Proposal for performance indicator in nuclear security in Korea through a review of domestic and overseas development cases

So Eun Shin [a*], Ha Neul Na [a], Youngsuk Bang [a], Heung Gyu Park [a], Yong Suk Lee [a],
[a]Future and Challenge Tech., Gyeonggi-do, Yongin-si, Giheung-gu, Yeongdeok-dong, Heungdeok1ro, 13
[*]Corresponding author: shin0811@fnctech.com

1. Introduction

The U.S. Nuclear Regulatory Commission (NRC) has been implemented the Reactor Oversight Process (ROP) since April, 2000 in order to inspect, measure, and assess the safety and security performance of operating commercial nuclear power plants and respond to any decline in their performance [1]. Many countries operating nuclear power plants have benchmarked their regulatory supervision with respect to NRC's ROP concept. In Korea, ROP for safety has been studied extensively; however, ROP for nuclear security has not received much attention. In a previous study, Shin et al., (2024) suggests the preliminary regulatory oversight framework of nuclear security in Korea [2]. The NRC ROP Framework development experience and current concept have been reviewed, applicability to domestic regulation has been analyzed, and Korean regulatory oversight framework of nuclear security has been conceptualized.

In NRC's ROP, nuclear power plants' performances have been measured and assessed based on objective Performance Indicators (PIs) reported by licensees and Inspection Findings (IFs) from NRC inspections. PI would be compared to the risk-informed thresholds to classify the plant performance condition into 4 stages, i.e., green, white, yellow, and red, and IFs would be evaluated by using the Significance Determination Process (SDP). Then, the NRC would determine an appropriate response based on the guidelines in an action matrix. PIs and their criteria could be the objective tool for measuring acceptable performance. Therefore, the PIs would be considered as a primary tool for measuring and assessing the performance. Inspection could be conducted for 1) areas not covered by PIs or where PIs could not fully cover the inspection area, 2) areas to verify the accuracy of a licensee's reports on performance indicators, and 3) a thorough review of the licensee's effectiveness in finding and resolving problems on its own.

In this study, the nuclear security PIs for Korean nuclear power plants have been proposed based on a review of domestic and overseas cases. Firstly, the systematic procedure for PI development has been established as shown in Fig. 1. According to the procedure, the previous PI development experiences have been analyzed, and the standards and requirements of PIs have been surveyed. Reviewing the inspection standards and procedures of Korea Institute of Nuclear Nonproliferation and Control (KINAC), the PI candidates have been proposed. Reflecting the KINAC expert opinions and the statistical analysis result of inspection findings, the set of PIs and its threshold have been established.

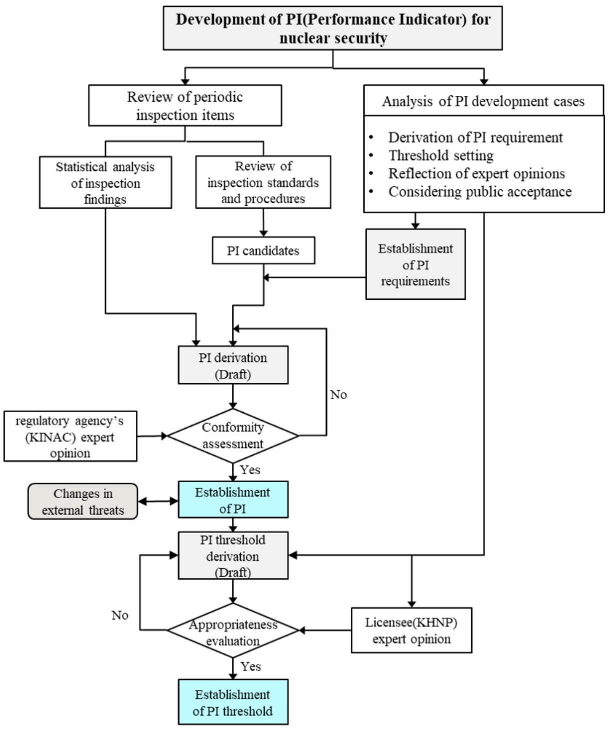

Fig. 1. Flowchart for PI development

2. Domestic and Overseas cases to develop PIs

In Korea, the safety performance indicator (SPI) system has been conducted since 1995, and the risk-informed PIs are publicly posted on the OPIS website [3]. The thresholds of PIs are primarily set by using Probabilistic Safety Assessment (PSA) results, and those not set by PSA are determined based on historical data, regulatory limits (regulatory requirements), and expert's judgment. For example, in the case of the Safety System Functional Failure (SSFF) indicator, the threshold was first adopted from one of the NRC's PIs, and then, as the operation data accumulated, the threshold value has been adjusted.

Note that the Safety Performance Indicators (SPIs) of the Korea Institute of Nuclear Safety (KINS) have been used only for reference and public disclosure.

Regulatory measures using the SPIs evaluation have not been implemented, and among the four classification levels of NRC PI (Green, White, Yellow, and Red), Orange (Warning) was chosen instead of Red (Unacceptable) in consideration of public acceptance. On the other hands, PIs for nuclear security have not been developed in Korea.

In the United States, U.S. NRC developed the requirements of PIs and initially listed about 80 PIs. Then, it had been reduced to 17 PIs, and finally 8 PIs have been selected through pilot research. The PI development history of NRC is summarized in **Table I**. The key developments for nuclear security PIs are as follows:

1. Four PIs for nuclear security as follows were suggested in SECY-99-007[4]
   · Protected Area Security Equipment Performance
   · Vital Area Security Equipment Performance
   · Personnel Screening Process Performance
   · Personnel Reliability Program Performance
2. Afterwards, in SECY-99-007A, the Vital Area Security Equipment Performance indicator was judged to be meaningless of evaluation and was removed from the PI evaluation targets.
3. Of the remaining three PIs, two PIs (Personnel Screening Process Performance and Personnel Reliability Program Performance) were also evaluated by the inspection program, so it was recommended to discontinue their PIs evaluation. As a result of checking Rev.6 of NEI 99-02 [5], these two PIs were deleted as it was revised from Rev.5 to Rev.6.
4. The PI for nuclear security is currently evaluated only for the Protected Area Security Equipment Performance, and detailed explanation and calculation method is described in NEI 99-02 (Rev.7).[6]

Table I. PI development history of NRC

SECY-02-0030(1986)	· Commission ordered development of PIs · About 80 PIs were listed · The properties that PIs must have derived · 17 PIs were developed and final 8 PIs were selected through pilot research · Developed PIs were revised to reflect opinion of industrial workers
SECY-99-007(1999)	· Program discontinued as new PIs are included in ROP · PIs used in ROP were described (The PIs selected for each cornerstone) · PIs that can be linked to PSA (setting thresholds using PSA results) were selected · Other PIs were selected based on data trend, technical specifications, or engineering judgment
	· If evaluation using PI is difficult or insufficient, evaluation is conducted by using inspection.
SECY-99-007A(1999)	· Some PIs were changed due to reflect various review opinions from stakeholders.
SECY-00-0049(2000)	· PIs were changed (The PI for containment building leakage was deleted)
SECY-04-0053(2004)	· MSPI (Mitigation System Performance Indicator) was preliminary applicated
SECY-05-0070(2005)	· Failure incidents applicated in MSPI were decided to include in SDP evaluation

Japan has adopted the ROP since 2020. According to PI guideline document in Japan [7], they referred to NEI 99-02 to present their performance indicators. Initially, they used the NRC's thresholds, but as performance data accumulated, they adjusted the thresholds to suit Japan's specific conditions.

3. Definition and Requirements of PIs for Nuclear Security

For the U.S. NRC, PI is defined as *a quantitative measure of a particular attribute of licensee performance that shows how well a plant is performing when measured against established thresholds*. PIs in order to enable the agency to arrive at objective conclusions about the licensee's safety performance. Licensees submit their data quarterly, the NRC regularly conducts inspections to verify the submittals and then uses its own inspection data plus the licensees' submittals to assess each plants' performance. [8] In other words, the performance of the power plant is evaluated by synthesizing the PI results and the inspection results, and the power plant is ultimately subject to regulatory measures by grade according to the action matrix. Meanwhile, specific information related to inspection findings and performance indicators associated with the security cornerstone will not be publicly available to ensure that security-related information is not provided to a possible adversary.

The Korean SPI system is used to monitor plant safety to investigate systems detrimental to reactor safety in order to enhance public confidence in the NPP operational safety and to follow the international trend in PIs. The SPI system is color coded by four levels (Green, Cyan, Yellow, and Orange), which is similar to the reactor oversight process (ROP) PIs from the NRC. [9] Korean Safety Performance Indicators (SPIs) is defined as *the data that evaluate the frequency of occurrence, the facility's operational status, and the radiation safety management of nuclear power plants*, and is an indicator that can provide a rough overview of the safety performance of nuclear power plants. The purposes of the indicator evaluation are as follows:

1. Confirm the safety performance of the nuclear power plant using quantified operational data
2. Identify trends in safety performance indicators
3. Provide the safety information of nuclear power plant for the public.

NRA in Japan also defined PIs are objective data on an operator's performance in each monitoring area (Reactor safety, Radiation safety, Safeguards). The NRA also evaluates the performance of power plants by synthesizing information obtained from the PIs and the results of the nuclear regulatory inspection. Similar to the NRC, regulatory measures are applied to the power plants according to the grade of the evaluation results through the Action Matrix.

Through the review described above, the definition of PIs for the nuclear security could be derived as follows. *Objective and quantitative measurements to evaluate the performance of nuclear power plants for nuclear security compared to the threshold*.

Table II presents the summary of reviewing requirements for PIs. Note that only requirements identified in multiple documents are listed.

The NRC staff began formal efforts to develop PIs in 1986 in response to direction from the Commission. The requirements presented during the initial PI development are described in **Table II**. The PI development program was discontinued once the new ROP PIs came into use [10]. Later, in the document SECY-99-007[4], which can be considered the basis for the development and improvement of the NRC ROP, the requirements for using ROP as a PI were presented.

In the NRA, operators report the safety status of their facilities as PI data, independent of inspections by nuclear inspectors. PI requirements are outlined in GI0006[11], the general guidance document for PI.

In 1995, the IAEA began a program to develop a set of international PIs to be used by plant operators to manage processes in the plant. The PIs were tested in a pilot program at four nuclear plants of different designs in different countries. Several documents were published as a result of this program, the latest being IAEA TECDOC 1141, Operational Safety PIs for Nuclear Power Plants.

Table II. Comparison of PI Requirements

United States		**JAPAN**	**IAEA (IAEA-TECDOC-1141) [13]**
NRC (SECY-86-317)[12]	**NRC (SECY-99-007)[4]**	**NRA (GI0006_r1)[11]**	
PIs must be related to nuclear power plant safety and regulatory performance.	The indicators must be valid and verifiable within the measurement areas.	From the perspective of ensuring and maintaining nuclear safety, the indicators should target monitoring areas related to nuclear facility safety, radiation safety, and the protection of specific nuclear materials (nuclear material safeguards).	Indicators must be directly related to safety. It must be possible to connect to the cause of the failure. It must be verifiable. The accuracy of data at each level must be quality controlled and verified.
-	Indicators must be objectively measurable.	Measurable data must be available.	The necessary data must be available or able to be generated.
The data must be accessible to the U.S. NRC in a timely manner.	-	Data must be available in a timely manner.	-
It should be developed to allow for clear differentiation of performance areas.	Thresholds should be set based on risk information.	Specific criteria must be established for performance evaluation.	The indicators must be quantifiable.
The data must be tamper-proof.	a reasonable sample of performance within the measurement areas should be provided.	-	Data should be difficult to falsify.
Indicators must be comparable across operators (nuclear power plants).	-	Indicators must be comparable between operators and, if possible, with overseas indicators.	-
Performance indicators must be independent.	-	Each indicator must be independent.	-
The performance indicators should be used as leading indicators (e.g., for forecasting future performance).	-	The indicators should be capable of identifying signs of performance degradation (deterioration) in the operator's safety assurance activities.	-

As the IAEA sets international nuclear safety standards that are designed to be applied to the operation of nuclear power plants in many countries around the world, the IAEA PI is not suitable for the NRC because the NRC PI needs to be more closely aligned with U.S. regulatory requirements and objectives.

Based on the documents presented in these requirements, requirements for Korean nuclear security PIs have been established as follows.

· Measurable data exists and cannot be manipulated (PI s that operators can objectively self-evaluate).

· It must be possible to set a threshold that allows performance evaluation. (Quantifiable)

· PIs must be independent. (The cause of the problem can be clearly analyzed, and the individual impact of each PI can be evaluated.)

· PIs must be comparable between power plants. (Contribution to effective operational management and performance improvement.)

· It must be possible to identify signs of deterioration in the nuclear security performance of the power plant. (Early warning of potential problems can be provided by analyzing long-term trends.)

· PI data must be available in a timely manner. (Problems occurring during operation should be quickly identified and responded to.)

4. Proposal for Performance Indicators in Nuclear Security in Korea

Initially, nuclear security PIs in Korea could be derived for each of the three elements of nuclear security (i.e., safeguards, physical protection, and cybersecurity). PI related to safeguards in terms of material accounting can be derived as the amount of uncounted nuclear material, but since the data on the amount of nuclear material for each nuclear facility is classified as security information managed by the IAEA, it cannot be disclosed. Therefore, PI for safeguard would not be appropriate regarding the PI requirements in Table II, i.e., data should be available in a timely manner. For cybersecurity, the degree of digitalization varies by type of reactors, which makes it difficult to compare nuclear power plants and violates PI requirement that comparisons should be possible by nuclear power plant. Therefore, the PIs for safeguards and cybersecurity would not be appropriate. In order to select PI related to physical protection, items that can be measured and quantified were first selected from inspectable areas for the physical protection. The object of PI evaluation was set by the unavailability of the physical protection system. And then, the equipment corresponding to the physical protection system was listed and grouped, and the following preliminary PIs were selected.

1. Intrusion Detection System (IDS) failure
2. Closed-circuit Television (CCTV) failure
3. Security screening equipment failure
4. Central control room and communication equipment failure

However, since the PI must be comparable between each power plant and also with overseas power plants, so 'Protected Area Security Equipment Performance' (the IDS and the CCTV unavailability) which is the same as the NRC and NRA, was ultimately determined as the PI for nuclear security in Korea.

NRC and NRA are using the same method for calculating PI using values reported for the previous four quarters, and calculated from four pieces of data as follows. Note that NRA adopted the PI and threshold of NRC initially, and later once the sufficient data collected, the threshold has been revised by reflecting the analysis results of statistical data and expert opinions.

1. CCTV compensatory hours: If CCTV cannot be used (due to poor quality or defect), the time required to assign a security officer to replace CCTV.
2. Intrusion Detection System (IDS) compensatory hours: If the IDS cannot be used (due to poor quality or defects), the time required to deploy a security officer to replace the IDS.
3. CCTV normalization factor: NRC and NRA use 400 and 30, respectively.
4. IDS normalization factor: NRC and NRA use 300 and 20, respectively.

The PI value is calculated by averaging the results of the IDS and CCTV unavailability indexes. [6]

$$IDS\ Unavailability\ Index = \frac{IDS\ Compensatory\ hours\ in\ the\ previous\ 4\ quarters}{IDS\ Normalization\ Factor\ \times 8760\ hrs}$$

$$CCTV\ Unavailability\ Index = \frac{CCTV\ Compensatory\ hours\ in\ the\ previous\ 4\ quarters}{CCTV\ Normalization\ Factor\ \times 8760\ hrs}$$

$$Indicator\ Value = \frac{IDS\ Unavailability\ Index + CCTV\ Unavailability\ Index}{2}$$

5. Conclusions

In this paper, domestic and overseas cases were reviewed to develop PI for nuclear security in Korea. Through cases, requirements and development direction for PI were established, and by referring to the lessons learned from the development process of leading countries such as the United States and Japan. The PIs that meet the requirements were derived from existing inspectable areas to suit domestic circumstances. The PI threshold should first be introduced by the NRC and then modified to suit domestic circumstances as related performance data accumulates in the future. Additionally, the PI will be updated and optimized according to the opinions of the operator (Korea Hydro & Nuclear Power), regulatory changes, and the emergence of new threats.

Based on the review of PI development and implementation, the following considerations are important for effectively developing and introducing nuclear security PIs in Korea.

- In terms of public acceptance, one of the PI classification levels should be set to “Orange (Warning)” instead of “Red (Unacceptable)”.
- Similar to the case with the NRA in Japan, it is considered reasonable to adopt the NRC's indicators and thresholds firstly, and then modify and supplement them to fit domestic conditions.
- PIs that meet the requirements of PIs should be derived from periodic inspection items.
- In nuclear security, since it is difficult to set thresholds based on PSA results, the indicators should be selected based on data trend, technical specifications, or engineering judgment.
- Ultimately, the indicators should be revised and supplemented by incorporating feedback from experts and operators.

The same PIs and evaluation methodologies as those used by leading countries' NRC and NRA are recommended to select to allow for comparisons between international power plants.

ACKNOWLEDGMENT

This work was supported by the Korea Foundation Of Nuclear Safety (KoFONS), funded by the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 2205014-0122-SB110).

REFERENCES

[1] NUREG-1649, Reactor Oversight Process, Rev. 6, U.S.NRC, 2016.
[2] Shin et al., A study on security oversight framework for Korean Nuclear Facility regulations, *Nuclear Engineering and Technology*, Volume 56, Issue 2, Pages 426-436, 2024.
[3] Operational Performance Information System for Nuclear Power Plant[OPIS], https://opis.kins.re.kr
[4] SECY-99-007, Recommendations for Reactor Oversight Process Improvements, United Stated Nuclear Regulatory Commission, 1999.
[5] NEI 99-02, Regulatory Assessment Performance Indicator Guideline, Nuclear Energy Institute, Revision 6, October 2009.
[6] NEI 99-02, Regulatory Assessment Performance Indicator Guideline, Nuclear Energy Institute, Revision 7, August 2013.
[7] ATENA 19-R01 (Rev.2), Guidelines for Safety Performance Indicators (PIs) for Use in Nuclear Regulatory Inspections, Atomic Energy Association, 2023.
[8] About Performance Indicators [NRC Website], 2024. https://www.nrc.gov/reactors/operating/oversight/pi-summary.html.
[9] Lee et al., A Feasibility Study on the Advanced Performance Indicator Concept for Improving KINS Safety Performance Indicators (SPI), Nuclear Engineering and Technology, Volume 43, Pages 105-132, 2011.
[10] SECY-02-0030, Summary Report on NRC’s Historical Efforts to Develop and Use Performance Indicators, United Stated Nuclear Regulatory Commission, 2002.
[11] GI0006, Guide for Performance Indicator, NRA
[12] SECY-86-317, Performance Indicator, United Stated Nuclear Regulatory Commission. 1986.
[13] IAEA-TECDOC-1141, Operational Safety Performance Indicators for Nuclear Power Plants, International Atomic Energy Agency, 2000.