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Example Analysis of Performance Issues in Passive Safety System using System Code

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1. Introduction

For the advanced Nuclear Power Plant, various Passive Safety Systems (PSSs) are introduced. Since PSSs do not use external power and operate by using the density difference and gravity, there are many concerns about whether the PSSs could sufficiently perform the safety function in various situations. There are some performance issues which could affect the PSS performance with low driving force such as presence of non-condensable gas, leakage, ambient temperature change, heat loss, aging deterioration, check valve, fire, and seismic. For this reason, system code analysis on performance issues of PSS is necessary.

In this study, by referring to the reports of OECD/NEA-WGRNR (Organization for Economic Co-operation and Development/Nuclear Energy Agency-Working Group on Regulations of New Reactors)[1], WENRA-RHWG (Western European Nuclear Regulators Association-Reactor Harmonization Working Group)[2] and the passive safety system regulation guidelines of KINS(Korea Institute of Nuclear Safety)[3], passive system regulation trends of domestic and foreign are investigated. After that, with the investigation results, conceptual problem analysis is designed and performed to evaluate the heat removal performance of PSS. Analyses on each performance issue are performed with MARS-KS V1.5 and the effect of the each issue on PSS performance is identified.

2. Performance issue of PSSs

With respect to passive system performance issues, KINS selected major issues with reference to OECD/NEA-WGRNR and WERNA-RHWG reports [3]. The selected passive system performance issues are as follows.

2.1 Performance Demonstration of PSSs

Since operation conditions of PSS could be different from an active safety system, the performance demonstration of PSS is also different from active system. In addition, it is necessary to check whether the operation condition of PSS is appropriate for the system code used in the performance demonstration, and to conduct validation if necessary. (e.g. Model Uncertainty of System Code)

2.2 Specific Range of Conditions and Consequences on Safety Analysis

Performance demonstration of PSS with low driving force has uncertainties in model, correlation, and initial/ boundary conditions. Therefore, it is necessary to evaluate the reliability of these uncertainties. (e.g. Presence of Non-Condensable gas, Leakage of Working Fluid, Change of Ambient Temperature, Heat Loss, and Aging Deterioration)

2.3 Assessment of Actuation of PSS

PSS has a lower probability of operation failure compared to an active safety system, but the operational availability of the component used to system actuation must be performed. In particular, when the operational availability of essential components is affected by the low driving force, validation must be made. (e.g. Operation of Check Valve)

2.4 Internal and external hazards consideration for passive systems

Even when environmental conditions change due to the occurrence of internal and external events, the passive system must be able to perform the original safety analysis. (e.g. Fire and seismic)

3. Example Analysis on Performance Issues

3.1 Development of Conceptual Problem

The design and input model of the conceptual problem for the evaluation of the effect of performance issues are as follows. Input models for single-phase and two-phase flow analysis are developed, respectively, and the design is almost identical as shown in the Fig. 1, except the pressurizer. The single-phase natural circulation system is developed for the PRHRS of AP1000, and the two-phase natural circulation system is developed for the PAFS of iPower. The fluid is heated (boiled) through the heater in the lower tank and is cooled (condensed) in the cooling tank. The natural circulation flow rate is about 0.7 kg/s for single-phase flow and about 0.32 kg/s for two-phase flow

3.2 Example Analysis of Performance Issues

Example analysis was conducted for each performance issue through the input model developed above, and the results are shown in Fig.2~10.

1) In case of **leakage of working fluid**, the pressure is slightly reduced due to a decrease in the amount of coolant in the system. However, if the leakage area is small, the effect on the heat removal performance of the PSS is negligible.
2) When the tank temperature changes according to the **ambient temperature**, there is little change in performance for a single-phase flow system, but for a two-phase flow system, the system pressure may be lowered due to a decrease of feedwater temperature.
3) **Heat loss** reduces the driving force and reduces the performance of the heat exchanger itself in the passive system, but can increase the overall hear removal rate of the system (heat loss + heat exchanger heat removal rate).
4) In the **presence of non-condensable gas**, heat exchanger performance is reduced due to reduced condensation heat transfer.
5) When the flow area in piping and heat exchanger tubes is reduced due to **aging deterioration** (pollution, etc.), the flow resistance increases and the heat removal performance of the PSS may decrease.
6) With a **check valve**, the performance of the PSS may be reduced due to the failure of the check valve in the two-phase flow system when the condition is low power and low flow rate in the long-term operation. This is because density and driving force of fluid are too low to flow through the check valve and the natural circulation flow cannot be formed normally.
7) When the temperature of the feedwater pipe after the heat exchanger increases due to a **fire**, the heat removal rate increases due to an increase in the heat source in the system. However, the surface temperature of the heater rod and the pressure of system are increased because the system heats more due to heat flux of fire.
8) **Effect of seismic** on the PSS heat removal performance is small even if the pipe deformation and the leakage also occurred.
9) When the **thermal hydraulic model uncertainty** is large, the PSS performance may change significantly.

3.3 Comprehensive effect Assessment of Performance Issues

The effects of leakage, ambient temperature, heat loss, non-condensable gas, aging deterioration, check valve, fire, seismic, and thermal hydraulic model uncertainty on passive system performance were evaluated. As a result of the analysis, the overall effects were not large unless a harsh situation was assumed to impair the PSS performance for each issue. Even if the impact of each issue is small, comprehensive effect assessments are performed using single-phase and two-phase flow models to qualitatively confirm the change in PSS performance when all factors occur simultaneously.

For the comprehensive effect analysis model, the leakage (area 0.01 mm^2), presence of non-condensable gas (1%), aging (flow path area -5%), check valve (operating differential pressure 0.1 bar), fire (heat flux 2 kW/m^2), seismic (pipe deformation at the end of the heat exchanger) and the heat transfer model uncertainty (-5%) were simultaneously applied. As a result of the analysis in Fig.11, the heat removal rate oscillated unstable, and the natural circulation flow rate oscillated and decreased due to the decrease in driving force. In addition, the system pressure and the surface temperature of the heater rod increased due to the decrease in the heat removal rate of the system. Consequently, although the effect of each issue on the single-phase system was negligible, the performance of the PSS was reduced when considered comprehensively. In addition to that, when evaluating performance of PSS, it is necessary to prove that there is sufficient margin to prevent the Cliff-Edge effect by comprehensively considering these issues.

4. Conclusion

The PSS has a small driving force, so its performance may vary greatly due to various internal and external factors (non-condensable gas, leakage, ambient temperature, heat loss, aging, check valve, fire, seismic, etc.). In order to confirm the effect of the performance issues on the PSS, an example analyses were performed on the conceptual model of the single/two-phase natural circulation heat removal system using MARS-KS.

As a result of the analyses, the effect of individual issues on system performance was small. However, it was confirmed that when performance issues are comprehensively considered, the performance of the system can be affected.

The results of this study provide qualitative insights into the effects and importance of various internal and external issues on the performance of the PSSs. In order to improve the reliability of the performance of the passive system, it is necessary to consider the performance issues when analyzing the safety of the passive system.

ACKNOWLEDGEMENT

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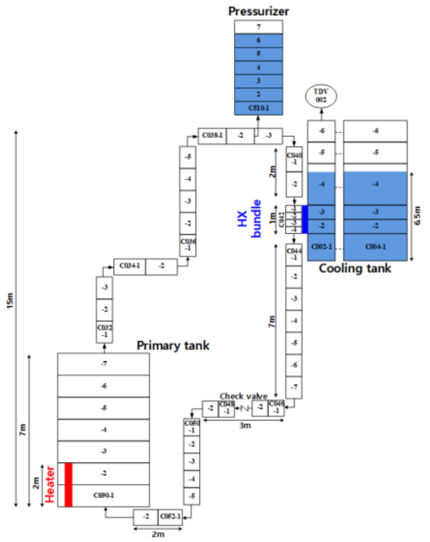
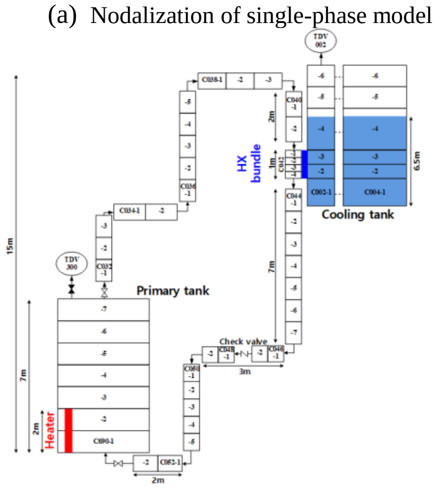


(a) Nodalization of single-phase model



(b) Nodalization of two-phase model

Fig. 1. Nodalization for example analysis of performance issues

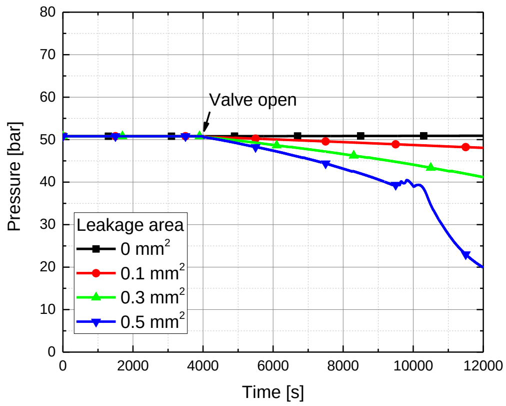


Fig. 2. Effect of working fluid leakage results (Single-phase analysis results)

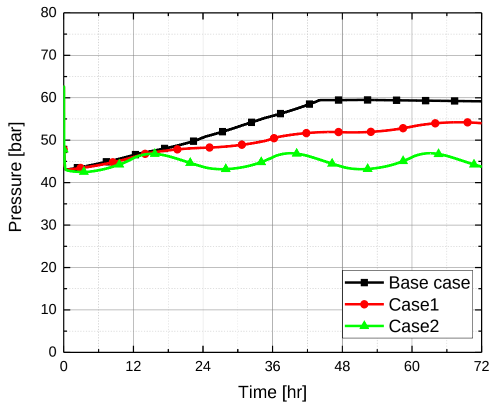


Fig. 3. Effect of ambient temperature results (Two-phase analysis results)

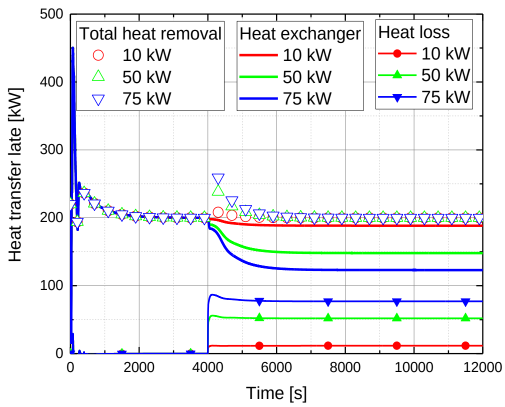


Fig. 4. Effect of heat loss results (Two-phase analysis results)

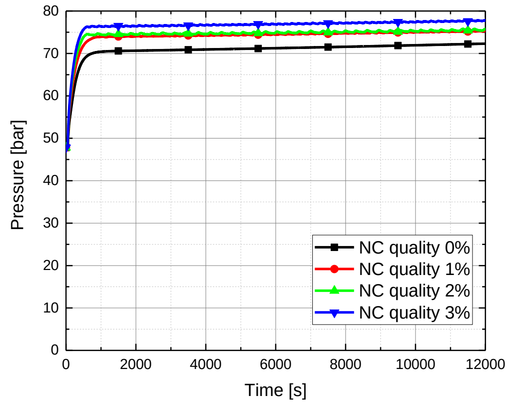


Fig. 5. Effect of NC gas results
(Two-phase analysis results)

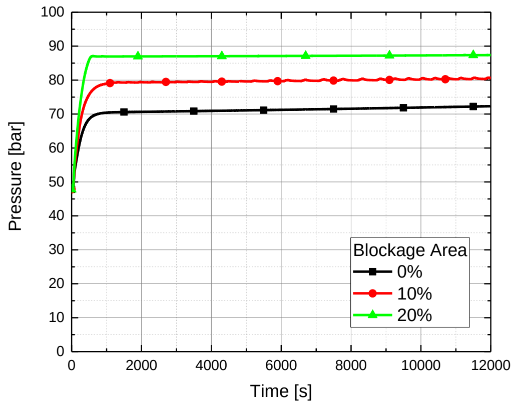


Fig. 6. Effect of aging deterioration results
(Two-phase analysis results)

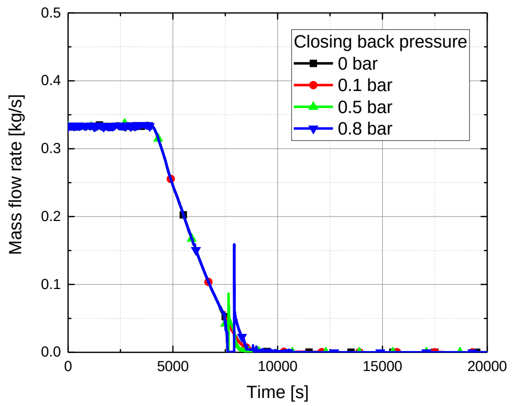


Fig. 7. Effect of check valve results
(Two-phase analysis results)

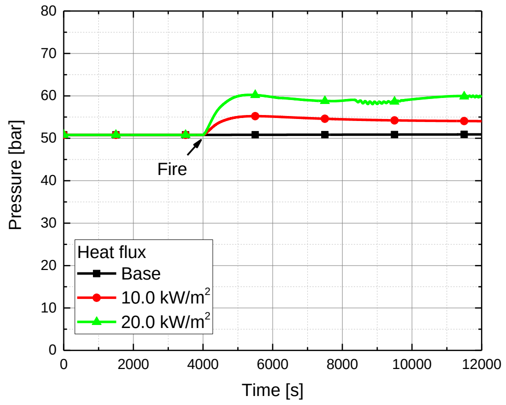


Fig. 8. Effect of fire results
(Single-phase analysis results)

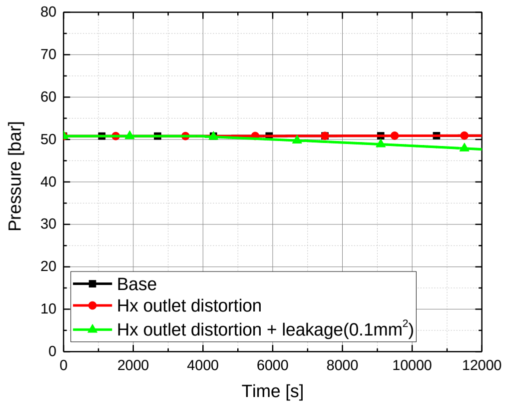


Fig. 9. Effect of seismic results
(Single-phase analysis results)

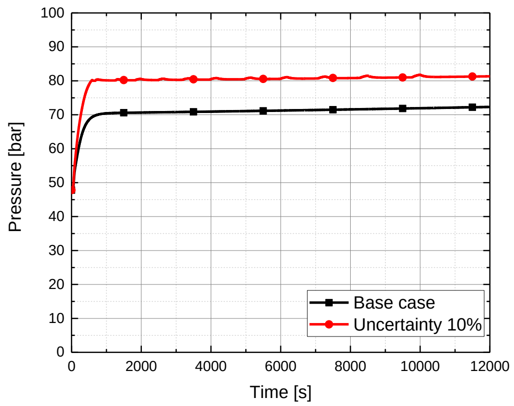
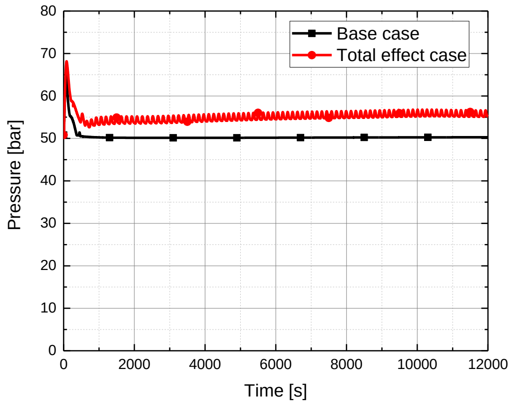
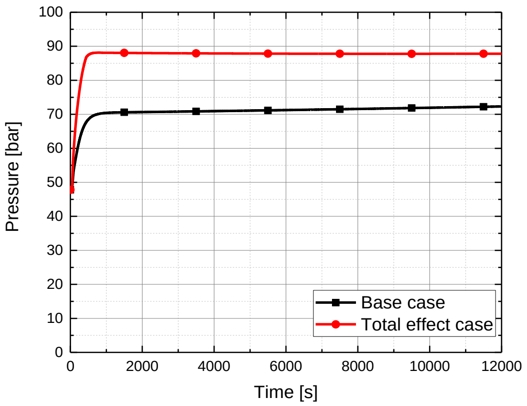


Fig. 10. Effect of model uncertainty results
(Two-phase analysis results)



(a) single-phase model



(b) two-phase model

Fig. 11. Comprehensive effect analysis results