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Original Article

A study on security oversight framework for Korean Nuclear Facility regulations

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ABSTRACT

Nuclear security has been emphasized to ensure the safety of the environment and humans, as well as to protect nuclear materials and facilities from malicious attacks. With increasing utilization of nuclear energy and emerging potential threats, there has been a renewed focus on nuclear security. Korea has made efforts to enhance the regulatory oversight processes, both for general and specific legislative systems. While Korea has demonstrated effective nuclear security activities, continuous efforts are necessary to maintain a high level of security and to improve regulatory efficiency in alignment with international standards.

In this study, the comprehensive regulatory oversight framework for the security of Korean nuclear facilities has been investigated. For reference, the U.S. regulatory oversight frameworks for nuclear facilities, with a focus on nuclear security, and the motivations of changes in regulatory oversight framework have been identified. By comparing these regulatory programs and frameworks, insights and considerations for enhancing nuclear security regulations have been identified. A comprehensive security inspection program tailored for the Korean regulatory oversight framework has been proposed, and has been preliminarily applied to hypothetical conditions for further discussion.

1. Introduction

Nuclear safety and nuclear security both aim to protect human life, health and the environment. However, their focuses and measures differ. Nuclear safety strives to ensure proper operating conditions and mitigate risks from unintended events, while nuclear security is to prevent, detect, and respond to malicious acts (intended actions) [1]. Since the inception of the nuclear industry, nuclear safety has been the top priority. However, attention to nuclear security has steadily increased over time [2-4]. Regulatory authorities have played a pivotal role in this evolution by establishing licensing criteria, setting regulatory requirements, inspecting licensee performances, and undertaking regulatory responses. It is important to note that the fundamental philosophy of the commercial use of nuclear energy remains unchanged, but the goals and strategies for its implementation have evolved based on regulatory circumstances and industrial needs. Therefore, the current regulatory framework and programs have evolved, reflecting several decades of technological developments and operational experiences.

Historically, nuclear stakeholders and the regulatory agencies/governments have grappled with striking a balance between essential and excessive regulations. The licensing burden has inflated the construction and operational costs of nuclear power plants, which hinders the competitiveness of nuclear energy. With limited financial and human resources, the expansion of procedures and regulations can prolong the licensing process and may result in insufficient inspections or reviews.

Given these challenges, many countries have developed their regulatory systems in line with international recommendations and standards. The U.S., a leader in both the nuclear industry and regulatory technologies, has become a reference for establishing the regulatory bases and requirements. Specifically, the U.S. NRC has developed the Reactor Oversight Process (ROP) to inspect, measure, and assess the safety and security performance of operating commercial nuclear power plants. Since its implementation on April 4, the ROP has adopted a risk-informed and performance-based approach, reducing regulatory burdens on both licensees and regulation staff [5,6]. It has been revised to resolve political and industrial concerns. Several countries have adopted the ROP framework, using it as a benchmark for their regulatory oversight programs [7].

Korea consistently emphasized the importance of nuclear safety and security, making significant efforts in this direction. In 1994, Korea

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enacted and promulgated 'Nuclear Safety Policy Statement' outlining the five basic principles of nuclear safety regulation: independence, openness, clarity, efficiency, and reliability [8]. On September 6, 2001, the Nuclear Safety Charter was enacted and declared, firmly asserting that nuclear safety is the paramount goal [9]. To assess the Korean nuclear regulatory framework and its efficacy, the Integrated Regulatory Review Service (IRRS) was conducted in 2011 [10]. The recommendations and suggestions from the IRRS's review were reflected, leading to a IRRS follow-up meeting in 2014 [11]. The conclusion was that the Korean nuclear regulatory system has aligned with IAEA safety standards, and improvements have been systematically executed through comprehensive action plans. In addition, the International Physical Protection Advisory Service (IPPAS) was conducted in 2014, determining that nuclear security in Korea has been substantially enhanced. As a result, Korea possesses a mature and well-established nuclear security regime to safeguard nuclear materials and radioactive sources [12,13].

Though the Korean government and stakeholders including the regulatory authority, plant owners and operators, and nuclear experts and researchers have made significant improvements, public concern over nuclear safety and security has continuously increased following the Fukushima Accident and Denuclearization movement in Korea. Notably, even though nuclear safety has been heavily emphasized, the nuclear security has only recently begun to receive attention, especially with the emergence of new threats, such as drones and cyber-attacks. In addition, due to the global expansion of nuclear energy utilization, there's an emphasized need for comprehensive regulatory assessment of nuclear facilities' performance, taking into account the interfaces among the safety, security and safeguards. It has been noticed that the Korean regulatory system is basically a deterministic approach with stringent inspection procedures and schedules. An explicit, performance-based, risk informed graded approach has yet to be implemented.

In this study, the security oversight framework aimed at enhancing the efficiency and effectiveness of Korean regulations has been studied. The preliminary security inspection program specific for the Korean regulatory oversight system has been suggested and applied to hypothetic scenarios. Firstly, the nuclear oversight regulation in the U.S. as a reference has been reviewed. The evolution of the U.S. regulatory program has been investigated and the motivations behind changes and the reasons for establishing the ROP have been identified. Especially, the strategic goals and implementation framework of the U.S. NRC have been reviewed, focusing on security considerations in the ROP. Secondly, the regulatory programs of the U.S and Korea have been compared. Korea, while aligning with international standards and recommendations, has developed its unique legal and institutional program and configurations. From this comparison, the suggestions on how to enhance and adapt the security oversight framework in Korean regulatory program have been made. Thirdly, the regulatory responses to inspection findings (IFs) of hypothetical scenarios between the proposed regulatory program and the existing Korean nuclear regulatory system have been compared. These scenarios based on security incidents both in Korea and overseas. The proposed regulatory program will be refined after discussions with both licensees and regulators. The suggested regulatory program will be refined after discussions with both licensees and regulators. In conclusion, the proposed framework and its initial (preliminary) application could be instrumental in establishing a legal basis for an integrated regulatory program. This will further improve the objectiveness and efficiency of overall plant performance assessments, facilitating decision-making for enforcement using quantitative information.

2. Review of U.S. Reactor oversight regulatory

2.1. U S.NRC's regulatory philosophy

Safety and security have been prioritized from the very beginning of commercial nuclear energy utilization. The emphasis on them has never been compromised; however, the focusing area has been shifted based on technological maturity, economic purposes and political issues. In particular, accidents at nuclear power plants have significantly influenced regulatory policies and practices, reflecting both public concerns and industrial consensus [2–4].

In the early stages (i.e., 1950~1960s), the emphasis on safety was placed on design features. Main safety functions and the concepts, such as the maximum credible accident and defense in depth, were established. Because there was insufficient information and data for regulatory decision-making, the regulatory agency (specifically, the Atomic Energy Committee, AEC) took a leading role in the research and development of nuclear safety system design and experiments. During 1960–1970s, the nuclear power industry experienced growth, and orders for nuclear power plant construction surged. However, the industry faced challenges due to inadequate workmanship, faulty materials and other construction-related issues. Therefore, there was an increased emphasis on regulations pertaining to construction activities, and quality assurance programs were established. It is noteworthy that in 1974, the AEC was divided into the NRC and the Energy Research and Development Administration (ERDA). This separation aimed to more efficiently regulate the commercial nuclear industry and to promote the nuclear energy utilization, respectively. The accident at Three Miles Island in 1979 had a significant impact on the nuclear community. Extensive investigations were conducted, revealing important lessons about the utility of probabilistic safety assessment, the significance of human factors, the need for clear procedures, and the importance of emergency plans. From that point onward, there has been a pronounced emphasis on the operational aspect of nuclear safety.

After that, international efforts have focused on the peaceful use of atomic energy and the protection of public health and the environment globally. Throughout nuclear history, the probabilistic approach to safety assessment has been a consistent emphasis, and its application has expanded. Risk-informed, performance-based regulations have demonstrated their worth by effectively monitoring the licensee performance and managing both the efforts and resources of regulatory personnel and licensees (i.e., graded approach).

Especially for security, the international treaty, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was established to prevent the proliferation of nuclear weapons and weapon technologies. It entered into force in 1970 [14]. Due to increasing concerns about terrorist attacks and a growing emphasis on strengthening nuclear security, physical protection has been highlighted. This aims to guard against theft, loss or unauthorized diversion of nuclear materials, and to prevent sabotage of nuclear facilities by individuals or groups. In 1972, IAEA prepared the INFCIRC/225, Recommendations for the Physical Protection of Nuclear Material in 1972 [15]. Subsequently, INFCIRC/274, known as the Convention on the Physical Protection of Nuclear Material(CPPNM), was established in 1980 [16]. Following the events of September 11, 2001, security requirements for nuclear facilities have been enhanced, and security-related information has been no longer publicly available. Meanwhile, the Convention for the Suppression of Nuclear Terrorism (ICSANT) was introduced, coming into effect in 2007. It defines nuclear and radiological terrorism as crimes and mandates appropriate punishment [17]. Furthermore, the Nuclear Security Summit (NSS) first held in 2010. This initiative began in 2009 when U.S. President Barack Obama underscored the importance of fortifying nuclear security for global safety during a speech in Prague [18]. The events and impacts on nuclear regulation above are summarized in Fig. 1.

2.2. Reactor oversight regulatory

U.S. NRC has established in 1975 and has been pursuing a mission to license and regulate the Nation's civilian use of radioactive materials to provide reasonable assurance of adequate protection of public health

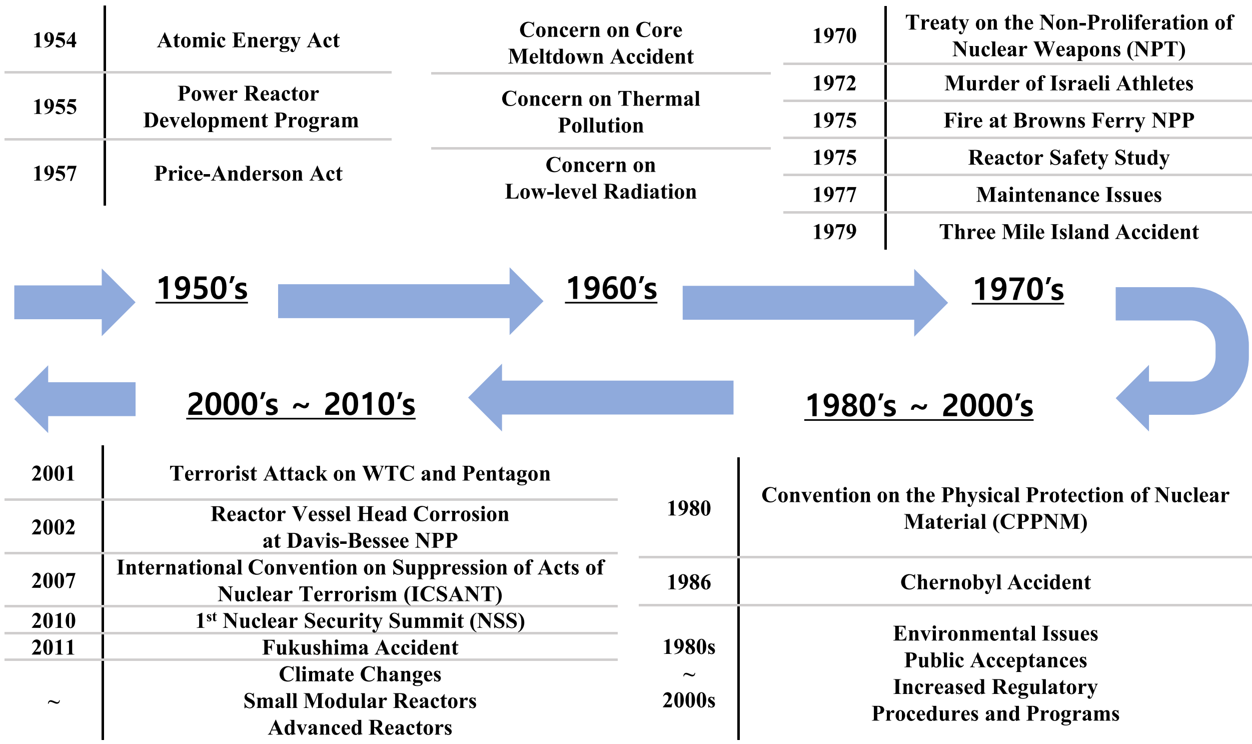

Fig. 1. Historical events and impacts on nuclear regulation.

and safety, to promote the common defense and security and to protect the environment [5]. NRC focuses its regulatory activities on protecting public health and safety and the environment through 1) developing regulations and guidelines for NRC staff, license applicants and licensees, 2) licensing applicant license or certification, 3) licensee operations and facility supervision, 4) evaluating operation experience and 5) conducting research, hold hearings, and securing independent reviews to support regulatory decisions. Among them, NRC regulatory oversight corresponds to regulatory supervision activities has been centered on inspection which consists of differentiated detailed activities (inspection, performance evaluation, regulatory action, claim/-clarification, investigation, incident response, etc.). In order for comprehensive and systematic assessment of licensee performance, Plant Performance Review (PPR), Systematic Assessment of Licensee Performance (SALP) program and Senior Management Meeting (SMM) were implemented with normal regulatory activities (inspection and performance indicators). Though successful regulatory oversight, there were criticisms that the regulatory oversight process 1) is at times not clearly focused on the most safety important issues, 2) consists of redundant actions and outputs, and 3) is frequently subjective, with NRC action taken in a manner that is at times neither scrutable nor predictable. To resolve those issues, NRC implemented ROP in 2000, with the goal of providing an objective, risk-informed, understandable and predictable approach to the oversight of nuclear power plant performance [19,20]. The ROP is a comprehensive program implemented by the U.S. NRC to assess the safety and performance of operating commercial nuclear power plants. The ROP is designed to ensure that nuclear power plants operate safely and comply with regulatory requirements [6]. According to MD 8.13, The regulatory framework for the ROP is a risk-informed, performance-based, tiered approach to assessing safety and security performance (Fig. 2). Fig. 3 is based on the U.S. NRC's regulatory framework and as described on the NRC website [6]. There are three key strategic performance areas: Reactor Safety, Radiation Safety, and Safeguards. Each strategic performance area has cornerstones, which are affected by cross-cutting areas (CCAs, see Fig. 2).

As can be seen in Fig. 3, NRC develops findings from inspections, and licensees collect performance indicator data. NRC evaluates IFs for safety significance using a significance determination process (SDP) and

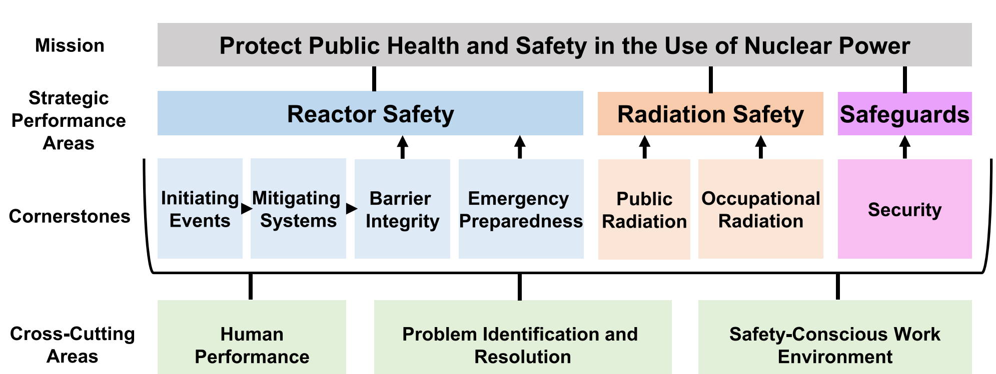

Fig. 2. U.S.NRC's reactor oversight framework.

compares performance indicators (PIs) against prescribed risk-informed thresholds (classified into 4 stages i.e. green, white, yellow, red). Then, the agency assesses the gathered information and determines an appropriate response based on the guidelines in an action matrix. This oversight program provides a more predictable and objective approach to enforcement that is commensurate with the plant performance declination and violations.

The ROP framework has been adopted and benchmarked by many countries [7]. Specifically, nuclear regulatory agencies in countries such as Japan, Canada and France operate their own regulatory frameworks by benchmarking the ROP framework of the United States. While these frameworks utilize risk information in the "monitoring-evaluation-response" stages, there are differences in detail from the NRC ROP. However, they all share a common concept: applying a regulatory response commensurate with the significance of safety and security events."

Especially, following the Fukushima accident, Japan has actively adopted the NRC ROP. The Nuclear Regulation Authority (NRA) underwent an IRRS mission from IAEA in 2016 [21] and participated in an IRRS follow-up meeting in 2020 [22]. In response to the recommendations and suggestions from the IRRS, NRA restructured its former inspection system, based on the US ROP. In order to gradually introduce the ROP over about two years, NRA's staffs underwent ROP training in the United States. Efforts were also made to amend legislation to allow the implementation of a new reactor oversight program and to develop regulatory inspection processes aligned with a graded approach. Unlike the NRC, which includes an emergency preparedness cornerstone, NRA evaluates the cornerstone of coping with severe accident and preventing large-scale damage, which is an enhanced response addressing Fukushima accident. Other than that, the regulatory frameworks used by the NRC and the NRA are mostly similar [23].

In Canada, the Canadian Nuclear Safety Commission (CNSC) oversees 14 Safety and Control Areas (SCAs) which break down further into 69 detailed areas. Of the 14 SCAs, both "Security" and "Safeguards and non-proliferation" areas are related to the security cornerstone of ROP. The CNSC also uses a risk-informed approach to its regulatory decision-making and has its own set of PIs to evaluate safety performance [24]. In France, the Autorité de Sûreté Nucléaire (ASN) oversees the safety of nuclear installations and materials. The ASN has its own regulatory framework, which includes standard inspections and assessments. The ASN conducts baseline inspections on 35 subjects grouped under 7 inspection themes. Notably, the part related to security is integrated and isn't inspected or supervised as a standalone area. If any IF indicates an immediate increase in risk, immediate risk mitigation measures is implemented. For findings linked to actual or potential accident outcomes, a comparative risk analysis is undertaken. Depending on the result, measures and sanctions with a graded approach are applied [25].

The CCAs used by Japan NRA include human performance, problem identification and resolution, and initiatives to foster a safety culture. The outcomes of CCA evaluations are categorized into three levels: +, 0, and -. These correspond to an 'Excellent case with commendable improvement measures' (+), 'No need for improvement' (0), and 'A requirement to bolster improvement measures' (−). The CCA evaluation result also factors into the comprehensive assessment result by PI and SDP evaluations. In contrast, the U.S.NRC incorporates the CCA both into the PI and SDP evaluations to provide a comprehensive assessment of a nuclear power plant's safety and security performance. On the other hand, Canada and France established their own regulatory frameworks with a graded approach for evaluation results while preserving their existing inspection systems as much as possible. A comparative overview of these reactor oversight systems is summarized in Table 1.

2.3. Security considerations in U.S. Nuclear regulations

NRC's strategic goals, long-term strategies and performance expectations have been provided in its strategic plan, prepared every 4 years since 2010. Strategic goals form the foundation for a set of performance goals and indicators, helping the agency monitor progress and provide direction. All organizations within the NRC have a pivotal role in realizing these strategic goals. As illustrated in Table 2, the security categorized under Nuclear Material Safety in the FY2000-2005 Strategic Plan [26]. After the events of September 11, 2001, the importance of physical security had received significant attentions. Since then, the nuclear security has been considered explicitly and stated in strategic goals, no longer just as a subset of safety. This evolution shows the NRC's amplified efforts towards security-related activities.

It's noteworthy that in the strategic goals for 2022–2026, safety and security have been jointly addressed, highlighting a more integrated approach to safety and security regulation. As a consequence of the terrorist attacks on September 11, 2001, NRC's ROP has been modified so that individuals could not obtain and use sensitive, security-related information about a nuclear facility's design, operation and protective capabilities for malevolent purposes [27,28]. In order to protect security-related information from public disclosure, NRC developed and implemented a distinct security assessment process in May 2005, separate from the safety cornerstones within the ROP.

However, the staff recognized that applying a separate assessment process would likely limit the regulatory response to a programmatic approach and would not allow for a holistic assessment of operator performance. Therefore, the security cornerstone was reintegrated into one ROP action matrix that would include inputs from all seven ROP

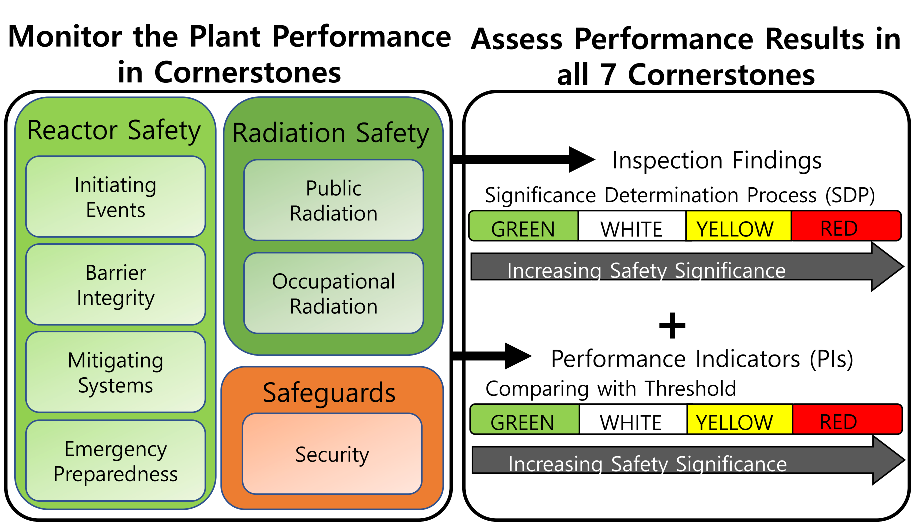

Fig. 3. Overview of U.S.ROP.

Table 1
Comparison of reactor oversight programs.

Division	United States	Japan	Canada	France
Regulatory Authority	NRC (Nuclear Regulatory Commission)	NRA (Nuclear Regulation Authority)	CNSC (Canadian Nuclear Safety Commission)	ASN (Autorité de Sûreté Nucléaire)
Evaluation Method	SDP (Cornerstones: 7), PI (Performance Indicators: 17)	SDP (Cornerstones: 7), PI (Performance Indicators: 14)	Severity Analysis (Safety and Control Area, SCA: 14) SPIs (Safety Performance Indicators: 25)	Comparative Risk Analysis Inspection Themes: 7 Subjects: 35
Security Related Area	Security	Physical Protection	Security, Safeguards and non-proliferation, Packing and transport	–
Evaluation Rating	Green-White-Yellow-Red	Green-White-Yellow-Red	High, Medium, Low, Negligible, Compliant	Zero, Low, Moderate, Significant, Extreme
Inspections	• Baseline Inspection • **Supplemental Inspection (95001, 95002, 95003)** • Special and Infrequently Performed Inspections	• Baseline Inspection • **Supplemental Inspection (1, 2, 3)** • Special Inspection	• **Type I Inspection** • Type II Inspection • Desktop inspection • Field inspection • Focused Inspection	• Standard Inspection • **In-depth Inspection** • Inspection with Sampling and Measurements • Reactive Inspection • Worksite Inspection
Integrated Performance Evaluation for Nuclear Power Plant	Action Matrix (Phase I ~ V)	Action Matrix (Phase I ~ V)	• FS(Fully Satisfactory), • SA(Satisfactory), • BE(Below Expectations), • UA(Unacceptable)	• Noncompliance, • Inappropriate Action, • Minor Deviation, • Impeding Performance of Duties
Follow-up Measures	Imposition of differentiated follow-up measures corresponding to evaluation results • Strengthen inspection (supplemental inspection) • Additional regulatory measures (administrative measures, etc.)	Imposition of differentiated follow-up measures corresponding to evaluation results	• Issuance of inspection report after request for corrective action • Implementation of differentiated compulsory measures (business operator notification/written notification/reinforced regulatory investigation, etc.)	• Implementation of differentiated compulsory measures (document confirmation/data request/planned corrective action request, etc.)

Table 2
Historical change of strategic goals of U.S.NRC.

Fiscal Years	Strategic Goals
2000~2005	Nuclear Reactor Safety/Nuclear Material Safety/Nuclear Waste Safety/International Nuclear Safety Support
2004~2009	Safety/Security/Openness/Effectiveness/Management
2008~2013	Safety/Security (Organizational Excellence)
2014~2018	Safety/Security
2018~2022	Safety/Security
2022~2026	Safety and Security/Organizational Health/Stakeholder Confidence

cornerstones on July 1, 2012 to more accurately reflect a holistic representation of licensee performance. Currently, the security performances of the plants are available on the web, but the details about the IFs are not publicly available.

3. Comparison of regulatory oversight framework of security in U.S. And Korea

3.1. Overview of Korean nuclear regulatory system

In Korea, Nuclear Safety and Security Commission (NSSC) plays a leading role in rulemaking/enforcement concerning nuclear facilities and activities to ensure safety. It also develops/implements nuclear regulatory policies. In response to the recommendations and suggestions of IRRS [11], the NSSC was established in 2011 as an independent organization, directly under the control of the President [29]. The NSSC is delegating technical reviews and inspections related to nuclear safety to the Korea Institute of Nuclear Safety (KINS) and those related to nuclear security to the Korea Institute of Nuclear Nonproliferation and Control (KINAC). KINS, a safety regulatory expert organization, was established in 1990. It has since been responsible for functions such as nuclear safety review, inspection, and the development of examination standards and guidelines [30]. In contrast, KINAC was established in 2006. As a regulatory expert organization, it oversees safeguards, physical/cyber protection, and export/import control regarding nuclear facilities and materials [31]. A diagram illustrating these relationships is presented in Fig. 4. It's important to note that in Korea, nuclear safety and security are regulated by separate organizations. While NSSC is in charge of decision-making and enforcement as the regulatory authority, the inspection and review of licensee performance for both safety and security measures have been independently conducted by two distinct organizations.

It is important to note that Korea underwent an IRRS evaluation in 2011 [10] and follow-up IRRS review in 2014 [11]. In 2011, the IRRS review team identified a number of good practices, made recommendations and suggestions that indicate where improvements are necessary or desirable to continue enhancing the effectiveness of regulatory functions in line with the IAEA Safety Standards. The IRRS review team concluded that certain aspects warranted attention or required improvements to enhance the overall performance of the regulatory system. In 2014, an IRRS follow-up mission has been conducted to review the Korean regulatory framework for nuclear and radiation safety, using the IAEA safety standards as the international benchmark. The mission also served as an avenue for information and experience exchange between the IRRS team and their Korean counterparts in the areas covered by the IRRS. The IRRS team concluded that the recommendations and suggestions from the 2011 mission were systematically addressed through a comprehensive action plan. Significant progress has been made in many areas and numerous enhancements were carried out following the implementation of the action plan. In this follow-up mission, the IRRS team determined that 9 of the 10 recommendations and all 12 suggestions made by the 2011 IRRS mission had been effectively addressed, and as a result, they could be marked as resolved.

In addition, Korea underwent an IPPAS mission, which evaluated the

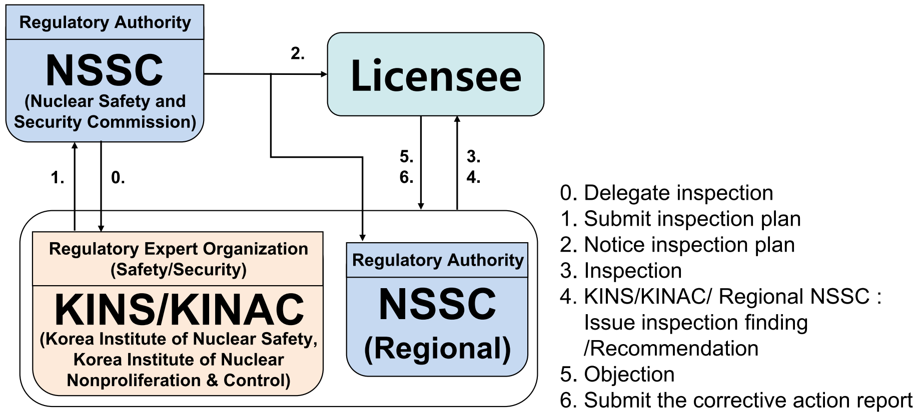

Fig. 4. Nuclear regulatory inspection in Korea: Inspection procedure diagram.

country's nuclear security-related legislative and regulatory framework for nuclear and other radioactive material and associated facilities. This review also covered the security arrangements for the transport of nuclear materials and radioactive sources, as well as for computer systems [12]. The IPPAS team reviewed physical protection systems at the Hanbit Nuclear Power Plant (NPP) operated by Korea Hydro and Nuclear Power Company (KHNP) and the High-Flux Advanced Neutron Application Reactor (HANARO) operated by the Korea Atomic Energy Research Institute (KAERI). They concluded that Korea has been effective in maintaining robust and sustainable nuclear security measures. Moreover, the team identified several exemplary practices in both the national nuclear security regime and the facilities they visited. Furthermore, they provided recommendations and suggestions to continually advance nuclear security.

3.2. Comparison of U.S. and Korean security regulatory system

Compared to the U.S., the Korean regulatory oversight system is distinct due to its delegation model. In Korea, the independent regulatory authority, the NSSC, assigns regulatory responsibilities for safety to KINS and for security/safeguards to KINAC. Although the NSSC retains the authority for final approvals and issuances, KINS and KINAC handle technical reviews and inspections [32]. One of the reasons of having two different organizations in Korea could be the geopolitical situation. The nuclear security as well as general security matters in all industrial and societal areas have been considered very importantly. It has been generally recognized that the nuclear security regulations in Korea have been applied and implemented in a stricter way than the ones of international recommendations and general standards. In addition, the nuclear facilities and nuclear materials in Korea have been also supervised strongly under the law of several other governmental entities, e.g., Ministry of Defense, National Intelligence Services. Another difference is that Korea has just one nuclear power company, KHNP. Unlike the U.S., which has numerous nuclear vendors and operators, the communications between stakeholders could be promoted with less conflict and the safety/security policies and decisions could be shared and applied in a consistent manner.

As noted in IRRS comments, the Korean regulatory program is basically deterministic and risk-informed performance-based approach has been implicitly and qualitatively incorporated. Though the IFs are reviewed by Advisory Committee before being brought up as the agenda of NSSC Meeting, there is no formal procedure or quantitative criteria for determining the significances of those IFs or failures. It is important to note that the use of risk informed approach, graded approach and performance based regulatory approach to review and assessment of a facility or an activity are recommended by IAEA requirements [33–35]. In addition, the synergy of 3S (safety, security and safeguards) has been increasingly emphasized for improving regulatory efficiency and effectiveness. Especially, there are interfaces that the enhancing the safety would beneficial for enhancing security and vice versa [1]. Therefore, the graded approach based on risk-information would benefit in Korean regulatory oversight program and match the international trends for regulatory/industrial society.

In U.S. ROP, the cultural aspects are considered as CCAs, i.e., human performance, problem identification and resolution and safety-conscious work environment. However, the current regulation oversight program in Korea does not have the formal regulation framework for continuous monitoring. Though the safety culture has been emphasized by regulatory authority and government for a long time, it relies on the licensee's voluntary programs. In view of assessing overall plant performance, those CCAs should be incorporated in regulatory oversight program.

In Table 3, the inspection procedures for security of U.S. NRC's ROP have been compared with KINAC's examination standards [36]. The title of KINAC's inspection guideline is not publicly disclosed, while the title of examination standards can be found on the website. KINAC's examination standards are largely divided into three categories: Safeguards, Physical Protection, and Cyber Security. The inspection aspects for both countries are covering overall similar areas with minor differences. For example, the security against the high-power electro-magnetic pulses is explicitly covered only in Korean regulations. Force-on-Force Testing which is required to conduct every 3 years for all nuclear power plants and certain other major nuclear facilities is not required in Korea. Regarding PIs, the data for availability of security systems and failures of the personnel screening and fitness for duty process have been selected as PIs in U.S. On the other hand, there is no PI program related to security in Korea.

It is important to note that it would not be appropriate to judge strictness or rigorousness only by existence of specific inspection program because the fundamental regulatory concepts for both countries are different in view of the risk-informed and performance-based regulation and holistic performance assessment in decision-making. The effort should be given to enhance the strength and to make up for shortcomings under the current regulatory program.

4. Preliminary application of comprehensive regulatory approaches

4.1. Preliminary regulatory oversight framework of security in Korea

Based on review of U.S. regulatory system and comparisons to Korean regulatory system, a preliminary regulatory oversight

Table 3
A comparison between US inspection procedures and Korean examination standards for regulatory oversight of security.

US (NRC ROP)	Korea (KINAC)
	Physical Protection
71130.01 Access Authorization	KINAC/RS-104 Access Control, KINAC/RS-105 Security Search
71130.02 Access Control	
71130.03 Contingency response – Force-on-Force Testing	KINAC/RS-116 Physical Protection Drill
71130.04 Equipment Performance, Testing and Maintenance	KINAC/RS-102 Intrusion Firewall System, KINAC/RS-103 Intrusion Detection and Evaluation, KINAC/RS-106 Communication System, KINAC/RS-108 Central Alarm Station and Alarm System
71130.05 Protective Strategy Evaluation and Performance Evaluation Program	KINAC/RS-107 Vital Area, KINAC/RS-109 Guard and Patrol, KINAC/RS-114 Physical Protection for Transportation, KINAC/RS-115 Insider Threat Prevention and Protection, KINAC/RS-101 Security Organization, KINAC/RS-113 Security Emergency Response Program, KINAC/RS-111 Record and Report
71130.06 Protection of Safeguards Information	–
71130.07 Security Training	KINAC/RS-110 Qualification of Physical Protection Workers
71130.08 Fitness-for-Duty Program	
71130.09 Security Plan Changes	KINAC/GR-101~103 (Review Guidelines according to Change)
	Cyber Security
71130.10 Information Technology Security (Cyber Security)	KINAC/RS-011 Cyber Attack Response Drill, KINAC/RS-015 Security on Computer and Information System, KINAC/RS-018 Cyber Security on Wireless Connection, KINAC/RS-019 Critical Digital Asset Identification, KINAC/RS-020 Protection from High-Power Electro-Magnetic Pulse
71130.14 Review of Power Reactor Target Sets	Only for the Vital Area, Vital Area Review Guidelines (Identification Vital Areas)
	Safeguards
71130.11 Material Control and Accounting	KINAC/RS-200 Account and Control of Special Nuclear Materials

framework of security in Korea has been proposed for improving comprehensiveness and objectiveness of Korean regulatory system and IAEA requirements. In developing the security regulatory oversight system, the followings are considered.

1. Goal is to establish the risk-informed (quantitative and qualitative)/performance based regulatory oversight framework in Korean security oversight program.
2. U.S. ROP Framework system and concept are selectively adopted while maintaining the current Korean security oversight system (legislative system and agency composition/responsibility).
   - According to Fig. 4, Korean security and safety regulatory activities are carried out by KINAC and KINS, respectively [32]. In this study, security is designated as a specialized area (same concept as strategic performance area of NRC ROP) and a regulatory oversight framework was developed.
   - KINAC's regulatory work for security is largely divided into "Safeguards", "Cyber Security", "Physical Protection" and "Export Control" [31]. The "Export Control" area, which is not related to regulatory supervision based on inspection work, was excluded in this framework. Thus, "Safeguards", "Cyber Security" and "Physical Protection" are selected as the key elements (same concept of cornerstone of NRC ROP) to achieve the mission, and regulatory supervision is performed. KINAC's examination standards are also presented divided into these three areas [36].
3. U.S. ROP framework concept is referenced: hierarchical composition (including CCA), regulatory supervision process (regulatory inspection/PIs, risk-informed performance evaluation and regulatory action based on the evaluation results), establishment of inspection system (including inspectable area), composition of risk-informed integrated performance evaluation factors (inspection results/performance factors), regulatory action matrix according to integrated performance evaluation.
4. The current regulatory inspection fields of KINAC are included. While maintaining the inspection system of the current regulatory system, the detailed requirements for implementation will be supplemented.
5. By referring to the safety-related common elements (same concept as CCA) proposal of KINS, and reflecting the unique characteristics and safety culture of Korean organizations, a security-related common elements are formed.
6. Risk-informed performance could be evaluated by referring to SDP/PI system of U.S. ROP.
7. To implement the regulatory action matrix based on integrated performance evaluation for the security cornerstone, Korean legal system should be amended and supplemented.

The preliminary security oversight framework of Korea is shown in Fig. 5.

- Monitor: The operating performance such as the availability of the security surveillance system might be monitored as a PI. Regulatory inspections (baseline/supplemental/special) are performed. The baseline inspection is considered the minimum inspection effort needed to ensure that plants meet the security cornerstone objectives.
- Assessment: PI data reported by operator is evaluated. Also, the issues that are difficult to be evaluated as PIs are inspected, and if they are designated as IFs through the screening process, the SDP is applied to evaluate the significance. The results evaluated by SDP and PI are displayed in color-coded system. In addition to the key elements, assessment for the common elements is also reflected in the comprehensive evaluation of plant.
- Response: According to comprehensive evaluation by considering PI, SDP and the common elements, a response is determined by using the guidelines in a preliminary action matrix shown in Table 4. Supplemental inspections for vulnerable areas or violation regulatory actions would be included.
- Management: Manage the integrated information about plant performance, IFs by focusing issues with the most significance.
  - Integrated information management: indicators, inspection results, etc.

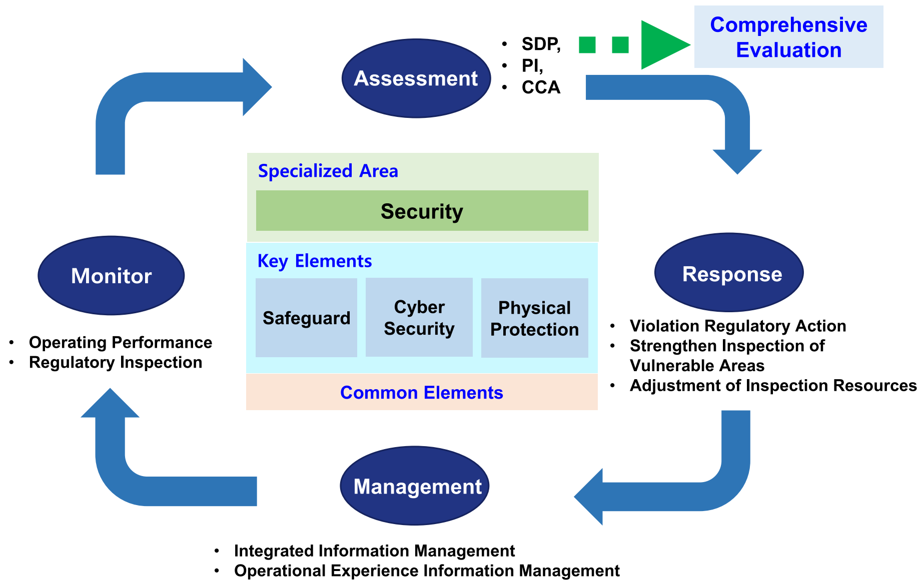

Fig. 5. Suggested security oversight framework for Korean nuclear facility.

- Operational experience information management: data collection, screening, analysis, feedback, monitoring, etc.

With the assessment results of three key elements and common elements in the security area, action metrics are applied and graded responses are performed. In other words, in addition to the PI/SDP evaluation results for the security-related key elements, the comprehensive grade is determined by additionally considering the evaluation result for common elements. An independent evaluation of the common elements issue can be performed and graded to five such as PI/SDP. If the corresponding common elements issue is the main reason or contributor to the performance degradation of the security-related cornerstone, it can be evaluated in conjunction with the security cornerstone [37]. As the safety regulatory oversight framework proposed by KINS also encompasses common elements evaluation, the detailed evaluation procedure for common elements will be established through consultation with KINS.

The preliminary action matrix is suggested under the assumption that the application of a graded approach in regulations can be implemented. The goal of the preliminary action matrix is to ensure appropriate and effective regulatory actions are taken to solve identified performance issues and maintain the safety and security of nuclear power plants. Based on the color-coded findings, the appropriate regulatory responses are determined. This may include increased inspections, additional oversight, enforcement actions, or other measures. Baseline inspection is performed periodically, regardless of power plant performance. Meanwhile, supplementary inspections are conducted according to their significances when a problem occurs (when necessary). As the comprehensive evaluation grade increases from 2 to 4, more man-hours and/or specialized competence are required for supplementary inspections.

4.2. Applicability evaluation of suggested regulatory security oversight framework

The proposed Korean security oversight framework has been examined by preliminarily applying to hypothetical cases, which are assumed based on Korean and overseas security incident cases. The SDP has been pre-established and the action matrix in Table 4 has been applied to determining a regulatory response. Comparison has been made in case of applying the current security oversight program.

Hypothetical Event Scenario #1: Physical Protection.

The security in Class III protected (shown in Fig. 6, Boundary between the outside and the power plant) area was found to be breached for approximately 2 months.

- A power plant policeman turned the CCTV direction to the other side and went fishing while on duty.
- Security area was accessed by opening the coastal barrier gate without keeping a log of the opening of the guard gate.

Fig. 7 shows the proposed the SDP for Physical Protection which is preliminary presented by referring to the NRC's SDP Guide for security [38]. According to a screening guide, the scenario for this performance deficiency is determined to be "More-than-Minor". A screening guide suitable for the Korean situation will also be developed, and in this study, the NRC's screening guide is referenced [39]. In Step 1 and Step 2, the evaluation criteria have been examined and the vulnerable period is identified, respectively. The preliminary evaluation criteria for physical protection are presented in Table 5. In Step 3, the significance would be

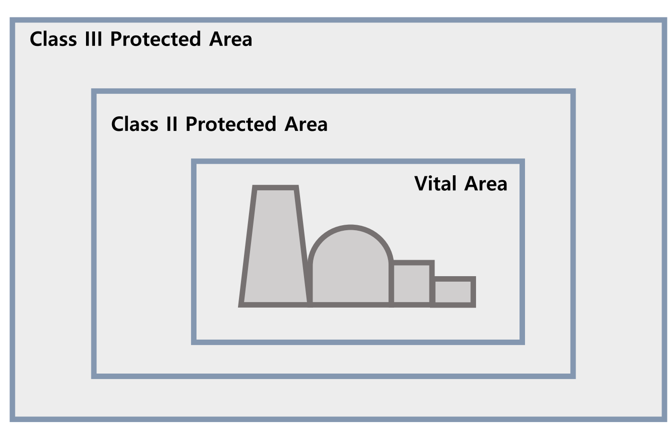

Fig. 6. Concept of Class II/III protected area, and vital area in Korea.

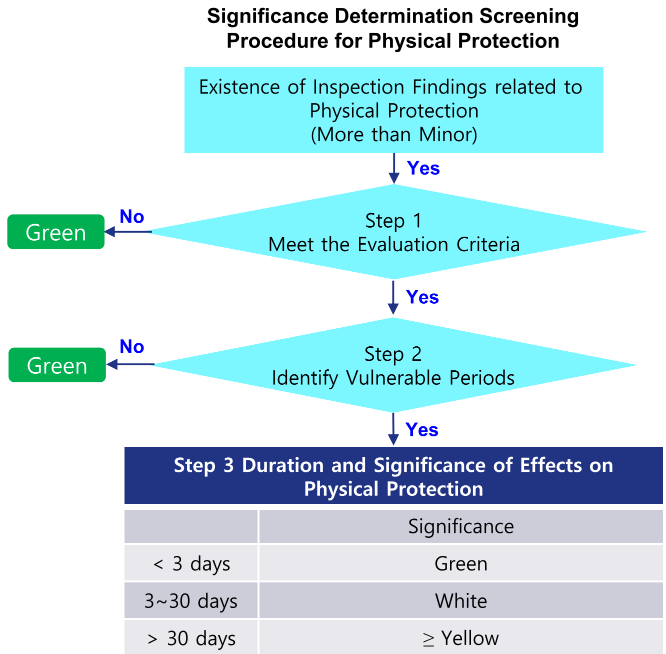

Fig. 7. Suggested the SDP for physical protection.

Table 4
Preliminary Korean action matrix for security oversight.

Comprehensive Evaluation Grade			Regulatory Response
Grade	PI, SDP	Common Elements	
1 (Great)	Green (All)	Improvement (+)	Baseline Inspection
2 (Good)	White (1–2)	Improvement (+)	Supplemental Inspection 1, Corrective Action Program (CAP)
3 (Normal)	White (3), or Yellow (1)	Normal (0)	Supplemental Inspection 2, Demand for self-inspection of degradation factors and establishment of improvement plans
4 (Degradation)	White (>3), or Red (1)	Degradation (−)	Supplemental Inspection 3, Special Inspection
5 (Unacceptable)	Yellow (>1), or Red (>1)	Degradation (−)	Order to Shutdown, Demand for establishment of comprehensive security assurance measures and comprehensive restart plan

determined.

The assumed scenario corresponds to the criteria #1 in Table 5 and the vulnerable period is more than 30 days. Therefore, the significance of effects on physical protection would be "yellow" in Step 3. One yellow corresponds to "Grade 3″ of the action matrix shown in Table 4. According to this action matrix, supplemental Inspection 2 is required and the enhanced inspections related to this degradation should be conducted. Also, the regulatory authority would monitor if degradation factors be self-inspected and improvement plans be established and implemented.

When the hypothetical event scenario is applied to the current regulatory system in Korea, it is expected that it is derived as an IF and requires a corrective action report from the licensee. If the corrective action taken by the licensee is deemed insufficient, additional measures are requested. However, if the corrective action is deemed appropriate, the IF is concluded, and the licensee is notified accordingly [40]. In contrast, by benchmarking the U.S. ROP, the significance of an IF and the regulatory response for it would be quantified and determined by the procedure. The comprehensive evaluation of safety-security interface and common elements related to the IF in the systematic method could minimize the subjectivity and prevent underestimation of the risk of the IF.

Hypothetical Event Scenario #2: Control and Accounting Special Nuclear Material (SNM)

The SNM was found in the protected area in 10 days after its lost notification.

- Recovery measures (located in approved location) were completed on the 10th day after the discovery of SNM loss.

Fig. 8 shows the Suggested the SDP for Control and Accounting SNM. This process also referenced the NRC's SDP Guide of security [38]. If any aspect of the findings relates to nuclear fuel (in any quantity) or more than 1 g of non-fuel SNM, it proceeds to Step 2. Since the recovery measures of SNM took more than 7 days, it proceeds to Step 3 [41]. Though it was considered as lost initially, it is recovered inside an approved location after 10 days. Therefore, it cannot be considered that the SNM has been lost or stolen, so the SDP level of this finding is determined to white.

One white corresponds to "Grade 2″ of the action matrix shown in Table 4. According to this action matrix, supplemental Inspection 1 is required. Corrective Action Program (CAP) which is a systematic process that operators use to identify, evaluate, prioritize, and correct issues, problems that could have an impact on plant performance is applied.

If the hypothetical incident scenario is applied to the current regulatory system in Korea, the IF related to control and accounting of nuclear materials should be investigated with respect to safeguards. Then, the special report should be submitted to IAEA and the special inspection should be initiated in accordance with the Comprehensive Safeguards Agreement between Korea and the IAEA. As the responsibility for the physical protection of nuclear materials primary lies with the country concerned, according to the "Regulations on Quantitative Control and Inspection of Specific Nuclear Material," the IF would be terminated after submitting a corrective action report [42].

The suggested regulatory oversight program would provide more objective and predictable regulatory responses commensurate with the risk significance. It is important to note that if the IF is evaluated only based on the security cornerstone, its significance could be underestimated. By conducting a comprehensive evaluation with consideration of safety and common elements, the significance for nuclear power plant performance could be assessed holistically and could correctly focus the limited regulatory resources on high-risk areas.

Table 5
The preliminary evaluation criteria for physical protection.

	The Evaluation Criteria for Physical Protection
1	**When the following cases were identified, the evaluation criteria for the passage of time were not utilized.** Case 1: There is no lock on the door to the protection area, and people can enter and exit freely.
	Case 2: The operator deliberately renders the physical protection system suspended or unusable.
	Case 3: In cases where unauthorized/undetected access is possible due to deterioration or inoperability of the physical protection system, The licensee is unable to ascertain the deterioration or inoperability of the physical protection system, or fails to implement prompt/appropriate corrective action despite prior confirmation.
2	**Issues that may be used for threats/destructive acts are not properly inspected, and issues that may be used for large-scale threats/destructive acts are brought into the protected area.**
3	**Suspicious vehicles without permission to enter are found in the protected area.**

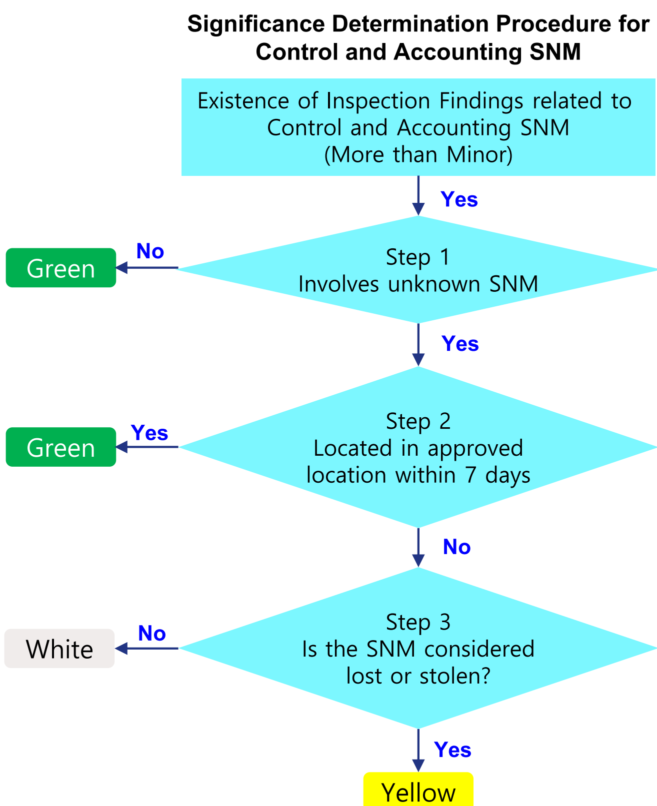

Fig. 8. Suggested the SDP for control and accounting SNM.

5. Conclusion

In this study, a preliminary security oversight framework has been established by reviewing the U.S. ROP and comparing it to the current Korean regulatory system. Since Korean NSSC is delegating technical reviews and inspections concerning safety to KINS and security to KINAC, the preliminary regulatory oversight framework focuses mainly on security. The proposed security oversight framework was applied to hypothetical security incident scenarios. Table 6 summarizes the event significance assessment and regulatory response determination under both the current Korean regulatory oversight system and the proposed security oversight framework.

In the case of the proposed security oversight framework, the reported inspection/operational performance results are evaluated by using SDP and PI, and an action matrix is utilized to execute regulatory actions proportionate to the significance. Details of SDP, PI, and action matrix will be established in further studies.

In Korea, there exists only an implicit procedure for assessing the significance of an IF. When identified as an IF, the process concludes with the submission of a corrective action report after implementing corrective actions, regardless of the IF's significance. As confirmed in the preliminary applicability presented in section 4.2, the suggested security regulatory oversight framework allows for a more explicit determination of regulatory actions in line with the significance of a given issue. The proposed security oversight program would offer a more objective and predictable regulatory approach and enhance regulatory efficiency by focusing efforts towards high-risk areas.

Table 6
Comparison of current Korean security oversight framework and the proposed comprehensive oversight framework.

	Current Security Oversight Framework	Comprehensive Security Oversight Framework (Newly suggested)
Regulatory oversight system applied in a security incident for an operating nuclear power plant	Regulations on Protective Inspections of Nuclear Facilities, etc. [43]	Suggested Korean Nuclear Facility Security Oversight Framework (Benchmarking US ROP)
Monitor	Periodic/Transport/Special Inspection	Baseline/Supplemental/Special Inspection, Operation Performance
Evaluation Method	1. Determine whether the incident is an IF, a recommendation, or a minor issue 2. In case of an IF, issue an IF table. 3. Require the corrective action. 4. Submit the corrective action report. 5. If the result of the action is appropriate, the case is closed.	PI/SDP (Green-White-Yellow-Red) Complementary perform an evaluation for the common elements
Response		• Comprehensive evaluation for SDP, PI, and common elements results by using an action matrix. • Application of a graded approach in regulations according to 5 grades

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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