An Implementation Strategy of Low Power Shutdown PSA for KHNP NPPs

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Abstract: Rightly after the Fukushima accidents, the Korean Regulatory Agency with the support from a group of academic and research experts evaluated the safety of Korean nuclear power plants including plants on construction. The expert group particularly focused on any possible design vulnerabilities in view of ultimate heat sinks and power sources considering external hazards such as seismic, flood or complex initiated events. They identified several common or plant-wise improvement factors and elicited 49 post-action items as near term Fukushima accident measures. One of the measures is to develop SAMG (Severe Accident Management Guideline) during LPSD (Low Power and Shutdown) operation in addition to the existing SAMG on the full power operation. At first, KHNP (Korea Hydro & Nuclear Power) decided to develop the LPSD PSA (Probabilistic Safety Assessment) models to increase the quality of LPSD SAMG. To get a technical adequacy, KHNP decided to revise the full spectrum of existing PSA models including full power, external or level 2 PSA incorporating up-to-date reliability data and methodologies. This paper presents an implementation strategy of developing LPSD PSA models including the status of upgrading full power PSA models at the end of 2013.

Keywords: LPSD PSA, PSA Technical Adequacy, SAMG, CCF, HRA

1. INTRODUCTION

Rightly after the Fukushima accidents, the Korean Regulatory Agency with the support from a group of academic and research experts evaluated the safety of Korean nuclear power plants including plants on construction. The expert group particularly focused on any possible design vulnerabilities in view of ultimate heat sinks and power sources considering external hazards such as seismic, flood or complex initiated events. They identified several common or plant-wise improvement factors and elicited 49 post-action items as near term Fukushima accident measures.

One of the measures is to develop SAMG during LPSD operation in addition to the existing SAMG on the full power operation. At first, KHNP decided to develop the LPSD PSA models to increase the quality of LPSD SAMG. To get a technical adequacy, KHNP decided to revise the full spectrum of existing PSA models including full power, external or level 2 PSA incorporating up-to-date reliability data and methodologies.

KHNP had performed two Peer Reviews by NEI (Nuclear Energy Institute) method[1] and ASME PRA Standard[2] for two types of plants. Because the comments and insights from the peer reviews were not fully reflected on all of the PSA models yet, we try to apply the major results of the peer reviews in this project. Moreover, we standardize the methodology of CCF (Common Cause Failure) and HRA (Human Reliability Analysis) which are the most influential factors to risk measures of NPPs.

LPSD PSA models will be developed for all the operating plants based on standard outage maintenance practices and Plant Operational Status (POS). Level 2 LPSD PSA models will also be developed for two types of pilot plants, one for PWR and the other for PHWR (Pressurized Heavy Water Reactor). In addition, we decide to newly develop the models for SFP (Spent Fuel Pool) as one of lessons learned from the Fukushima accidents.

Because KHNP had the fire PSA models based on only EPRI FIVE (Fire Induced Vulnerability Evaluation)[3] methodology guided by IPEEE (Individual Plant External Event Evaluation) requirements, we decide to apply the new methodology of NUREG/CR-6850[4] to fire PSA models of a pilot plant. Through this project, we expect to improve the quality of PSA models and to set a fundament of risk management for all operating status. Also, we anticipate providing the major input data and insights to SAMG.

2. IMPLEMENTATION STRATEGY OF LOW POWER SHUTDOWN PSA

The quality of LPSD PSA models is closely related to that of full power PSA models. Figure 1 shows the development and implementation strategies of LPSD PSA based on the full power PSA models.

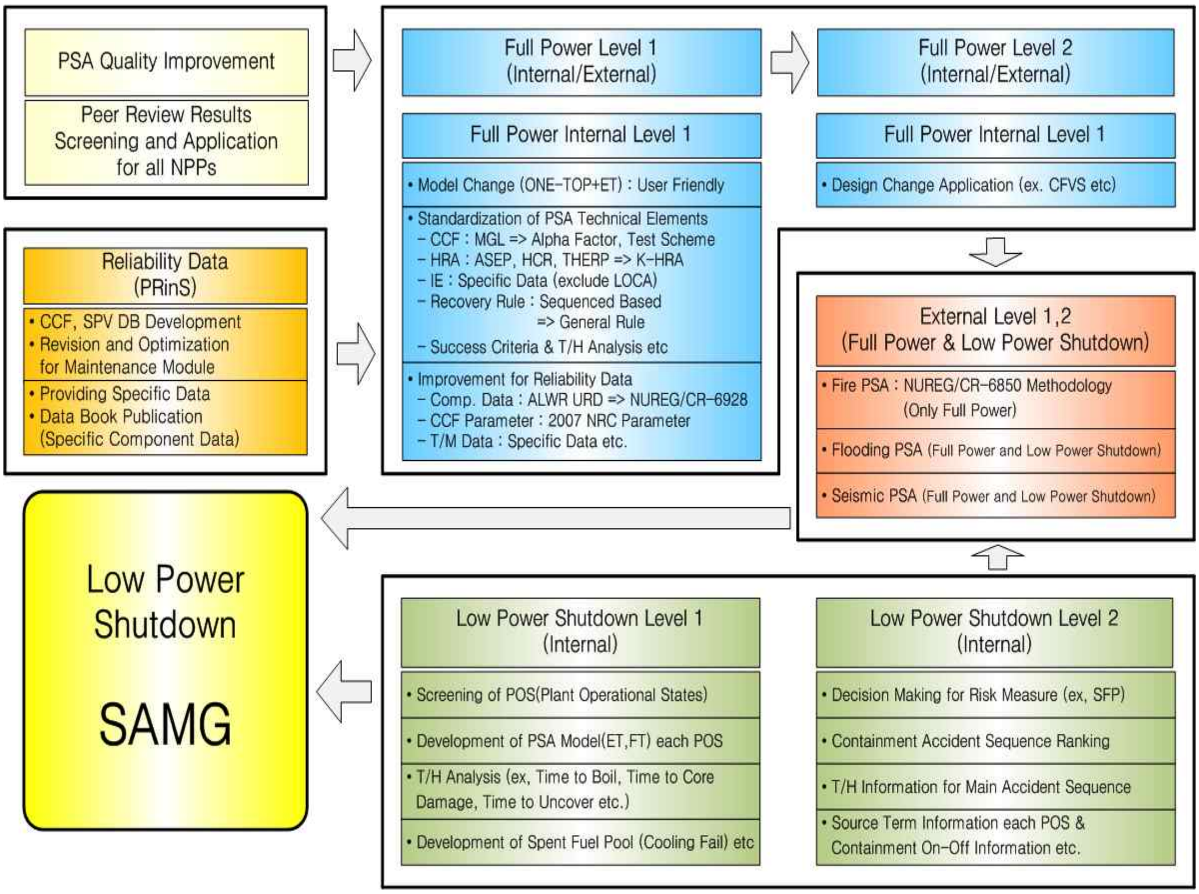

Figure 1. Implementation Strategy of Full spectrum Risk Analysis for KHNP NPPs

To ensure the quality of full power PSA models, the insights of the peer reviews are applied and the reliability data are updated with KHNP operating experiences spanning all commercial operation periods and combined with the latest generic data. The frequency of initiating events is based on country-specific empirical data by preference, and the rests applied the values provided by latest NUREG/CR-6928[5]. The generic component reliability database also used NUREG/CR-6928 instead of EPRI ALWR URD (Advanced Light Water Reactor Utility Requirement Document) [6] database. And, we perform more cases of thermal hydraulic analyses, review the existing MAAP parameter files and, verify the results of MAAP by comparing those of MARS (Multi-dimensional Analysis of Reactor Safety) [7] for main accident sequences such as feed and bleed scenarios.

As for the standardization of PSA technical elements in Figure 1, CCF and HRA have the most significant impacts on the risk measures. KHNP has used MGL (Multiple Greek Letter) parameter method for CCF analysis. However, we decided to apply Alpha Factor method because of convenience in uncertainty analysis and combining the latest international research results or data for CCF events. Also, we surveyed the test schemes of components which need modeling as CCF events to develop domestic-specific CCF Database. In case of HRA, we apply K-HRA (Korean Standard HRA)[8] methodology, which was developed and validated in 2005 based on ASEP (Accident Sequence Evaluation Program)[9] and THERP (Technique for Human Error Rate Prediction)[10] methodology. We shall develop LPSA PSA models based on the full power PSA models upgraded with the technical adequacy.

3. STANDARDIZATION AND QUALITY IMPROVEMENT OF PSA ELEMENTS

Through performing living PSA and configuration risk management, many issues related to standardization were raised for the application and management of PSA models. So, we need to standardize and manage the technical elements of PSA by applying consistent guidelines and methodologies. It is also necessary to increase the quality by applying the results and the insights from the previous peer reviews. And, we update component reliability data by using the latest operating experiences.

3.1 Application of Peer Review Findings and Model Standardization

Domestic and foreign experts performed the official peer reviews for two PSA models. KHNP has the various types of reactors such as KSNP (Korea Standard Nuclear Power), Westinghouse, Framatome, and CANDU typed reactor. Therefore, we should consider the characteristics according to reactor type when applying peer review results to other reactor types. We summarized the findings and observations from two peer reviews, 198 lists from WH type and 50 lists from KSNP. The following are the main findings and observations. The first is about using the latest reliability data or not. So, we updated IE (Initiating Event) frequencies as well as component failure data based on new generic data (NUREG/CR-6928). The second is about applying the latest references as for RCP seal modelling, SGTR modelling, and so on. It also requires that the more T/H analyses should be performed in detail to increase the quality on HRA. Considering the test schemes is recommended when estimating CCF factors. Lastly, the documents shall be reinforced such as calculating sheets and description about assumptions.

The standardization of PSA models has a close relationship with the living PSA and configuration risk management. We should maintain RIMS (RIsk Monitoring System) models as well as PSA models. PSA models are different from RIMS models in assumptions, modeling method, operating configurations to be modeled, the structures of models, and so on. Thus, integrated management is needed for smooth promotion of living PSA and RIA (Risk-Informed Application). Figure 2 shows the current status of configuration and the direction of standardization of PSA models and RIMS models.

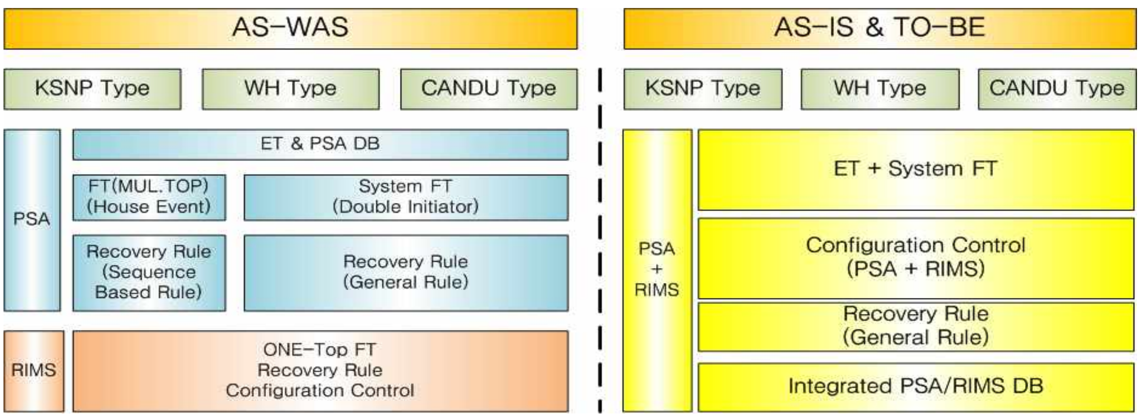

Figure 2. Integration scheme of PSA & Risk monitoring system model

3.2 Standardization of PSA Technical Elements

In this project, we emphasized the standardization of CCF, HRA, and Initiating Events. First, CCF is one of the most important factors on risk measures. We used MGL parameter method as CCF analysis assuming only staggered test scheme. Assuming staggered tests only is underestimating the risk as a factor of redundancy multiplication in CCF modeling. So, we shall consider test schemes and use Alpha Factor method which can easily analyze uncertainty and estimate parameters. In addition, we developed CCF Calculator to estimate specific CCF parameter and will develop CCF DB Module which is interchangeable with ICDE (International CCF Data Exchange) database. Figure 3 shows the user interfaces of CCF Calculator. Also, designing of database structure to estimate CCF parameter in conjunction with ERP (Enterprise Resource Planning) system is scheduled because the ERP has insufficient information of raw data and contents requested by ICDE Report Form.

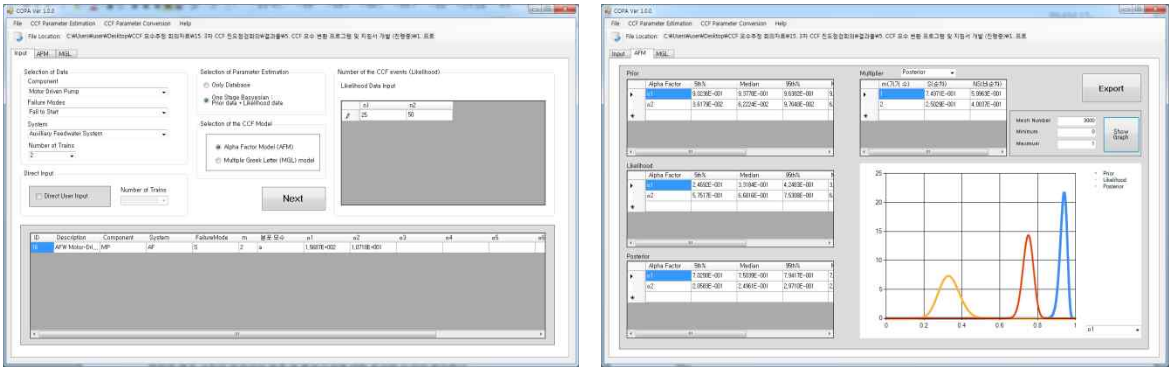
Figure 3. Calculator of CCF Parameter Estimation

Several HRA methodologies such as ASEP, THERP and HCR (Human Cognitive Reliability) are currently applied to PSA models and large difference existed by performing institutes and analysts. Technical issues are insufficiency of plant-specific analysis, lack of consistent quantification procedure, and documentation of bases. We applied standardized HRA methodology (K-HRA) consistently, because it gives detailed instruction to maintain the consistency of analysis through consensus among HRA experts in Korea. K-HRA methodology was validated through participation in various programs of NRC and OECD/NEA in order to secure the international confidences.

Initiating events analysis methodology and data are also applied to the each project-wise model. The emphasizing point is documentation on classification bases, grouping of initiating events, and FMEA (Failure Mode and Effect Analysis) on supporting systems. In case of initiating event frequencies, we used new data from NUREG/CR-6928 for LOCA (Loss of Coolant Accident) group and domestic empirical data for transient group.

3.3 Application for Newly Generic Data

Component reliability data of domestic nuclear power plants has been used with the generic data generated from ALWR URD. It does not only reflect latest component failure characteristics bus also does not match with PSA bases reflecting the “As-is, As-operated” status. Therefore, we used NUREG/CR-6928 data which is generated from the recent operating power plants. The database has following major differences as compared to conventional ALWR URD data; 1) Provides normal running, normal standby data for 9 major components 2) Provides fail to load and run data for normal standby system 3) Demand failure data is beta distribution and running failure data is gamma distribution.

PRinS (Plant Reliability Data Information System)[11], developed for the Korean specific database generation, also needed to be update by revision of PSA model. We reviewed, compared and evaluated the newly revised PSA model and database to apply NUREG/CR-6928. Also, we validated the maintenance history analysis results generated from systematic data gathering guidelines. These results were utilized to analyze the trends of component failure and to supplement design through publication of specific data book. Table 1 shows and compares the generic data of major components and latest specific data. Specific data is produced from failure history of domestic 16 PWRs. The key finding at this time is the Korean specific failure rate of DG and AFW pump is lowered, but, that of fans and chillers is increased.

Table 1. Reliability Data Trend for key Components

Component/Failure Mode	EPRI URD	KSNP	NUREG/CR-6928	New Data
DG FTR	2.40E-03	2.40E-03	8.48E-05	8.48E-05
DG FTS	1.40E-02	2.00E-02	7.43E-03	9.73E-03
AF MDP FTS	3.00E-03	7.07E-03	1.85E-03	1.87E-03
AF TDP FTS	1.50E-02	1.78E-02	9.52E-03	2.54E-03
ESW Pump FTS	2.40E-03	1.06E-02	2.23E-03	2.32E-03
HPSI Pump FTS	1.00E-03	5.66E-04	1.85E-03	1.87E-03
MOV FTS	4.00E-03	1.39E-03	1.07E-03	1.40E-03
Circuit Breaker FTS	3.00E-04	3.00E-04	2.55E-03	7.35E-04
Fan FTS	6.00E-04	6.00E-04	1.79E-03	1.48E-03

3.4 Development of LPSD PSA Model

KHNP evaluated Mid-Loop Operation of LPSD PSA[12] for two pilot plants in early 2000. After the Fukushima accidents, development of LPSD SAMG is under way and LPSD PSA should provide the plant characteristic information in developing specific LPSD SAMG. Thus we will develop internal and external LPSD Level 1 PSA model. In addition we have plans to analyze Fuel Damage Frequency due to loss of cooling in Spent Fuel Pool and to start LPSD Level 2 PSA for the first time in Korea. In LPSD Level 2 PSA, we will analyze containment accident sequence by POS, source term, and fuel building release sequences in case of loss of spent fuel pool cooling. The outputs of LPSD Level 2 PSA will be primarily utilized to develop LPSD Specific SAMG.

4. CONCLUSION

After the Fukushima accident, the significance of severe accident and PSA came to the public as well as to the industry itself. Among 50 safety-related plans, in this paper, we suggest the implementation strategies to provide major input data of LPSD SAMG through development of LPSD PSA. Also, we suggest the standardization of full-power PSA technical elements and methodologies which are the basis of development of LPSD PSA, solutions to problem of current PSA model for living PSA, application of new data. Above this, we will use NUREG/CR-6850 as a new methodology for pilot plants in case of fire risk, assess risk due to loss of Spent Fuel Pool cooling and revise the thermal-hydraulic analyses results. We established the implementation strategy for the purpose of improving safety of plants and quality of PSA.

This scheme will be an important opportunity to upgrade the PSA level in Korea. The results of LPSD PSA implementation strategy will contribute to conforming of regulatory requirement and legislation of PSA which requests the application of new methodology, RIA, PSA quality, performing optimized Living PSA through user-friendly PSA model and established long-term Roadmap.

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