officials, whose expertise provided invaluable insights into the nuances of nuclear safety operations and governance. Following this expert review, the questionnaire underwent a pre-test with 10 respondents, selected from outside the main sample but possessing similar characteristics, to refine clarity, comprehension, and flow of questions. Feedback from this pre-test led to minor adjustments in wording to enhance the overall quality of the instrument. Responses were captured using an

ordinal scale, ranging from the worst perception to the best perception, for example, 'Very Unsure' to 'Very Sure' for questions on effectiveness, and 'No Commitment' to 'Fully Committed' for questions on leadership commitment, allowing for nuanced quantitative measurement of perceptions. Quantitative data obtained from the questionnaires were then processed using PSPP statistical software (Sihombing et al., 2024).

Interview and Focus Group Discussion (FGD)

To complement the quantitative survey data and gain deeper qualitative insights into the institutional dynamics and lived experiences of the organizational change, semi-structured interviews were conducted with 20 key respondents. These individuals were purposively selected to ensure a comprehensive representation of perspectives from various critical functions and hierarchical levels within BRIN's nuclear-related facilities. Respondents included top and middle management responsible for nuclear operations, experienced nuclear operators with direct involvement in facility activities, nuclear safety, quality assurance personnel overseeing safety protocols, and nuclear security personnel. They work at various nuclear facilities located in three sites: Serpong, Bandung, and Yogyakarta. This purposive sampling strategy was employed to capture diverse viewpoints and expert knowledge on issues such as decision-making delays, the clarity of institutional roles, the evolving safety culture, nuclear emergency drill, nuclear security, and resource allocation challenges post-merger.

The interviews and FGD were guided by a semi-structured protocol, which allowed for consistency across interviews by covering core themes while simultaneously providing the flexibility to explore emergent issues and delve deeper into specific responses. All interviews were conducted with the explicit informed consent of the participants, to ensure accuracy and completeness of data capture. The results of the interviews and FGDs were compared and integrated with the results of the questionnaire both in the form of open and close questions to obtain more accurate conclusions.

Field Observation and Document Analysis

To gain a firsthand understanding of real-time safety practices and the practical implications of institutional changes, field observation was conducted at the RWTI. The scope of observation specifically included: (1) adherence to established safety procedures during waste handling and processing, (2) observable interactions among staff related to safety communication and compliance, (3) the general condition of critical safety infrastructure and equipment, and (4) management's response to safety issues at RWTII. This direct observation provided valuable context for the perceptions gathered through surveys and interviews, highlighting any discrepancies between formal policies and actual operational practices.

Concurrently, an in-depth analysis of relevant documents was performed. These documents included internal operational reports, official nuclear safety policies, recent safety audit records, and strategic planning documents from both BATAN (pre-merger) and BRIN (post-merger). The analysis of these documents allowed for triangulation of data by comparing stated policies and past performance with current perceptions and observed practices. For instance, comparing historical audit findings from BATAN with current BRIN documents provided insights into the continuity (or discontinuity) of safety priorities and the formalization of safety management systems within the new organizational structure.

Data Analysis

Quantitative data derived from the structured questionnaires were analyzed using descriptive

statistics, including frequencies, and percentages, to identify prevailing trends and patterns in staff perceptions regarding leadership commitment, role clarity, aging management, and emergency preparedness within BRIN. While the primary focus was on descriptive analysis to delineate the current state of nuclear safety management post-merger, non-parametric statistical analyses using Mann–Whitney test were conducted to find out whether there is a significant difference between two independent groups, as the study's exploratory nature emphasized in-depth understanding of the overall organizational changes.

Qualitative data from semi-structured interview and respondent's answer of open question from questionnaire were grouped by theme and generated using a word cloud generator to identify the most highlighted themes. This involved reading through the transcripts to identify recurring patterns, concepts, and categories that emerged directly from the data, without imposing preconceived theoretical frameworks at the initial coding stage. Codes were then grouped into broader themes such as 'perceived leadership gaps', 'organizational confusion', 'safety culture erosion', 'resource allocation challenges', and 'decision-making delays', reflecting the participants' lived experiences and perspectives.

A robust triangulation approach was central to the data analysis process, serving not merely as a validation technique but as a method for synthesizing insights and constructing a comprehensive understanding. Findings from the quantitative survey, which highlighted specific areas of concern (e.g., low leadership commitment, ineffective span of control), were further explored and contextualized through the qualitative data from interviews and focus group discussions (FGDs). For instance, quantitative data indicating low leadership commitment to nuclear safety were enriched by interview narratives explaining the reasons behind this perception, such as lack of direct communication or prioritization of non-nuclear goals. Field observations and document analysis at the RWTI then provided an additional layer of confirmation, allowing us to assess the real-time implementation of stated policies and observed practices against the reported perceptions. This iterative process of comparing, contrasting, and confirming findings across these three distinct data sources allowed us to draw robust conclusions and formulate actionable policy recommendations.

The conclusion, which serves as the basis for formulating recommendations, was drawn through triangulation approach, by combining respondents' perceptions gathered from the questionnaire, in-depth exploration of those perceptions through interviews and in-depth interviews, focus group discussions (FGDs), and field visits to confirm the results of the triangulation (Braun & Clarke, 2006).

Validity and Reliability

To ensure the rigor and trustworthiness of this study, both the validity and reliability of the data collection instruments were meticulously addressed.

Questionnaire Validity

The questionnaire instrument's validity was established through several steps. Firstly, content validity was rigorously ensured via an expert review process. Three former high-ranking officials from BATAN, each possessing over 20 years of experience in nuclear safety regulation and operations, served as expert reviewers. Their extensive background and deep understanding of nuclear safety standards and institutional practices made them ideal candidates to assess whether the questionnaire items accurately and comprehensively covered the relevant domains of nuclear

safety management and organizational change. Secondly, the instrument underwent a pre-test with 10 respondents, selected for their similar demographic and professional profiles to the main study population but not included in the final sample. Feedback from this pre-test was crucial in identifying ambiguities, clarifying phrasing, and refining item structure, thereby enhancing the questionnaire's clarity and respondent comprehension. While formal statistical construct validity analyses were not performed given the exploratory nature of this qualitative-dominant mixed-methods study, the aforementioned steps were taken to maximize the instrument's ability to accurately capture the intended constructs related to nuclear safety perceptions.

Questionnaire Reliability (Internal Consistency)

The internal consistency reliability of the questionnaire was assessed using Cronbach's Alpha. This statistical measure evaluates the extent to which items within a scale measure the same underlying construct. Cronbach's alpha consistently provided accurate estimates in all replications and demonstrated robustness (Malkewitz et al., 2023).

The acceptability of the measurement can be seen in **Error! Reference source not found.**. The value of Cronbach's Alpha ranges from 0 to 1. A Cronbach's Alpha value greater than 0.60 indicates that the tested questionnaire is considered reliable or consistent and can be used as a measurement tool in research related to knowledge, attitudes, and behavior (Anggraini et al., 2022).

Table 2 Interpretation of Cronbach's Alpha Consistency Values (Gliem & Gliem, 2003)

Alpha Value	Consistency values
≥ 0.90	very high
0.80 – 0.89	high
0.70 – 0.79	adequate
0.60 – 0.69	low
< 0.60	un acceptable

Mann–Whitney U test

The Mann–Whitney U test is used to determine whether there is a significant difference between two independent groups in terms of ranking or order of values. This test is useful for providing insights to support policy intervention decisions. To determine whether the difference between groups is statistically significant, the p-value (Asymp. Sig. (2-tailed)) is examined. If the p-value is less than 0.05, it indicates a significant difference. If the p-value is equal to or greater than 0.05, there is no significant difference. When a significant difference exists, interventions may be targeted only at specific groups whose perceptions are considered unfavorable. Conversely, if there is no significant difference, a comprehensive intervention may be implemented if the overall perception is generally poor, or no intervention is necessary if the perceptions align with the expected result. In certain situations, such as when effect sizes are small and sample sizes are limited, the Mann-Whitney test has been shown, as noted by others, to offer greater sensitivity in detecting group differences (Cook, 2025).

Interviewer Bias and Thematic Consistency (Qualitative Reliability)

Interviewer bias in the semi-structured interviews was minimized through the consistent use of a detailed interview guide, ensuring that all core themes were explored uniformly. The reliability of the qualitative findings was also verified through thematic consistency across multiple data sources. This involved cross-referencing recurring themes identified in interview transcripts with observed behaviors during field visits and relevant information extracted from analyzed documents. This process ensured that the qualitative insights were not isolated but consistently supported by convergent evidence, thereby enhancing the overall trustworthiness of the findings.

Respondents' answers to the open-ended questions in the questionnaire were analyzed for trends and patterns using *Word Frequency Analysis* within the framework of *text mining*, and the results were visualized in the form of a *word cloud*. Word frequency analysis was assessed by Wooclap, an opensource application. The interview findings were compared with the results of the word frequency analysis to assess the consistency of the interview result. According to Stanca et al., a word cloud visually displays the frequency of various words that appear in the results of a survey, whether derived from questionnaires or interview transcript (Stanca et al., 2023).

RESULTS

Statistical Analysis

Cronbach's Alpha

The Cronbach's Alpha value for the items specifically measuring the effectiveness of BRIN as a new institution in implementing the nuclear safety system at each nuclear installation was found to be 0.948. This exceptionally high value, derived from two key items (N of Items = 2), indicates a very strong internal consistency, suggesting that these two items are highly correlated and reliably measure the same dimension of effectiveness

Furthermore, for a broader set of nuclear safety items—encompassing the implementation of the safety management system, nuclear governance, safety span of control, safety culture implementation, and leadership commitment—the Cronbach's Alpha value was 0.704. This value indicates an adequate and acceptable level of internal consistency for these five items (N of Items = 5). Generally, a reliability coefficient of 0.70 or higher is considered acceptable in social science research (UCLA, 2019).

Mann-Whitney U Test

Regarding the Mann–Whitney U test, several sample comparisons were conducted between independent groups in terms of the ranking or order of values, as presented in Table 3.

Table 3 The result of Mann–Whitney U test

Independent Variable	Group of Independent Variable	p-value
1. Safety System Implementation		
Age of Respondent	<25 and > 65 year	0.930
Education of Respondent	High school and Doctoral Degree	0.796
Area of Working	Nuclear and Non-Nuclear Area	0.592
Gender	Male and Female	0.636
2. Safety Governance Implementation		
Age of respondent	<25 and > 61-65 year	0.470
Education of Respondent	Under Graduate and Doctoral Degree	0.247
Area of Working	Nuclear and Non-Nuclear Area	0.967

Gender	Male and Female	0.545
3. Implementation of Safety Culture		
Age of respondent	26-30 and > 51-60 year	0.648
Education of Respondent	Under Graduate and Doctoral Degree	0.235
Area of Working	Nuclear and Non-Nuclear Area	0.827
Gender	Male and Female	0.219
4. Top Leader Commitment		
Age of respondent	31-40 and > 51-60 year	0.325
Education of Respondent	Under Graduate and Master Degree	0.564
Area of Working	Nuclear and Non-Nuclear Area	0.404
Gender	Male and Female	0.253

Based on the results of the Mann–Whitney U test (sample), all p-values have values > 0.05, which means that the independent variable groups are not significantly different. This means that policy interventions cannot be carried out only on certain groups, but must be carried out comprehensively.

Institutional Organization and its Governance Related to Nuclear Facilities and Nuclear Safety

Impact on Organizational Span of Control and Resource Allocation

The institutional transformation of BATAN into BRIN consolidated previously autonomous nuclear facilities under a single Directorate for Nuclear Facilities Management (DNFM) within the broader Deputy for Research and Innovation Infrastructure (DRII). This structural simplification, while aiming for administrative efficiency, raised significant concerns among staff regarding the effectiveness of the span of control in maintaining nuclear safety. A survey question posed to respondents inquired: "Could the span of control to maintain safety be implemented properly considering that many nuclear facilities are the responsibility of the DNFM?". As shown in Fig. 2**,** a substantial 65.5% of the 171 respondents who answered, expressed either 'not sure' or 'very unsure' about the effectiveness of this span of control. This finding highlights a widespread apprehension among personnel that the consolidation might pose a long-term threat to nuclear safety, potentially leading to hidden vulnerabilities where directors are assigned tasks exceeding their capacity.

Qualitative insights from in-depth interviews further illuminated these concerns, particularly regarding resource allocation and decision-making processes. Interviewees frequently cited that access to critical resources, including the procurement of spare parts for systems, structures, and components (SSCs) vital for nuclear safety, became highly dependent on the Deputy level as the Proxy of Budget User (KPA). This bureaucratic layer introduced significant delays, impeding the timely execution of maintenance crucial for aging nuclear facilities. The observed gap in decision-making authority, where technical operational decisions requiring immediate action still relied on higher-level approval, was consistently identified as a major impediment to effective safety management. While the placement of quality assurance and safety function staff under the DNFM was perceived as helpful in increasing management effectiveness, the overarching dependency on the Deputy for critical budget-related safety decisions remained a concern. This span of control is very important, considering that many of BRIN's nuclear facilities are aging, so aging management is key in maintaining nuclear safety.

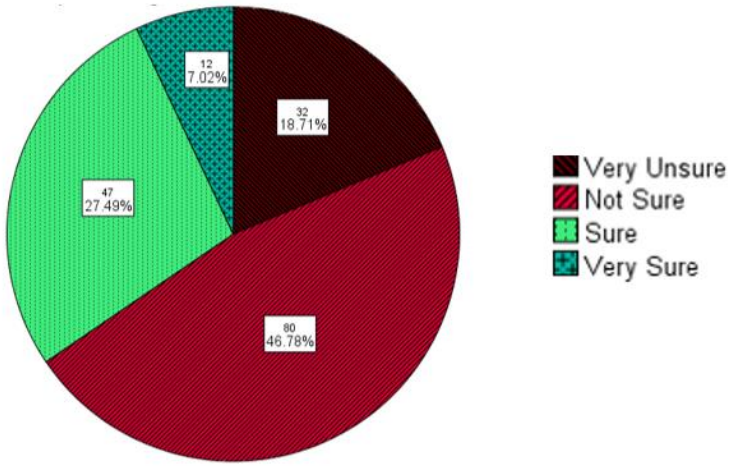

Fig. 2 Respondents level of confidence in the effectiveness of the span of control at DNFM in maintaining nuclear safety

During the field observation at RWTI, our finding of main issues related to resource allocation and changes in radioactive waste treatment procedures due to organizational changing which has the potential to reduce nuclear safety as follows.

a. The interim storage (IS) facility for radioactive waste is nearing its maximum capacity, yet BRIN has not demonstrated any intention to develop a plan for its expansion. This stands in contrast to BATAN, which had previously formulated a comprehensive development plan prior to its integration into BRIN. The lack of such planning poses a risk of disrupting the management and provision of radioactive waste services, which hold national significance, and of course has the potential to be a hidden threat to nuclear safety.

b. The budget allocation is not disclosed to the coordinator of radioactive waste treatment. When essential spare parts are needed, the coordinator must submit a request but is uncertain whether it will be approved by the top management or the Budget User Authority (KPA).

c. The radioactive waste treatment procedures that previously adhered to established standards under BATAN have been replaced by new procedures that prioritize cost efficiency over nuclear safety. In addition, the execution of these procedures has been delegated to third-party contractors who lack sufficient knowledge and understanding of nuclear safety requirements.

Perceptions of Nuclear Safety Governance and Systemic Weaknesses

The perceived effectiveness of nuclear safety governance under the new isomorphic organizational structure also revealed significant challenges. When asked about the overall functioning of nuclear safety governance, considering one director manages six nuclear facilities and resource authority rests at a higher level, 52.76% of 163 respondents expressed concerns, believing it would either 'not function well' or 'not running and worrying' (Fig. 3). This apprehension underscores a perceived erosion of 'impartiality' in radioactive waste management

at RWTI, where the director's broad responsibilities could potentially intervene with strict adherence to waste management standards.

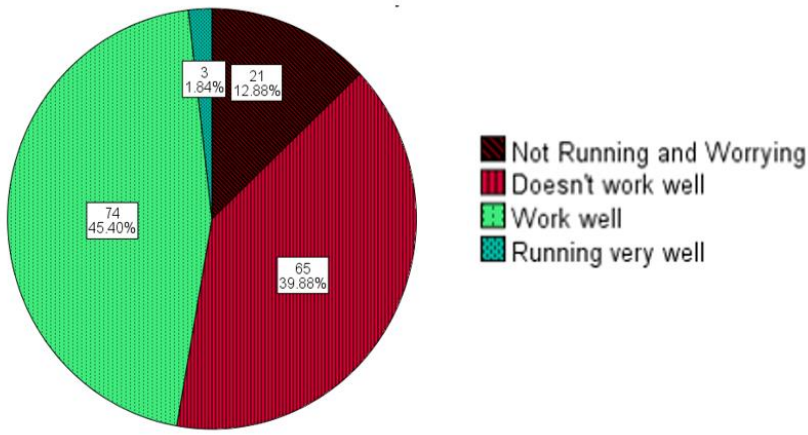

Fig. 3 Respondents level of confidence in the governance of nuclear safety in the nuclear installation

Based on open-ended questionnaire responses and in-depth interviews, several key systemic weaknesses in nuclear safety governance were identified:

a. *Compartmentalization and Coordination Deficiencies*: The separation between the research organization and the facility management organization has led to compartmentalization, significantly hindering communication, coordination, and consultation crucial for integrated safety operations.
b. *Lack of Dedicated Safety Entity*: There is no dedicated organizational unit explicitly responsible for implementing the nuclear safety system; this vital function is currently managed only by a team, indicating a lack of institutional prioritization.
c. *Limited Authority for Safety Implementation*: The research organization itself lacks the necessary authority to fully implement emergency response systems and other critical safety protocols.
d. *Emergent Risks from Open Platform System*: The implementation of an 'open platform' and 'co-working space' (CWS) system within BRIN poses a potential safety threat, as it allows employees unfamiliar with nuclear safety culture to work in close proximity to nuclear facilities without adequate safety induction.
e. *Communication Gaps*: A notable lack of two-way communication between top management and technical operators contributes to a disconnect in safety understanding and priorities.
f. *Budget Uncertainty*: The absence of dedicated and certain budget allocations for nuclear safety initiatives further compounds operational challenges.
g. *Declining Safety Culture Awareness*: A pervasive lack of understanding and awareness of nuclear safety culture among the majority of BRIN employees, coupled with the absence of regular safety inductions in nuclear areas, was consistently reported.

h. *Complex Procurement Bureaucracy*: The procurement processes are perceived as overly complex and slow, delaying critical responses from authorities regarding safety-related needs.
i. *Reduced Safety Monitoring and PPE Provision*: Radiation monitoring is no longer routinely conducted, and adequate attention is not given to the provision of personal protective equipment (PPE) for radiation safety.
j. *Diminished Safety Training*: Safety culture training and workshops are no longer regularly conducted, leading to a decline in employees' competence regarding safety culture.

These identified deficiencies, particularly the failure to implement essential corrective actions, directly contradict the principles of HROs, which emphasize preoccupation with failure, reluctance to simplify interpretations, sensitivity to operational details, commitment to resilience, and deference to expertise, and could potentially weaken the nuclear safety system, increasing the risk of future accidents (Veazie et al., 2019).

Organizational Learning and Competence Erosion

Based on the Focus Group Discussions (FGDs) and interviews conducted at nuclear facilities, the following findings were obtained:

a. During the FGD held at the Yogyakarta Nuclear Area on 6–7 September 2023, it was revealed that there is no scheduled training program related to nuclear emergency preparedness and security.
b. The FGD at the Serpong Nuclear Area on 15–16 June 2025 indicated that facility-level emergency training has been conducted; however, area-level training has not yet been implemented.
c. In the FGD at the Bandung Nuclear Area on 29–30 August 2023, it was revealed that safety culture gatherings are only carried out partially, and there is no clear nuclear safety training program in place.

Based on the questionnaire results, most respondents answered that it had never been done (51,95%) and there was a nuclear emergency training plan. 11.69% of respondents answered that there had never been training but there was a plan. 16.23% answered that emergency training had been carried out and 20.13% answered that they did not know (Fig. 4).

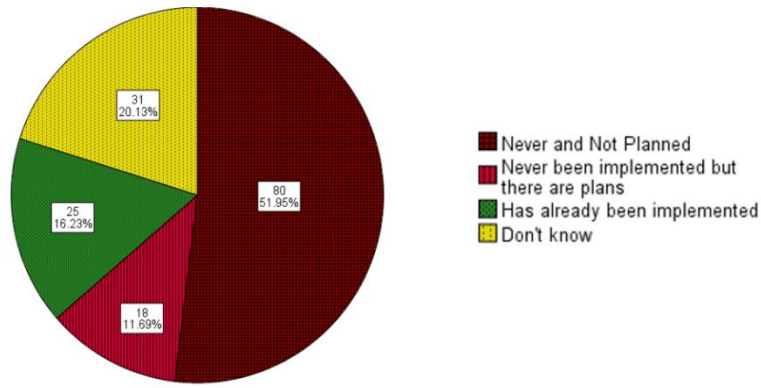

Fig. 4 Respondents' answers to nuclear emergency training questions

Findings from in-depth interviews, the result of questionnaire and responses to open-ended questionnaire items consistently indicate a significant decline in organizational learning mechanisms crucial for maintaining nuclear safety. Specifically, safety culture training and seminars, which were previously integral to BATAN's continuous learning environment, are no longer being conducted regularly within BRIN. This cessation has directly led to a reported decline in employee competence and awareness in critical safety areas.

A key contributing factor to this erosion is the current absence of a dedicated Center for Nuclear Education and Training within BRIN. This contrasts sharply with international best practices, such as those demonstrated by the Joint Research Centre (JRC) in Europe, which actively provides comprehensive education and training services related to nuclear safety, security, decommissioning, and radioactive waste management (Michailidou et al., 2024). The lack of such dedicated training programs within BRIN directly threatens the long-term sustainability of capabilities, competencies, and a robust safety culture, thereby posing a significant and escalating risk to nuclear safety. As articulated by Callan et al., culture represents the collective learning of a group, suggesting that without continuous reinforcement through training and engagement, the established safety culture risks degradation. This aligns with the understanding that various problems can be addressed by developing an organizational culture that involves all members, fostering a unified perspective on the organization's vision (Callan et al., 2004).

Management System and leadership for nuclear safety

Effective management commitment is paramount for cultivating a positive health and safety culture, positioning it as a top priority within an organization's vision and mission. While BRIN has formal regulations related to nuclear facility safety and activities at the directorate level, such as the 'Guidance of Management System for Directorate of Nuclear Facility Management – BRIN' and specific decrees on nuclear emergency preparedness and material control, the adoption of these into operational regulations at the top management level remains a critical area for improvement. This gap is particularly significant when considering IAEA Safety Fundamental Principles 1 and 3, which emphasize that primary responsibility for safety lies with the highest leadership, and that leadership must prioritize safety in all operations (IAEA, 2006) .

The transition and restructuring from a specialized nuclear entity to an isomorphic organization present notable challenge in adapting the safety management system. Although a nuclear safety management system exists, it was initially implemented primarily at the DNFM directorate level. This approach, however, poses a potential for bias and decentralization, given that ultimate responsibility for nuclear safety rests with the Chairman of BRIN. Consequently, for effective accountability and consistent implementation, the nuclear safety management system necessitates elevation to the top management level of BRIN's structure, with systematic cascading to all operational units.

Respondents' perceptions regarding the presence and implementation of a nuclear safety management system within their work units were varied. Out of 151 respondents, 17.2% stated that no such system was available, while 17.88% reported it was available but difficult to implement. A substantial 42.4% indicated that the system was available and implemented but

required minor improvements, and only 22.5% considered it available and well-implemented (Fig. 5).

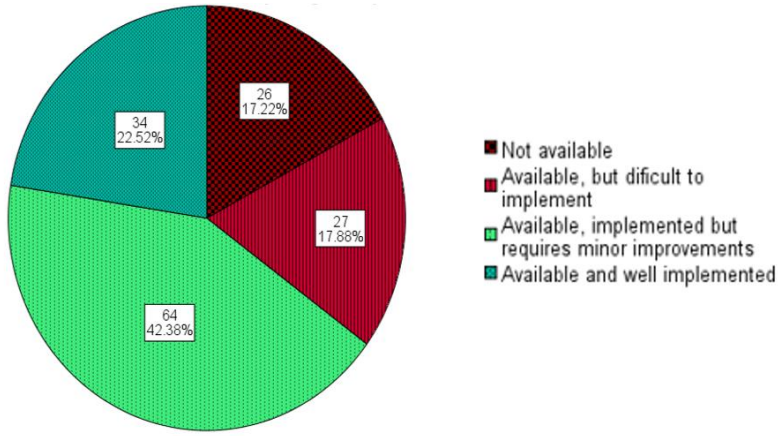

Fig. 5 Respondents' answer regarding availability and applicability of nuclear safety management system

Perceptions of top management's commitment to nuclear safety also revealed significant concerns. Among 173 respondents, a majority (52.6%) perceived top management as having 'slight commitment' to nuclear safety, and a further 26% believed there was 'no commitment at all'. In contrast, only 5.8% perceived 'very committed' and 15.61% 'considerable commitment' (Fig. 6). This stark disparity underscores a critical perceived lack of strong leadership prioritization of nuclear safety at the highest levels of the organization.

According to the NSW Work Cover Authority in the Management Commitment presentation materials (Kitney, 2013), management commitment is an efforts to create a positive health and safety culture by placing it as a top priority in the organization's vision and mission (Kitney, 2013). The other definition (WHSQ), mentioned that the management commitment is an effort to ensure a safe workplace includes secure work systems, incident reporting, valuing staff contributions, and providing safe tools.

Based on the results of interviews with DNFM management, it was revealed that several regulation related to the safety of nuclear facilities and activities have been made, such as:

a. Guidance of Management System for Directorate of Nuclear Facility Management – BRIN.
b. Decree of the BRIN Chairman regarding the Nuclear Emergency Preparedness and Countermeasures Team for the B.J. Habibie Science and Technology Park, Serpong, year 2023.
c. Decree of the Director of Nuclear Energy Facilities Management regarding Responsibility of Management and Control of Nuclear Materials.

In the Guidance of Management System, nuclear safety is included in the scope of the management system, in addition to the nuclear quality and security system (Pedoman Sistem Manajemen Direktorat Pengelolaan Fasilitas Ketenaganukliran Badan Riset Dan Inovasi Nasional, 2022). Based on the above conditions, it is shown that BRIN already commits,

especially at the directorate level, but partially. It still needs to be improved so that all regulations related to nuclear safety have been adopted and adapted in BRIN level, becoming operational regulations. Especially for nuclear safety management, it has not been adopted at the BRIN top management level. This is very important, remembering in safety principle 1 and principle 3.

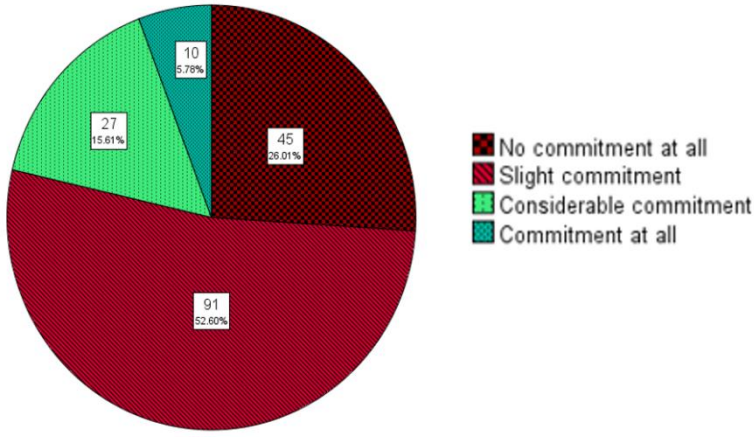

Fig. 6 Respondents' answers regarding top leader's commitment to nuclear safety

The implementation of a strong safety culture, essential for maintaining nuclear safety and aligned with HRO principles, also showed weaknesses. When asked about safety culture implementation in their work unit (from 153 respondents), a large majority (74.68%) reported either 'do not know' or 'no longer any safety culture activities'. Only 11.69% stated that activities existed but were rare, and 13.64% reported regular implementation (Fig. 7).

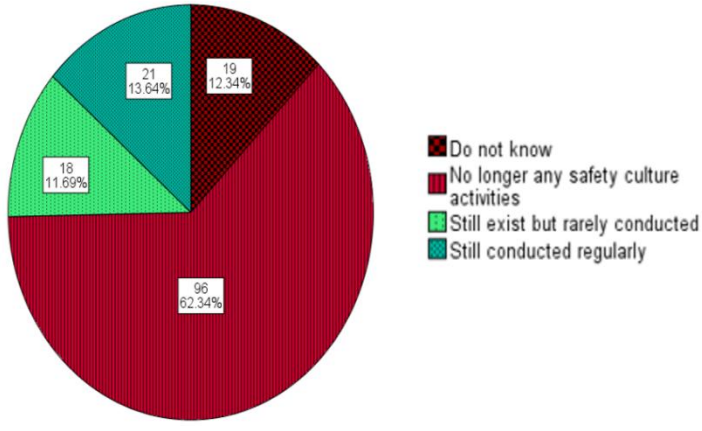

Fig. 7 Respondents' answers regarding safety culture activities

Furthermore, the effectiveness of BRIN's organization in nuclear accident preparedness, crucial for an entity managing aging nuclear facilities, was widely doubted. Out of 162 respondents, 73.45% indicated that BRIN would be 'not effective' or 'less effective' in responding to a nuclear accident. Only 26.45% considered BRIN 'fairly effective' or 'very effective' (Fig. 8). These findings collectively suggest that, following organizational restructuring, prevention of nuclear accidents has not yet achieved the priority status it demands.

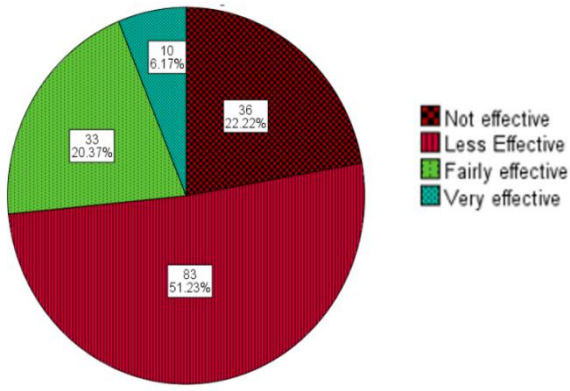

Fig. 8 Respondents' answers regarding the effectiveness of BRIN in nuclear accident preparedness

The responses from respondents who answered open-ended questions regarding issues that should be considered related to nuclear safety by BRIN as a new and isomorphic organization, which are outlined in word cloud information, show that the management system is the issue most frequently raised by respondents. Other important issues are leadership, governance, responsibility, coordination/communication, training, human resources, infrastructure (related to aging) and the need for a special organization as shown in Fig. 9.

Fig. 9 Word cloud showing nuclear safety issues that must be considered by BRIN

Interview and FGD results further highlighted the need for frequent dialogue on nuclear safety between leaders and safety practitioners. Regular management meetings and coordination with regulatory bodies could significantly enhance institutional leadership's awareness of nuclear safety. Participation in international activities, such as IAEA leaders' meetings or general

conferences, was also suggested as a means to elevate leadership awareness. While middle-level management often perceived the institution as striving to fulfill regulations, this view frequently diverged from the implementing staff's perspective, emphasizing the need for robust two-way communication to bridge this gap. Ultimately, nuclear safety transcends mere regulatory compliance; it necessitates the cultivation of a deeply embedded safety culture among all individuals directly or indirectly involved with nuclear activities and facilities. These findings provide critical feedback for strengthening top management commitment and establishing robust leadership in nuclear safety management.

To summarize the empirical findings across various dimensions of nuclear safety governance, the Table 4 highlights the most critical issues identified in this study. Each domain reflects a specific organizational challenge, its corresponding key finding based on quantitative and qualitative data, and the potential risk implication if left unaddressed. These findings collectively illustrate how institutional restructuring has introduced vulnerabilities that could compromise the reliability and resilience expected in high-risk nuclear operations.

Table 4 Summary of organizational deficits and associated nuclear safety risks

Domain	Key Finding	Risk Implication
Span of Control	65.5% of respondents expressed doubt about the effectiveness of oversight	Overextension → gaps in safety monitoring
Budget Control	Budget User Authority (KPA) hinders critical procurement	Delay in SSC (Structures, Systems, Components) maintenance
Safety Culture	74.68% reported no awareness or absence of safety culture activities	Loss of safety awareness
Leadership	52.6% perceived top leadership as lacking commitment to safety	Weak foundation for High Reliability Organization (HRO)
Emergency Preparedness	73.45% viewed BRIN as unprepared for a nuclear emergency	Potential failure in crisis response

DISCUSSION

Addressing Prevention of Accidents through Enhanced Governance in an Isomorphic Structure

Our findings reveal significant challenges to accident prevention within BRIN, directly linked to the consequences of institutional restructuring and the aging of its critical nuclear infrastructures, such as the Triga 2000 Bandung (60 years old), Kartini Yogyakarta (46 years old), and GA Siwabessy reactors (38 years old), alongside their supporting fuel element manufacturing and radioactive waste processing installations. IAEA Principle 8 unequivocally mandates that every practical measure must be taken to prevent and mitigate nuclear or radiation accident risks. However, our survey data indicating that 65.5% of respondents expressed uncertainty about the effectiveness of safety control, coupled with qualitative insights on decision-making delays for spare parts procurement, directly signify an erosion of the 'preoccupation with failure' and 'sensitivity to operations' principles critical for HROs.

The revitalization of aging nuclear facilities is essential to prevent incidents and even potential nuclear accidents. Such revitalization requires special attention from top leadership, as it involves the mobilization of resources, including competent human resources and substantial funding. A decline in human resource competence and budget uncertainty may delay revitalization efforts, creating a hidden threat with the potential to escalate into a nuclear accident. The case at RWTI,

where issues such as the lack of prioritization for interim storage of radioactive waste, uncertain budget allocation for the operation and maintenance of waste treatment facilities, and the neglect of operational procedures are evident, represents a failure in the prevention of accidents. These issues are a consequence of an isomorphic organizational governance structure.

The organizational simplification into a broader, isomorphic structure, where one director manages six diverse nuclear facilities with limited immediate budget authority, creates a significant 'span of control' challenge that directly impacts proactive accident prevention. This structural arrangement makes it difficult to prioritize the specialized and urgent needs of aging management, a crucial aspect of accident prevention. The IAEA highlights that such "wide organizational changes" can lead to the "reduction or removal of several critical components, including routine nuclear safety education and training, regular safety culture workshops, self-assessments related to nuclear safety and security and internal audits (IAEA, 2014). Our results corroborate this, showing a drastic decline in safety culture activities and training, which directly undermines the 'defense in depth' approach essential for mitigating accident consequences. This has been shown in the survey results that most of the respondents (74.68%) reported either 'do not know' or 'no longer any safety culture activities' at BRIN.

The case of the Goiania accident in Brazil, where neglect of safety culture and unauthorized activities led to a severe radiological incident, serves as a stark reminder of the critical importance of a robust safety culture (Croft et al., 1988). In BRIN's context, the widespread perception of low top management commitment (78% expressing slight or no commitment), combined with reduced safety training and monitoring, increases the latent risk of human error and complacency. This suggests that BRIN, as an organization managing substantial and aging nuclear facilities, faces a critical imperative to re-establish strong leadership and an unwavering commitment to prioritizing nuclear safety as its foremost concern, moving beyond mere regulatory compliance to ingrained organizational values.

The absence of a nuclear safety and security management system at the top management level, as reflected in the survey results from open-ended questionnaire responses and illustrated in the word cloud, represents a critical concern for the assurance of nuclear safety. This is in line with the results of Ylonen's research that integrated management of safety and security (IMSS) is essential for effectively preventing and preparing for potential accidents (Ylönen & Björkman, 2023).

Comparative Institutional Responses to Nuclear Risk and Challenge of Isomorphism

The findings of this study critically underscore the implications of institutional restructuring on nuclear safety management, especially in developing countries where the administrative consolidation of scientific agencies, driven by isomorphic pressures, may inadvertently dilute sectoral focus and expertise. Indonesia's post-integration experience with BRIN reveals distinct vulnerabilities compared to established nuclear programs globally. Our survey results, which highlight that 65.5% of respondents were uncertain about effective safety control and 78% perceived limited top-leadership commitment, strongly indicate an erosion of institutional clarity and safety culture. This contrasts sharply with the institutional frameworks observed in leading nuclear nations (OECD-NEA, 2023).

In Japan, for instance, the post-Fukushima reforms led to the deliberate establishment of the Nuclear Regulation Authority (NRA) as an independent entity. This functional and structural separation explicitly aimed to disentangle safety governance from research or promotional functions, thereby ensuring regulatory impartiality and rebuilding public trust (Funabashi &

Kitazawa, 2012). This approach directly counters the mimetic isomorphism seen in BRIN, where the consolidation of research, operations, and oversight functions risks blurring accountability. The Japanese model emphasizes the critical importance of a clear, independent institutional design for safety in high-reliability contexts, a principle seemingly overlooked in BRIN's current structure.

Similarly, China's institutional realignment demonstrates the importance of maintaining centralized yet specialized institutions for nuclear safety. The National Nuclear Safety Administration (NNSA) operates independently under the Ministry of Ecology and Environment, ensuring a dedicated focus on safety that is integrated into national energy plans (Mu et al., 2015). The Chinese model exemplifies vertical clarity and a dedicated investment in safety, a framework that our study shows is conspicuously absent in BRIN's current configuration. These international examples reinforce the argument derived from Institutional Theory: while institutional forms may be adopted for perceived efficiency, such isomorphic pressures can have detrimental effects when they do not align with the functional requirements of high-risk sectors.

Furthermore, European Union initiatives, particularly those coordinated by the Joint Research Centre (JRC), offer another relevant comparison. JRC actively sustains nuclear competence through continuous training and safety culture programs. This sustained commitment to capacity building was a consistent practice under BATAN but appears significantly diminished post-integration into BRIN, as evidenced by our findings on reduced safety training and education. This suggests that institutional continuity in fostering expertise and safety culture plays a vital role in sustaining robust safety systems.

Collectively, these global examples underscore that while administrative integration might offer superficial efficiencies, a loss of sectoral specialization, dilution of leadership commitment, and erosion of continuous learning can severely compromise safety culture and operational performance. For Indonesia, without a strategic realignment of BRIN's internal structures to reinforce nuclear-specific oversight and decision-making authority, the risks to long-term nuclear safety management are likely to persist or escalate. Therefore, this study strongly supports the proposition that institutional design must be functionally driven, especially in high-risk sectors. Embedding nuclear safety functions at the highest level of organizational hierarchy, reinstating safety-focused training, and clarifying the operational span of control are not merely organizational reforms; they are strategic imperatives for ensuring long-term nuclear safety and reliability.

Organizational Structure and Its Implications for High-Reliability Governance

The current organizational structure of BRIN, particularly the Directorate for Nuclear Facilities Management (DNFM) with its broadly defined authority and limited autonomy, presents significant challenges for effectively addressing long-term nuclear safety, especially for aging facilities that demand dedicated oversight and specialized attention. Our findings explicitly show that this broad span of control contributes to a perceived ineffectiveness in maintaining safety, validating the concern that a single director overseeing diverse nuclear facilities may dilute attention and increase accident likelihood. This structural simplification, adopted under mimetic isomorphism, treats nuclear assets generically rather than as high-risk infrastructures demanding unique governance.

The structure of an organization fundamentally shapes its business processes and the effectiveness of safety management. For high-reliability sectors like nuclear energy, organizational procedures must ensure thorough and methodical safety significance assessments across all operational conditions and potential events. However, our results indicate that safety criteria, while formally existing, face challenges in consistent implementation and top-level prioritization within BRIN. Special emphasis on human factors, including personnel qualifications and their ability to effectively carry out duties, is critical; yet, the perceived decline in safety training and competence within BRIN directly threatens this.

Maintaining a strong safety culture is vital, as its success hinges on accurately identifying and mitigating risks that extend beyond tangible elements like staffing and competencies to encompass the underlying attitudes, values, and beliefs of personnel. Our findings, showing a majority of respondents unaware of or experiencing rare safety culture activities, signal a critical erosion. This is further complicated by the crucial role of trust in organizational success, impacting employee engagement, teamwork, and efficiency. In the nuclear sector, addressing structural weaknesses is essential as trust underpins performance and stability. The connection between organizational culture and trust is influenced by leadership behavior and communication, which our study found to be deficient, particularly the lack of two-way communication between top management and operators. This aligns with Orikpete et al.'s emphasis on human factors, safety culture, organizational effectiveness, and individual performance as key to understanding nuclear facility operations (Felix Orikpete & Raphael Ejike Ewim, 2024).

The reluctance of BRIN to adopt comprehensive ISO international standards, despite BATAN's prior adherence, further underscores the challenge. As Dey notes, such standards are beneficial for strengthening public trust in nuclear energy (Dey, 2024). The current isomorphic organizational structure, as Kinder et al. suggest for public organizations, proves ill-suited for entities managing significant nuclear facilities when applying generic solution (Kinder et al., 2023). Such structures inherently struggle to prioritize nuclear safety as a primary concern, leaving leadership and safety commitment heavily dependent on individuals who may not possess adequate nuclear safety culture understanding.

In our findings, the key organizational issues as shown in the word cloud include the management system, particularly in relation to nuclear safety; leadership and management commitment to nuclear safety; governance; safety responsibilities; coordination and communication between management and operators; and procedures to ensure nuclear safety. This may undermine the confidence of employees, particularly nuclear operators, in the top management. Iddrisu emphasized that trust plays a crucial role in organizational success, impacting important outcomes like employee engagement, teamwork, and efficiency (Iddrisu, 2025). In the nuclear sector especially, addressing structural weaknesses is essential, as trust underpins strong performance, innovation, and long-term stability. The connection between organizational culture and trust is influenced by leadership behavior, communication approaches, and employee relationships.

An isomorphic organizational structure is not suitable for entities that include minor units responsible for managing significant nuclear facilities. Such structures often struggle to prioritize nuclear safety as a primary concern. Strong leadership and commitment to safety heavily depend on the individual in charge, who may not necessarily possess an adequate understanding of nuclear safety culture.

In sum, BRIN’s isomorphic structure risks obscuring specialized safety needs under

generalized governance frameworks. The Indonesian case underscores that administrative consolidation, if not paired with nuclear-specific safeguards, may generate latent safety vulnerabilities. A strategic rethinking of institutional design is thus essential for aligning national innovation agendas with high-reliability governance.

RECOMMENDATION

Based on the critical findings revealing a dilution of leadership commitment, compromised safety management systems, and erosion of safety culture due to the institutional restructuring of BATAN into BRIN, this study proposes several strategic policy recommendations. These recommendations are grounded in the principles of HROs, Institutional Theory, and Organizational Learning, aiming to strengthen nuclear safety governance and ensure sustainable, long-term safety performance within Indonesia's public research agency. As indicated in our findings, the statistical analysis shows that policy improvements cannot be carried out partially for specific groups, but must be implemented comprehensively across the entire organizational entity.

Realigning Organizational Structure and Granting Autonomy for Enhanced Specialization

Our findings consistently demonstrate that the current isomorphic organizational structure, which concentrates control of six diverse nuclear facilities under a single Directorate for Nuclear Facilities Management (DNFM) with limited autonomy, results in an ineffective span of control and hampers the timely prioritization of critical safety functions. This structural simplification, while intended for administrative efficiency, inadvertently undermines the 'deference to expertise' principle of HROs and the domain-specific focus vital for nuclear safety.

Therefore, we recommend a fundamental realignment of the nuclear organization within BRIN. Specifically, the DNFM should be disaggregated into at least three distinct directorate-level organizations. This separation could be based on geographical location (e.g. Serpong, Bandung, Yogyakarta facilities) or, more effectively, on the type of activity and/or infrastructure (e.g., one directorate managing research reactors, and another overseeing non-reactor facilities such as radioactive waste processing, nuclear fuel, and radioisotope production installations). Crucially, each of these new directorates must be granted increased operational and budgetary autonomy to manage their respective facilities efficiently, ensuring prompt decision-making, particularly concerning urgent maintenance and procurement for aging infrastructure.

A more robust and long-term policy recommendation, strongly supported by comparative institutional analysis with countries like Japan and China, is to consider re-establishing a dedicated, more autonomous public organization specifically responsible for nuclear energy implementation. This would facilitate the re-embedding of nuclear-specific expertise, leadership, and safety culture, thereby mitigating the risks associated with the current dilution of focus within a broader, multidisciplinary research agency. This reflects the principle that institutional design must follow function, especially in high-risk sectors where functional separation is critical for accountability and public trust.

In order to implement the nuclear energy law with full dedication to ensuring the safe operation of nuclear facilities, the mandate for the establishment of an implementing body must be reinstated. A stronger recommendation is to return to being an organization that is more specifically concerned with nuclear energy, as an implementing body.

Strengthening Impartial Oversight through Elevated Safety and Quality Assurance Functions

Our study reveals concerns regarding the 'impartiality' of radioactive waste management and a general weakening of internal audits, which are critical for maintaining safety and security standards. This highlights the necessity for an independent oversight function within BRIN. To ensure adherence to the principle of impartiality and to effectively carry out audit functions, the Safety, Security, and Quality Assurance (SSQA) unit must be elevated in its organizational standing.

We recommend adjusting its position to be equivalent to a directorate level (e.g., reporting directly under the Deputy of Research and Innovation Infrastructure – DRII, but with a distinct mandate). This structural elevation would provide the necessary authority and independence for the SSQA function implementer to conduct unbiased assessments, audits, and ensure compliance across all nuclear facilities. Such a structure would mirror best practices observed internationally, where independent regulatory and oversight bodies are crucial for maintaining public trust and operational safety (IAEA, 2014).

Elevating the Nuclear Safety Management System to Top Leadership Level

The survey results, indicating that a significant 78% of respondents perceived top management's commitment to nuclear safety as 'slight' or 'non-existent', underscore a critical gap in leadership buy-in. While a safety management system exists at the directorate level, its effectiveness is compromised without full integration and prioritization at the highest echelons of BRIN. In alignment with IAEA Safety Fundamental Principles 1 and 3, which assign primary responsibility for safety to the highest level of leadership and mandate its prioritization, the nuclear safety management system must be formally elevated to the top level of BRIN's organizational structure.

This elevation would serve as a concrete demonstration of the highest leader's unwavering commitment to nuclear safety, ensuring that safety is ingrained as an institutional priority rather than merely a departmental concern. Furthermore, given that most of BRIN's nuclear infrastructures are aging, special and dedicated aging management strategies are urgently needed as an integral part of this overarching safety management commitment. This requires clear allocation of resources, specialized personnel, and continuous oversight from the top management to mitigate the increasing risks associated with older facilities.

Reinvigorating Safety Culture through Continuous Socialization and Internalization

Our findings highlight a worrying erosion of safety culture, with 74.68% of respondents indicating they were either unaware of or no longer experienced safety culture activities. This decline, exacerbated by the absence of a dedicated Center for Nuclear Education and Training, poses a long-term threat to nuclear safety and the principles of Organizational Learning. To counteract this, safety culture must be regularly and extensively socialized and internalized among all DNFM staff and the broader research community utilizing or working near nuclear facilities.

Given BRIN's strategic implementation of 'open platforms' and 'co-working space' areas, which inherently introduce diverse personnel, it is crucial to develop robust safety induction programs and continuous reinforcement mechanisms. This requires intensive and two-way communication between leadership and all implementing levels to ensure that management's

commitment to nuclear safety translates into daily practices and deeply embedded organizational values. Reinvigorating safety culture through consistent training, workshops, and transparent communication will be fundamental in preventing the accumulation of 'hidden deficiencies' that could lead to serious incidents.

Prioritizing Regular Nuclear Emergency Preparedness and Response Drills

The survey results indicating that 73.45% of respondents perceive BRIN's effectiveness in responding to a nuclear accident as 'not effective' or 'less effective' underscore a critical gap in emergency preparedness. In adherence to IAEA Safety Fundamental Principle 9, which mandates continuous maintenance of emergency preparedness and response capabilities, it is imperative that nuclear emergency drills, both on-site and off-site, be carried out regularly. These drills are not merely procedural exercises but serve as a vital commitment to preventing nuclear accidents and ensuring effective mitigation in the event of an incident. Regular drills will enhance coordination with stakeholders, improve employee competence, and test the robustness of emergency procedures, thereby reinforcing the organization's resilience as an HRO.

Collectively, these recommendations reinforce the central thesis of this study: that nuclear safety cannot thrive under generalized institutional models. Specialized governance, visible leadership commitment, and a revitalized safety culture are not optional , they are prerequisites for Indonesia’s safe nuclear future.

LIMITATIONS

This study is still limited in scope due to the short time elapsed since the organizational transition from BATAN, a specialized nuclear energy organization, to BRIN, a more isomorphic-type organization. While this study provides critical insights, it is based on perceptions at a specific point in time and further longitudinal research would be beneficial. The research has not yet explored specific in-depth cases. Future research could explore the mid-term and long-term impacts of such isomorphic transformations on nuclear safety performance indicators, or develop comparative analyses across more developing nations undergoing similar reforms.

CONCLUSIONS

This study reveals how bureaucratic restructuring, when not aligned with functional imperatives, can significantly erode nuclear safety governance. Through a mixed-methods investigation of Indonesia’s integration of BATAN into BRIN, we show that sectoral leadership has been diluted, safety protocols weakened, and organizational learning mechanisms disrupted. These developments threaten the fundamental pillars of an HRO.

Firstly, despite BRIN's inherent responsibility and stated commitment to nuclear safety regulations, our research reveals a critical deficit in top management commitment, highlighting the urgent need to elevate nuclear safety as a core institutional priority. This lack of robust leadership buy-in at the highest level directly undermines IAEA Safety Principles 1 and 3, which mandate ultimate responsibility and prioritization of safety.

Secondly, the existing organizational structure, characterized by a broad span of control and limited autonomy for nuclear facilities management, has been perceived as ineffective by staff. This structural simplification challenges the principles of HROs, particularly regarding effective decision-making, resource allocation for critical components, and diligent aging management for BRIN's aging nuclear infrastructures. The observed decline in safety culture activities and the absence of a dedicated nuclear education and training center further exacerbate this issue, indicating an erosion of organizational learning mechanisms vital for competence and resilience.

Thirdly, Indonesia's prior experience with BATAN showcased a reputable and high-performing nuclear safety management system when it operated as a specialized entity. The current restructuring into a more isomorphic organization, however, poses a long-term risk to nuclear safety, as the consistent prioritization of nuclear-specific functions cannot be guaranteed. This risk creating hidden safety threats due to diluted expertise, fragmented accountability, and a weakened safety culture.

In conclusion, this study offers a crucial lesson for other countries contemplating similar bureaucratic consolidation models, particularly in high-risk sectors. It underscores that while administrative efficiency may be a goal of public sector reform, it must not come at the expense of specialized safety governance. The Indonesian case exemplifies how institutional design must inherently follow function, emphasizing the strategic necessity of embedding nuclear safety at the highest organizational echelons, ensuring dedicated resources, and fostering a continuous safety culture to safeguard public well-being.

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Conflict of Interest

The authors declare no conflicts of interest.

Informed Consent

All participants in the research provided their full and explicit informed consent.

Authorship contribution

YSB Susilo, MB Setiawan: Conceptualization, Writing-Original draft; DS Wisnubroto, Suparman, F Hermana, T Tjiptosumirat: Conceptualization, Methodology; J Sukmana, Rr. AP Rijanti, RM Saputra, KS Widana: Writing-Reviewing, software; A Purwaningsih, D Anggraeni, N Luhur: Questionnaire, Data curator and Data Analysis.

Data Availability Statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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