

## Methodology for Selecting Periodic Safety Inspection Items to Reinforce the First Level of Defense-in-Depth

Jihan LIM, Jinyoung PARK, Younwon PARK, Heesung ANN  
BEES Inc., Suite L508, 193 Munji-ro, Yuseong, Daejeon, 34051 Republic of Korea  
Corresponding Author [wib565@bees.pro](mailto:wib565@bees.pro)

### 1. Introduction

Defense-in-Depth (DID) concept is the basic principle of nuclear safety and thus the importance has been reviewed through the Fukushima accident. Table 1 shows the objectives and definitions of each 5 different DID levels.

Table 1 Definition of DID [1]

Levels	Objectives
1	Prevention of abnormal operation and failures
2	Control of abnormal operation and detection of failures
3	Control of accidents within the design basis
4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents
5	Mitigation of radiological consequences of significant release of radioactive materials

Domestic regulatory periodic safety inspection (PSI) currently in Korea is being conducted by assuming that all Structures, Systems, and Components (SSCs) of nuclear power plants have the same importance in terms of safety and functional issues, and also focused on performance verification of the SSCs. In other words, DID concept has not been reflected and only single line defense concept has been applied in the regulatory PSI system.

Therefore, the objectives of this research were to replace the single line defense concept based regulatory PSI system to multi-level DID by developing two methodologies for selecting regulatory PSI items as followings;

- 1) To reflect the accident causes and recurrence prevention countermeasures
- 2) To prevent probabilistic safety analysis (PSA) Level 1 initiating events from occurring

### 2. Methodology for selecting regulatory PSI items to reflect the accident causes and recurrence prevention countermeasures

This methodology is to reinforce the PSI items ① by preventing the accidents occurred during operations, and ② by reflecting the accident causes and recurrence prevention countermeasures to PSI items.

#### 2.1 Detailed process of the methodology

The specific subsequence processes to reinforce PSI items using recurrence prevention countermeasure according to the methodology are as follows;

- 1) Investigate the event causes and preventive measures
  - Review the accident report [2] and grade evaluation report [3] precisely and deduct the preventive measures
- 2) Reanalyze the event causes and preventive measures
  - Convert the deduced preventive measures to original preventive measures which can be generally applied to the same reactor type
  - Deduct the primary or root causes of the accidents from detail contents which are written in accident report [2] and reanalyze the causes in the field of 3 categories (equipment, operator, and procedure)
- 3) Itemize the preventive measures
  - Subdivide the preventive measures into 3 levels (facility, item, and sub-item) to accord with objective of PSI.
  - Current PSI items have hierarchies which are consisted of 3 levels. Nuclear power plant is divided into 12 facilities, and each facility has a number of PSI items in systems and equipment and each PSI item has some sub items. [4] Thus, the designated facility, system and equipment for each preventive measure provide hierarchies which correspond to the original PSI system, and appoint sub-items allowing the reanalyzed results which contribute to the prevention of accidents practically.
- 4) Compare analysis of the original PSI items and itemize the preventive measures
  - Classify the items into 3 types (maintaining, supplementation and new) based on the itemized results for preventive measures, and compare the types with current PSI items of single line defense concept.
  - Classify whether the categorized types are overlapped with current PSI items or not.  
Note: 'Maintaining' is that the itemized preventive measures can be overlapped with

current PSI items. ‘Supplementation’ is that specific inspection sub-items are added. ‘New’ is that specific new inspection items are added.

- Compare any changes of each DID level before and after applying the itemized preventive measures in current PSI items.

Fig. 1 shows regulatory PSI guide for standard nuclear power plants and their relevant facilities, which were developed by Korea Institute of Nuclear Safety (KINS). The guide was referenced to develop the methodology.

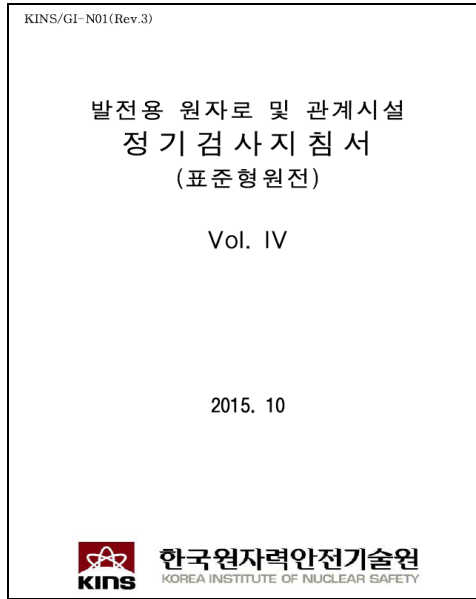


Fig. 1 Regulatory PSI guide for standard nuclear power plants and their relevant facilities [4]

## 2.2 Case studies

The case studies on 76 accidents, that were occurred and reported in OPR 1000 [5][6], were sampled among accidents registered in Nuclear Safety and Security Commission according to notification No. 2014-17 of Nuclear Safety and Security Commission. [7] Fig. 2 shows the “Accident and Failure Investigation Report” reported by KINS and the report was referenced to develop the methodology.

As investigation results, 52 items, 3 items and 17 items were categorized as ‘maintaining’, ‘supplementation’ and ‘new’ respectively. In addition, 10 items were deleted in the PSI items because they were not suitable for PSI items in this newly developed technology. Table 2 shows comparison between current and new PSI items. 20 items were newly added in DID Level 1 and other levels were the same.

### 3. Methodology for selecting PSI items to prevent PSA Level 1 initiating events

This methodology was developed so as to keep the nuclear reactor to its normal operation condition by preventing PSA initial events.

#### 3.1 Detailed process of the methodology

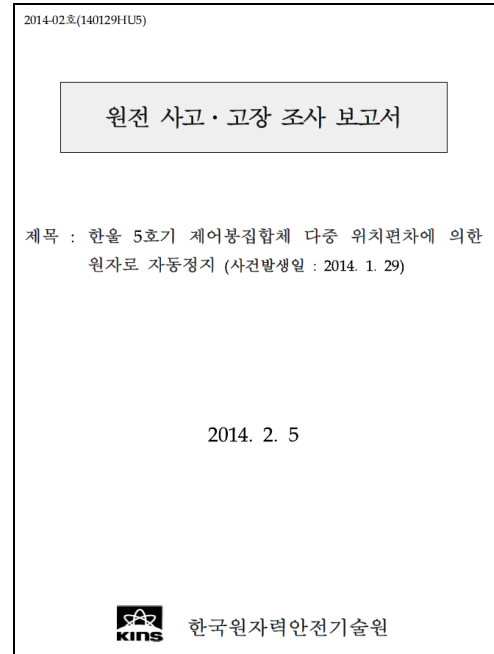


Fig. 2 Accident and Failure Investigation Report

Table 2 Comparison between current and new PSI items

DID level	Current PSI items		New PSI items by reflecting preventive measures	
	No of items	Ratio (%)	No of items	Ratio (%)
1	250	56.7	270	58.6
2	90	20.4	90	19.5
3	79	17.9	79	17.1
4	22	5.0	22	4.8
5	0	0	0	0
Sum.	441	100	461	100

The subsequence procedures studied were as following;

- 1) List preliminary initial event per each initial event
  - In the PSA report on OPR 1000, preliminary initial events were listed, classified and reviewed for setting the initial events. In this stage, preliminary initial events are re-organized for 16 initial events.
  - This process makes it possible to analyze causes and progression sequence of domestic accidents with initial events through the preliminary initial events.

- 2) Analyze the accident report
  - Deduce accident causes and sequences by analyzing accident report of OPR 1000. More than 2 causes can be deduced according to accident sequence.
- 3) Analyze the connection between preliminary initial events and accidents.
  - Confirm which accident can trigger PSA initial event by analyzing the connectivity on preliminary initial event and accidents.
- 4) Identify the connection between initial events and accidents by applying the preliminary initial event.
  - Preliminary initial events are sort of former phase of initial event. Thus, confirm initial events and accident connections by analyzing the connectivity on preliminary initial event and accident.
- 5) Analyze the connectivity on preventive measures which are connected with the initial events and current PSI items and also analyze the impact analysis on DID
  - Classify itemized preventive measures of accidents, which were connected with initial events of PSA, as one of categories as to 'maintaining', 'supplementation' and 'new'. These preventive measures are itemized by applying methodology for selecting regulatory PSI items to reflect the accident causes and recurrence prevention countermeasures.
  - Compare any changes of each DID level before and after applying the itemized preventive measures which were connected with initial events of PSA in current PSI item.

### 3.2 Case studies

The case studies on 76 accidents, that were occurred and reported in OPR 1000 [8], were sampled among accidents registered in Nuclear Safety and Security Commission according to notification No. 2014-17 of Nuclear Safety and Security Commission [7].

Firstly, we deduced 58 preliminary initial events about 16 initial events by reviewing the PSA report and conducted analysis of connectivity on prevention measures with the preliminary initial events. As a result, 18 out of 58 preliminary initial events were identified and 8 out of 16 initial events were found to be connected with specific accidents in 65 of 76 accidents. Secondly, we supplemented the current PSI items by applying the itemized preventive measures and their classification results.

Table 3 shows comparison between current and new PSI items. 12 items were newly added in DID Level 1 and other levels were the same.

Table 3 Comparison between current and new PSI items

DID level	Current PSI items		New PSI items by reflecting preventive measures	
	No of items	Ratio (%)	No of items	Ratio (%)
1	250	56.7	262	57.8
2	90	20.4	90	19.9
3	79	17.9	79	17.4
4	22	5.0	22	4.9
5	0	0	0	0
Sum	441	100	453	100

## 4. Conclusions

From the two methodology studies to reinforce the first level of DID on PSI items, followings were concluded;

- 1) In the Methodology for selecting regulatory PSI items to reflect the accident causes and recurrence prevention countermeasures, the ratio of PSI items corresponded to the DID level 1 was increased from 56.7 % to 58.6 %.
- 2) In the methodology for selecting regulatory PSI items to prevent PSA Level 1 initiating events, the ratio of PSI items corresponded to the DID level 1 was increased from 56.7 % to 57.8 %.
- 3) The rate of increase was relatively small because current PSI items were already focused in DID level 1 (56.7%).
- 4) These two methodologies could be utilized to reinforce the first level of DID of PSI since the operator can have more concern on managing the accident preventive measures and contribute to eliminate causes of accidents consequently.

## Acknowledgements

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