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The State of the Art in VHTR PIRT and Event Classification for Regulatory Safety Assessment Methodology

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1. Introduction

The VHTR (Very High Temperature Reactor) is defined as a helium-cooled, graphite moderated reactor with a core outlet temperature in excess of 900°C and a long-term goal of achieving an outlet temperature of 1000°C. Figure 1 shows two candidates core type, one is prismatic core option and the other is pebble bed core option. The VHTR is suited for a broad range of applications, including the production of hydrogen and electricity.

Korea plans to obtain the operating license for demonstration reactor of VHTR by 2022. The current regulatory technologies for nuclear facilities are based on the LWRs (Light Water Reactors). So it is required to develop the regulatory technologies considering the characteristics specific to VHTR. It is essential for developing the safety assessment methodology to develop the PIRT (Phenomena Identification and Ranking Table) and to establish the event classification and acceptance criteria.

The state of the art in VHTR PIRT and event classification for regulatory safety assessment methodology will be introduced here.

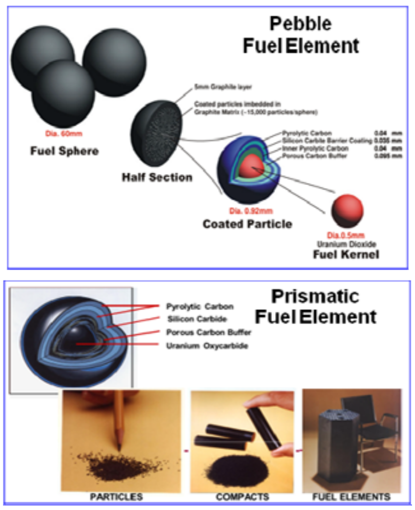

Figure 1. Pebble Bed and Prismatic Core Option

2. VHTR PIRT and Event Classification

The PIRT 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, 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. It is to 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. The PIRT specific to VHTR is being developed based on the approach, which consists of nine distinct steps[1] as follows

- Step 1: Define the issue that is driving the need for a PIRT.
- Step 2: Define the specific objectives for the PIRT.
- Step 3: Define the hardware and the scenario for the PIRT.
- Step 4: Define the evaluation criterion.
- Step 5: Identify, compile, and review the current knowledge base.
- Step 6: Identify plausible phenomena, that is, PIRT elements.
- Step 7: Develop importance ranking for phenomena.
- Step 8: Assess knowledge level (KL) for phenomena.
- Step 9: Document PIRT results.

KNGR LBLOCA PIRT[2] and SMART-P PIRT[3] use 15 Steps as shown in Figure 2. Though there are some differences between VHTR and KNGR/SMART-P PIRT, the philosophy and procedures are very similar.

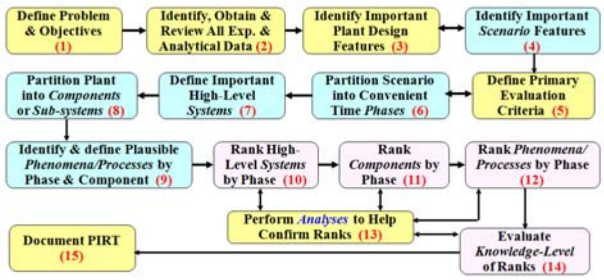

Figure 2. KNGR and SMART-P PIRT Procedures

NRC conducted a PIRT exercise in major topical areas of VHTR. The topical areas are as follows:

- ACTH (Accident analysis and thermal-fluids including neutronics)
- Fission product transport
- High temperature materials
- Graphite
- Process heat and hydrogen production.

The scope of this study is focused on accident analysis and thermal-fluids. Importance evaluations involve judgments of how certain phenomena would impact consequences during an accident. Each phenomenon's assessment and importance ranking was made relative to its importance to the FOMs (Figures of Merit) established by the panel. The four general FOMs selected by the ACTH are as follows:

• Level 1: Dose at the site boundary due to radioactivity releases

• Level 2: Releases of radioactivity that impact worker dose

• Level 3: Fuel failures or conditions (e.g., high temperature) with the potential to impact fuel failure

• Level 4: Includes the following:

- Fraction of the fuel above critical temperatures for extended time periods
- RPV, supports, core barrel, or other crucial in-vessel component service conditions
- Reactor cavity concrete time at temperature
- Circulating coolant radioactivity (including dust).

The 7 PIRT charts were prepared according to various events as follows:

• Normal operation (20-100% power) PIRT chart

• General LOFC (Loss of Forced Circulation) PIRT chart

• Pressurized LOFC PIRT chart

• Depressurized LOFC PIRT chart

• Air ingress LOFC PIRT chart

• Reactivity (ATWS) PIRT chart

• IHX (Intermediate Heat Exchanger) failure (molten salt) PIRT chart

The rationale for the selection of the importance and knowledge level are supplied in PIRT chart.

Also, it is important to establish the event classification for the development of regulatory technology. The current event classification applied to LWRs according to event is shown in Table 1. Subsequent to Fort St. Vrain, the next U.S. gas reactor project was the GA (General Atomics) MHTGR (Modular High-Temperature Gas-Cooled Reactor) sponsored by DOE[4]. Table 2 shows MHTGR occurrences and events. In part due to the MHTGR experience, GA in the follow-on GT-MHR (Gas Turbine-Modular High Temperature Reactor) design project defined four event categories for the GT-MHR plant safety assessment. This is shown in Table 3[5]. The differences between the LWR table and the HTGR table are evident.

Table 1. FSAR Chapter 15 Accident Categories

1. Increase in heat removal by the secondary system
2. Decrease in heat removal by the secondary system
3. Decrease in reactor coolant system flow rate
4. Reactivity and power distribution anomalies
5. Increase in reactor coolant inventory
6. Decrease in reactor coolant inventory
7. Radioactive release from a subsystem or component
8. Anticipated transients without scram

Table 2. GA MHTGR Occurrences/Events

Occurrence / Event	A00-1: Main-loop transient with forced core cooling
	A00-2: Loss of main and shutdown cooling loops
	A00-3: Control-rod-group withdrawal with control rod trip
	A00-4: Small steam generator leak Anticipated Operational Occurrences (A00s)
	A00-5: Small primary-coolant leak
Design Basis Events (DBEs)	DBE-1: Loss of heat transport system (HTS) and shutdown cooling system (SCS) cooling
	DBE-2: HTS transient without control rod trip
	DBE-3: Control-rod withdrawal without HTS cooling
	DBE-4: Control-rod withdrawal without HTS and SCS cooling
	DBE-5: Earthquake
	DBE-6: Moisture inleakage
	DBE-7: Moisture inleakage without SCS cooling
	DBE-8: Moisture inleakage with moisture-monitor failure
	DBE-9: Moisture inleakage with steam-generator-dump failure
	DBE-10: Primary-coolant leak
	DBE-11: Primary-coolant leak without HTS and SCS cooling
Emergency Planning Basis Events (EPBEs)	EPBE-1: Moisture inleakage with delayed steam generator isolation and without forced cooling
	EPBE-2: Moisture inleakage with delayed steam generator isolation
	EPBE-3: Primary-coolant leak in all four modules with neither forced cooling nor helium purification system pumpdown

Table 3. GT MHR Event Categories

1. Conduction Cooldown
2. Turbomachinery Failure Modes
3. Heat Exchanger Failure Modes
4. Reactivity Excursion

Since at this point there does not appear to be an accident categorization system officially approved by the NRC for advanced gas-cooled reactors, the collective experience provided by the Fort St. Vrain plant, the MHTGR and the GT-MHR has been investigated in this study.

3. Conclusion

The VHTR design characteristics are very different from existing LWRs. So it is essential to develop new regulatory technology for VHTR. The PIRT and event classification are being developed to supply the basis for VHTR licensing technology.

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