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Performance Degradation Analysis for Passive Safety System under Parameter Combination

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1. Introduction

Passive Safety Systems (PSS) have been widely adopted in Advanced Light Water Reactors (ALWRs) due to their higher reliability and safety compared to active safety systems [1].

Recently, a functional failure approach was introduced to evaluate the reliability of PSS [2]. This approach defines functional failure of PSS as a situation where the current performance (capacity) of PSS is insufficient to meet the required performance (load) under changed operational or design conditions, due to uncertainties in parameters and environmental conditions, even when PSS is being operated. Combination of changed parameters in PSS also raises complexity in performance and reliability evaluation of PSS that natural circulation provides less driving force compared to forced convection. Therefore, it is necessary to identify a parameter combination which has higher possibility of occurrence and significant performance degradation in passive safety system.

In this study, sensitivity analysis was conducted using MARS-KS code [3] to provide analysis data to identify what parameter combination lead to performance degradation of passive safety system in integrated PWR-type small modular reactor.

2. MARS-KS modeling

Simplified input model, V-SMART model based on SMART100 as a reference, was developed for research purpose.

In the V-SMART model as shown in Fig. 1, merged-single train of steam generator, reactor coolant pump, Passive Residual Heat Removal System (PRHRS) and Passive Safety Injection System (PSIS) were applied to reduce computational cost and maintain key physical phenomena for symmetric accident condition.

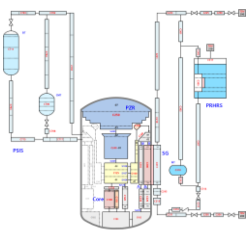


Fig. 1. V-SMART model for MARS-KS analysis.

Total Loss of Flow (TLOF) accident was selected to focus on the effect of parameter change and combination in PRHRS and Reactor Coolant System (RCS). Selected parameters related to PRHRS heat transfer, pressure drop and RCS are listed in Table I.

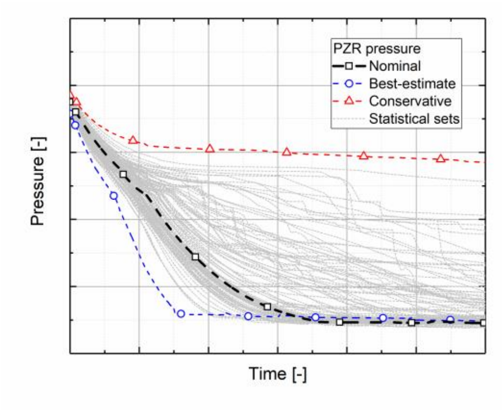
Table I: Selected parameters for sensitivity analysis

	Parameters
RCS parameters	• Initial core power • Initial RCS flowrate • Initial pressurizer level • Initial RCS pressure
PRHRS heat transfer parameters	• Model uncertainty (boiling, condensation) • Thermal conductivity of PRHRS heat exchanger • Initial temperature of ECT • Heat loss (temperature, heat transfer coefficient) • Non-condensable gas
PRHRS pressure drop parameters	• Pipe roughness • Flow area reduction by fouling • Model uncertainty (single and two-phase flow friction factor)

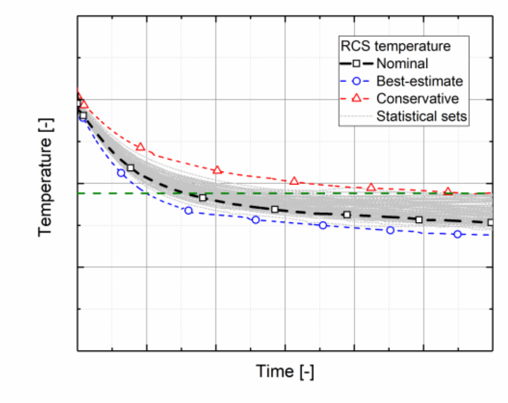
3. Analysis results

Sensitivity test for performance degradation analysis was conducted with 100 statistical sets of parameter combination which selected by random sampling from DAKOTA program [4] with assigned probabilistic distribution (normal or uniform) for each parameter. Additionally, best and worst parameter combination for TLOF were also selected by author within assigned range and analyzed as best-estimate case and conservative case, respectively. Also, the minimum DNBR, maximum RCS pressure and RCS temperature were considered as safety requirements in this study.

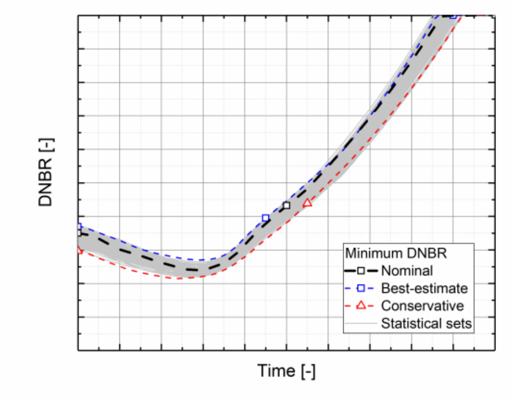
Analysis results for all 103 cases including nominal, statistical sets, best-estimate and conservative are shown in Fig. 2. Analysis results of RCS pressure (see Fig. 2(a)), RCS temperature (see Fig. 2(b)) and minimum DNBR (see Fig. 2(c)) were bounded by best-estimate and conservative cases and met the safety requirement. However, performance degradation of PRHRS heat removal in several cases of statistical sets was occurred, as shown in Fig. 2(d), while analysis results of all cases were met the safety requirements.



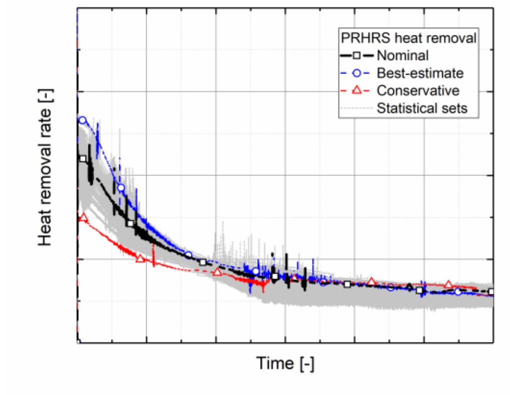
(a) RCS pressure



(b) RCS temperature



(c) Minimum DNBR



(d) PRHRS heat removal

Fig. 2. Results of performance degradation analysis.

4. Conclusions

Performance degradation of PRHRS under randomly selected parameter combination was analyzed. By the analysis of V-SMART model, all parameter combination including nominal, best-estimate and conservative cases were met the safety requirement of TLOF accident. However, performance degradation of PRHRS during TLOF accident was occurred with several sets of parameter combination. Those results can provide the insight that what parameter combination lead to performance degradation of PRHRS. Furthermore, detailed analyses are required to determine the realistic safety margin.

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