

The Development of Phenomena Identification and Ranking Table for Innovative Small Modular Reactor

Yerim Park*, MinJeong Kim, and Dong-Hyuk Lee

Korea Hydro & Nuclear Power Co., LTD. Central Research Institute, 70, Yuseong-daero, 1312 beon-gil, Yuseong-gu, Daejeon, Republic of Korea

*Corresponding author: yerim.park@khnp.co.kr

***Keywords : i-SMR, PIRT, Passive System, DBA, SPACE**

1. Introduction

Under the leadership of Korea Hydro & Nuclear Power Co. (KHNP), the Korean nuclear industry is advancing the standard design of an innovative small modular reactor (i-SMR). The goal is to submit the standard safety analysis report by 2025 and obtain the standard design approval by 2028. In the i-SMR, the passive safety systems are applied to enhance the safety of the nuclear power plant and ensure maximum safety margins. For this new reactor type, it is essential to establish unique design basis accident classifications reflecting the characteristics of the i-SMR. When an identified accident occurs, it is necessary to analyze important physical phenomena that may take place in the primary and secondary systems, as well as in the containment vessel. Therefore, the development of a phenomena identification and ranking table (PIRT) for the i-SMR is required. The developed PIRT can be utilized to improve the thermal-hydraulic models of safety analysis codes, validate safety analysis codes and derive experimental items.

Since the i-SMR design is still under development, this study is based on the design specifications established as of December 2023.

2. Development Methodology and Process

To develop the PIRT, an expert panel composed of professional expert from industry, academia, and research institutes was organized. The panel included 17 experts specializing in nuclear safety analysis and thermal-hydraulic experiments. Over a period of 10 months, the panel conducted nine meetings to determine accident scenarios, important systems and components, important thermal-hydraulic phenomena for each component, importance rankings, and knowledge levels.

The PIRT development process was established by referring to previous PIRT development research, particularly studies conducted by Gary Wilson et al. The process was simplified based on these references [1-3].

2.1 Definition of Problem and Objective

To confirm the safety of the i-SMR, it is essential to analyze design basis accidents and multi-failure

accidents. Due to the characteristics of i-SMR, the thermal-hydraulic behavior is expected to differ from that of commercial nuclear reactors. The PIRT aims to systematically identify important thermal-hydraulic phenomena during accident scenarios.

2.2 Identification of Key Design Features

By 2023, KHNP completed the conceptual and basic design of the i-SMR. The key design features are summarized in Table I [4].

Table I: The Key Design Features of the i-SMR

Design Feature	Value
Core Power	520 MWth
Electric Power	170 MWe
Steam Generator	1 EA
Type of Steam Generator	Once-through Helical Type
Reactor Coolant Pump	4 EA
Type of Reactor Coolant Pump	Vertical, Canned Motor, Mixed Flow
Core Damage Frequency	$< 10^{-9}$ /RY
Large Early Release Frequency	$< 10^{-10}$ /RY
Design Life-time	80 yr

2.3 Collection of Experimental and Analytical Data

The Verification test research for the newly introduced design features of the i-SMR is currently being conducted. In this study, passive safety system tests conducted for APR+ and i-POWER, as well as LOCA and Non-LOCA analyses performed in the basic design phase of the i-SMR, were reviewed.

2.4 Selection of Target Accident and Scenario Review

The accident categories classified in Regulatory Guide 1.70 were reviewed, and representative accidents for LOCA and Non-LOCA scenarios were selected. The target accidents were selected as a steam line break (SLB)

outside the containment vessel and a modular makeup and purification system (MMPS) charging line break accident. The scenarios for these accidents are described in detail in the references [5, 6].

2.5 Categorization of Accident Phase and Determination of Figure of Merit

For the SLB accident, the accident sequence was divided into two phases: pre-trip and cool down phase. The selected figure of merit (FOM) were the departure from nucleate boiling ratio and the primary system temperature.

For the MMPS charging line break accident, the phases were divided into three: pre-trip, core boil-off, and circulation cool down. The selected FOM were the peak cladding temperature, core water level, and containment vessel pressure.

2.6 Classification of Component and Identification of Thermal-hydraulic Phenomena

The system and component were categorized into 6 major systems, 20 sub-systems, and 61 individual components. The major systems are divided into fuel system, reactor coolant system, passive auxiliary feedwater system, passive containment cooling system, passive emergency core cooling system and containment vessel system. The 126 important thermal-hydraulic phenomena were identified and categorized.

2.7 Determination of Importance Ranking and Knowledge Level

The importance ranking and knowledge level were classified into High, Middle, and Low. The phenomena that do not occur were marked as N/A. The detailed criteria and descriptions for these classifications are presented in Table II and Table III. Based on panel discussions, the importance ranking and knowledge level for each important thermal-hydraulic phenomenon were determined. The importance ranking level was determined according to each accident phase.

Table II: The Description of Importance Ranking

Classification	Importance Ranking
High	High Influence on FOM Experimental Simulations & Analytical Modeling, with High Accuracy, are Critical
Middle	Moderate Influence on FOM Needs to be Experimentally Present and/or Analytically Modeled with Moderate Degree of Accuracy
Low	Low Influence on (or low Importance to) FOM Very Low Importance

Table III: The Description of Knowledge Level

Classification	Importance Ranking
High	Fully Known (70~100%) Small Uncertainty
Middle	Partially Known (30~70%) Moderate Uncertainty
Low	Very Limited Known (0~30%) Large Uncertainty

2.8 Documentation

The PIRT report was published by summarizing the discussions and results from the expert panel meetings.

3. Result

In SLB accident, three thermal-hydraulic phenomena with middle or high importance level but middle knowledge level were derived. These phenomena occur in the reactor coolant system and passive auxiliary feedwater system heat exchanger.

The 19 thermal-hydraulic phenomena were identified where the importance ranking was middle or high, but the knowledge level was middle, in MMPS line break accident. The identified phenomena include heat transfer in the containment vessel inner wall.

4. Conclusion

In this study, the PIRT for i-SMR was developed, selecting SLB and MMPS charging line break accident as target accident. The important thermal-hydraulic phenomena of the i-SMR were identified through the PIRT. The PIRT can be utilized in developing the i-SMR design feature model in safety analysis code and improving the code to ensure its applicability. In addition, the PIRT can be utilized in deriving experimental items for the thermal-hydraulic verification of the i-SMR. Within the i-SMR development project, integral effect tests and separate effect tests will be conducted to reduce uncertainties in the thermal-hydraulic phenomena of the i-SMR.

ACKNOWLEDGMENTS

This work was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korea Government (MSIT) (No. RS-2024-00403548).

REFERENCES

- [1] Gary E. Wilson, "The role of the PIRT process in experiments, code development and code applications associated with reactor safety analysis", Nuclear Engineering and Design, Vol. 186, pp. 23-37 (1998).
- [2] Korea Hydro & Nuclear Power (KHNP), PIRT Report for Multiple Failure Accidents, (2016)

- [3] Korea Atomic Energy Research Institute (KAERI), Development of a Phenomena Identification and Ranking Table (PIRT) of Thermal Hydraulic Phenomena for SMART, KAERI/TR-3780/2009, (2009)
- [4] Korea Hydro & Nuclear Power (KHNP), Technology Development for Innovative Small Modular Reactor (I), (2023)
- [5] Korea Hydro & Nuclear Power (KHNP), LOCA safety analysis report for iSMR, iSMR-K-X-PDR(R)-23004-P (Rev.A), (2023)
- [6] Korea Hydro & Nuclear Power (KHNP), Non-LOCA safety analysis report for iSMR, iSMR-K-X-PDR(R)-23005-P (Rev.A), (2023)