Indonesia's Emerging Threat: How Nuclear Trafficking Exploits National Vulnerability

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ABSTRACT

Nuclear and radioactive trafficking has emerged as a critical issue on the global agenda, posing significant threats to national security and increasing the risk of terrorism. Developing nations such as Indonesia face unique challenges and vulnerabilities that render them particularly susceptible to such illegal activities. This study investigates the specific factors contributing to Indonesia's heightened risk of nuclear and radioactive trafficking, employing the Threat, Vulnerabilities, and Consequences (TVC) Framework as a structured analytical tool. Key issues examined include inadequate government awareness and response mechanisms, porous borders that facilitate the illicit movement of goods, and the presence of orphan sources, radioactive materials that are poorly tracked or uncontrolled. Furthermore, the analysis of potential risks and consequences highlights the serious implications of nuclear trafficking, including environmental damage, public health crises, and the potential for catastrophic terrorist attacks. The study reveals how exploitative actors may leverage Indonesia's institutional and infrastructural weaknesses, emphasizing the urgent need for policy reform, capacity building, and strengthened regional cooperation. Ultimately, addressing these vulnerabilities is essential not only for Indonesia's national security but also for regional stability and global safety.

Keywords: Nuclear, Radioactive, Trafficking, TVC Framework, Indonesia

Perdagangan ilegal nuklir dan radioaktif telah menjadi isu krusial dalam agenda global yanag menimbulkan ancaman signifikan terhadap keamanan nasional dan meningkatkan risiko terorisme. Negara-negara berkembang seperti Indonesia menghadapi tantangan dan ancaman yang membuat mereka menjadi sangat rentan terhadap aktivitas ilegal tersebut. Studi ini menganalisis faktor-faktor yang berpengaruh terhadap meningkatnya risiko perdagangan gelap nuklir dan radioaktif di Indonesia, dengan menggunakan framework Threat, Vulnerability, dan Consequences (TVC) sebagai alat analisis terstruktur. Isu-isu yang dikaji dalam studi ini meliputi mekanisme pencegahan dan respons pemerintah yang kurang memadai, perbatasan rentan yang memfasilitasi pergerakan barang ilegal, dan keberadaan sumber-sumber berbahaya seperti orphan sources, yaitu bahan radioaktif yang kurang pengawasan atau tidak dikendalikan oleh pihak berwajib. Kemudian, analisis potensi risiko dan konsekuensi juga menyoroti dampak serius dari perdagangan ilegal nuklir, termasuk kerusakan lingkungan, krisis kesehatan masyarakat, dan potensi aktivitas terorisme. Studi ini mengungkap bagaimana aktor-aktor kejahatan transnasional dapat memanfaatkan kelemahan kelembagaan dan infrastruktur Indonesia, yang menekankan kebutuhan mendesak akan reformasi kebijakan, pengembangan kapasitas, dan penguatan kerja sama regional. Pada akhirnya, mengatasi kerentanan ini penting tidak hanya bagi keamanan nasional Indonesia, tetapi juga bagi stabilitas regional dan keselamatan global.

Kata Kunci: Nuklir, Radioaktif, Trafficking, TVC Framework, Indonesia

Introduction

In the contemporary security landscape, threats extend beyond conventional crimes to include unconventional and unpredictable offenses. Transnational crimes such as trafficking now encompass not only the trade, transfer, theft, and smuggling of people, weapons, or animals, but have also evolved to include the far more dangerous trafficking of nuclear weapons and radioactive materials. This shift has elevated nuclear threats to a formal global concern, recognized by numerous countries, especially in the aftermath of the 9/11 attacks, which heightened awareness of the potential for terrorist activities involving weapons of mass destruction (Alkış, 2022). According to the International Atomic Energy Agency (IAEA), nuclear security involves preventing acts of trafficking, theft, sabotage, illegal possession, and unauthorized transfer of nuclear or radioactive materials. It also encompasses detection, countermeasures, and response strategies to address such incidents.

Nuclear security is thus deeply connected to the challenges of terrorism, trafficking, and cross-border smuggling, all of which are forms of transnational crime. These offenses frequently involve the illegal movement of radioactive materials without government approval or in violation of laws, for purposes such as illegal sale or use in activities capable of causing mass destruction. The IAEA, through its Incident and Trafficking Database (ITDB), reports that from 1993 to 2024, there were 4,390 recorded incidents involving illegal nuclear and radioactive materials worldwide (IAEA, 2025). These incidents cover theft, illegal transfers and smuggling, unauthorized sales, and fraudulent claims of nuclear materials. Southeast Asia is a region of particular concern due to its significant nuclear sector potential and its position as a source and transit point for illegal radioactive and nuclear materials (Ackerman et al., 2025). The region's close integration with global trade networks, both legal and illegal, further increases opportunities for transnational crimes such as nuclear trafficking.

Nuclear security is a matter of global concern, extending beyond the interests of any single nation to encompass entire regions such as Southeast Asia. While regional cooperation is essential, active participation from individual countries, including Indonesia, is crucial for the success of nuclear security initiatives. In Southeast Asia, several collaborative efforts have been established to enhance nuclear security, notably the ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM). This network demonstrates the shared commitment among Southeast Asian countries to prevent nuclear-related crimes through joint action and aligned interests. Indonesia actively contributes to these regional efforts by exchanging information and building capacity in nuclear safety, security, and the peaceful use of nuclear energy (Trajano & Caballero-Anthony, 2020). Given Indonesia's vulnerability to terrorism and the potential proliferation of weapons of mass destruction (WMD), its role in regional nuclear security is especially important. However, Indonesia chose not to join the Proliferation Security Initiative (PSI), an international initiative aimed at intercepting the trafficking of WMDs. According to information from the FPKS, Indonesia declined the invitation to participate in PSI due to concerns that it might undermine national sovereignty as an archipelagic state and conflict with Indonesia's obligations under the United Nations Convention on the Law of the Sea (UNCLOS) 1982 (Nurhasya, M. J., 2017).

Indonesia's commitment to nuclear security is further reflected in its support for a nuclear-weapon-free zone in the region. In 1995, Indonesia and nine other ASEAN member states signed the Southeast Asia Nuclear-Weapon-Free Zone (SEANWFZ) Agreement (Kuswardini, S., 2018). Despite this significant step, concerns remain about the effectiveness of the agreement in fully protecting Southeast Asian countries from

nuclear threats. These concerns highlight ongoing vulnerabilities in nuclear security, particularly for Indonesia, and underscore the need for continued vigilance and cooperation at both national and regional levels. Indonesia serves as a prime example of these vulnerabilities, as the occurrence of crimes involving nuclear theft, trafficking, and smuggling has collectively positioned the country as a focal point for national security concerns. Indonesia's use of nuclear energy, the presence of nuclear materials and expertise, and the operation of three research reactors with additional development underway for power generation all highlight points of risk (World Nuclear News, 2022). Notable cases include the trafficking of seven trucks suspected of carrying nuclear materials in Tasikmalaya, West Java, which were smuggled from Bangka Belitung, and the discovery of an orphan source of radioactive cesium-137 in a populated area (Suryaman, 2020). These incidents underscore the urgency of addressing vulnerabilities related to the control and security of radioactive and nuclear materials, given their potential use in the creation of 'dirty bombs' or radiological dispersal devices that threaten national security.

Drawing on previous research, such as Huda et al. (on vulnerabilities in Indonesia's nuclear security) and Trajano & Caballero-Anthony (on regional cooperation and security threats), it is clear that most studies treat vulnerability and threat factors as separate issues. However, there has been limited analysis focused on mapping the interconnected vulnerability factors in Indonesia that could elevate the risks of nuclear-related crimes. This gap restricts the ability to anticipate the specific factors and risks that may affect state and regional security should nuclear or radiological material trafficking occur in or through Indonesia. This study addresses this gap by introducing a more comprehensive and integrated framework. By employing the Threat, Vulnerabilities, and Consequences (TVC) framework, this research aims to map and connect these three critical components, comprehensively illustrating how and why radioactive or nuclear trafficking could pose a serious threat to Indonesian security. Furthermore, this approach underscores the importance of improved policy, capacity building, and collaboration among domestic and regional stakeholders. Such efforts are crucial for addressing vulnerabilities and ensuring the stability of national, regional, and global security.

Method

This study employs a qualitative research method, following the analytical framework outlined by Miles and Huberman (1994), which consists of three phases of data reduction, data display, and conclusion drawing. Data collection is based on both primary and secondary sources. Primary data are obtained from official institutional documents and relevant policy materials, while secondary data are gathered through literature reviews and journal articles that provide supporting information for the study. In the data reduction phase, information related to potential or existing threats, such as past incidents in Indonesia, regional vulnerabilities, regulatory measures, interventions, and the role of local actors, is extracted and filtered from both primary and secondary sources. The subsequent data display phase involves organizing and mapping this information in detail, adapting it to the chosen analytical framework: the Threat, Vulnerability, Consequences (TVC) Framework. The study then presents a descriptive analysis that connects local conditions, policies, and factual data to the TVC components relevant to nuclear trafficking in Indonesia. Finally, in the conclusion and verification phase, the study synthesizes findings to highlight the interconnectedness of threats, vulnerabilities, and risks arising from illegal nuclear activities in Indonesia. This section is complemented by recommendations for mitigation and further measures that can serve as a reference for enhancing Indonesia's nuclear security.

Results and Discussion

By applying the Threat, Vulnerability, and Consequences (TVC) Framework as a risk assessment tool, this section provides a comprehensive analysis of Indonesia's potential exposure to nuclear trafficking risks. Unlike previous studies that often address threat, vulnerability, and consequences as isolated factors, the TVC framework integrates these components, facilitating an analysis that connects threat factors specific to Indonesia, the country's existing vulnerabilities, and the possible consequences that may arise. Through this integrated approach, risk is understood not only as the result of specific actors but also as a product of the interaction among emerging capabilities, systemic weaknesses, and their potential impacts. Within the context of nuclear security, and consistent with the methodology used by the International Atomic Energy Agency (IAEA), the TVC framework offers a risk-informed perspective. This enables the identification of vulnerability factors most susceptible to exploitation and emphasizes the policy implications of these risks. In doing so, the TVC framework supports a more holistic and actionable understanding of nuclear security threats and informs targeted strategies for mitigation in Indonesia (IAEA, 2015).

Threat

The first component, Threat, refers to the potential risks posed by illegal actors, activities, or actions associated with nuclear trafficking and radioactive materials that could endanger Indonesia. Threats to nuclear security can manifest in various forms, including attacks on facilities or individuals (such as workers), which may result in economic losses or fatalities, theft or smuggling of radioactive or nuclear materials for specific purposes, infiltration of companies or facilities, and the misuse of legitimate business channels for illicit activities (Ackerman et al., 2025). Essentially, the relationship between illegal actors and nuclear threats is twofold: threats can emerge from legal and policy loopholes or inadequate enforcement, as well as from the motivations and capabilities of perpetrators (Caskey et al., 2024). This duality underscores the importance of threat assessments that consider both the capability and intent of potential actors.

The RN-STAT (Radiological Nuclear Smuggling Threat Assessment Tool) is an instrument used to evaluate such threats, focusing on illicit actors as a central concern. Incidents involving nuclear security may be linked to specific criminal groups, both regionally and nationally. While direct attribution is often challenging due to the covert nature of these activities, the risk remains significant because such actors may possess hidden capabilities. As a result, threat assessment in this domain is probabilistic, emphasizing potential future risks rather than solely relying on past incidents. Transnational criminal syndicates operating across borders, regardless of their country of origin, are particularly concerning due to their advanced capabilities and strong motivations to participate in the illicit trade of nuclear materials (Ackerman et al., 2025). These groups often possess extensive operational reach, sophisticated trafficking networks, and the expertise required to adapt and innovate their smuggling methods. The nuclear security threat landscape thus includes not only domestic criminal organizations but also powerful international syndicates that may seek to expand into nuclear trafficking if the opportunity is profitable or strategically advantageous.

A notable example is Yamaguchi-Gumi, a major criminal organization originating from Japan, which has demonstrated the capacity for illegal activities related to nuclear trafficking in Southeast Asia, including Indonesia. With a vast operational network,

diverse criminal modalities (including trafficking), and connections to the nuclear industry through front organizations, Yamaguchi-Gumi employs strategies such as smuggling, bribery, document falsification, and covert corruption to achieve its objectives (Adelstein, 2012). Their complex operations and substantial resources are critical enablers for smuggling, including the movement of nuclear materials. Motivations for such groups typically center on profit and power, given the value and strategic nature of nuclear and radioactive materials. Their association with other illicit organizations, like the extremist group Aum Shinrikyo, known for smuggling weapons and potentially radioactive materials, exemplifies their potential to expand their criminal enterprises into new and lucrative areas, such as the trafficking and smuggling of nuclear or radioactive materials (Nadeau & Adelstein, 2016).

Among local actors with the potential and capability to engage in nuclear and radioactive material trafficking, Hercules Rozario Marcal's organization stands out due to its operational reach and history of involvement in various criminal activities in Indonesia. While its current motivation for nuclear crimes may not be high, the group's established capabilities are cause for concern regarding possible future involvement in such offenses (Ackerman et al., 2025). Another significant threat to Indonesia's nuclear security is posed by the terrorist group Jemaah Anshorut Daulah (JAD), an Indonesian militant alliance closely aligned with ISIS (Allard & Da Costa, 2017). This connection enhances their capacity for transnational and illegal activities. JAD's strong ideological motivation drives them to instill mass terror and fear, particularly among groups with differing beliefs. The group's demonstrated interest in acquiring and utilizing radioactive materials to create new forms of terror mirrors global trends, where terrorist organizations seek to exploit the psychological effects of radioactive weapons—often causing panic and long-term economic disruption that far exceeds the immediate physical damage (Allard & Da Costa, 2017).

A concrete example of this threat is the 2017 dirty bomb plot, where militants planned to use low-grade radioactive material such as Thorium-232 (Th-232) and convert it into more dangerous Uranium-233 (U-233) for use in an attack (CBRNe World Staff, 2017). Reports indicated plans to combine U-233 with the powerful homemade explosive triacetone triperoxide (TATP) to create a nuclear device (Allard & Da Costa, 2017). Fortunately, law enforcement intervened, raiding homes and arresting five suspects in Bandung, West Java, before the attack could be carried out. This incident underscores that nuclear security threats may arise from domestic as well as international actors, with Indonesian militant groups demonstrating both intent and increasing capability to employ unconventional weapons.

Contemporary nuclear security frameworks recognize that both local and transnational criminal groups present significant risks. Although few nuclear security incidents have been conclusively linked to specific criminal organizations, modern threat analysis prioritizes potential and probability over past occurrence (Ackerman et al., 2025). The preceding discussion assesses the characteristics, capabilities, and motivations of these groups to better predict their likelihood of engaging in nuclear crimes. Rather than documenting proven incidents, this approach serves as a proactive risk assessment tool, identifying groups most likely to exploit opportunities or incentives to commit nuclear-related offenses.

Vulnerability

The second component, vulnerability, refers to the dynamic factors that increase the likelihood of a threat succeeding. Vulnerability is a condition that exists within a system

or environment, be it physical, technical, organizational, cultural, or natural, that can be exploited if a threat is realized (Willis et al., 2006). In the context of nuclear security, vulnerability describes weaknesses that make nuclear and radioactive materials susceptible to attack or misuse (IAEA, 2015). It can be measured as the probability that an attack will result in damage, such as loss of life or physical harm, if it were to occur.

The history of nuclear development in Indonesia began in the 1950s, when the government sent several scientists to the United States to study nuclear technology (Susiati et. Al., 2023) Indonesia's first president, Sukarno, firmly rejected Indonesia's involvement in the nuclear arms race during the Cold War because he believed it would only lead to global destruction. Even so, he regarded nuclear technology as a strategic capability that the nation needed to master for peaceful purposes. This view aligned with Indonesia's active participation in the establishment of the International Atomic Energy Agency (IAEA) in 1957. Indonesia took part in the agency's founding process, sent delegates to its first conference in Vienna, and fulfilled its membership commitments, including financial contributions and the creation of a national institution dedicated to nuclear affairs. These steps reflected Sukarno's ambition to ensure that Indonesia did not fall behind in the development of modern technology (Sylvia, 2021).

Indonesia's interest in developing nuclear infrastructure intensified in the mid-1960s. In 1964, the government-initiated plans for its first major nuclear facility in the Serpong Nuclear Area in Tangerang. The project continued through the following decades and reached operational status in the early 1980s. Developed with significant international assistance, the Serpong reactor became a central component of Indonesia's early nuclear research capabilities (Susiati et al., 2023). Indonesia's early engagement with nuclear technology reflected a strategic effort to build national expertise and infrastructure, positioning the country to advance in peaceful nuclear applications while keeping pace with global scientific developments.

Since 2010, nuclear power plants (NPPs) have been considered as part of Indonesia's regional renewable energy plans (Wisnubroto et. Al., 2019). Achieving sustainable development goals requires the use of clean energy. To support this, the central government has encouraged the development of nuclear power plants, as outlined in Presidential Regulation No. 5 of 2006, which permits nuclear energy to provide up to 5% of the country's electricity. This initiative is further reinforced by Law No. 17 of 2007, covering the nation's Long-Term Development Plan for 2005–2025 (Susiati et. Al., 2022). Indonesia's long-term engagement with nuclear technology demonstrates a strategic effort to develop national expertise, infrastructure, and clean energy capacity. However, this early and ongoing development, if not paired with strong oversight and regulatory frameworks, has also introduced vulnerabilities in the management of nuclear materials, highlighting the importance of robust supervision to prevent potential risks. From that trajectory, it becomes clear that the existence of nuclear technology in Indonesia not only laid the foundations for national technological progress but also opened the possibility for various challenges to emerge, including risks of misuse that require continuous and strict oversight.

In Indonesia, several specific factors contribute to heightened vulnerability. First, geography: as an archipelagic nation with more than 17,000 islands and extensive coastlines, Indonesia's strategic location between Asia and Australia is both an advantage and a challenge. While this positioning benefits Indonesia economically and politically, it also presents opportunities for criminal actors. Border areas are particularly vulnerable to cross-border crimes, including illicit trafficking and smuggling of nuclear and radioactive materials (Ulfa et al., 2018). Inadequate infrastructure and insufficient

border security personnel further exacerbate these vulnerabilities, as they are not proportional to the vast length of Indonesia's borders (Setiawan et al., 2020).

Second, the issue of orphan sources is a significant concern. Orphan sources, radioactive materials not under regulatory control, often due to theft, illegal activities, or abandonment, pose a heightened risk in an archipelagic context like Indonesia (Sanyoto et al., 2014). Notable incidents include the theft of 21 radioactive sources from PT Krakatau Steel in 2000, which have never been recovered and remain unsupervised (Liputan6, 2000). The discovery of Cesium-137 in a residential area in Batan Indah, Serpong, in 2020, further highlighted the dangers associated with open sources (Jemadu, 2020). This area, surrounded by communities, was found to contain unauthorized and illegally owned radioactive material, which was eventually identified and secured by BAPETEN (Jemadu, 2020). These cases underscore the need for robust detection and regulatory systems. While Indonesia has made progress in implementing early detection and response mechanisms, efforts remain constrained by the vast network of transportation routes and the limited resources of regulatory bodies like BAPETEN. The ongoing challenge is to strengthen oversight and ensure that any sources of nuclear or radioactive material are swiftly identified and brought under control to minimize risks to the public and the environment.

Another significant factor contributing to Indonesia's vulnerability is its ease of international access, which enables extensive interaction with countries around the world. Indonesia is served by 37 international airports and 172 seaports, including 21 international ports. While these numerous access points facilitate trade and mobility, not all are equipped with adequate detection systems for nuclear or radioactive materials (Huda et al., 2022). The absence of sufficient monitoring infrastructure at these borders increases the risk that nuclear security threats could enter the country undetected. Indonesia has made efforts to address this vulnerability, such as installing Radiation Portal Monitors (RPMs), large sensors capable of detecting nuclear materials, at several major ports. In collaboration with the International Atomic Energy Agency (IAEA), which provided partial funding, Indonesia has installed RPMs at seven key ports (ASEAN Regional Forum, 2024). However, this coverage is insufficient, as it represents less than 5% of all ports in Indonesia. Joko Trianto, an engineer at the National Nuclear Energy Agency (BATAN) and head of RPM engineering activities, highlighted this shortfall, emphasizing the need for RPM installations at vital sites, land borders, and airports to strengthen national security (Herlinawati, 2019).

As previously mentioned, historical factors also contribute to Indonesia's vulnerability. The country's experience with mass riots and terrorist attacks, such as the Bali bombings (2002–2005), the JW Marriott Hotel bombing in Jakarta (2003), and the 2016 bombing and shooting on Jalan MH Thamrin, reveals persistent threats to national security. These incidents, while not directly involving nuclear or radioactive materials, demonstrate the seriousness of illegal activities and the potential for future threats. The evolving technological landscape increases the possibility that terrorist groups could exploit nuclear or radioactive materials. For instance, in 2017, police arrested a terrorist group in Bandung that illegally possessed gas mantles suspected of being used for thorium extraction, underlining the growing awareness and knowledge among criminal groups about the potential misuse of such materials (Permana, 2017). These factors underscore the need for comprehensive monitoring, robust border security, and proactive intelligence efforts to address Indonesia's vulnerabilities and prevent the use of nuclear and radioactive materials in criminal or terrorist activities.

Consequences

The final component, consequences, in the context of nuclear security crimes, especially trafficking and smuggling of nuclear and radioactive materials can manifest in various forms. The severity of these consequences depends on factors such as the nature, location, and circumstances of each incident. Illegal actions like nuclear trafficking, when combined with existing vulnerabilities, significantly increase the overall risk. Among the most concerning scenarios is the use of a Radiation Exposure Device (RED), where radioactive material is placed in a public area, potentially exposing large numbers of people to harmful radiation (IAEA, 2015). Even more dangerous is the potential use of explosives combined with nuclear material to create an improvised nuclear device (IND), which could cause catastrophic destruction if detonated in a strategic location.

Beyond these scenarios, the deliberate dispersion of radioactive materials using radiological dispersal devices (RDDs) in public spaces also poses a grave threat, with the potential to cause fatalities and injuries on a large scale. These three types of threats, RED, IND, and RDD, each carry comprehensive negative consequences, including substantial economic losses due to property damage, as well as social and psychological trauma, environmental contamination, and complex political and diplomatic challenges. Such consequences can undermine national, regional, and even global stability. This article details four primary areas of impact resulting from these threats and vulnerabilities: health and safety (loss of life), economic losses, environmental damage, and socio-political instability (IAEA, 2015).

Focusing on the consequences for humans, health and safety risks, including loss of life, are among the most severe. Illegal activities involving nuclear and radioactive materials can inflict significant harm on the human body. Exposure to blasts or prolonged radiation can lead to severe injuries, organ damage, acute radiation sickness, a higher risk of cancer, and even death. These dangers are particularly acute in the case of an IND, where victims may suffer not only from radiation exposure but also from explosion-related injuries such as severe burns (Andersson et al., 2009). Indonesia has faced real-life threats in this area, especially with incidents involving the theft and smuggling of nuclear or radioactive materials and the creation of orphan sources. For instance, the Cesium-137 case in Indonesia was classified as an International Nuclear Event Scale (INES) Level 1 nuclear anomaly, below the threshold for a formal nuclear incident (Kompas.com, 2020). Still, the potential consequences remained serious, as exposure to such material can result in burns, acute radiation sickness, long-term health risks, and even death, underscoring the importance of robust preventive measures (Utami et al., 2024).

Criminal incidents and illegal activities related to nuclear security can have far-reaching consequences for both the economy and the environment (Andersson et al., 2009). The immediate and long-term damage from such events demands substantial mitigation efforts to protect victims, including both physical and psychological support, which can be extremely costly. Environmental contamination, affecting soil, water, and entire ecosystems, may require years, if not decades, of decontamination and can result in the permanent displacement of communities and the abandonment of local industries. The financial burden of such recovery is immense, and disruptions to business operations and supply chains often extend well beyond the incident's location.

At the same time, the social and political ramifications, at national, regional, and global levels, can be unpredictable yet highly significant (IAEA, 2015). On a national level, incidents can provoke public outrage, widespread panic, and a loss of trust in the

government, potentially destabilizing society and interrupting vital national processes, such as elections. Regionally and globally, these events may cause diplomatic friction and undermine international stability (IAEA, 2015). The use of dirty bombs, or radiological dispersal devices (RDDs), highlights the gravity of such threats, as they combine conventional explosives with radioactive material to maximize psychological and societal disruption. While dirty bombs do not produce the immense blasts associated with nuclear weapons, their primary danger lies in dispersing radioactive material over a targeted area (Centers for Disease Control and Prevention, 2022). Although the immediate physical damage may be less severe than that of a nuclear weapon, the psychological impact, mass panic, enduring fear, and eroded public confidence in authorities can be even more profound (Alkış, 2022). These consequences, in turn, intersect with other issues, including health risks, economic costs, environmental degradation, and the potential emergence of new orphan sources. Ultimately, the scale of these impacts is determined not only by the criminal acts themselves but also by how effectively state and institutional responses address vulnerabilities and strengthen nuclear security systems. Robust prevention, rapid response, and sustained efforts are crucial to minimizing the risks of illegal activities, terrorism, trafficking, smuggling, and related threats.

Mitigation

To mitigate crimes involving nuclear and radioactive materials, Indonesia should develop a comprehensive framework grounded in the Threat, Vulnerabilities, and Consequences (TVC) approach, emphasizing the need for a multi-layered and integrated strategy. While the country has made notable progress, persistent challenges remain in coordination, technology, and human resources. Institutionally, Indonesia's commitment is evident through the establishment of the Center for Security Culture and Assessment (CSCA) in 2014 and I-CONSEP, a center of excellence for nuclear security and emergency preparedness (Haditjahyano, 2014). However, the existing policy landscape is often fragmented, resulting in overlapping responsibilities and weak synchronization among key institutions such as BAPETEN, BIN, POLRI, TNI, and the Directorate General of Customs and Excise. Addressing these issues will require comprehensive policy alignment and granting greater independent authority to regulatory bodies.

Legal provisions are also critical in countering threats to national security, particularly those involving nuclear and radioactive materials. Current regulations in Indonesia contain several gaps that hinder effective prevention and mitigation of such crimes. The present legal framework lacks specific measures to address dangerous activities involving nuclear material, and the absence of clear penal provisions to deter offenders remains a significant weakness. These shortcomings underscore the urgent need to reform existing laws, such as Law No. 10 of 1997, ensuring that Indonesia's legal system is equipped to respond effectively to evolving threats related to nuclear and radioactive materials (Soeparna & Tanega, 2022). Firm regulations are essential for building public trust and ensuring transparency in the handling of crimes involving nuclear and radioactive materials. Laws must be rigorously designed with a robust legal foundation to effectively prosecute perpetrators and demonstrate the government's commitment to nuclear security. To this end, the government should prioritize prevention, detection, and response strategies by regularly updating the legal framework to better address the evolving challenges in nuclear security. Comprehensive regulations, routine inspections, and realistic testing of security systems, supported by ongoing legal reforms, are key to establishing an effective and efficient governance structure (Bunn & Bunn, 2002).

Despite these efforts, Indonesia continues to face substantial gaps in technology and infrastructure. The country relies heavily on imported detection equipment, such as Radiation Portal Monitors (RPM), which are currently limited to a handful of major ports and airports (Huda et al., 2022). As a result, thousands of entry points remain unmonitored, leaving them susceptible to illicit trafficking, an issue compounded by Indonesia's geographic complexity. To address this, investment in domestic research and development of detection technology is critical. The development of radiation detectors tailored to Indonesia's unique geographic and operational needs will extend the reach and effectiveness of mitigation efforts (Huda et al., 2022). Additionally, further strengthening centers of excellence such as the CSCA and I-CONSEP, particularly by expanding security culture training to non-nuclear sectors like hospitals and industry, will help secure radioactive materials that could otherwise become orphan sources. On the regional front, Indonesia plays an active role in the ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM), which promotes cooperation, best practice sharing, and capacity building across Southeast Asia (Trajano & Caballero-Anthony, 2020). Collaboration with international institutions such as the IAEA and the European Union enhances Indonesia's ability to safeguard its borders, especially its vulnerable land and maritime entry points. Through joint cross-border exercises and information sharing, this cooperation supports the prevention, investigation, and disruption of illegal activities involving nuclear and radioactive materials, benefiting all ASEAN member states.

Human resource development is another key aspect of mitigation. Although frontline officers (FLOs) receive training, frequent staff turnover often results in a loss of expertise (Huda et al., 2022). This highlights the need for a continuous training system to maintain and enhance skills over time. Furthermore, a holistic approach to education and training, integrating both technical and humanities perspectives, is vital for fostering a strong security culture in all sectors utilizing nuclear or radioactive materials. Ultimately, a resilient nuclear security system depends on adequate infrastructure, advanced detection technologies, and the competence of the personnel who operate them (Caskey et al., 2024). These efforts can also be advanced by enhancing nuclear security knowledge through educational capacity building and knowledge sharing with other countries. Indonesia's participation in the International Nuclear Security Education Network (INSEN), under the auspices of the IAEA, enables it to strengthen human resource capabilities to support global nuclear security. Through developing, promoting, and sharing excellence in nuclear security education with universities, research institutions, and other stakeholders, Indonesia can contribute to creating a more robust and collaborative international security environment (Chew, 2016).

The impact of this collaboration is seen in educational activities and meaningful contributions to the field. Indonesia can further expand its role through targeted outreach and public education programs. These initiatives are effective counters to threats such as terrorism, trafficking, nuclear smuggling, and other radioactive material crimes (Trajano & Caballero-Anthony, 2020). Raising public awareness is especially critical, given how risks like dirty bombs can have immediate and widespread effects. An informed and educated public not only reduces the appeal of such attacks for terrorists but also enhances overall community resilience. These efforts are also designed to foster public participation in strengthening nuclear security, recognizing the public's right and opportunity to be involved in government policy. By addressing existing gaps, leveraging opportunities, strengthening coordination, developing local detection technologies, and investing in human resources, Indonesia can advance its prevention and response capabilities. Ultimately, these measures will reduce vulnerabilities and help build a more resilient and integrated nuclear security system.

Conclusion

Indonesia faces significant vulnerabilities to trafficking in nuclear and radioactive materials, a threat exacerbated by both its geographic and institutional characteristics. As an archipelagic nation with extensive and porous borders, Indonesia is challenged by weak oversight of orphan sources, which creates substantial opportunities for criminal and terrorist groups to exploit. Analysis using the Threat, Vulnerabilities, and Consequences (TVC) framework illustrates how these weaknesses can be leveraged to steal, smuggle, or misuse nuclear materials, potentially resulting in environmental disasters or catastrophic attacks. Without focused mitigation efforts, especially in governance and international cooperation, these vulnerabilities will persist as prime targets for illicit actors.

While Indonesia demonstrates its commitment to nuclear security through participation in the Southeast Asia Nuclear-Weapon-Free Zone (NWFZ) and consideration of the Proliferation Security Initiative (PSI), both initiatives have limitations. The NWFZ cannot fully guarantee a region free from nuclear threats, as its effectiveness depends on cooperation from external parties. Meanwhile, joining the PSI raises concerns about Indonesia's sovereignty, especially regarding the potential for interdiction measures to conflict with freedom of navigation under UNCLOS and the risk of unilateral actions. As a result, Indonesia must carefully balance international cooperation with the protection of its sovereignty and adherence to its legal and foreign policy principles.

To effectively address this risk, Indonesia must adopt strategic and coordinated actions as a national effort. First, strengthening regulatory controls over radioactive materials is essential to prevent orphan sources from falling into the wrong hands. This involves enacting robust laws and policies, maintaining stricter inventories, and enhancing oversight of all users of radioactive materials, from hospitals to industry. Second, border security systems should be improved through investments in technology and comprehensive personnel training. Expanding the installation of radiation detection facilities at more entry points, alongside better inter-agency coordination, will help close security gaps often exploited by criminal actors.

Furthermore, fostering regional and international cooperation is vital in combating this transnational threat. Sharing information, best practices, and resources with neighboring countries and global partners not only strengthens Indonesia's internal defenses but also contributes to broader regional and global security. Addressing these threats and vulnerabilities is therefore critical not just for Indonesia's national security, but for regional stability and the global nonproliferation regime. Achieving this requires strong policy reforms, effective governance, active community and stakeholder participation, technological innovation, and strategic international partnerships to prevent future nuclear proliferation and trafficking.

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