VHTR Thermal Fluids PIRT Development Based on the Previous PIRTs Developed by Licensee and Regulatory Authority

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1. Introduction

The PIRT (Phenomena Identification and Ranking Table) provides a structured means of identifying and analyzing a wide variety of off-normal sequences that potentially challenge the viability of complex technological systems. As applied to VHTR (Very High Temperature Reactor), the PIRT is used to identify a spectrum of safety-related sequences or phenomena that could affect those systems, and to rank order those sequences on the basis of their frequencies, their potential consequences, and state of knowledge related to associate phenomena.

VHTR Thermal Fluids PIRTs were developed by KAERI, ANL, and NRC [1, 2, 3]. PIRTs of KAERI and ANL evaluated the importance levels of phenomena for each system/component according to events and sequence phase. But knowledge level were not evaluated because the detailed design was not yet decided. For NRC PIRT, the importance and knowledge levels of Issues were evaluated instead of phenomena. The Issue of NRC PIRT contains the phenomena and system/component information together and doesn't distinguish the system/component separately [4].

The KINS VHTR Thermal Fluids PIRT has been developed to obtain the complete PIRT shape by complementing the PIRTs of NRC, KAERI and ANL. KINS VHTR PIRT is focused on the Prismatic Modular Reactor (PMR) design. Pebble Bed Reactor (PBR) design was excluded from KINS PIRT through the discussion at the PIRT Panel meeting.

2. Development of KINS VHTR Thermal Fluids PIRT

2.1 Event Classification

Table 1 shows the event classification of KAERI, ANL, and NRC PIRT. Although there are some differences in the event sequences between NRC and KAERI/ANL, the events except for water ingress can be matched with each other. Load Change can be included in Normal Operation. Conduction Cooldown is the same concept with LOFC (Loss Of Forced Circulation). General LOFC is absorbed to Pressurized LOFC and Depressurized LOFC in KINS PIRT. NGNP design options with a high-pressure steam generator (Rankine cycle) in the primary loop are not considered in NRC PIRT. Hence, water ingress was eliminated from current NRC PIRT. But water ingress is included in KINS PIRT to maintain the conservative regulatory position. If detailed design is determined and the possibility of water ingress is shown to be very low, it will be eliminated in KINS VHTR PIRT. So the seven event categories were selected for KINS VHTR PIRT as shown in Table 1.

Table 1 PIRT Event Classification

KAERI/ANL	NRC	KINS
- High Pressure Conduction Cooldown (HPCC) - Low Pressure Conduction Cooldown (LPCC) - Load Change - Water Ingress - Rod Withdrawal ATWS - Hydrogen Plant Upset	- Normal operation - General LOFC (Loss Of Forced Circulation) - Pressurized LOFC - Depressurized LOFC - Air ingress LOFC - Reactivity (ATWS) - IHX failure	- Normal operation - Pressurized LOFC - Depressurized LOFC - Air ingress LOFC - Water-Steam Ingress - Reactivity (ATWS) - IHX failure (Hydrogen Plant Upset)

2.2 PIRT Phenomena

There are 100 issues in NRC PIRT and 50 phenomena in KAERI and ANL PIRTs. The issues of NRC PIRT and the phenomena of KAERI and ANL PIRTs were analyzed and divided into 36 phenomena in Table 2. The phenomena for PCU (Power Conversion Unit), IHX (Intermediate Heat Exchanger), and RCCS (Reactor Cavity Cooling System) are very complex and diverse but the detailed design for these systems is not determined. So the phenomena for PCU, IHX and RCCS are integrated as shown in shaded parts of Table 2. If the detailed design for these systems is determined, then the phenomena will be divided into more concrete phenomena.

2.3 System/Component Classification

Conventionally, the PIRT for each event sequence is divided by system/component categories. The PIRT of KAERI and ANL supplies system/component classification. But NRC PIRT type is different from

KAERI and ANL PIRT, and system/component information is included in the Issue of NRC PIRT. System/Components of KINS PIRT are classified as shown in Table 3 considering System/Component classification of KAERI and ANL PIRTs and the System/Component-related information from Issue of NRC PIRT.

Table 2 PIRT Phenomena

No	Phenomena	No	Phenomena
1	Bulk CO Reaction (Homogeneous Chemical Reaction)	19	PCU (Power Conversion Unit) Characteristics and Performance
2	Cavity Structural Integrity	20	Jet Discharge
3	Gas Conduction Heat Transfer	21	Material Properties of Fuel and Reflector
4	Confinement Valve and Filter Characteristics	22	Multi-Dimensional Heat Conduction
5	Contact Heat Transfer	23	Molecular diffusion
6	Control and Reserve Rod Worth	24	IHX Characteristics and Performance
7	Convective Heat Transfer	25	Pressure Drop
8	Core Configuration	26	Pressure Waves
9	Core Decay Heat (including Power Distribution)	27	RCCS Characteristics and Performance
10	Critical Flow	28	Radiation Heat Transfer
11	Dust from Core	29	Reactivity Feedback
12	Thermal Mixing and Gas Species Stratification	30	Stored (Wigner) Energy Releases (Annealing)
13	Fluid Properties	31	Flow Distribution
14	Gas/water purge and Gas Species Distribution	32	Thermal Resistance/Heat Capacity of Shroud
15	Conduction to Ground	33	Thermal Striping
16	Graphite Hydrolysis	34	Two-Phase Flow
17	Graphite Oxidation	35	Water/Steam Ingress from SCS, S/G or PCU Unit
18	Hot Plume	36	Xenon Concentration

Table 3 System/Component Classification

System	Component
Reactor Vessel	Inlet Plenum
	Riser
	Top Plenum and Components
	Core & Reflectors
	Outlet Plenum and Components (including Lower Head)
Hot/Cold Pipe	
IHX	
SCS, S/G, PCU	
RCCS	Reactor Cavity (Confinement)
	RCCS

2.4 Importance and Knowledge Level Ranking

Five PIRT panels are gathered from academia, industry and national research institute. They evaluated importance and knowledge levels from 1 to 5 points for system/component, phenomena, and events determined in the previous sections. Though the five-level ranking is applied to the individual panel PIRT ranking, the ranking results are simplified to three-level ranking having High, Medium, Low ranks in the process of integration. Table 4 shows the final KINS VHTR Thermal Fluids PIRT examples for core and reflector component. The phenomena with high importance level and low knowledge level will be significant for the corresponding component and event.

The direct comparison between KINS PIRT and the previous PIRTs of KAERI, ANL, and NRC is difficult due to the differences of PIRT shape, phenomena, system/component, and events. KINS PIRT developed here has the conventional PIRT shape composed of phenomena, event, and system/component except that the event sequence phase is not considered. KINS PIRT encompasses all the phenomena, events, system /component considered in the previous PIRTs of KAERI, ANL, and NRC. So it represents the viewpoint of the regulatory authority as well as the licensee.

Table 4 KINS VHTR Thermal Fluids PIRT

No.	Component	Phenomena	Normal Operation (Load Change)		Pressurized LOFC		Depressurized OFC		Air Ingress LOFC		Water-Steam Ingress		Reactivity (ATWS)		IHX Failure (Hydrogen Plant Upset)	
			IL	KL	IL	KL	IL	KL	IL	KL	IL	KL	IL	KL	IL	KL
1	Core & Reflectors (Includes Bypass)	Bulk CO Reaction (Homogeneous Chemical Reaction)							H	H	H	M				
		Cavity Structural Integrity							M	L						
		Confinement Valve and Filter Characteristics							M	M						
		Contact Heat Transfer			H	M	H	M	H	H	H	M	M	M	M	M
		Control and Reserve Rod Worth	M	M									H	M		
		Convective Heat Transfer			H	H	H	M	M	M	H	M	H	M	M	M
		Core Configuration	H	H	H	M	H	M	H	M	H	M	M	M		
		Core Decay Heat (including Power Distribution)	H	M	H	H	H	M	H	M	H	M	H	M	H	M
		Critical Flow	H	M			H	M	H	M	H	M			H	M
		Dust from Core			H	M	H	M	H	M	H	M	H	L	H	L
		Flow Distribution	H	L	H	M	M	L	H	M	H	M	H	L	H	M
		Fluid Properties	H	M	H	H	M	H	H	H	H	H			M	H
		Gas Conduction Heat Transfer	H	H	L	H	L	H	M	H	M	H	M	H	L	H
		Gas/water purge and Gas Species Distribution	M	H					H	M	H	M				
		Graphite Hydrolysis									H	M				
		Graphite Oxidation							H	M	H	M				
		Hot Plume	H	M					H	L	H	L				
		IHX Characteristics and Performance			H	M							H	M	H	L
		Material Properties of Fuel and Reflector	H	M	H	M	H	M	H	M	H	H	H	H	H	H
		Molecular diffusion							H	H	H	H				

3. Conclusion

KINS VHTR Thermal Fluids PIRT has been developed based on the previous PIRTs by KAERI, ANL, and NRC. It will be used as an early screening tool to identify, categorize, and characterize phenomena and issues that are potentially important to risk and safety of VHTR. If the detailed design of VHTR is settled, then the phenomena, event, and system /component will be adjusted accordingly. And KINS VHTR PIRT will also be revised through re-evaluating the importance and knowledge level for the newly established phenomena, event, and system/component.

REFERENCES

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