The Study on Level 1 Internal PSA of Innovative Passive Reactor Conceptual Design

Kyungsoo Lee [a*], Sujin Park [a], Pyungtark Park[a], Horim Moon [b]
[a]*KEPCO E&C, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, Republic of Korea*
[b]*KHNP CRI, Ltd. 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, 34101, Republic of Korea*
[*]*Corresponding author: ksl@kepco-enc.com*

1. Introduction

After the Fukushima accident, research and development to improve safety of nuclear power plants (NPPs) has been pursuing in the nuclear power industry. Accordingly, the conceptual design of innovative passive reactor has been performed to enhance the safety from APR+ and APR1400 design in Korea. Innovative passive reactor has adopted the passive safety systems to improve the safety function and it has been developed as a leading model reflecting lessons learned from the Fukushima accident. The adopted passive systems include (1) PECCS (passive emergency core cooling system) and (2) PCCS (Passive Containment Cooling System), (3) PAFS (passive auxiliary feedwater system). The passive safety systems does not need the power supply because it works as natural circulation by gravity, condensation and evaporation to guarantee plant safety [1]. Preliminary Scoping PSA for innovative passive reactor has been performed to assess the passive system safety level and to find the safety improvement items for innovative passive reactor. The goal of this paper is to present results of a level 1 internal events PSA at power operation of innovative passive reactor that adopted risk-informed design and the passive safety system.

2. Methods and Results

Innovative passive reactor Preliminary Scoping internal events PSA was basically performed based on PRA Process Guide, PSA Procedures Guide and IAEA PSA Processes. The event tree analysis method was used to identify the accident sequences and the fault tree analysis method was used to model the safety systems.

2.1 Use of PSA in Design Process (Risk-Informed Design)

The conceptual design of innovative passive reactor has been developed and improved by applying the insights from PSA results. The design of innovative passive reactor including passive safety systems are used as inputs for Preliminary Scoping PSA models. The insights of PSA is again used for improving the conceptual design of innovative passive reactor.

The PSA model has been revised along with conceptual design change of innovative passive reactor. And the iteration process is performed until the design concept satisfies the safety target. The process of PSA modeling with the conceptual design change is presented in Fig.1.

As a result, the revised Preliminary Scoping PSA result has been reflected for design optimization performance.

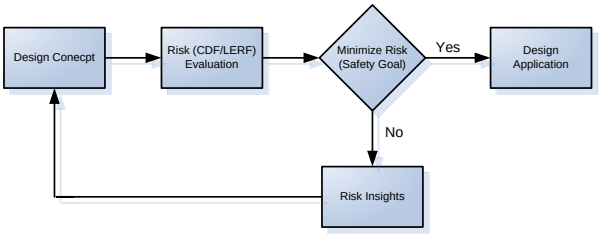

Fig. 1. Process of design change and optimization using PSA

2.2 Preliminary Scoping PSA Modeling

Innovative passive reactor Preliminary Scoping PSA is modeled in terms of a set of initiating events, event sequences composed of functions or system success or failure, and logic models that describe combinations of basic events that define the possible success and failure states. There are six major tasks associated with the Level 1 internal events PRA at-power as follows:

- Plant familiarization,
- Accident sequence definition,
- System modeling,
- Data assessment,
- Accident sequence quantification and
- Sensitivity and Importance analysis

This paper has been conducted based on innovative passive reactor conceptual design information or NPPs [2, 3] data. NUREG/CR-6928 [4] was used as a generic data resource for reliability data of innovative passive reactor Scoping PSA. Scoping PSA model has been developed and quantified using SAREX [5]

2.3 Initiating Events Selected for Innovative Passive Reactor PSA

For innovative passive reactor PSA, an initiating event list was drawn by reviewing logical evaluation methods such as master logic diagram, the initiating event list of nuclear power industries, and the initiating event list of passive NPPs. The initiating events list is shown in Table I. Success criteria of each sequences

regarding the initiating events and information on accident scenarios have been decided based on the analysis results of the reference NPP and MAAP [6].

Table I: Initiating Events for Innovative Passive Reactor

Category	Initiating Event
Loss of Coolant Accident (LOCA)	1. Large LOCA (LLOCA)
	2. Medium LOCA (MLOCA)
	3. Small LOCA (SLOCA)
	4. Steam Generator Tube Rupture (SGTR)
	5. Interface System LOCA (ISLOCA)
	6. Reactor Vessel Rupture (RVR)
Transients	7. Large Secondary Side Breaks Upstream of MSIV (LSSB-U)
	8. Large Secondary Side Breaks Downstream of MSIV (LSSB-D)
	9. Loss of Feedwater Line (LOFW)
	10. Loss of Condenser Vacuum (LOCV)
	11. Loss of Instrument Air (LOIA)
	12. Total Loss of CCW (TLOCCW)
	13. Loss of Class 125V A DC (LODC A)
	14. Loss of Class 125V B DC (LODC B)
	15. Loss of Offsite Power (LOOP)
	16. Station Blackout (SBO)
	17. General Transients (GTRN)
	18. Anticipated Transient Without Scram (ATWS)

2.4 PSA Results

According to the PSA analysis, the passive safety systems design could mitigate accidents even in extreme cases such as SBO, and hence it may improve overall innovative passive reactor safety levels. The total CDF (Core Damage Frequency) of innovative passive reactor is estimated as around 3.6% of that of APR1400. This value meet safety target of Top-Tier Requirement for innovative passive reactor's. Scoping PSA has been performed to optimize the risk-informed design by evaluating risk level of concept design for the passive safety system. Also, the insights of scoping PSA has been reflected to concept design iteratively. Therefore, it is concluded that there is no critical vulnerability.

3. Conclusions

The PSA model of innovative passive reactor has been developed by using a risk-informed design. The PSA model of innovative passive reactor evaluates the risk with the plant specific safety system which are acted passively. The risk insight of the PSA model is offered for design improvement. The safety level of the innovative passive reactor conceptual design has been revised reflecting insights of evaluations of the risk-informed design based on PSA models (design change). This process of evaluating the design and reflecting the evaluation results on the design was repeatedly performed for optimized design.

The PSA model of innovative passive reactor has been developed by reviewing the characteristics of conceptual passive system design, emergency response strategies and the Top-Tier Requirements of innovative passive reactor. The well-constructed PSA model of innovative passive reactor provides meaningful insights for safety improvement of innovative passive reactor conceptual design and it actually helps to optimize design.

As a result, the risk-informed design improvement and the application of passive safety system design improve the overall innovative passive reactor safety level and help to achieve the safety target of innovative passive reactor Top-Tier Requirement and regulatory safety goal.

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