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Korea SDP Regulatory Process based on Regulatory PSA Model

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The regulatory PSA model which was named MPAS were developed. For the risk-Informed/performance based approach utilization, Korea significance determination process with Web-SEM and RYAN is under develop. Based on two management program, the risk assessment for pilot NPPs was conducted.

Keywords: SDP, Web-SEM, RYAN, MPAS.

1. Introduction

Recently, the public interest in nuclear safety has been heightened due to the serious accident at the Fukushima nuclear power plant, the site black out(SBO) at Kori Unit 1, and the forgery of quality documents for safety-related facilities. As a result, there is a need to comprehensively evaluate the safety level of nuclear power plants in the course of safety issue investigations, reactor shutdown incident investigations, and regular inspections, and reflect them in the regulatory decision-making process. The Korea Atomic Energy Research Institute (KAERI) and Korea Institute of Nuclear Safety (KINS) developed a PSA model (MPAS, Multi-purpose Probabilistic Analysis of Safety) for regulatory verification by representative operating nuclear power plant type (WH600, WH900, OPR1000, CANDU, FRAMATOME) through mid-to long-term research in the past (2011). These models had been updated with the latest reliability data (2018). And the rest of MPAS model in Korea have been recently developed (2022). At that time, KINS developed a Risk-Informed Periodic Inspection (RIPI) program that improved the existing periodic inspection target items by utilizing the PSA model for regulatory verification, and partially reflected the results in the periodic inspection guidelines.

The evaluation guidelines were organized, and a plan for realization was derived. In addition, a two-step significance determination process such as Web-Signification Evaluation Management Program (Web-SEM) and PC-based RYAN (Risk Analysis for ASP/SDP of NPP) that can conduct and manage risk assessments according to each role in the process from KINS field inspectors who perform safety regulation tasks to PSA departments, that is, experts who conduct more detailed assessments.

2. Development of PSA model for Regulatory Verification

Korea is making efforts to develop measures that can simultaneously improve the safety and settlement of NPP through various risk-Informed/performance based approach utilization projects, such as operational inspections using NPP risk-Informed/ performance-based approach, improvement of technical guidelines, and maintenance regulations. Basic work for NPP operation is in progress using risk-Informed/performance-based approach. In addition, it provides quantitative standards to objectively and clearly establish a comprehensive safety performance evaluation plan, confirms and verifies its implementation, and independently verifies licenses and permits for NPP operation (Risk Informed Application) using risk information being introduced by industries. The PSA model for NPP regulation verification, which is a means to secure independent regulatory review, was developed in consideration of the following.

- Industry PSA model review
- Selection of regulatory verification model specifications and requirements
- Development of risk-informed utilization verification model

The development of regulatory PSA models for representative NPPs of each reactor type has begun (2011). A PSA model with plant specific reliability data for regulatory verification for Korea power plants is being developed through detailed evaluation and verification of success criteria (2022).

2.1 Reliability Data

Reliability data is an important factor that directly affects PAS model results. It is necessary to apply the latest reliability data except for the reliability data applied differently according to the design characteristics of the reactor type. Reliability data is generally classified into five major categories as follows.

- Initiating Event Data
- Component Unavailability
- Unavailability due to Testing and Maintenance
- Common Cause Failure Data
- Special Event Data

In the following, the reliability data applied to the OPR1000 MPAS model for each reliability data presented above is described more details.

2.1.1 Initiating Event Data

Initiating event Data were classified into 3 criteria as follows and data were applied.

1) Rare event: For a rare event with a low probability of occurrence, general data is used as it is in consideration of the severity of the accident or the absence of operation experience data.

2) Events that have occurred: Korea operation experience data is used for events that have occurred at least once in the last 25 years.

3) Events that have not occurred but have occurred in general data: For accidents that have occurred in general data sources, domestic driving experience data is processed with general data and Bayesian

2.1.2 Unavailability Data

1) Component Unavailability data

The component unavailability data of the OPR1000 MPAS model is applied with the 2015 updated version of NUREG/CR-6928(2015) which is the state of the art data provided by the NRC.

2) Unavailability due to Testing and Maintenance

In order to reflect the operating experience, the history of unavailability of component due to test and maintenance for a certain period was investigated, and the unavailability due to test and maintenance was calculated according to the OPR1000 design specific characteristics.

3) Common Cause Failure Data

The CCF data of the OPR1000 MPAS model is applied with CCF Parameter Estimations 2015 (2016) which is the state of the art data provided by NRC, and α-Factor model was applied. The CCF data can be applied differently depending on the test method (sequential or non-sequential). The test method for the equipment considering the common cause failure was determined based on the results already analyzed by the NPP operator.

3. Risk assessment management model development

The significance determination process of Korea regulatory findings consists of two stages. In the first step, the inspector briefly assesses the plant risk using the Web-SEM, and if the result is less than White ($1x10^{-6}$/yr), the risk assessment is terminated. If the evaluation result is White or higher, the second step is to conduct a detailed analysis using RYAN, to seek the insight, or to point out findings for which PSA analysis is not possible or findings that require modification of the PSA model to determine whether or not to analyze in detail.

3.1 SDP evaluation procedure

Instead of adopting the SDP system of the US NRC as it is, a methodology was developed to confirm to the Korea regulatory inspection system. Considering the fact that Korea MPAS models for regulatory verification have only been developed up to level 1 of internal events, the scope of quantitative significance determination process was limited to internal events.

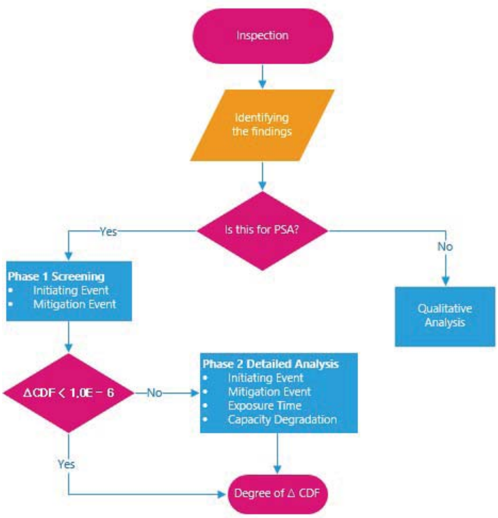

Fig. 1. Flow Chart for Korea Risk Assessment

3.1.1 Check basic inspection findings

- NPP and unit specific information
- Inspection information, inspection title-Inspection date/Issuance date/Request date/Completion date-Inspection content-References
- Information subject to findings - Inspection facility field/details - Target system and equipment
- Component malfunction information - Whether or not the target facility/system/device function is lost

3.1.2 Risk Classification Criteria

After calculating the increase and decrease with the reference core damage frequency (in the absence of equipment unavailability, the core damage frequency, test and maintenance effects are considered), the risk significance determination of the findings is evaluated based on the increase in the core damage frequency. Findings importance level was classified as follows by citing the NRC SDP level classification standard based on the increase in core damage frequency.

- Green level: 1e-6/yr < △CDF, Very low safety significance
- White grade: 1e-6/yr < △CDF < 1e-5/yr, Low to moderate safety significance
- Yellow level: 1e-5/yr < △CDF < 1e-4/yr, Substantial safety significance
- Red grade: 1e-4/yr < △CDF, High safety significance

3.1.3 Step 1: Screening by inspectors

In the Web-SEM, the inspector enters the core damage frequency evaluation stage using the MPAS model when the inspection findings are judged to be capable of PSA evaluation. In this step, the core damage frequency is calculated by simply clicking the system or component mapped to P&ID. Then it will be automatically transformed into the basic event or initiating event. If the result of the screening analysis is less than White, the evaluation is terminated as the finding does not significantly affect the safety of the power plant. No additional review or revision of the MPAS model is made at this stage. Risk classification are the same as those of the US NRC. If necessary, you can request a review from the specialized department.

3.1.4 Step 2: Detailed Assessment by the PSA Expert

In general, if the result of the first stage screening analysis is White or higher ($1x10^{-6}$/yr), the inspector requests the PSA specialized department to evaluate the finding, and the PSA expert performs the basic analysis regarding the finding as follows.

(i) Can finding trigger an initiating event?
(ii) Does it affect the function of the mitigating system?
(iii) Is it likely to trigger an initiating event and affect the function of the mitigating system at the same time?
(iv) How long did the found-probable state last?
(v) How much does the Finding state degrade the device's performance?

PSA experts review the analysis results of the screening analysis, derive considerations, or modify the PSA input for inspection findings not possible for PSA analysis as it is. When the basic analysis is completed, the PSA expert will perform the analysis using RYAN, a PC-based detailed evaluation program (2013) as follows.

Consideration of Exposure Time

The exposure time is calculated to reflect the failure period of the SSC identified during the event occurrence period to the RYAN analysis. Exposure time refers to the time from the time of the last normal operation, including maintenance time, to the point of failure.

Equipment Failure Modeling

In the PSA model, failure modes are based on basic events to reproduce structural, systemic, and component failures. The severity of failure events caused by component malfunctions is modeled according to NUREG/CR6823 by dividing them into (1) Catastrophic Failure, (2) Degraded Failure, and (3) Incipient Failures.

CCF Modeling

The failure of multiple components in the main system due to the failure of the auxiliary system supporting the main system was handled by directly connecting the auxiliary system fault tree without handling it as a CCF. Only CCFs between components with the same specifications in the same system were considered.

Initiating Events

Depending on the type of failure of the main system, the method of dealing with the initiating event can be divided into four types as follows.

- Case 1– Initiating event only. A PD (Performance Deficiency) causes an initiating event with subsequent reactor trip and the same PD does not cause other complications.
- Case 2– Initiating event and mutually exclusive SSC (SDP only). A PD causes an initiating event with subsequent reactor trip and the same PD causes an observed unavailability of a SSC that is mutually exclusive of the initiating event.
- Case 3– Initiating event and mutually inclusive SSC. A PD causes an initiating event with subsequent reactor trip and the same PD causes an observed unavailability of a SSC that is mutually inclusive of the initiating event.
- Case 4– SSC unavailability increases the initiating event frequency. A PD results in a degraded or unavailable SSC that could increase the frequency of an initiating event; however, no reactor trip occurred (e.g., failure of a single service water pump).

3.2 SDP evaluation Module

3.2.1 Web-SEM SDP Evaluation Module

Web-SEM, the first-stage risk assessment program, consists of an information provision system for evaluation and a module that transmits input information to AIMS program that quantitatively evaluates the MPAS model, and helps execution. In other words, it converts the accident scenario into a minimal cutsets so that the event tree and fault tree of the MPAS model can be quantified through the AIMS program, making it possible to calculate using the reliability data of each basic event. The risk analysis history including the reliability data of the MPAS model created by AIMS is stored in the database in the form of a minimal cutsets. When the user modifies and inputs the initial event or equipment unavailability designated for risk assessment to suit the purpose of analysis, the basic reliability data of the generated accident sequences database is updated and the CCDP value is calculated.

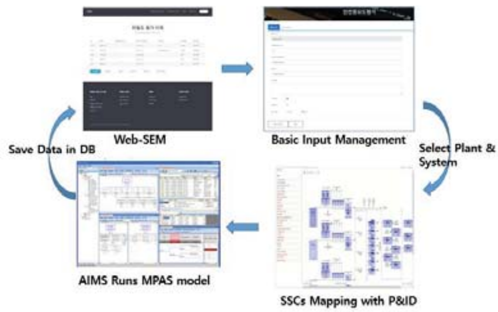

Fig. 2. Web-SEM Module Relationship Diagram

The operating principle of the SDP evaluation management module of the screening phase with Web-SEM is as follows.

- The user inputs the evaluation into Web-SEM.
- Web-SEM runs AIMS* according to the user's command to perform the evaluation, and WinSIMA delivers the results to Web-SEM.
- Web-SEM constructs an AIMS input file using the data and input data stored in the internal DB according to user input and transmits it to WinSIMA.
- When the transfer is complete, WinSIMA issues an execution command to AIMS.
- When the AIMS execution is completed and the PSA calculation result is confirmed, WinSIMA informs Web-SEM that the calculation has been completed, and Web-SEM collects the result, inputs it into the DB, and processes it together with the previously collected AIMS calculation result to create new statistical data.
- The generated data is displayed on the user's web browser screen according to the user's request.

* As a program that runs the MPAS model for regulatory verification, Web-SEM is installed on the server where AIMS is installed.

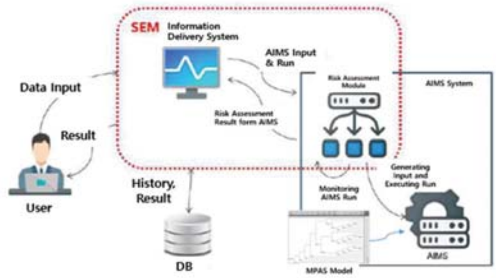

Fig. 3. Configuration of Web-SEM

3.3 PC-based RYAN Evaluation Module

The second-phase detailed SDP evaluation module was developed to be operated based on a PC (Fig. 4), it is possible to select whether to perform a new evaluation or review the existing evaluation results.

PC-based RYAN performs evaluation based on the MPAS model in the same way as Web-SEM. At this time, when basic evaluation data is entered into RYAN, a command is transmitted to AIMS to analyze the accident sequences and details of the MPAS model. The evaluation proceeds using the reliability data. However, since the second phase risk assessment is performed by a PSA expert, inputs were developed to enable detailed evaluation through more diverse inputs such as initiating event, type of mitigation system, exposure time, and component performance degradation coefficient.

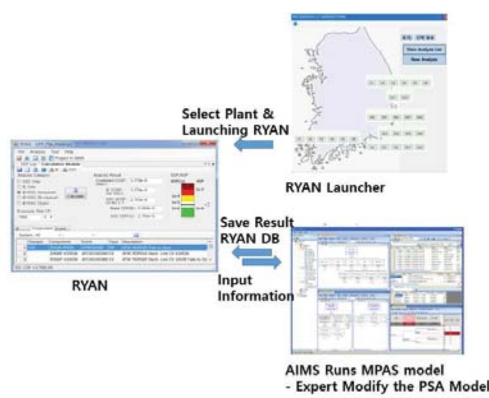

Fig. 4. RYAN Module Relationship Diagram

4. Pilot evaluation

The purpose of the periodic inspection indication/recommendation importance evaluation (SDP) is to help regulatory decision-making by providing quantitative risk information on indications issued in the course of regular inspections performed during each planned preventive maintenance in accordance with the Enforcement Decree of the Nuclear Safety Act. In order to select the target for pilot application, the findings pointed out in all regular inspection reports issued between 2010 and 2017 were collected. A total of 420 cases were issued during the period, and among them, 113 cases were derived that could be considered to have an impact on the basic event or initial event modeled in the PSA. Fifty-seven candidates were derived, targeting only the intellectual matters that affect the first-stage total power internal events. Among the 57 candidates derived, 24 cases issued for standard NPPs in Korea and clearly revealing the contents of safety performance deterioration through the inspection report table were selected as final demonstration subjects. Among the cases selected for SDP evaluation, the comprehensive results of 24 cases excluding cases that could not be evaluated due to limitations of the current model are as follows. In the case of the SDP evaluation, 38% of the total was screened out. The reason for selective removal is that the content of the complaint was evaluated as having nothing to do with performance degradation or that performance degradation did not actually occur (75%), or when the device related to the complaint was not reflected in the MPAS model (25%). As a result of reviewing the cases that were not screened out, as a result of SEM evaluation, 21% of the total was evaluated as Green, 0% of the total were evaluated as White, 17% of the total were evaluated as Yellow, and 25% of the total were evaluated as Red. In the case of RYAN, 32% of the total was evaluated as Green, 9% of the total was evaluated as White, 9% of the total were evaluated as Yellow, and 9% of the total were evaluated as Red. Since SEM makes very conservative assumptions (for example, exposure time of 1 year), it showed more conservative results than RYAN's results considering realistic situations using the information that can be obtained. In particular, in the case of cases evaluated as red in SEM but rated as a lower level in RYAN, the main reasons for the difference in results were the application of realistic exposure time and modeling as an increase in the probability of failure instead of unavailability of the component. However, the reliability data of RYAN considered in the Korea SDP evaluation assumes a component failure with a very conservative probability of 50% for devices where performance degradation is assumed, and since the RYAN evaluation result is conservative, additional research is under conducted on the application of the reliability data.

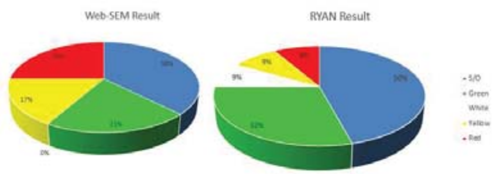

Fig. 5. Risk Assessment Result for Pilot NPP

5. Conclusion

In order to improve public understanding, it is necessary to quantitatively evaluate the possible impact on the public of possible accidents /accidents at NPs and the impact of regulatory activities on improving the safety of NPPs, and to reflect risk information in regulatory decision-making. To this end, KINS has made efforts to develop a PSA model for regulatory verification and implement the risk information utilization regulation, but it is being used limitedly in actual regulatory work.

Web-SEM quantifies the initiating event subject to analysis as 1.0, other initiating events as 0.0, SSC unavailability as True, and exposure time as 1 year (basic assumption). PSA expert using PC-based RYAN reviews operating events and inspection findings to derive information necessary for detailed evaluation, review MPAS model assumptions, event tree, fault tree, initiating event frequency, success criteria, component reliability data, CCF data Since the evaluation can be performed using the MPAS model suitable for the current state of the NPPs. And it is necessary to review the failure rate, human error probability, and design changes, more realistic and accurate results are derived from the Web-SEM analysis results.

The Korea SDP methodology and support system developed through this study can perform quantitative safety criticality evaluation on operation incidents and inspection findings that occurred during NPP operation without causing major changes within the Korea regulatory system, and more analysis. It is believed that the improvements necessary to secure the validity of the methodology, quantitative risk scale, and support system developed through experience can be derived.

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