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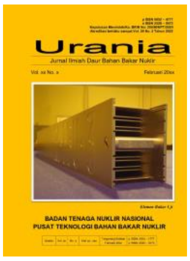

A CRITICAL REVIEW OF RADIOACTIVE SUBSTANCES SECURITY MANAGEMENT IN INDONESIA: REGULATORY FRAMEWORK AND IMPLEMENTATION CHALLENGES BASED ON ACTUAL INCIDENTS

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ABSTRACT

A CRITICAL REVIEW OF RADIOACTIVE SUBSTANCES SECURITY MANAGEMENT IN INDONESIA: REGULATORY FRAMEWORK AND IMPLEMENTATION CHALLENGES BASED ON ACTUAL INCIDENTS. The utilization of radioactive sources in various sectors, including medicine and industry, offers significant benefits to public welfare but also poses serious risks if not managed securely. This review article highlights the urgent need for a comprehensive understanding of radioactive substances security, which is conceptually distinct from radiation safety. The purpose of this review is to critically analyze the change of Indonesia's regulatory framework for radioactive substances security, evaluate the implementation challenges, and formulate policy recommendations based on domestic and international case studies. The methodology employed is a systematic literature review and comparative case study analysis of scientific literature, recent regulations, and incident reports from credible institutions such as the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN) and the International Atomic Energy Agency (IAEA). The analysis aims to identify trends, gaps, and causal relationships between policy and practices. It had been found that regulatory framework in Indonesia, particularly through Government Regulation (GR) No. 45 Year 2023 and BAPETEN Regulation (BR) No. 5 Year 2024, has evolved to specifically address security threats. However, implementation faces significant challenges such as insufficient number of human resources and large geographic area. Case studies of the Goiânia incident and the Serpong incident demonstrate that failures in security management can have fatal and widespread consequences. It is concluded that strengthening radioactive substances security management in Indonesia requires not only a robust regulatory framework but also strategic investment in technological innovation, enhancement of qualification and competency personnel, and the establishment of a solid security culture.

Keywords: radioactive substances security, ionizing radiation safety, government regulation.

INTRODUCTION

The use of radioactive materials has become an integral part of modern life, providing significant benefits in various sectors such as nuclear medicine, food irradiation, and oil and gas exploration [1]. The benefits obtained, particularly in the diagnosis and treatment of critical diseases such as cancer, are vital for improving human quality of life. However, along with its benefits, the use of radioactive sources also presents inherent risks that require strict management. The potential dangers of radiation to humans and the environment have been well-documented in scientific literature, including cell damage, increased cancer risk, and genetic effects on exposed populations [2].

Risk management in the utilization of radioactive sources has traditionally been divided into two interconnected domains with different focuses: safety and security. Radiation safety focuses on protection from unintentional accidents or operational failures, while radioactive substances security targets deliberate threats, such as theft, sabotage, or unauthorized use. This report argues that with the increasing global threat from terrorism and material misuse, the urgency to strengthen the security aspect of radioactive sources has become a top priority [3].

Conceptual Differences: Ionizing Radiation Safety vs. Radioactive Substances Security

Although often used interchangeably, the concepts of safety and security have fundamental differences that are important to understand in the context of risk management. According to definition in GR No. 45 Year 2023, ionizing radiation safety is a condition in which humans and the environment protected from the harmful effects of ionizing radiation through radiation protection measures [4]. Its purpose is to prevent unintentional operational accidents or human errors that could lead to unnecessary radiation exposure.

Meanwhile, radioactive source security is measures taken to prevent sabotage, unauthorized access, destruction, loss, theft, and/or unauthorized transfer of radioactive sources [5]. The main difference is in the source of the threat: safety focuses on unintentional events, while security focuses on intentional and malicious acts.

This conceptual difference is reflected in the paradigm shift of Indonesia's regulations. Act No. 10 Year 1997 is fundamental regulatory framework on nuclear energy, followed by GR No. 33 Year 2007 [6]. However, the issuance of GR No. 45 Year 2023 as revision of GR No. 33 Year 2007, and BR No. 5 Year 2024 marks a significant update that explicitly separates and details security aspects, reflecting the government's official recognition that threats to radioactive sources now come not only from accidents but also from intentional and malicious acts [4]. This shift indicates that nuclear energy regulation in Indonesia has adopted a more proactive approach to the evolving dynamics of global threats. This article will argue that a comprehensive approach must encompass both aspects in an integrated manner to create a resilient protection system.

Table 1 presents the fundamental differences between these two concepts to clarify the context of the discussion.

Table 1. Fundamental Differences between Ionizing Radiation Safety and Radioactive Substances Security [4]

Dimension	Ionizing Radiation Safety	Radioactive Substances Security
Obejctive	To protect humans and the environment from unintentional radiation effects.	To prevent unauthorized access, theft, or misuse of radioactive sources.
Nature of Threat	Accidents, equipment failure, operational errors.	Intentional acts (sabotage, terrorism, theft).
Focus on Action	Radiation protection, work procedures, exposure control.	Access control, inventory, physical surveillance, emergency response.
Legal Basis	GR No. 45 Year 2023 Article 4 paragraph (1).	GR No. 45 Year 2023 Article 4 paragraph (2) and BR No. 5 Year 2024.
Responsible Parties	Licensees, Radiation Protection Officers (RPOs), radiation workers.	Licensees, radioactive source security officers, and BAPETEN.

Objective and Scientific Contribution

The main objective of this review is to analyze Indonesia's regulatory framework for radioactive substances security, evaluate the implementation challenges, and formulate recommendations to strengthen security management. This review makes several significant scientific contributions:

a. provide a comprehensive overview of the recent regulatory framework in Indonesia, highlighting from Act No. 10 Year 1997 [6] to GR No. 45 Year 2023 [4] and its derivative regulations.
b. offer a critical analysis of implementation challenges, identifying the root causes beyond mere non-compliance.
c. use real incident case studies, both domestic and international, to provide empirical evidence of the consequences of security failures and to justify the urgency of this topic.

METHODOLOGY

This study uses a descriptive-qualitative approach, combining systematic literature review with comparative case study analysis. This methodology is particularly suitable for a review article, as its primary focus is to critically evaluate existing regulatory frameworks, policies, and implementation challenges through the synthesis of information from various authoritative sources.

Research Approach

This research uses a descriptive-qualitative methodology to allow for a deep, contextual analysis of the dynamics of nuclear oversight in Indonesia by examining official documents, scientific publications, and incident reports. The comparative case study method is applied to analyze major international and domestic incidents, such as the Goiânia incident and the Serpong incident, to highlight the practical consequences of security failures and draw relevant lessons for the Indonesian context. This methodology ensures the originality of the research by identifying trends, gaps, and causal relationships that might not be apparent from a superficial reading of the source material.

Data Collection

Data for this review was gathered from a diverse range of credible sources to ensure comprehensiveness and validity. The main sources include:

a. official regulations and legal documents: primary legal and regulatory documents were obtained from the official Jaringan Dokumentasi dan Informasi Hukum (JDIH) of the BAPETEN and the Badan Pemeriksa Keuangan (BPK), including GR No. 45 Year 2023 [4], GR No. 33 Year 2007 [7], BR No. 5 Year 2024 [4], and Act No. 10 Year 1997 [6].
b. scientific and academic publications: to conduct a systematic review of articles that publish research and review articles on nuclear science and technology. These publications provide critical insights into implementation challenges and research innovations [1], [2], [8], [9].
c. international standards and reports: to provide a global perspective, by referring on key publications from international bodies such as the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP) [10], [11], [3], [12], [13]. These documents establish the fundamental principles and recommendations that underpin regulatory framework in Indonesia.
d. incident and policy reports: reports on nuclear and radiological incidents, both internationally (e.g., Goiânia) and domestically (e.g., Serpong), were analyzed to provide empirical evidence of security vulnerabilities [14], [15]. Official announcements and policy documents from government agencies such as BAPETEN, and universities such as UGM were also utilized to understand the broader context and responses to these incidents [16], [17].

Data Analysis

The data analysis process was conducted through a thematic synthesis approach, where information from all sources was systematically reviewed, categorized, and integrated to identify recurring themes, patterns, and causal links. The analysis is focused on four main themes, as follow:

a. development of regulations over time and the reasons behind the revision.
b. implementation challenges due to insufficient human resources and geographic difference.

c. role of technological innovation in addressing these challenges.
d. policy implications requiring multi-stakeholders collaboration. This approach enabled the construction of a comprehensive and integrated overview of the challenges and opportunities in strengthening radioactive substances security in Indonesia.

RESULTS AND DISCUSSION

Fundamental Concepts and Regulatory Framework

This section is the theoretical foundation for analysis by reviewing the fundamental concepts and regulatory frameworks essential for understanding radioactive source management. It studies the biological effects of ionizing radiation, the principles of radiation protection, and the national and international regulatory framework. By integrating those information will aim to establish a clear and comprehensive basis for the subsequent discussion of implementation challenges and case studies.

a. Biological Effects of Ionizing Radiation and Protection Principles

To understand the importance of radioactive source management, it is important to know the effects due to ionizing radiation. In general, ionizing radiation is divided into three main types:

- **Alpha Radiation (α)**: Consists of helium-4 ($^4He^{2+}$) nuclei with two protons and two neutrons. Alpha particles have very low penetrating energy and are easily absorbed by materials such as a sheet of paper or even the outermost of skin tissue. These particles are generally harmless as an external source of exposure but can cause serious damage if inhaled or ingested [18].
- **Beta Radiation (β)**: Consists of high-speed electrons (β^-) or positrons (β^+). Beta particles are smaller than alpha particles and have higher penetrating energy. They can penetrate the skin, potentially causing burns, and can be absorbed by light materials like glass. Large doses of beta exposure can cause damage to the skin, eyes, and internal organs [18]
- **Gamma Radiation (γ)**: This is high-energy electromagnetic radiation with no mass or charge, similar to X-rays but with greater energy. Gamma radiation has very high penetrating energy and can pass through thick materials such as concrete or lead. Due to its highly penetrative nature, large doses of gamma radiation are very dangerous to human health, potentially causing genetic damage and cancer [19].

Exposure to ionizing radiation can damage cells and DNA, causing two main types of biological effects:

- **Deterministic Effects**: Effects that have a dose threshold, where the severity of the effect increases with the dose received. Examples include skin damage, acute radiation syndrome, and damage to the hematopoietic system [8].
- **Stochastic Effects**: Effects whose probability of occurrence increases with the dose of radiation received, but whose severity is independent of the dose. The main examples of stochastic effects are an increased risk of cancer and genetic abnormalities [8].

To minimize those risks, the international radiation protection system, recommended by the International Commission on Radiological Protection (ICRP) and adopted by the IAEA [20], is based on three fundamental principles:

- **Justification**: Any decision that alters a radiation exposure situation must result in a positive net benefit. This means that the benefits gained from an activity using radioactive sources must be greater than the risks and harm caused [4].
- **Optimization (ALARA)**: Radiation exposure must be kept as low as reasonably achievable, taking into account economic and social factors [ALARA]. The goal is to achieve the best level of protection under the given circumstances [4]
- **Dose Limitation**: The total dose received by any individual from radiation sources must not exceed the dose limits set by the regulatory authority [11]. These limits are established to ensure that the risks from exposure, especially stochastic effects, remain at an acceptable level [4], [21]

b. National and International Regulatory Frameworks

In Indonesia, the Nuclear Energy Regulatory Agency (BAPETEN) is the government authority for responsibility in control the use of nuclear energy. BAPETEN has the authority to formulate national policies, issue regulations, and conduct inspections to ensure radiation safety and security for workers, the public, and the environment [22].

Regulatory framework in Indonesia has undergone significant evolution to respond to increasingly complex needs. The main legal basis is Act No. 10 Year 1997 [6]. Subsequently, BAPETEN issued regulations in more specific areas, including BR No. 4 Year 2020 on Radiation Safety in the Use of X-ray Machines [23].

The most important development is by issuing of GR No. 45 Year 2023, which replaced PP No. 33 Year 2007 [4]. This recent regulation not only updates dose limits based on the ICRP recommendations [3], [10], [11], [12], [13], [20], but also explicitly separates and details the requirements for radioactive substances security. BR No. 5 Year 2024 as derivative of the government regulation regulate in detail the categories and levels of security, and security assessments and programs conducted by licensee [24].

The recent regulations also emphasize the concept of a safety culture and a security culture. This concept affirms that radioactive substances security is not merely the task of the regulator but a collective responsibility shared by all relevant parties, from licensee to field personnel [24]. RPOs and radioactive source security officers shall have appropriate qualification and competency personnel by certification issued by BAPETEN [24].

Internationally, the IAEA plays important role in setting global standards through the publication of the IAEA Safety Standards Series [3], [10], [11], [12], [13], [20]. Although these standards are not legally binding for member states, they serve as the main references adopted by many countries, including Indonesia, in establishing their national regulations [4].

Table 2 shows comparison of the radioactive substances security in regulatory framework in Indonesia before and after GR No. 45 Year 2023 coming into force.

Table 2. Comparison of the Radioactive Substances Security [4], [7]

Aspect	Pre-2023 Period	Post-2023 Period
Main Legal Basis	GR No. 33 Year 2007 on Ionizing Radiation Safety and Radioactive Source Security.	GR No. 45 Year 2023 on Ionizing Radiation Safety and Radioactive Substances Security.
Security Definition	Related to preventative measures against unauthorized access, destruction, loss, theft, and/or unauthorized transfer of radioactive sources.	More detailed: radioactive substances security is measures to prevent sabotage, unauthorized access, destruction, loss, theft, and/or unauthorized transfer of radioactive substances.
Emphasis	Combined safety and security in one regulation. Emphasis on general radiation safety.	Explicitly separates and details specific aspects of radioactive substances security, which is regulated in more detail in BAPETEN Regulation.
Technical Provisions	Generally covered the responsibilities of licensee and radiation protection requirements.	More detailed, including the obligation to conduct a security assessment, analyze threat and vulnerability levels, and develop a comprehensive radioactive substances security program.
Key Concepts	Responsibility of licensee, radiation protection officers.	Responsibility of licensee, security culture, and qualification for radioactive source security officers.

Case Studies: Incidents, Threats, and Lessons

This section provides analysis in detail of key incidents that emphasize the importance of robust radioactive substances security. From case studies in international and domestic, it will take a lesson-learned as well as consequences of security failures. This anaylisis not only illustrates the potential dangers but also justifies the need for a comprehensive regulatory and technological framework.

a. International Incident: The Goiânia Case Study

The Goiânia incident in September 1987 in Brazil is a classic example of a failure in radioactive substances security management. The event began when an abandoned radiotherapy unit in an old medical clinic was found by two scavengers [14]. They dismantled the machine to salvage its lead and sold it to a junkyard, unaware that it contained a capsule filled with highly radioactive Cesium-137 powder [14].

The junk dealer later opened the capsule, attracted by the strange blue light emitted by the powder. The radioactive powder was accidentally spread and traded among friends and family, and even used by children as a toy, leading to widespread contamination throughout the city. Symptoms of radiation poisoning began to appear days later, including burns, hemorrhaging, and a decrease in white blood cell count. The incident resulted in contamination of hundreds of people, with four confirmed deaths, as well as significant property damage [14].

The main lesson from Goiânia was not an operational failure, but a fundamental failure in security management. The inadequate managed radiation source, known as an orphan source, was the trigger for the disaster [14]. This incident demonstrates that a lack of control over the life cycle of radioactive sources, especially during the disposal or decommissioning phase of a facility, can have far greater consequences than an operational accident.

b. The Threat of "Orphan Sources" and Radiological Terrorism

Incidents such Goiânia highlight the threat of orphan sources, which are sealed radioactive sources that are no longer under the control of the owner, either because of lost, stolen, or improperly disposed of [14]. History records many other orphan source incidents, such as the accident in Setif, Algeria, where an Iridium-192 source that fell off a truck caused serious injuries and death.

Furthermore, the existence of orphan sources increases the risk of radiological terrorism, particularly through the use of a dirty bomb or radiological dispersal devices (RDDs) [2]. A dirty bomb is a device that combines a conventional explosive (e.g., dynamite) with radioactive material. The main goal of an RDDs is not to create mass destruction like a nuclear bomb, but to cause mass panic through the spread of radiological contamination and public anxiety. The consequences of such an attack include not only physical injuries from the explosion but also psychological trauma, economic disruption, and the need for expensive and time-consuming large-scale decontamination [2]. The effectiveness of radioactive substances security management must therefore also be measured by its ability to maintain public trust and prevent widespread social disruption [3].

c. Relevance of Domestic Incidents: The Serpong Case Study

The threat of orphan sources is not just an overseas concern. The discovery of a Cesium-137 radioactive source in the Batan Indah housing complex in Serpong in 2020 is tangible proof of a domestic vulnerability [1]. Although this incident was not as severe as Goiânia, its discovery shows that orphan sources can emerge in Indonesia. The event was quickly handled by BAPETEN, which immediately conducted a survey and decontamination of area [25]. Experts from Gadjah Mada University also issued a reassuring statement to the public, emphasizing that the incident could be managed and there was no need for excessive concern about nuclear technology as a whole [17].

This incident shows that while regulatory framework in Indonesia and emergency response mechanisms are functional, the occurrence of an orphan source highlights existing gaps in the security system, particularly in the life cycle management of radioactive sources. Table 3 presents a comparison between the Goiânia and Serpong incidents.

Table 3. Comparison of Radioactive Source Incident Case Studies (Goiânia vs. Serpong) [14], [17], [25]

Aspect	Goiânia Incident	Serpong Incidents
Year	September 1987	February 2020
Location	Goiânia, Brazil	Batan Indah Housing Complex, Serpong, Indonesia
Radioactive Material	Cesium-137 (Cs 137)	Cesium-137 (Cs 137)
Chronology	Scavengers dismantled a radiotherapy machine; powder spread widely	A radioactive source was found in a residential area
Human Impact	Hundreds contaminated, 4 deaths	No reports of serious injury or death
Response	A team of doctors, a helicopter with detectors, and decontamination. Prussian Blue and GM-CSF were administered to contaminated patients	BAPETEN conducted a survey, decontamination, and source retrieval

Implementation Analysis and Challenges

This section transitions from theoretical foundations and international case studies to a critical evaluation of Indonesia's current radioactive substances security management system. It assesses the practical challenges of transforming a comprehensive regulatory framework into an effective implementation, with particular attention to resource constraints, the integration of technological innovation, and the cultivation of a resilient security culture across all stakeholders.

a. Gaps in Regulation Implementation

Currently, regulatory framework in Indonesia, particularly with the enactment of GR No. 45 Year 2023, has become highly comprehensive and aligned with international standards, with the greatest challenge is in its implementation. Several case studies and research have shown gaps between established policies and compliance at the operational level. For instance, a study found that the application of radiation protection in hospital radiology installations was not fully in line with BR No. 4 Year 2020, especially regarding the availability and use of protective equipment such as lead gloves and glasses [23]. Other findings also indicated non-compliance in the health monitoring of radiation workers in some facilities [10].

The causes of these gaps are not solely due to a lack of will on the part of licensee, but are also affected by logistical and structural factors. One of the fundamental problems faced by the regulatory body is the insufficient number of inspectors and the large geographic area of Indonesia where radioactive source utilization is undistributed well [1], [26]. This condition directly hinders effective law enforcement, creating security gaps where non-compliant practices may go unnoticed.

b. The Role of Technological Innovation in Surveillance

To bridge the gap between regulations and implementation, the role of technological innovation becomes crucial. A study suggests that the implementation of online inspection or remote inspection can be an effective solution to overcome the insufficient number of inspectors [21]. By using this technology, BAPETEN can conduct online inspection of documents and records, allowing for more frequent and efficient inspections without always having to be physically on-site. This approach can also be tailored based on the risk level of the facility, where low-risk facilities with a good track record can be fully supervised online, while high-risk facilities still require physical inspection [1].

The use of surveillance technology, such as unmanned aerial vehicle (UAV)-based radiation source mapping systems, can also significantly reduce radiation exposure to RPOs and increase the effectiveness of identifying orphan sources [21]. This type of innovation not only improves efficiency but also supports the optimization principle, or ALARA, in radiation protection directly. Hence, it shows that investing in technology can be an effective bridge between regulations and implementatios.

c. Security Culture, and Enhancement of Qualification and Competency Personnel

In addition to the regulatory framework and technological innovation, the human factor also plays a central role. The recent regulations define security culture as a combination of individual character, attitudes, and behavior that support and enhance the security of radioactive substances [12]. This concept emphasizes that security is not just a technical issue but also a matter of behavior and awareness at the individual and organizational levels.

The enhancement of qualification and competency personnel, such as for RPOs and radioactive substances security officers, is important to realizing this culture [24]. Meanwhile, the recent regulations have detailed the qualification and competency requirements, including education and certification, to ensure that responsible personnel have adequate knowledge and skills [24]. BAPETEN has been demonstrating a proactive commitment to enhancing awareness, strengthening professional competency, and facilitating the dissemination of international best practices among practitioners, through seminars, stakeholders dialogues, and technical workshops.

CONCLUSIONS

The result shows that radioactive substances security management in Indonesia has made significant progress, particularly to the new, specific, and comprehensive regulatory framework such as GR No. 45 Year 2023 and BR No. 5 Year 2024. The paradigm shift not only focus on safety, but also focus on security which reflects a deep understanding of the nature of modern threats. However, fundamental challenges still exist, especially the implementation in logistic, such as insufficient number of inspectors. The Goiânia and Serpong incidents highlight that security management failures have fatal consequences and the potential to reduce public trust.

Based on this analysis, strategic and operational recommendations can be formulated to strengthen radioactive substances security management in Indonesia. These recommendations aim to align domestic practices with international legal and normative instruments, leverage technological innovation to overcome structural and geographical challenges, and institutionalize a resilient security culture that takes in place accountability and awareness at all organizational levels. Recommendations based on the results of the study for stakeholders are as follows:

a. For Regulators (BAPETEN)

- Adopt and implement of innovative supervision technologies such as online inspection and integrated management systems to overcome geographical challenges and insufficient human resource.
- Strengthen training and certification programs for RPOs and radioactive source security officers to ensure qualification and competency in accordance with requirements.
- Conduct regular and transparent compliance audits to identify and close existing implementation gaps.

b. For Licensee (Industry and Medical Facilities)

- Build a security culture at all organizational levels, where every individual has an awareness of and responsibility for radioactive substances security.
- Invest in continuous professional training and development for all personnel involved with radioactive substances.
- Implement best practices recommended by the IAEA, especially regarding the inventory and securing of radioactive substances, to prevent the emergence of orphan sources.

c. For Academics and Researchers

- Carry out longitudinal case studies to assess how recent regulations affect compliance levels in the field.
- Develop supporting models and technologies to assist in surveillance and law enforcement, such as portable dosimeters linked to a centralized system.

The strengthening of radioactive substances security management in Indonesia requires a comprehensive regulatory framework in alignment with international standards, the strategic adoption of advanced monitoring and control technologies, and the cultivation of a robust security culture that is embedded at all organizational levels, from frontline personnel to senior policymakers.

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