

Preliminary Identification of Thermal-Hydraulic Phenomena for the Development of a PIRT for the HECTAR

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) is developing HECTAR, a high-temperature gas-cooled reactor (HTGR) intended for industrial process heating applications. As the design progresses, ensuring the reliability of safety analyses has emerged as a critical technical challenge for licensing and regulatory approval.

To conduct reliable safety analyses, it is essential to systematically identify dominant thermal-hydraulic phenomena under normal and accident conditions and evaluate their importance. The Phenomena Identification and Ranking Table (PIRT) is a structured methodology that identifies key phenomena associated with specific accident scenarios and systems, evaluating the importance and knowledge level of each phenomenon based on expert judgment. This approach provides a technical basis for reviewing the adequacy of analysis models, as well as for code development, improvement, and the establishment of experimental plans. [1]

In this study, prior to the formal development of a PIRT for HECTAR, a preliminary identification of thermal-hydraulic phenomena was performed. This involved reviewing HECTAR's design characteristics and key systems/components, and analyzing existing HTGR PIRTs and relevant literature. As a result, representative thermal-hydraulic phenomena anticipated to be significant under HECTAR's design and accident conditions were derived. These will serve as a technical basis for the subsequent phased development of the PIRT.

2. Design Review of HECTAR

HECTAR comprises the Reactor System, the Heat Transport System (HTS), and the Reactor Cavity Cooling System (RCCS). The Reactor System transfers fission heat generated in the core to the helium coolant and safely contains it within the pressure boundary. The HTS forms the primary heat removal pathway, transferring this thermal energy to the secondary system. Furthermore, the RCCS controls the temperature of the cavity concrete during normal operation and provides passive safety functions by removing decay heat during accidents.

Within the reactor system, the helium coolant-releasing heat in the steam generators-enters at a low temperature through the inlet nozzle at the bottom of the reactor pressure vessel (RPV). It reaches pressure

equilibrium and is distributed within the inlet plenum. The coolant then moves along the riser between the core barrel and the RPV inner wall, to the upper plenum. Upon reaching the Upper Plenum, the coolant undergoes redistribution before flowing downward through each fuel channel, absorbing heat generated by fission within the Core and Reflector regions. During this process, heat from the TRISO fuel is conducted through the graphite matrix and reflector, then convectively transferred to the helium. The high-temperature helium, heated as it passes through the core, collects in the lower plenum. After thermal mixing, it is transferred through the outlet nozzle into the hot gas duct.

The HTS conveys the high-temperature helium exiting the reactor through the cross duct to the steam generator, where heat exchange occurs. It then recirculates the cooled helium back to the reactor. The cross duct comprises a dual-duct structure consisting of a high-temperature gas duct and a low-temperature gas duct, forming the flow path for the primary system. Within the steam generator, heat exchange occurs between the primary-side single-phase helium and the secondary-side feedwater, thereby producing high-temperature, high-pressure steam. After heat exchange, the cooled helium overcomes pressure drop and is forcibly circulated by the Helium Circulator, re-entering the reactor system.

The RCCS is a passive safety system designed to remove radiant heat emitted from the RPV outer wall. Riser tubes installed between the RPV outer wall and the concrete containment wall absorb radiant heat emitted from the vessel surface, heating the internal coolant and inducing natural circulation due to density differences. The heated coolant is collected in the outlet header and transferred to the air cooler, where heat is released to the external atmosphere. The cooled water is distributed through the inlet header to the downcomer tubes, descends to the lower section, and reconnects to the riser to continue the cycle. The cooling tower, located outside the reactor building, releases the heat transferred through the RCCS riser to the atmosphere, which serves as the ultimate heat sink.

3. Identification of Key Thermal-Hydraulic Phenomena

Based on a review of existing literature on HTGR, key thermal-hydraulic phenomena were identified for each system and component of HECTAR, taking into account

its design characteristics and system configuration. The derived phenomena are summarised in Fig. 1, with emphasis on the thermal-hydraulic behaviour expected to dominate under both steady-state and accident conditions.

In the core region of the reactor system, the dominant phenomena include 1) heat generation by fission and conductive heat transfer in solid structures, 2) convective heat transfer in the helium coolant, and 3) bypass flow through inter-block gaps. In the steam generator of the HTS, the principal phenomena include 1) single-phase

convective heat transfer on the primary helium side, 2) two-phase heat transfer associated with boiling on the secondary side, and 3) pressure drop characteristics within the flow paths.

The identified thermal-hydraulic phenomena will form the basis for subsequent assessment of importance and knowledge level in the development of the PIRT framework. These phenomena will be further refined and updated in accordance with the progress of HECTAR design and safety analysis.

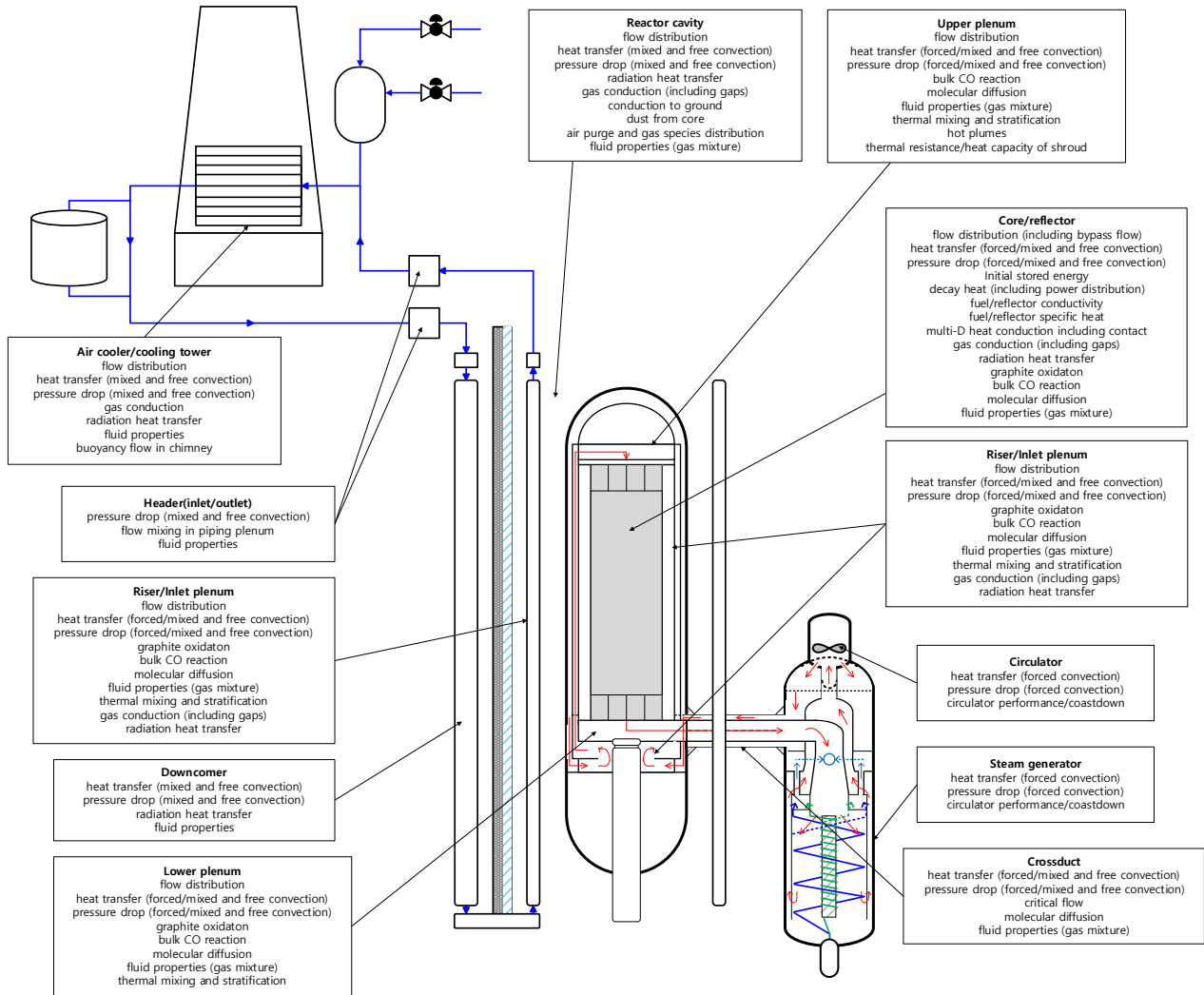


Fig. 1. Main thermal-hydraulic phenomena in HECTAR

4. Conclusion

This study performed a design review and identified key thermal-hydraulic phenomena as a foundational step toward the development of a PIRT for HECTAR. The configuration and flow characteristics of the reactor system, HTS, and RCCS were examined, and the phenomena expected to govern system behaviour under steady-state and accident conditions were derived.

The scope of this paper is limited to the identification of candidate phenomena for future PIRT development. Quantitative evaluation and ranking of the Importance Level (IL) and Knowledge Level (KL) was not conducted within the present study.

Based on the identified phenomena, a PIRT structured as illustrated in Table I will be developed in subsequent work. The IL and KL of each phenomenon will be systematically assigned as High, Medium, or Low through expert panel evaluation, ultimately leading to the

establishment of a comprehensive PIRT to support HECTAR design and safety analysis.

Table I: Main thermal-hydraulic phenomena in HECTAR

System	Component	Phenomena	Accident #1		Accident #2	
			IL	KL	IL	KL
			NRC	NRC	NRC	NRC
Sys #1	Comp #1-1	Phenomena #1-1-1	H	L	H	L
		Phenomena #1-1-2	M	M		
		Phenomena #1-1-3		M		M
	Comp #1-2	Phenomena #1-2-1	H	L	H	L
		Phenomena #1-2-2	H	M	H	M
		Phenomena #1-2-3	H	M	H	M
	Comp #1-3	Phenomena #1-3-1	H	L	H	L
		Phenomena #1-3-2	H	L		
		Phenomena #1-3-3	H	L	M	L
Sys #2	Comp #2-1	Phenomena #2-1-1	M	L	H	L
		Phenomena #2-1-2		M		M
	Comp #2-2	Phenomena #2-2-1	H	L	H	L
		Phenomena #2-2-2	H	M	H	M
Sys #3	Comp #3-1	Phenomena #3-1-1	H	L	H	L
	Comp #3-2	Phenomena #3-2-1	L	M	L	M
		Phenomena #3-2-2	H	L	H	L
Sys #4	Comp #4-1	Phenomena #4-1-1	H	M	H	M
		Phenomena #4-1-2	H	M	H	M

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