Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

A Study on the Safety Enhancement Idea of EU-APR Design Using the LPSD PSA

Keun Sung Lee [a*], Do Hyun Whang [a], Eden KIM [b*], Hyun-bin CHANG [b]
[a]*Central Research Institue of Korea Hydro & Nuclear Power Co., Ltd. :1312-70 Beon-gil, Yuseongdaero, Yuseong-Gu, Daejeon, Korea, 305-343*
[b]*FNC Technology Co., Ltd. : 32 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, Korea, 16954.*
[*]*Corresponding author: leekeunsung@khnp.co.kr*

1. Introduction

In order to enlarge and to diversify the export market of APR1400, the EU-APR design was developed. The EU-APR design complied with the latest Revision D of the European Utility Requirements (EUR) aiming at the development of a standard design that can be built and licensed in Europe with minor changes.

The EU-APR design adopts various advanced safety features for the improvement of risk. The risk associated with the nuclear power plant can be identified through the probabilistic safety assessment (PSA).

Thus, this paper reviews the EU-APR design for safety features and suggests the safety enhancement idea to contribute to risk reduction using the LPSD Level 1 and Level 2 PSA.

2. Methods and Results

2.1 Review of EU-APR Design

The EU-APR design has innovative system configurations to enhance safety based on the APR1400 design. For example, the mid-loop level control system (MLCS), the passive ex-vessel retaining and cooling system (PECS), the severe accident containment spray system (SACSS) and the containment filtered venting system (CFVS).

The MLCS is considered to prevent uncontrolled RCS level drop event during the mid-loop operation for the EU-APR, which is not incorporated into APR1400 type plant in Korea. As MLCS is adopted during the mid-loop operation for decay heat removal and inventory control, the total LPSD CDF was reduced to 66% compared to the model without MLCS [7].

The PECS, SACSS, and CFVS are installed to prevent the emission of fission product to the outside of containment in the event of a severe accident. A brief description of the system function is as follows.

- PECS: Retain the core debris and prevent both the molten corium-concrete interaction and basemat melt-through.
- SACSS: Prevent the containment failure due to the over-pressurization and remove fission products from the containment atmosphere.
- CFVS: Prevent the containment failure due to over-pressurization.

In the EUR volume 2 chapter 1 and chapter 17, The Criteria for Limited Impact (CLI) should be applied for the Level 2 PSA as a risk metrics instead of the large early release frequency (LERF). The CLI is defined in EUR Volume 2 Chapter 1 appendix B [5]. It involves following four design targets.

- No emergency protection action beyond 800 m from the reactor,
- No delayed action at any time beyond about 3 km from the reactor,
- No long term action at any distance beyond 800 m from the reactor,
- Limited economic impact out of the plant.

It is calculated that the above three mitigation systems reduce the cumulative frequency of exceeding CLI by 95.5% compared to those without [8].

2.2 Insight from EU-APR PSA Results

As a result of the above analysis, the soundness of the EU-APR was improved through various safety features. Nevertheless, The EU-APR PSA results show design vulnerabilities as follows.

The EU-APR uses common heat, ventilation and air conditioning (HVAC) systems to remove heat from safety injection (SI) pump rooms and shutdown cooling / containment spray (SC/CS) pump rooms. If the HVAC system is not available, the temperature of SI pump room and SC/CS pump room would rise simultaneously. Thus, operation of shutdown cooling system (SCS) for decay heat removal is failed. And feed and bleed by safety injection for decay heat removal and inventory control is also failed. In order to complement the EU-APR design vulnerabilities, two supplementary measures were examined and sensitivity analysis was performed.

2.3 Sensitivity Analysis

As a result of the minimal cutset review of LPSD Level 1 PSA of POS 1, 2, 14, and 15, the core damage frequency due to loss of SI and SC/CS equipment room cooling was about 0.5%, so it was excluded from sensitivity analysis. Therefore, only POS 3 ~ 13 which has LPSD operation characteristics were analyzed.

- Case 1: Recovery by operator action
  Apply to recovery action in which the operator installs a mobile fan cooler to cool the equipment room when the SI and SC/CS equipment room HVAC fails.
- Case 2: Independent installation of HVAC system for SI and SC/CS equipment room cooling
  SI pump room and SC/CS pump room are equipped with independent HVAC system so that cooling ability would not be lost coincidentally for the same reason.

For the case 1, the probability of operator recovery action failure is conservatively assumed to be 0.1. This value is commonly used as a screening value in human failure events. To carry out recovery action, the recovery procedure should be specified ahead of performing action.

For the case 2, In order to model the independent HVAC system in the SI pump room and the SC/CS pump room, the existing HVAC system in the SI pump room was maintained and the SC/SC pump room was replaced by new HVAC system which is modeled on the same level as the existing HVAC system. In addition, it is assumed that another type of HVAC is installed. Thus, there is no common-cause failure between SC/CS pump room and SI pump room cooling system.

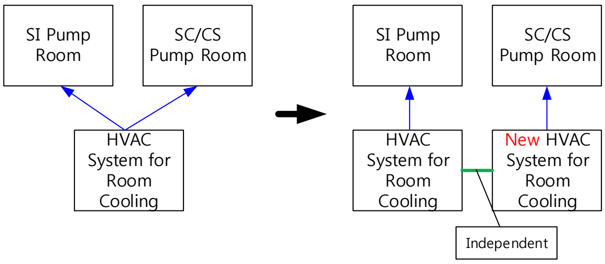

Fig. 1. Independent HVAC system modeling for sensitivity analysis case 2

The sensitivity analyses results are shown in the below table.

Table I: The decreasing rate of the fraction of CDF and exceeding CLI

CASE	Δ CDF	Δ exceeding CLI
CASE 1	-10.1%	-10.9%
CASE 2	-38.0%	-25.5%

According to the sensitivity analysis case 1, the fraction of the CDF decreases by 10.1% and the fraction of exceeding CLI decreases by 10.9%. In this case, an operator can recover room cooling by using mobile fan cooler, still SI and SC/CS pump are failed for the same reason yet. Furthermore, the probability of operator recovery action failure is not guaranteed.

According to the sensitivity analysis case 2, the fraction of CDF decreases by 38.0% and the fraction of exceeding CLI decreases by 25.5%. In this case, even if one HVAC system fails, the other system is not affected. So, there is an option to mitigate before or after the core damage, which reduces the risk effectively.

3. Conclusions

As a result of the EU-APR PSA conducted last year, it was confirmed that the safety was improved compared to the existing APR1400.

However, for the safety enhancement of the EU-APR, the result of the EU-APR PSA was reviewed and found the design vulnerability that the HVAC system cooling for SI pump room and SC/CS pump room is shared. This design feature would cause the loss of safety injection system and decay heat removal system coincidentally. Two methods are suggested to supplement this characteristic in this study.

Firstly, an operator recovers a room cooling by using mobile fan cooler when the HVAC system is failed. From the result of sensitivity analysis case 1, the fraction of CDF decreases by 10.1% and the fraction of exceeding CLI decreases by 10.9%.

Secondly, install an independent HVAC system and separate SC/CS pump room from the existing HVAC system. From the result of sensitivity analysis case 2, the fraction of CDF decreases by 38.0% and the fraction of exceeding CLI decreases by 25.5%.

According to the result of this study, installation of additional independent HVAC system is more effective way than operator recovery action after a loss of the HVAC system.

ACKNOWLEDGMENT

This work was supported by the Major Technologies Development for Export Market Diversification of APR1400 of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy.

REFERENCES

[1] US NRC, Evaluation of Potential Severe Accident during Low Power and Shutdown Operations at Surry Unit 1, NUREG/CR-6144, 1995.
[2] ANS, Low-Power and Shutdown PRA Methodology, ANSI/ANS-58-22-2014(Trial-Use), 2014.
[3] IAEA-TECDOC-1144, Probabilistic Safety Assessments of Nuclear Power Plants for Low Power and Shutdown Modes, March 2000.
[4] EPRI, An Analysis of Loss of Decay Heat Removal Trends and Initiating Event Frequencies (1989-2000), EPRI-TR-1003113, 2001.

[5] European Utility Requirements for LWR Nuclear Power Plants, Rev. D, 2012.
[6] KEPCO E&C, SAREX^{TM} User's Manual, KEPCO Engineering & Construction Company, 2011.
[7] K.S Lee, S. Choi, and E. Kim, A Study on the Risk Reduction Effect by MLCS (Mid-loop Level Control System) of EUAPR using the Low-Power and Shutdown PSA Result, KNS *conf*., 2016
[8] K.S. Lee, D.H. Hwang, and H. Chang, Quantitative Safety Impact of Severe Accident Management Systems for EU-APR during Low Power Shutdown Operation, KNS *conf.*, 2016