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Use of PSA in the Conceptual Design Phase of an Innovative PWR

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1. Introduction

A conceptual design of a new innovative PWR (pressurized water reactor) is being developed in a project for "A study on the basic requirements of the premium NPP (nuclear power plant) and the strategies for innovative safety enhancement". In this paper, the innovative PWR represents a reactor developed in the project.

In the design stage of an NPP, a PSA (probabilistic safety assessment) can be used to estimate the overall safety of the plant and confirm whether the safety target is achieved or not. It can also be used to find the weakness in the design and derive the optimal design.

This paper describes the PSA activity performed for the development of the innovative PWR concept.

2. Concept of New Innovative Reactor

PSA models are developed for two types of NPPs in this study. One is for a NPP composed of active safety systems with PAFS (passive auxiliary feedwater system) and the other is for the innovative PWR composed of full passive and active safety systems.

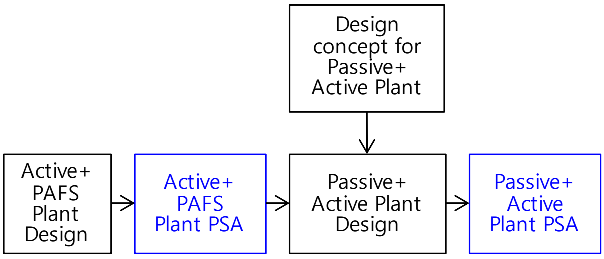

Fig.1. PSA models for 2 types of PWRs

In the innovative PWR, the passive safety systems are used as a final means for critical safety functions (CSF) and the active safety systems are used as supporting means. The overall safety concept of the innovative PWR is illustrated in Table 1. Passive safety systems perform the safety functions for the decay heat removal and inventory makeup without active systems. Active safety systems also fulfill the safety functions. Thus, the innovative PWR has full diversity for safety functions. Each passive and active system consists of 2 x 100% trains.

Table 1. Passive and active safety systems for CSFs

CSF	Passive	Active
Decay heat removal	− PAFS − PCCS Cooling (for LOCA)	− AFWS − SCS
Inventory makeup	− High pressure : HP SIT or CMT − Medium pressure : SIT − Low pressure : ADS + IRWST gravity injection	− High pressure : POSRV + SCS − Medium pressure : SIT − Low pressure : SCS

The safety concept for a PWR with active safety systems and PAFS can be found in the APR+ document [1], where each active system consists of 4 x 100% trains and PAFS consists of 2 x 100% trains.

3. Development of PSA Model

PSA models are developed based on the design concept for 2 types of PWRs. Because the innovative PWR has no detail design yet, the design features for the safety systems are based on the APR+ design. The human error and failure of the I&C are not considered because the main focus of the project is given to the hardware design of the safety systems for decay heat removal and inventory makeup at this moment. The basic assumptions and modeling strategy used in the PSA are described in Table 2.

Table 2. Major assumptions used in PSA

Area	Assumptions
System design	No detail system design. Based on APR+ design incorporating the design concept of the innovative PWR.
Initiating events	Use the initiating events in APR+ PSA. Add ADS spurious open & DVI LOCA for the innovative PWR. Exclude Reactor vessel rupture & Interfacing systems LOCA.
Accident scenario	Simplify the scenario based on CSF. Assume each train has 100% capacity.
System fault tree	Exclude the minor components in CDF. Exclude some systems (ESFAS, Aux charging pump). Treat some systems as an undeveloped event (Startup FW pump, IA, RPS).

Reliability data	IE : APR+ data. Component data : Shinkori 1& 2 PSA. CCF : NRC 2005 Data. HRA : not considered.
PSA S/W	Use AIMS-PSA [2] & FTREX [3].

4. Use of PSA in Design Process

During the design process, the PSA is repeated until the goal is satisfied: prepare the design concept, perform the PSA, review the PSA result, and check if the goal is satisfied. If not, find a way to improve the safety and repeat the process. It follows a kind of risk-informed design process.

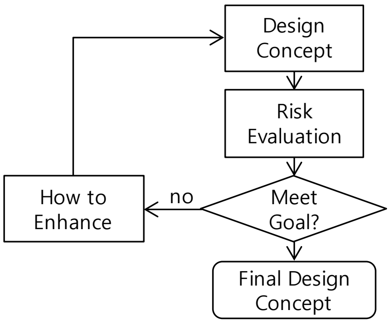

Fig. 2. Iterative procedure to use PSA in design of a plant

Fig 3 represents the PSA results performed for various design concepts of the innovative PWR.

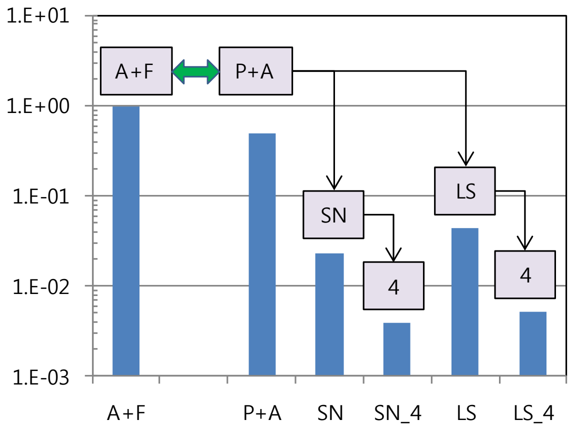

Fig. 3. CDF ratio for various design concepts

The CDF (core damage frequency) for the innovative PWR (case P+A) is evaluated as 50% of the CDF for the active plant with PAFS (case A+F). The safety is not improved as much as expected, even though the full passive features are introduced. The bottle neck to reduce the CDF is the failure of a recirculation sump valve that results in a failure of both passive and active features for a long-term inventory makeup after the initial inventory makeup succeeds in the case of a LOCA event. Note that the active plant with PAFS is designed to continue the inventory makeup without a sump recirculation valve; otherwise, it can be a large contributor to the CDF.

Two ideas are considered to prevent the failure of both a passive and active inventory makeup due to sump recirculation failure. One is a design concept to enable the continuous inventory makeup through the IRWST without a sump recirculation valve (case SN). The other is to use the shutdown cooling system for a long-term decay heat removal without further inventory makeup through the sump, if the initial inventory makeup and decay heat removal are achieved so as to meet the shutdown cooling entry condition (case LS). A PSA analysis shows that any one feature can reduce the CDF by more than 10 times.

If any one feature is introduced, the major contributor to a CDF is a failure of 1 train in the case of a DVI LOCA, because the DVI LOCA results in unavailability of 1 out of 2 trains for both a passive and active inventory makeup. The introduction of 4 train shutdown cooling system can reduce the CDF greatly (case 4) against this event. Sensitivity analyses are performed for the other design alternatives, but those do not reduce the CDF greatly.

5. Conclusions

This study was performed to use a PSA in the design of an innovative PWR for the purpose of deriving the optimal design concept with a high level of safety. In the design of an innovative PWR with passive and active systems, it is important to remove any cause resulting in simultaneous failures of passive and active features and to guarantee the redundancy of each system from the PSA point of view. The PSA can model the safety features comprehensively and find any weakness in the design. The PSA is a useful tool to enhance the safety of a plant at the design stage.

Acknowledgement

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