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Survey on the Study of the PIRTs for the NGNP

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1. Introduction

As a method of developing the regulatory infrastructure including data, codes and standards, and analytic tools for advanced reactors, NRC has used the PIRT (Phenomena Identification and Ranking Table) process for providing the identification and ranking of safety-significant phenomena and identifying and prioritizing research needs [1]. Several PIRT activities have been conducted for advanced reactor design type (e.g. HTGR)

With regard to these activities, we surveyed the current status of major PIRT-related study, reviewed associated documents and summarized key safety issues and gap analysis focused on the NGNP (Next Generation Nuclear Plant) [2].

These results will contribute to identify key safety issues and provide regulatory research needs concerning the development of a domestic (V)HTR.

2. Background

Phenomena-based approaches to research planning and prioritization have been previously applied for the advanced reactor designs during the early 1990s (MHTGR, PRISM, and PIUS), with the goal of providing an initial comprehensive identification and assessment of significant gaps in the data and modeling needed for safety analysis of the respective reactor design [3].

For the PBMR and GT-MHR, the NRC's PIRT efforts have been focused on HTGR TRISO fuel performance (i.e. FP retention and transport) as affected by fuel fabrication variables, irradiation parameters, and accident conditions such as power transients, loss of cooling heatup accidents, air ingress with oxidation, or moisture ingress with hydrolysis.

Under the Energy Policy Act of 2005 (EPAct), NRC and DOE have a mission to develop jointly the licensing strategy for the NGNP. The elements of the NGNP licensing strategy include a description of analytic tools that the NRC will need to develop to verify the NGNP design and its safety performance, and a description of other research and development activities. For this, NRC conducted a PIRT exercise in major topical areas of NGNP.

3. Summary of PIRTs and gap analysis for NGNP

The NGNP PIRTs were performed by NRC in the following topical areas: TRISO-Coated Particle Fuel [4, 5], Accident and Thermal Fluids, Fission-Product Transport and Dose, High-Temperature Materials, Graphite, and Process Heat and Hydrogen Co-Generation Production [6, 7]. General gap analysis results were cited for primary phenomena in specific topical area of the NGNP PIRTs. Each panel for these topical areas was selected from a mix of researchers and experts in academia, national laboratories, and international organizations.

3.1 TRISO-Coated Particle Fuel

The Depressurization Heatup Accident with Air Ingress was characterized by a large of highly ranked phenomena. One-half of these were directly related to phenomena associated with the interaction of air with the various components of TRISO-coated particle fuel. Changes in the chemical form of fission products, kinetics, and temperature distributions associated with a chemical attack by air were "High" for the remaining layers (except for the kernel and buffer layer) of the TRISO-coated particle fuel. The phenomena associated with the interaction of water with the various components of TRISO-coated particle were only ranked "High" for the fuel element and outer PyC layers.

General TRISO-coated particle fuel PIRT findings were grouped by two screening criteria. The first screening criterion was the importance ranking of "High" in three or more of the six conditions (manufacture, operation, depressurization, accident, reactivity accident, water ingress accident, air ingress accident) and the knowledge level of "Medium" or "Low."

1) The thermodynamic state of the fission products in the kernel may require additional research for the water- and air-ingress accidents.
2) The knowledge level for cracking of the inner PyC layer was judged by all panels to be either in the Low or Mid-range. Research to achieve better understanding of this phenomenon needs for this phenomenon
3) Gas phase diffusion through the inner PyC layer or the fuel element may require additional research
4) The chemical form of the metallic fission products transported through the fuel element needs for a better understanding of this phenomenon

The second screening criterion was the appearance of a phenomenon three or more times when considering all conditions and all components of the TRISO-coated particle fuel.

1) Gas-phase diffusion may require additional research effort
2) Particle layer cracking needs for a better understanding of this phenomenon
3) Pressure or pressure loading on particle layers may require additional research

3.2 Accident and Thermal Fluids

The most significant phenomena identified in this area included the following:

1) Primary system heat transport phenomena (conduction, convection, and radiation), including the reactor cavity cooling system performance
2) Reactor physics phenomena (feedback coefficients, power distribution for normal and shutdown conditions) as well as core thermal and flow aspects

3) Postulated air ingress accidents

Gap analysis for some primary phenomena rated as high importance with "Low" or "Medium" knowledge level were shown in Table 1. Here only described the technical elements needed to be tested, analyzed, simulated, etc in more detailed manner.

Table 1 Primary phenomena and gap analysis with respect to accident scenarios

Accident scenarios	**Primary phenomena**	**Gap analysis**
Normal operation	• Core coolant bypass flow	• required in-core testing • possible to perform a parametric analysis
D-LOFC	• Effective core thermal conductivity • Afterheat correlations • RCCS performance	• considerable error bounds for pebble bed cores • tracking fuel histories during operation can be challenging • needed to simulate large pressure pulses in D-LOFC accidents that could damage the RCCS
Air ingress accident	• Air ingress phenomena	• difficult to characterize these accident scenario and an extremely wide variety of possible boundary conditions

3.3 Fission-Product Transport and Dose

The key phenomena identified in this area included the following:
1) Fission product contamination of the graphite moderator and primary circuit including the turbine
2) Transport of fission products into the confinement building and the environment
3) Behavior of the fission product inventory in the chemical cleanup or fuel handling system during an accident
4) Transport phenomena (such as chemical reactions with fuel, graphite oxidation) during an unmitigated air or water ingress accident
5) Quantification of dust in the reactor circuit from several sources

The primary issues related to the confinement design which would have a major impact on gap priorities were FP release via normal helium leakage, and the effects of dust-borne FPs and mechanical shock and vibrations during rapid discharge in a D-LOFC accident.

3.4 High-Temperature Materials

Key aspects identified in this area were:
1) High-temperature stability and a component's ability to withstand service conditions
2) Issues associated with fabrication and heavy-section properties of the reactor pressure vessel
3) Long-term thermal aging and possible compromise of reactor pressure vessel surface emissivity as well as the reactor cavity coolant system
4) High temperature performance, aging fatigue and environmental degradation of insulation

Technology gaps for NGNP reactor materials corresponded directly to those identified by the PIRT panel. Those included issues related to high temperature components such as RPV, IHX, insulation materials, control rod composites, in-vessel metallic structures, etc.

3.5 Graphite

Significant phenomena noted by the panel were:
1) Material properties (creep, strength, toughness, etc.) and the respective changes caused by neutron irradiation
2) Fuel element coolant channel blockage due to graphite failure
3) Consistency in graphite quality including replacement graphite over the service life
4) Dust generation and abrasion

The technology gaps for graphite corresponded directly to those identified by the PIRT panel. Those included issues concerning graphite manufacturing, confirmatory data for new grades, irradiation creep data, codes and standards, theoretical model at higher dose and temperatures, development of model for neutron irradiation induced displacement damage in graphite, graphite analytical models (oxidation, property changes, and creep induced by irradiation), etc.

3.6 Process Heat and Hydrogen Co-Generation Production

The PIRT panel found that the most significant external threat from chemical plant is from a release of ground-hugging gases.
1) Oxygen was determined to be the most important due to its combustion aspects
2) It was concerned with the high importance of HX failures and associated phenomena for blowdown.

4. Concluding remarks

In this study, we investigated the current status of major PIRT-related researches and especially summarized gap analysis results as well as key safety issues suggested in the NGNP PIRTs.

We can infer that these PIRTs results can help to identify safety issues and prioritize research needs in conceptual design stage of a domestic (V)HTR, if applicable. Therefore, early identification and resolution of safety issues need to be prepared for a domestic (V)HTR under development. For this, we need to follow up the existing international (V)HTR experiences and researches.

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