Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2009

Development of Preliminary PIRTs of Thermal-Hydraulic Phenomena for KALIMER-600

Young-Min KWON [*], Hae-Yong JEONG, Kwi-Seok HA, Won-Pyo CHANG
Korea Atomic Energy Research Institute, 1045 Daedeok St.,Yuseong, Daejeon 305-353 KOREA
[*]*Corresponding author: ymkwon@kaeri.re.kr*

1. Introduction

Sodium Cooled Fast Reactors (SFRs) are the most technologically developed of the GEN IV systems. The primary mission of the SFRs is the management of high-level wastes, in particular management of plutonium and other actinides. The SFR system is the nearest-term actinide management system among the GEN-IV system candidates. The mission of the SFR can be extended to electricity production if design innovations that reduce capital cost. KAERI has been performing design studies of KALIMER-600 [1] at the conceptual level.

To bring KALIMER-600 to deployment, several technology gaps in fuel cycle and reactor system must be closed. Research on both sides of the fuel cycle and the reactor system is necessary to bring KALIMER-600 to deployment. For the reactor system, technology gaps exist in assurance or verification of passive safety, and completion of the metallic fuel database including irradiation performance data.

R&D programs for the KALIMER-600 safety are necessary to support the SFR deployment. The safety R&D challenges for the KALIMER-600 in the context of the GEN IV systems are: (a) to verify the predictability and effectiveness of the inherent passive benign responses to design basis events and accommodated beyond design basis events (b) to provide assurance that accommodated beyond design basis events considered in licensing can be sustained without loss of coolability of fuel and structural integrity.

The Phenomena Identification and Ranking Table (PIRT) is an effective tool for providing an expert assessment of safety-related phenomena and for assessing R&D needs for KALIMER-600 licensing. The nine-step PIRT process has been established as a methodology for providing expert assessments of safety-relevant phenomena.

2. KALIMER-600 PIRT

A PIRT exercise will be conducted using panels of technical experts covering major technical areas relevant to KALIMER-600 safety and licensing. The PIRT panel is comprised of several experts covering three technical areas; thermal fluids, neutronics, and accident analysis.

The PIRT is a structured expert elicitation process designed to support decision making. The KALIMER-600 PIRT process consists of nine distinct steps. These steps are described below

<u>Step 1, Issue Definition:</u> There are needs for development of technical bases and analytical tools to perform safety analyses and other R&D needs to support KALIMER-600 licensing.

<u>Step 2, PIRT Objectives:</u> The objectives are to identify safety-related phenomena across the entire spectrum from the normal plant operation to the postulated accident scenarios, ranking the importance of these phenomena relative to established evaluation criteria, and assessing the existing knowledge base for its adequacy to investigate the safety significance of these phenomena.

<u>Step 3, Hardware and Scenarios:</u> Since KALIMER-600 is in the conceptual design stage, major systems and components at a top level for analyzing phenomena are focused on. The PIRT panel considers many phenomena associated with reactor systems, particular in the safety-related systems such as the fuel and sub-assembly, the reactor core, major PHTS and IHTS components, the reactor shutdown systems, passive decay heat removal system, and so on. The panel has to consider the inherent safety characteristics of the reactor core due to reactivity feedback effects by Doppler, sodium density, and structural expansion. The passive cooling of the reactor core by natural circulation sodium loop after reactor scram is necessary for decay heat removal.

Consideration of a wide range of postulated accidents are based in part on extensive review of system design experience, as well as on detailed and extensive accident analysis and available information from foreign SFR licensing exercises. Not all of the faults need to be handled since some realistic faults are bounded in terms of propagation and consequence by the limiting representative fault. PIRT evaluation on the specific accident scenarios is done using a matrix-building block format that allows consideration of all the important phenomena or processes, minimizing repetition. The scenarios selected for consideration by the KALIMER-600 PIRT panel are as follows: (1) Normal operation, (2) Uncontrolled control assembly withdrawal from full power, (3) Total loss of primary coolant flow, (4) Total loss of main feed water, (5) Reactor vessel leak, (6) Flow blockage of a fuel subassembly, (7) Uncontrolled control assembly withdrawal from full power without scram, (8) Total loss of primary coolant flow without scram, (9) Total loss of IHTS flow without scram.

<u>Step 4, Evaluation Criteria:</u> Importance evaluations involve judgments of how certain phenomena would impact the expected consequences during an accident. The PIRT panel needs to concentrate on the thermal fluid aspects of the events but also consider neutronic

behavior where appropriate. Each phenomena assessment and importance ranking should be made relative to its importance to the figure of merits (FOMs) established by the panel.

The ultimate evaluation criteria or FOM for judging the relative importance of safety-related phenomena is an offsite radiological dose to the plant personnel in the site and to the environment. Since the common FOM for the events is the radiological dose, alternative physical limits which ensure that the radiological limits are not exceeded are used because they can be more easily applied to the conceptual design process. The key phenomena-based criteria for alternative physical limits are as follows: (1) No fuel melting, (2) No cladding failure, (3) No sodium boiling, and (4) Maintenance of primary boundary integrity

Step 5, Current Knowledge Base: This step involves familiarization with the current knowledge base on SFR technology, with particular focus on safety-relevant physical phenomena and/or processes associated with hardware and scenarios. The panel member's evaluations of phenomena importance ranking and knowledge level are occasionally subject to different interpretations. For example, some phenomena are important for one postulated accident but not so important for other accidents. In some cases, an evaluation of importance ranking is based on a judgment of how much is known about the phenomena independent of its importance.

Step 6, Phenomena Identification: This step involves identification of all plausible safety-relevant phenomena for hardware and scenarios. The objective is to develop a preliminary but comprehensive list of phenomena which is relevant to safety. The panels consider in their deliberation a phenomenological hierarchy starting at the system level and proceeding through component and subcomponent levels, and so on. Because of the innovative safety-related design philosophy of KALIMER-600, the importance of physical-based phenomena relies on the inherent and passive safety characteristics. The panel evaluates thermal-fluid and neutronic phenomena and processes deemed pertinent to the KALIMER-600 safety features. As a preliminary guide, four types of safety challenge will be evaluated as follows: (1) challenge to reactivity control, (2) challenge to heat removal, (3) challenge to sodium chemical reaction, and (4) challenge to confinement of radioactivity.

The most significant phenomena for KALIMER-600 safety will include the followings but the final decision will be made when the PIRT is done: (a) reactor physics phenomena, (b) primary system cool down phenomena, (c) decay heat removal phenomena through the PDRC, and (d) sodium chemical reaction phenomena, and etc.

Step 7, Importance Ranking: Identified phenomena are ranked for their importance relative to the evaluation criteria adopted in step 4. The process consists of individual and independent ranking by panel members, discussion of individual rankings considering the rationale, and collective ranking based on the discussion. A ranking breakdown of High, Medium, and Low proved to be sufficient in past PIRT exercises and are adopted for the present exercise.

Phenomena identification in postulated accident sequences involves a determination of factors important to the consequences of events. Since KALIMER-600 relies largely on inherent and passive safety features, the important phenomena include physical characteristics such as material properties, heat transfer coefficients, and reactivity feedback coefficients rather than engineered design features such as mechanical or electrical components. A qualitative judgment of a phenomenon's importance is not straightforward since it may be crucial to consequences of some event scenarios, while it may not be a matter in other ones.

Step 8, Knowledge Level: The level of knowledge regarding each phenomenon is assessed by the panel. The process consists of individual and independent assessment, including the rational and collective assessment based on the discussion. A qualitative ranking is adopted for the present exercise.

Step 9, Documentation: The documentation includes PIRT objectives, tables of identified phenomena, importance and knowledge level ranking, and supporting text describing the process of phenomena identification and rationale of the ranking process.

3. Conclusion

The nine-step PIRT process has been established as a methodology for providing expert assessments of safety-relevant phenomena for the KALIMER-600 design. The PIRT panel has been evaluating both normal operations and postulated accident scenarios including typical unprotected ATWS events, concentrating the thermal fluid aspects of the event but considering the neutronic behavior as well where appropriate. The panels will identify safety-related phenomena on the typical postulated accident scenarios, ranking the importance of these phenomena relative to established evaluation criteria, and assessing the existing knowledge base for its adequacy to investigate the safety significance of these phenomena..

The complete composite tables and rationales will be documented through the application of the PIRT process to KALIMER-600. The more significant phenomena which rated with high importance are highlighted in a tabular form. The detailed rationales and assessments will be also presented in the Tables in which more phenomena are identified by the panel.

REFERENCES

[1] D. H. Hahn et al., KALIMER-600 Conceptual Design Report," KAERI/TR-3381/2007. 2007.

[2] Y. M. Kwon, "Guidelines for KALIMER-600 Phenomena Identification and Ranking Tables," SFR-SA-421-WR-01-2009, KAERI Internal Report, August 2009.