

## Development of a Pre-operational Test Evaluation Strategy for SMART100 PRHRS Using the Robustness Assessment Methodology

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### 1. Introduction

Passive Safety Systems (PSSs) operate based on natural phenomena such as natural circulation and density differences, and therefore have the advantage of not relying on external power or active components such as pumps. However, due to their inherently small driving force, PSSs are sensitive to various performance degradation factors.

In previous study, Korea Institute of Nuclear Safety (KINS) developed Robustness Assessment Methodology for PSSs, as illustrated in Fig. 1 [1], and systematically evaluated the impact of performance degradation factors under accident conditions using system code, MARS-KS[2].

In this study, the previously developed Robustness Assessment Methodology is applied to derive a pre-operational test evaluation strategy for SMART100. Since PSSs do not utilize pumps, pre-operational testing requires verification that system performance can be adequately demonstrated under plant operating conditions comparable to actual operation. Due to practical constraints, it is not feasible to conduct numerous test cases for PSS during pre-operational testing. Therefore, the most limiting condition must be identified to demonstrate that the system can sufficiently contribute to accident mitigation even under restrictive test environments.

Accordingly, this study establishes representative plant conditions for pre-operational testing and applies the robustness assessment methodology to identify the most appropriate limiting condition for PRHRS performance verification.

### 2. Development of the Reference Model for SMART100 Pre-operational Test

Since it is difficult to replicate full accident conditions during pre-operational testing, a strategy was adopted in which the most limiting condition was

analytically identified, and testing was proposed under that condition.

The reference input model was developed based on the SMART100 research model (Fig.2) with the following assumptions(Fig. 3):

- Removal of core heat source
- Pump heat generation assumed as 2 MW
- Pressurizer pressure: 15 Mpa
- Steam generator pressure: 5.72 Mpa
- RCS flow rate: design value

In the reference model simulation, PRHRS was actuated to analyze the cooling behavior of the RCS. As shown in Fig. 4, the RCS temperature reached the safe shutdown temperature (488 K) approximately 12,000 seconds after PRHRS actuation. The PRHRS heat removal rate (Fig. 5) increased rapidly in the initial phase and then converged as it balanced the 2 MW pump heat generation.

### 3. Preliminary Evaluation Based on the Robustness Assessment Methodology

Through the application of Robustness Assessment Methodology to SMART100, major performance degradation issues of PRHRS were identified [2] as summarized in Tables 1. Pre-operational test of PRHRS were performed considering these issues (Figs. 6 - 9).

The evaluation results indicated that degradation of PRHRS heat exchanger performance due to aging (25% reduction in heat removal capability) was the most conservative condition. Under this condition, the time to reach the RCS safe shutdown temperature was delayed by approximately 2,000 seconds compared to the reference case.

Furthermore, in cases involving non-condensable gas accumulation, a reduction in PRHRS heat removal performance was observed, resulting in a tendency for RCS temperature to increase during the later phase of the transient. This indicates that if PRHRS heat removal becomes lower than the pump heat generation (2 MW)

due to the presence of non-condensable gas, sufficient cooling cannot be maintained.

Based on these evaluation results, a condition in which PRHRS heat exchanger performance is reduced to 75% of its nominal capacity was proposed as the optimal pre-operational test scenario (Fig. 10). Although the time to reach the safe shutdown temperature was delayed by approximately 2,000 seconds compared to the reference case, sufficient cooling capability was ultimately confirmed.

Therefore, by conducting testing under the most limiting credible condition, the operability of the passive safety system can be demonstrated with a relatively small number of test cases.

#### 4. Conclusions

In this study, Robustness Assessment Methodology for PSSs was applied to the development of a pre-operational test strategy for SMART100 PRHRS. The following conclusions were derived:

- Development of a reference model for pre-operational testing
- Evaluation of essential performance degradation issues and parameter combinations
- Proposal of a 75% PRHRS performance condition as the optimal limiting test scenario

However, performing cooling tests under actual plant operating conditions during pre-operational testing may impose excessive mechanical or thermal stress on plant components. Therefore, future work will focus on proposing a more practically applicable pre-operational test strategy that ensures equipment integrity while maintaining sufficient conservatism.

In addition, the methodology will be extended to develop pre-operational test evaluation strategies for PSIS as well as other passive safety systems.

#### ACKNOWLEDGMENTS

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#### REFERENCES

[1] J. Lee et al., Development of robustness assessment methodology for passive safety system against potential

performance issue, Nuclear Engineering and Design, 449, 114755, 2026.

[2] 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.

Table 1. Major performance degradation issues of PRHRS

Derived Major Performance Issues for PRHRS		
Distortion of temperature distribution	Heat loss	$HTC_{\text{pipe}} \leq 10$ W/m <sup>2</sup> K
	Fire	Heat flux $\leq 10$ kW/m <sup>2</sup>
Change of heat transfer rate	NC gas	$m_{\text{NC}} \leq 1$ kg/EA
	Ambient Temp	$HTC_{\text{ETC}} \leq 10$ W/m <sup>2</sup> K
	Aging/Blockage(HX)	$A_{\text{blockage}} \leq 25\%$ of $A_{\text{pipe}}$
	Model uncertainty (heat transfer)	Fouling factor: 0.75 ~ 1.25
Additional operation issue	Single Failure	-
	Operation delay (1EA)	$t_{\text{delay}} \leq 50,000$ sec

Derived Major Uncertainty Parameters for PRHRS

Parameter	Nominal value	Uncertainty
Core power	365 MW	3% (Uniform)
Fouling factor	1.0	12.5% (Normal)
Area (PRHRS)	0.01533 m <sup>2</sup> (Steam line)	12.5% (Normal)
	0.00426 m <sup>2</sup> (Return line)	
ECT Temp.	298.15 K	15.0 K (Uniform)
NC gas	0.0 kg/EA	0.5 kg/EA (Normal)

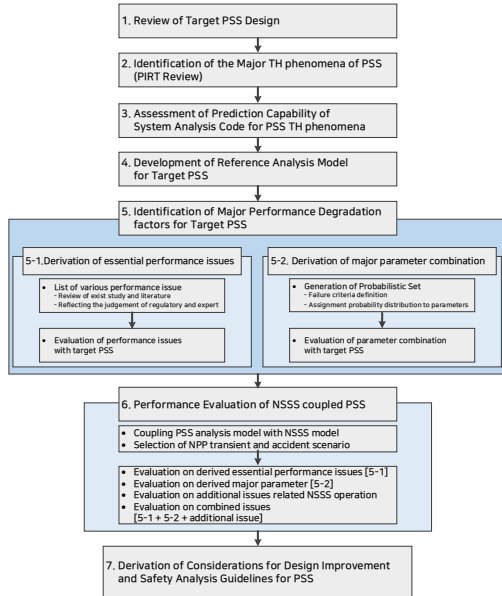


Fig. 1. Robustness Assessment Methodology for Passive Safety System [1]

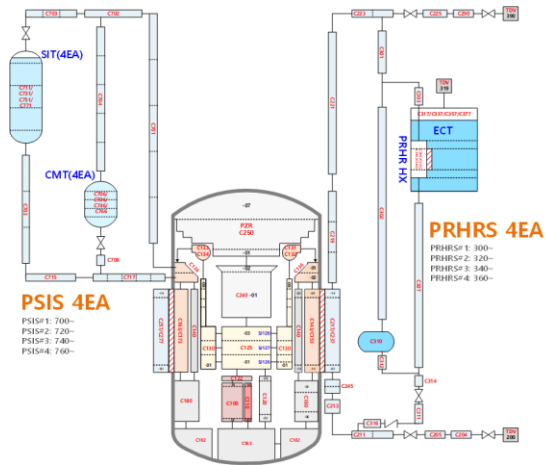
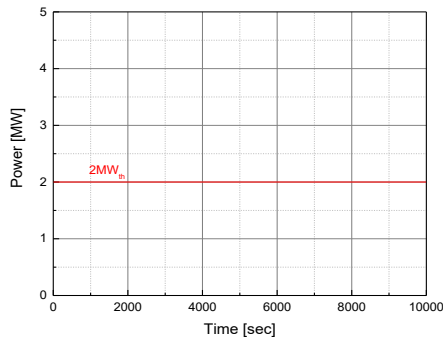
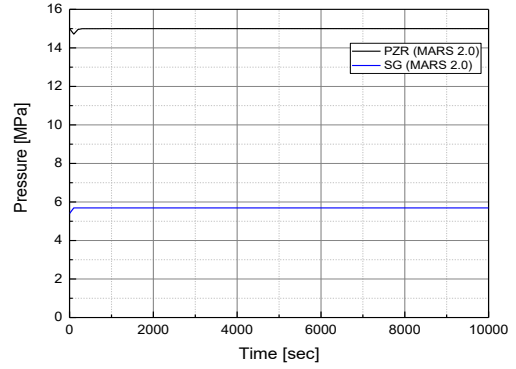


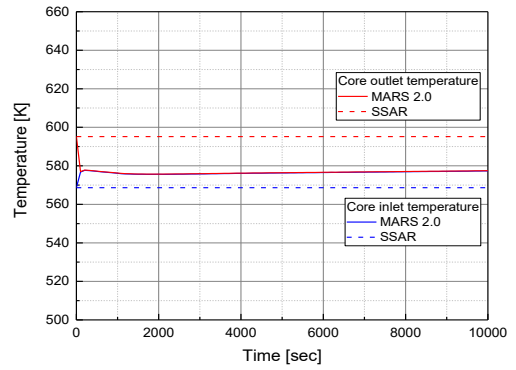
Fig. 2. Nodalization of SMART100 input model for MARS-KS



(a) Power



(b) PZR/SG pressure



(c) Core inlet/outlet temperature

Fig. 3. Steady state calculation results for PRHRS pre-operational test

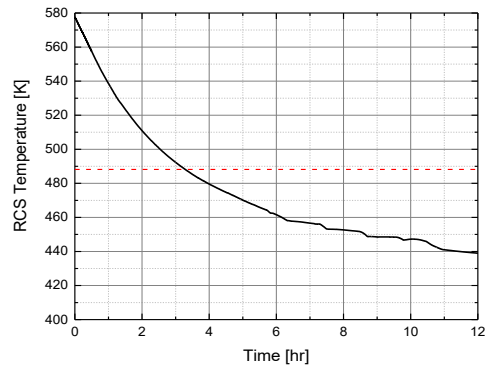


Fig. 4. Assessment result of reference model – RCS Temperature

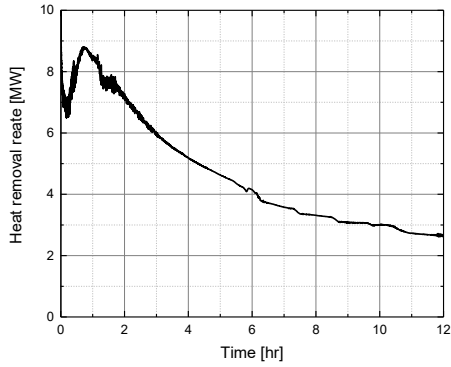


Fig. 5. Assessment result of reference model – PRHRS heat removal rate

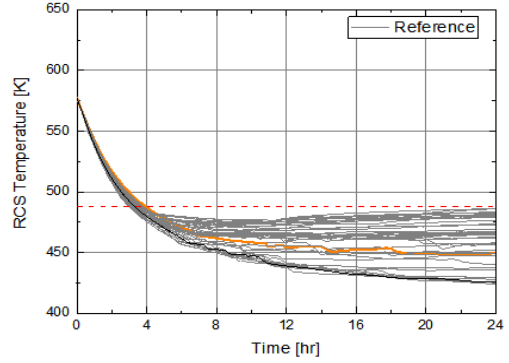


Fig. 8. Assessment result of major parameter combinations – RCS temperature

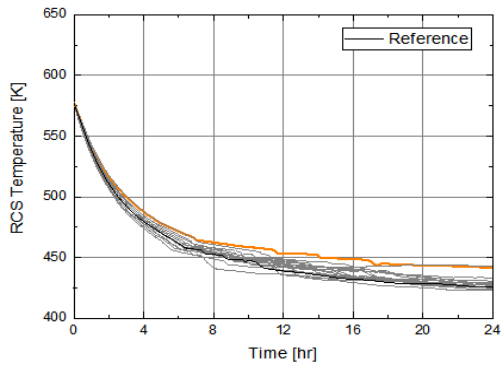


Fig. 6. Assessment result of essential performance issues – RCS temperature

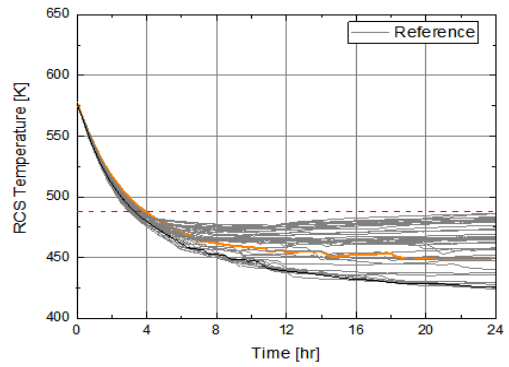


Fig. 9. Assessment result of major parameter combinations – Heat removal rate

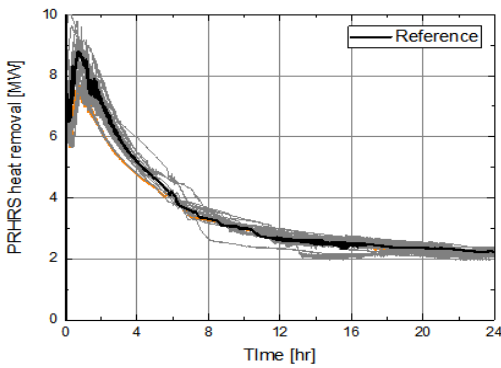


Fig. 7. Assessment result of essential performance issues – PRHRS heat removal rate

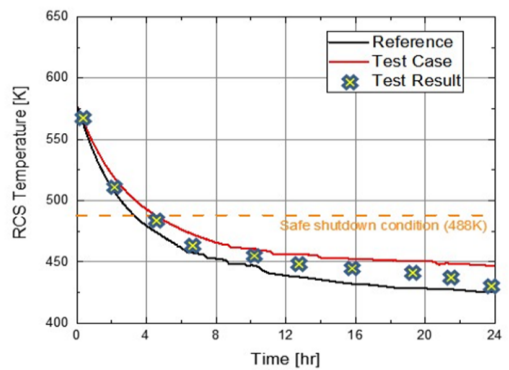


Fig. 10. Derivation of pre-operational test condition for PRHRS