Analysis of Performance Issues in Passive Emergency Core Cooling System using System Code

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1. Introduction

For improvement of the safety of nuclear Power Plants (NPPs), a lot of Passive Safety Systems (PSSs) are being developed. However, since the existing NPP regulatory guidelines target active safety system, guidelines for PSSs are still lacking. In this study, prior to the development of the PSSs regulatory guidelines, the intrinsic characteristics of PSSs and the difference between the active safety systems are analyzed through the performance evaluation of the system. Because the PSSs have weak driving force, it is greatly affected by the pressure drop in the pipe. Therefore, when evaluating the performance of the system, the pressure drop predictability of system codes should be verified. Therefore, Lee et al. [1] evaluated the pressure drop predictability of MARS-KS with natural circulation loop type experiments. And to investigate the current issues affecting the performance of PSSs, KINS (Korea Institute of Nuclear Safety) reviewed the reports of OECD/NEA-WGRNR (Organization for Economic Co-operation and Development/Nuclear Energy Agency-Working Group on Regulations of New Reactors)[2], WENRA-RHWG (Western European Nuclear Regulators Association-Reactor Harmonization Working Group)[3]. With the reference to those reports KINS selected major issues about performance of PSSs [4]. With those issues, Lee et al [5] applied performance issues to passive heat removal type systems and evaluated the change of system performance with issues. In this paper, the performances issues are applied to the Passive Emergency Core Cooling System (PECCS) and the effect of performance issues will be evaluated with conceptual problem

2. Performance issue of PSSs

The main performance issues of PSSs presented by KINS are as follows [4].

- Leakage of coolant
- Change of atmosphere temperature
- Heat loss
- Non-condensable gases in system
- Aging of pipe and heat exchanger
- Operability of check valve
- Fire in containment building
- Pipe deformation due to seismic event
- Model and correlation uncertainties of analysis code

3. Example Analysis on Performance Issues

3.1 Analysis of Reference model

To analyze the effect of performance issues on PECCS, a conceptual model of PECCS was developed as shown in the figure 1. The model consists of a Vessel, Core Makeup Tank (CMT), Safety Injection Tank (SIT), connecting pipes, and valves. The geometries of CMT and SIT are as follows.

CMT Geometry:

- Water Volume/level: 35 m^3 / 6 m
- Pipe diameter: 54 mm
- Length: 100 m

SIT Geometry:

- Water Volume/level: 90 m^3 / 10 m
- Pipe diameter: 54 mm
- Length: 125 m

In the reference model analysis, the loss of coolant accident was simulated by opening the discharge valve located at the top of the reactor vessel. The system pressure is decreased due to the discharge of coolant, and CMT and SIT are sequentially injected according to the operating pressure. The effect of issue on the system performance was analyzed through the injection behavior and the heater surface temperature. The analysis result of the reference input model is shown in the figure 2.

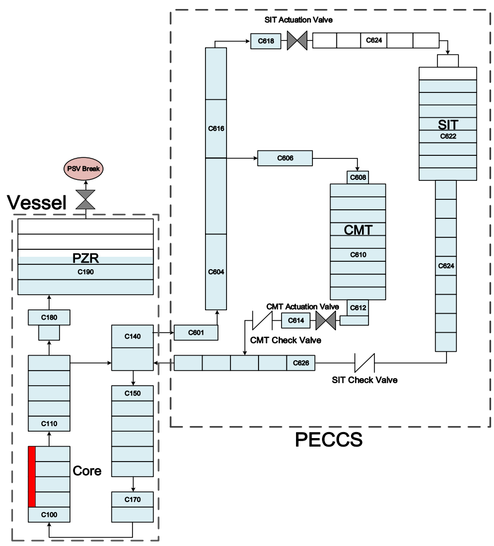
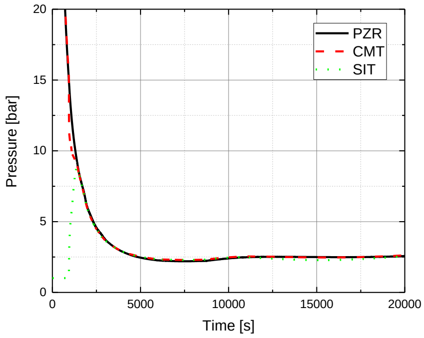
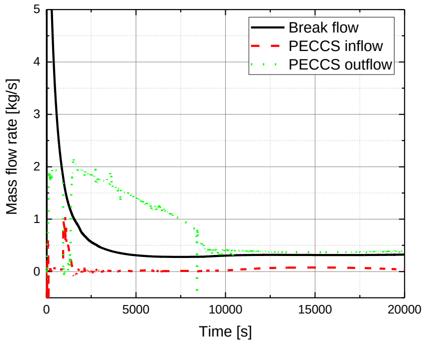


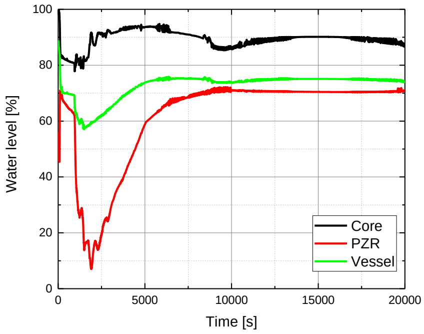
Fig. 1. Nodalization for example analysis of performance issues



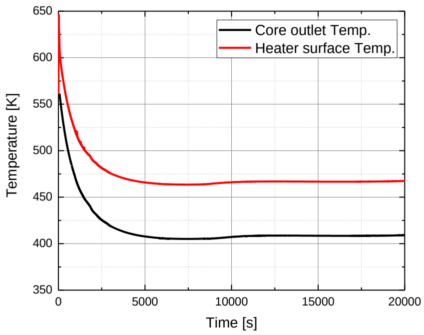
(a) Pressure



(b) Mass flow rate



(c) Water level



(d) Temperature

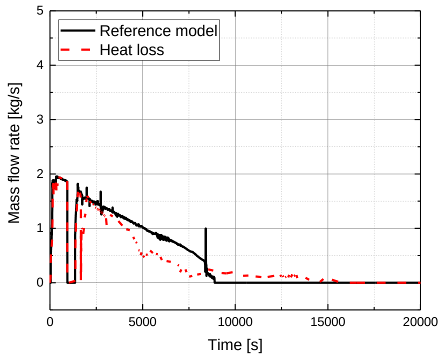
Fig. 2. Reference model results

As shown in the results, system pressure decreases drastically with valve opening, and PECCS operates with CMT actuation signal and SIT actuation signal. With the injection of coolant, the water level in the reactor vessel is recovered and shows stable behavior. The heater surface temperature increases rapidly at the beginning of the accident (~650K), but then decreases stably and is maintained at about 465K.

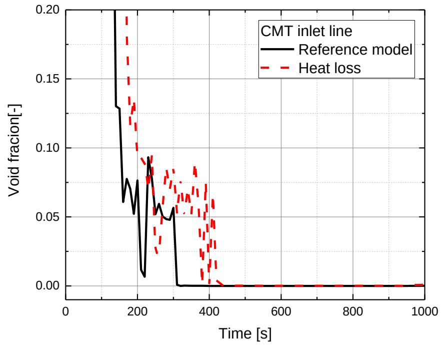
3.2 Example Analysis of Performance Issues

Example analysis was conducted for each performance issue through the input model developed above. In these analyses, the effect of issues about leakage, ambient temperature, fire, NC gases on the PECCS performance is expected to be small. And other results are summarized in Fig. 3~7.

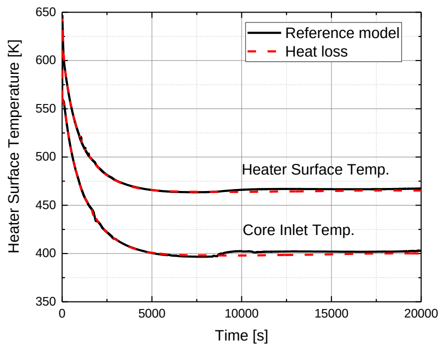
1) **PECCS pipe heat loss** can increase pressure drop since two-phase flow in the inlet pipe might be formed with vapor condensation, but the change in PECCS cooling water injection performance is small.
2) **Seismic events** (changes in pipe shape) and **aging** (reduction of pipe area) can increase the pressure drop in the flow path and reduce the cooling water injection performance of PECCS.



(a) Mass flow rate

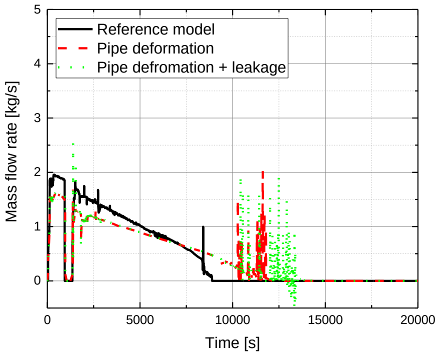


(b) Void fraction at CMT inlet

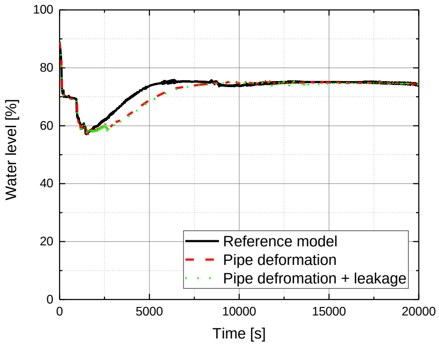


(c) Temperature

Fig. 3. Effect of heat loss in pipe results

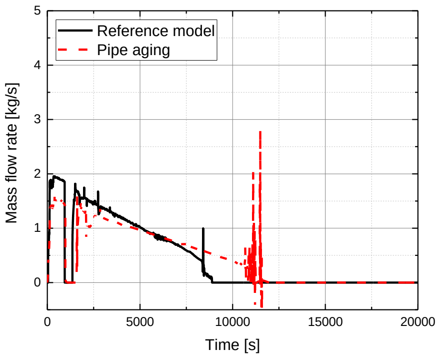


(a) Mass flow rate

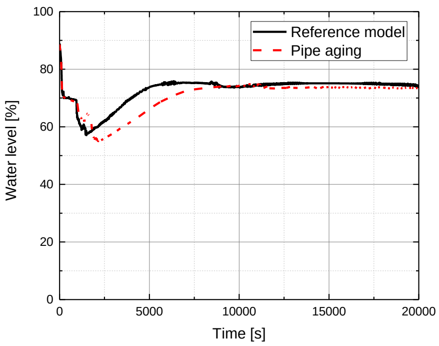


(b) Vessel water level

Fig. 4. Effect of seismic event results



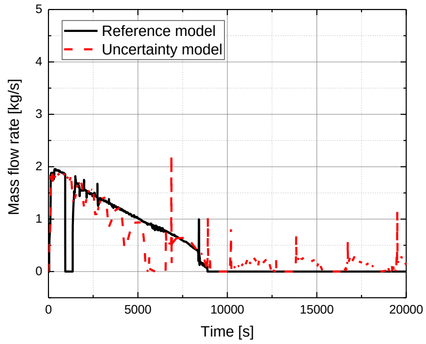
(a) Mass flow rate



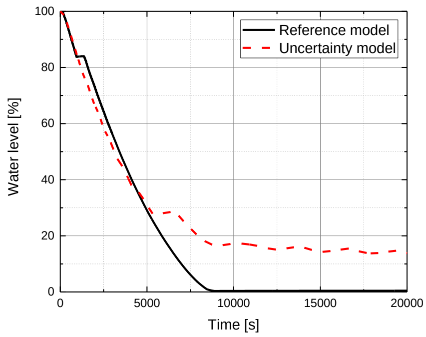
(b) Vessel water level

Fig. 5. Effect of pipe aging results

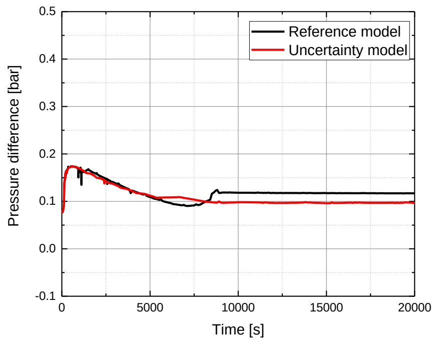
3) When the **model uncertainty** is large, the predictive performance of PECCS coolant injection may change significantly. In the CMT tank, wall condensation at the inner wall could make uncertainty. With this uncertainty, CMT pressure relatively low since a large amount of steam is condensed on the upper part of the tank. Also, as the driving force decreased, check valve could be closed.



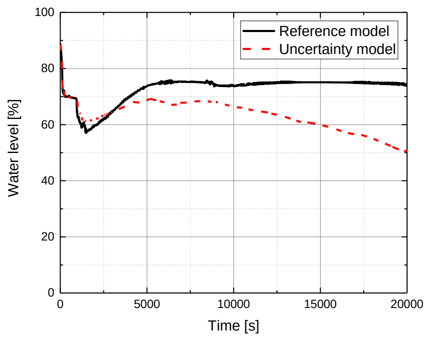
(a) Mass flow rate



(b) CMT water level



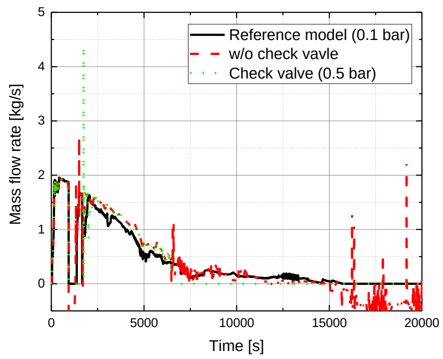
(c) Pressure difference between CMT inlet/outlet



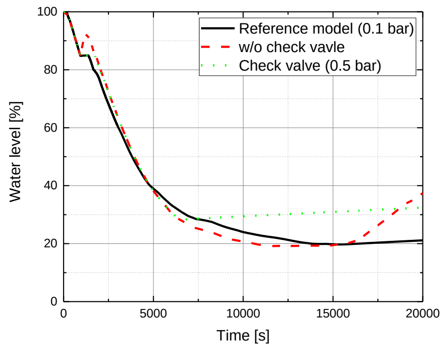
(d) Vessel water level

Fig. 6. Effect of model uncertainty results

4) In the presence of a **check valve**, the reduction in driving force may cause the valve to close, reducing the performance of the driven system. Furthermore, if the check valve is not properly modeled, it may distort the phenomenon as the coolant flows back into the CMT.



(a) Mass flow rate



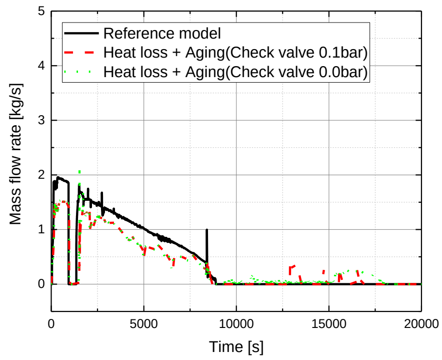
(b) CMT water level

Fig. 7. Effect of check valve results

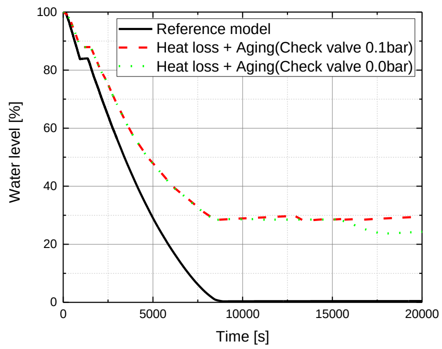
3.3 Comprehensive effect Assessment of Performance Issues

Although the effect of individual performance issues may be negligible, when they occur simultaneously, the change in system performance can vary greatly. Therefore, in this study, the effect on PECCS injection performance was analyzed when comprehensively considering the heat transfer model uncertainty (wall condensation at tank inner wall), heat loss (tank outer wall), and aging (pipe flow area) that directly affect the CMT injection flow rate.

As shown in analysis result, the CMT injection flow rate decreases and shows unstable behavior. Furthermore, in order to the large amount of condensation in the CMT, the pressure of CMT decreases and core make-up water injection is stopped after about 8,500 seconds. When the operating differential pressure of the check valve is 0.1 bar, the core make-up water is intermittently injected into the reactor vessel, but the amount is very small. In conclusion, although the effect of each issue on the PECCS is small, the effect can be large if these issues are considered comprehensively.



(a) Mass flow rate



(a) CMT water level

Fig. 8. Comprehensive effect analysis results

4. Conclusion

The PSS has a small driving force, so its performance may vary greatly due to various internal and external factors. In order to confirm the effect of issues on the PECCS performance, an example analyses were performed on the conceptual model of the PECCS using MARS-KS v1.5.

Firstly, effect of fluid leakage, atmospheric temperature, fire, NC gas, and piping heat loss on the PSS injection performance is small. Performance of PECCS could be reduced with earthquake, aging deterioration, and model uncertainty. Check valve may fail under low driving force condition, and the PSS performance may decrease. In order to analyze the effect of issues when they occur simultaneously, comprehensive effect analysis was also conducted in this study.

The results of this study provide qualitative insights about the effects of various internal and external issues on the PECCS performance. Since these results could give understanding how each performance issues affect the system, it is expected that this study could be helpful to actual design of the PSSs.

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.

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