Analysis of PERSERO experiments for applying robustness assessment methodology to PSS

Jehee Lee [a*], Seong-Su Jeon [a], Nhan Hien Hoang[a], Ju-Yeop Park [b]
[a] *FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea*
[b] *Korea Institute of Nuclear Safety, 62 Kwahak-ro, Yuseong, Daejeon, Korea*
[*] ***Corresponding author: capable91@fnctech.com***

***Keywords :** Passive Safety System, Performance issue, Robustness assessment methodology PERSEO experiment

1. Introduction

With the increasing adoption of nuclear power plants around the world and the development of various new types of reactors, passive safety systems (PSS) are being developed and introduced in various configurations. PSS utilizes natural phenomena to mitigate accidents and keep the plant safe without the use of external power. With the development of various types of PSS, there is a demand for performance evaluation of the capability of PSS to perform accident mitigation in various conditions. Especially, since PSSs have weaker driving forces and less driving experience than conventional safety systems, there are various uncertainties in the event of an accident. In addition, since the system analysis code used for safety system performance evaluation was mainly developed for the existing Active Safety System, it is necessary to demonstrate the applicability of the safety analysis code to the introduction of PSS.

For this reason, Robustness Assessment Methodology has been developed to predict changes in the performance and behavior of PSSs in various environments [1, 2]. The Robustness Assessment Methodology utilizes a system analysis code to evaluate the performance of a PSS given performance issues and uncertainties. In this study, the PERSEO (in-Pool Energy Removal System for Emergency Operation, [3]) experiment, a PSS experiment facility, was analyzed in MARS-KS to verify the applicability of the developed robustness assessment methodology.

n this paper, a brief summary of the Robustness Assessment Methodology is presented and the PERSEO experiment is described. It also includes the process of creating a reference input model according to the procedures in the Robustness Assessment Methodology.

2. Robustness Assessment Methodology

The Robustness Assessment Methodology takes into account the characteristics of the PSS and evaluates system performance through seven steps, as shown in Figure 1.

1) Review of Target PSS Design
2) Identification of the Major Thermal-Hydraulic (TH) Phenomena of PSS
3) Assessment of Prediction Capability of System Analysis Code for PSS TH Phenomena
4) Development of Reference Analysis Model for Target PSS
5) Identification of Major Performance Issues for Target PSS
6) Nuclear Steam Supply System (NSSS) coupled PSS Performance Evaluation
7) Derivation of Considerations for Design Improvement and Safety Analysis Guidelines for PSS

A detailed description of each step of the methodology can be found in the References [1, 2].

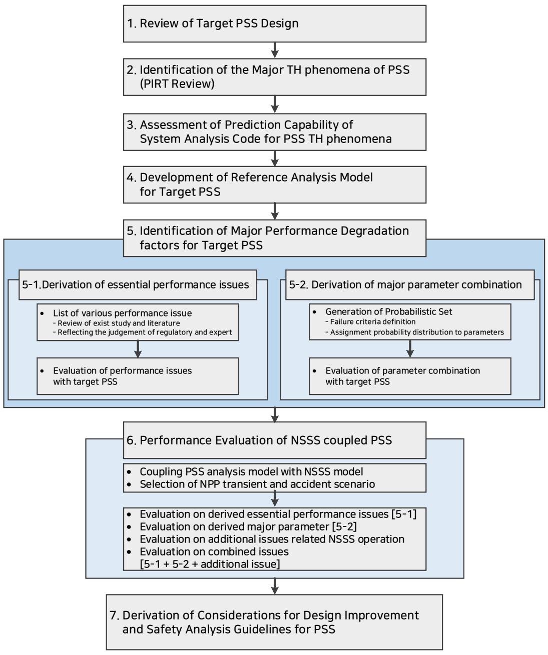


Fig. 1. Robustness Assessment Methodology for PSS

3. Description of PERSEO Experiment

The PERSEO experiment is a passive heat removal system experimental facility conducted at the SIET laboratory and was designed for full scale testing of the GE-SBWT's in-pool heat exchanger. Since this experiment has been used as a benchmark calculation for the OECD/NEA/CSNI/SGAMA group and has been analyzed by various system analysis codes, we decided to utilize it in this study.

3.1 PERSEO experiment facility

A schematic of the PERSEO experiment facility is shown in Figure 2. Steam injected into the Pressure

Vessel (PV) is injected into the heat exchanger along the steam line. The steam condensed in the heat exchanger is returned to the PV through a heat exchanger tube and then released outside the PV. The water pool that serves as the heat sink is composed of the Overall Pool (OP) and the Heat eXchanger Pool (HXP). Initially, the HXP is filled with gas, and water from the OP is introduced through the opening of the triggering valve to remove the heat from the primary system transferred from the heat exchanger. The geometry of the main components of the PERSEO experiment is shown in Table 1.

3.2 PERSEO Test No.7 description

PERSEO Test No. 7 consists of two parts. Part 1 is the system stability test, which evaluates the behavior of the system at different HXP grid water levels (1.4 m, 3.5 m). Part 2 is the long-term cooling performance test, which evaluates the change in system cooling performance as the bath water level decreases during long-term operation. The experiment procedure for PERSEO Test No.7 is shown in Tables 2 and 3.

4. Analysis of PERSEO Experiment

4.1 Modeling of PERSEO experiment

Figure 3 shows the MARS-KS nodalization for the analysis of the PERSEO experiment. Saturated steam is continuously injected into the PV (C100) from the steam source (TDV080), and the steam is condensed in the heat exchanger (C250). The condensate is returned to the bottom of the PV and a drain tank (TDV090) is used to keep the water level in the PV constant. HXP and OP were each modeled using two Pipe Components to simulate convection in the tank. The triggering valve was also simulated using MARS-KS's Servo Valve to ensure that the flow was similar to the experiment. The steam generated by heating the HXP is returned to the OP through the steam duct, which is modeled to allow for natural circulation between the pools.

4.2 Analysis results of Test 7 Part 1

The analysis results of Test 7 Part 1 are shown in Figure 4. As shown in the figure, the flow rate of the triggering valve was predicted similarly to the experiment, but the water level and natural circulation flow rate of primary side were predicted to be low, due to underprediction of the heat removal performance in the heat exchanger. It was concluded that the default condensation model of MARS-KS underpredicted the amount of condensation, and it was found that doubling the heat transfer rate as shown in Figure 5 resulted in a simulation more similar to the experiment.

Table 1. Geometry of main components of PERSEO

Component	Volume [m^3]	Height [m]	Etc.
PV	43	13	
HX		1.8	120 tubes I.D: 46.2mm
HXP	29	5.7	
OP	173	5.8	

Table 2. Experiment procedure of PERSEO Test 7 Part 1

RELEVANT THERMAL HYDRAULIC ASPECTS	TIME [S]	QUANTITY
Triggering valve opening and closure (1st)	10,475 – 10,608	
Triggering valve opening and closure (2nd)	10,621 – 10,655	
Maximum level in the HXP for the first filling step	10,683	1.41 m
Small heat removal from the primary side	10,600 – 11,000	3.5 MW
Slow water consumption in the HXP	11,049	1.41 → 1.40 m
Instabilities for steam condensation in the Injector	10,930 – 11,290	Negative HXP relative P
Triggering valve opening and closure (3rd)	11,039 – 11,260	
Maximum level in the HXP	11,050	3.4 m
Maximum exchanged power	11,260 – 11,845	21.5 MW
HXP minimum level	14,800	1.25 m
OP average temperature	13,000	~ 55°C

Table 3. Experiment procedure of PERSEO Test 7 Part 2

RELEVANT THERMAL HYDRAULIC ASPECTS	TIME [S]	QUANTITY
Triggering valve opening	300 - 326	
Maximum level in the HXP	531	3.25 m
Maximum exchanged power	531 – 2,282	21 MW
OP discharge valve opening	1,150	
Triggering valve closure	3,215 - 3,338	
HXP level decreasing and loss of mass from boil-off	2,282 – 5,735	
Primary side depressurization beginning for end of test	4,685	

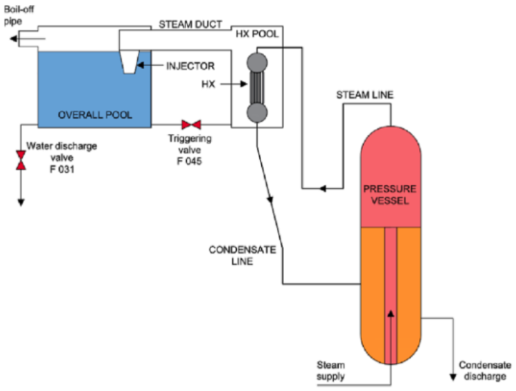


Fig. 2. Schematics of PERSEO facility [3]

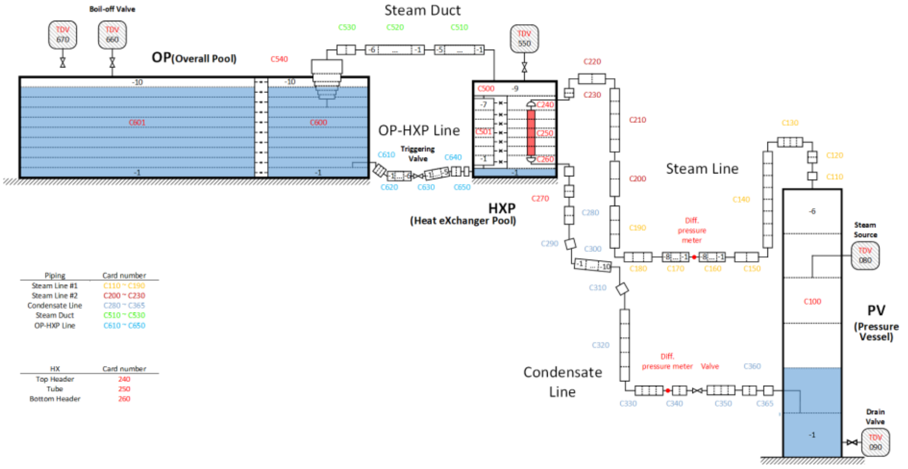


Fig. 3. Nodalization of PERSEO facility for MARS-KS

4.3 Analysis results of Test 7 Part 2

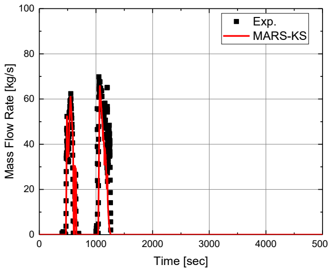
The results of analyzing Test 7 Part 2 are shown in Figure 6. Similar to Part 1, the results of the other variables showed some difference, predicting a lower heat removal rate in the heat exchanger. In Part 2, the behavior of primary side was relatively stable, so the primary flow rate was fixed similar to the experiment and the difference in results was analyzed. As a result, the system showed some improvement in heat removal performance, but still predicted lower values than the experiment (Fig. 7). In addition, as in Part 1, increasing the heat removal rate by a factor of 2, the analysis results are much closer to the experimental results (Fig. 8).

5. Conclusions

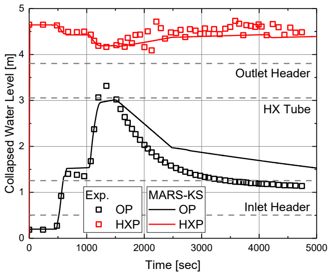
In this study, Analysis of PERSEO experimental facility was conducted to validate the applicability of the Robustness Assessment Methodology. The experimental simulation was performed using MARS-KS, and the analysis showed that the condensation heat transfer model of the system had a significant impact on the results. In the future, we will review the pure steam condensation heat transfer model to create a suitable reference input model for this experiment. We will also validate the applicability of the Robustness Assessment Methodology by analyzing various performance issues that have a major impact on PERSEO performance through baseline inputs.

ACKNOWLEDGEMENT

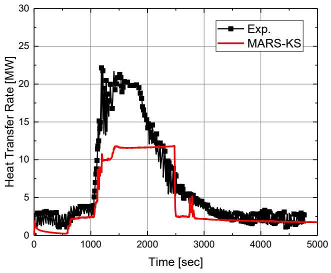
We acknowledge that this research has been conducted with a support from the national nuclear safety research titled "Study on Validation of Consolidated safety Analysis Platform for Applications of Enhanced Safety Criteria and New Nuclear Fuels (Contract No. 2106002)" funded by Nuclear Safety and Security Commission of KOREA.



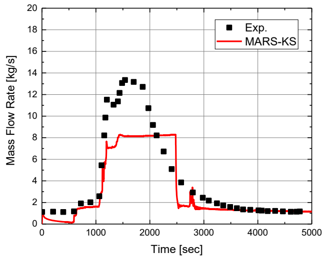
(a) Mass flow rate – Triggering valve



(b) Water level – OP, HXP

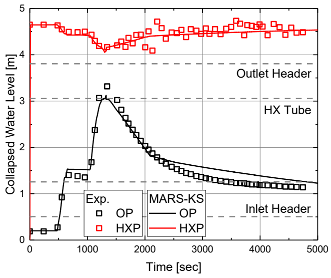


(c) Heat removal rate

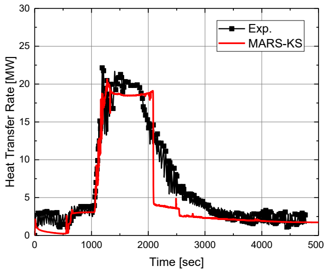


(d) Mass flow rate – Primary side

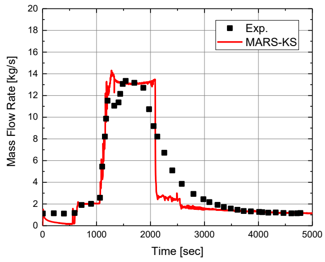
Fig. 3. Analysis result – Part 1 (default)



(a) Water level – OP, HXP

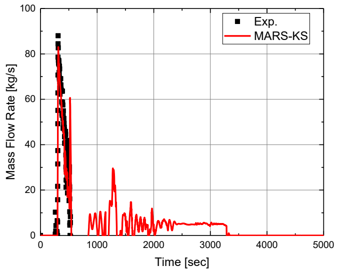


(b) Heat removal rate

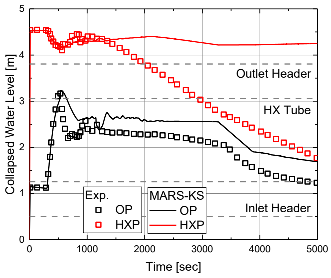


(c) Mass flow rate – Primary side

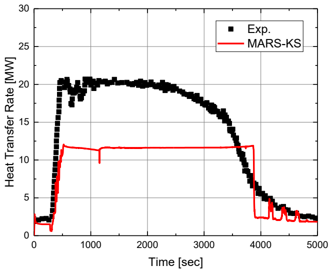
Fig. 4. Analysis result – Part 1 (heat transfer x2)



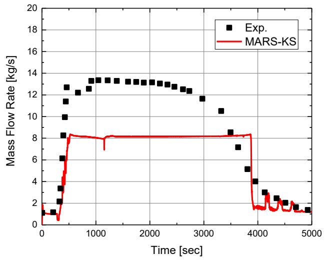
(a) Mass flow rate – Triggering valve



(b) Water level – OP, HXP

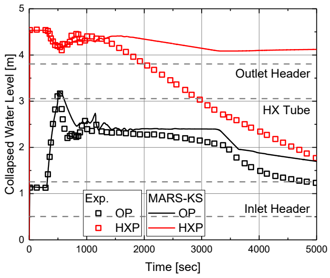


(c) Heat removal rate

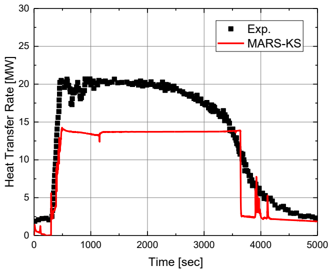


(d) Mass flow rate – Primary side

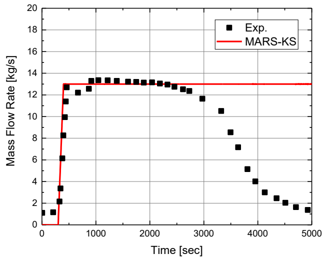
Fig. 5. Analysis result – Part 2 (default)



(a) Water level – OP, HXP

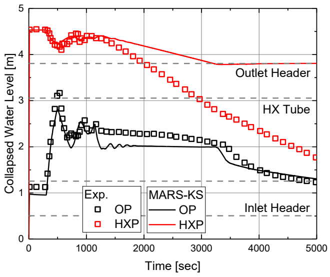


(b) Heat removal rate

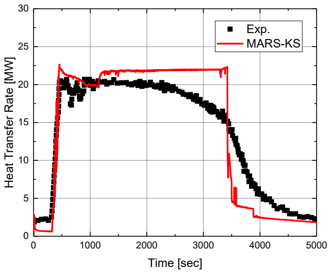


(c) Mass flow rate – Primary side

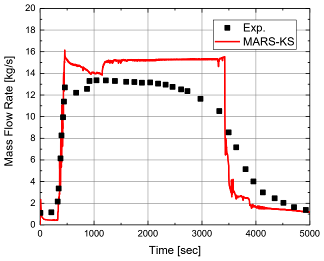
Fig. 6. Analysis result – Part 2 (Fixed primary flow rate)



(d) Water level – OP, HXP



(e) Heat removal rate



(f) Mass flow rate – Primary side

Fig. 7. Analysis result – Part 2 (heat transfer x2)

REFERENCES

[1] J. Lee et al., Effect evaluation on performance issues of passive safety system - Part I. Passive heat removal system, Nuclear Engineering and Design, 403, 112160, 2023.

[2] J. Lee et al., Effect evaluation on performance issues of passive safety system - Part II. Passive emergency core cooling system, Nuclear Engineering and Design, 411, 112446, 2023.

[3] F. Mascari et al., OECD/NEA/CSNI/WGAMA PERSEO benchmark: Main outcomes and conclusions, Nuclear Engineering and Design, 405, 112220, 2023.