Phenomena Identification and Rankings in Domestic PWR Accident Conditions

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1. Introduction

This study aims at identifying the plausible thermal-hydraulic (T-H) phenomena and processes during domestic Pressurized Water Reactors (PWRs) accidents, and ranking their relative importance against the respective safety criteria. Korea Institute of Nuclear Safety (KINS) is structuring the best-estimate REactor Thermal-hydraulic Analysis System (KINS-RETAS), to be used for a regulatory audit of the applicant's safety analysis results [1]. The T-H system code MARS, originally developed by KAERI [2], is a pivot code in the KINS-RETAS, where the RCS T-H responses to postulated plant conditions are simulated. According to the Software Quality Assurance (SQA) guidance [3], the verification and validation (V&V) of MARS is required to confirm its adequacy to the targeted application, simulation of T-H phenomena in the system to the component levels during the reactor conditions of normal operation to DBA in domestic PWRs. Consolidation of the previous LBLOCA PIRT results [4-11], compensated by the PIRTs for other transients except the LBLOCA, is needed to organize the part of the MARS code V&V matrices.

2. Approach for Developing Consolidated PIRTs

The LBLOCA have been the focus of the extensive safety assessment efforts in a traditional safety approach. Various thermal-hydraulic phenomena are found for the accident scenarios, where many safety systems are activated or challenged and interactions among those safety systems are produced. For this reason, most PIRT developments have concentrated on the LBLOCA. However, all phenomena and process to be simulated by a system code do not appear in the LBLOCA scenarios. The LBLOCA investigation only may fail to notice the plausible phenomena in a RCS overpressure or significant reactivity feedback conditions, or a smaller break-initiated LOCA to be found in the Small Break LOCA (SBLOCA) and non-LOCA scenarios.

Instead of repetition of the PIRT process, the phenomena and processes important to code V&V can be identified through consolidation of the previous LBLOCA PIRTs. It can be made through cross-correlation of the previous PIRTs against the base PIRT scheme. When doing this, some differences exist in phase division, phenomena description, system and component partitioning, and ranking scale among the previous results. The consolidation approach or process is as follows:

1) Base PIRT scheme is defined as that used in KNGR LBLOCA PIRT development [9].
2) An equivalency assessment is performed to confirm whether the phenomena of different titles among the PIRTs are equivalent in definition or not.
3) A ranking adjustment is made for the case where the rankings of equivalent phenomena differ among the PIRTs. Especially for the PIRTs with phase division different from the base PIRT, the rankings are adjusted with phase division alteration.
4) Consolidation of the PIRTs is completed by converting all ranking values assigned by the five levels ranking scale in the base PIRT to those corresponding to the three levels ranking scale, High, Medium and Low.

Table 1 Relationship of Importance Levels among PIRT Ranking Scales

Base PIRT [9]		Westinghouse PIRT [4.5.6]		Present study	
Ranking	Meaning	Ranking	Meaning	Ranking	Meaning
5	Highest of high	9	Highest	H	High
		8			
4	High	7			
3	Medium	6	↑	M	Medium
		5			
		4	↓		
2	Low	3		L	Low
1	Lowest of low	2			
		1	Lowest		

3. Cross-correlation of LOCA PIRTs

There are six distinct LBLOCA PIRT results of worth to be used for the consolidated PIRT; they were derived from evaluation for different reactor designs or of different purposes, as seen Table 2. The first three was developed for Westinghouse (WH) reactor designs, the next two for Combustion Engineering (CE), and the last based on APR1400 PIRT was extended to Kori 1 of the Low Pressure Safety Injection System (LPSIS) of the Upper Plenum Injection (UPI) and the SBLOCA.

Table 2 Previous LBLOCA PIRT Studies

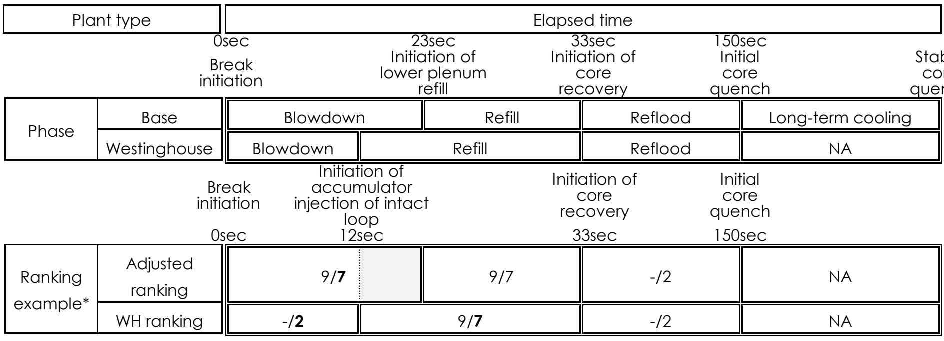
	WH PIRT	AP600 PIRT	KREM PIRT	KNGR PIRT	APR1400 PIRT	SPACE PIRT
Reactor design	WH-4 loop [4], WH-2 loop [5, 6]	AP600 [7]	Kori 3&4, Yonggwang 1&2 [8]	KNGR, preliminary design of APR1400 [9]	APR1400 [10]	APR1400, including UPI design & SBLOCA [11]
Organizatio n	Westinghouse	Westinghouse	KNFC	KINS/INEEL	KAERI	KAERI
Purpose	Evaluation of code uncertainty (CSAU)	Code application to innovative design	Development of realistic ECCS EM	Development of realistic ECCS EM	Phenomena identification in new	Development of T-H system codes

3.1. Westinghouse LBLOCA PIRT

The WH LBLOCA PIRT adopts three phases such as blowdown, refill and reflood, and nine importance ranking levels of Table1. The definitions for blowdown and refill are not the same as those of the base PIRT scheme, as seen in fig.1. As a result, when the Westinghouse PIRT is altered by the base PIRT scheme, two different importance rankings of blowdown and refill are likely to be assigned to one blowdown period of the base PIRT scheme, as the ranking example of fig.1. The ranking of a phenomenon is assigned to be the highest value of rankings allowed for the equivalent phenomena of the compared PIRT results (a higher value (9/7) is allowed to the importance level of blowdown). The equivalency check also was performed for every phenomenon used in the base and WH PIRTs, and 14 phenomena were found to be new, compared. The AP600 and KREM PIRTs use the assessment scheme or method slightly different from WH LBLOCA PIRT. When the AP600 PIRT results were modified against the base PIRT scheme, oscillation of core makeup inventory during reflood period was found to be new.

3.2. Combustion Engineering LBLOCA PIRT

The CE LBLOCA PIRTs was consolidated by using the same way as the WH PIRTs. According to the SI design unique to the APR1400, its PIRT considers the periods before and after end of fluidic device actuation as early reflood and late reflood, respectively. Similarly to alteration of the WH PIRT phase division, two different importance rankings of reflood and long term cooling may be in the reflood; then a higher value of two importance levels in early and late reflood phases is allowed to the importance level in the reflood.



* ranking example for a phenomenon: In ranking A/B, 'A' represents ranking determined by experts and 'B' represents ranking determined by AHP

Figure 1 Alteration of Westinghouse PIRT Phase Division by Base Scheme

3.3. UPI Design Consideration

From investigation of CCTF and Semi-scale test results, the UPI effect was reflected to the consolidated PIRT as follows:

1) For upper plenum component, increase "Mixture level," "Multidimensional flow" and "Upper plenum-core CCF," and include "Condensation" phenomenon.
2) For core region, increase "Multidimensional flow" and "Void generation/distribution."

4. Non-LOCA PIRTs

To select accidents for phenomena investigation, various types of the initiating events in FSAR Chapter 15 were investigated: RCS overcooling and under-cooling events, RCS flow decrease events, reactivity anomaly events, RCS overfilling events, and RCS coolant loss events. To manifest various phenomena, the PIRT needs to be prepared for the initiating events to activate the safety system, mostly the bounding accidents of each category. The selected accidents are Main Steam Line Break (MSLB), Main Feed Line Break (MFLB), and Steam Generator Tube Rupture (SGTR). Because MFLB could cause either a RCS cooldown or a RCS heatup, the LONFWS were chosen as the RCS undercooling PIRT. The previous non-LOCA PIRT studies were fully utilized to identify and rank the phenomena [

4.1. Main Steam Line Break

The following three cases, commonly found in the SARs were investigated to identify the accident phases:

1) MSLB at hot zero power with offsite power available
2) MSLB at hot full power with offsite power available
3) MSLB at hot full power with loss of offsite power

In investigating the three cases, most of the phenomena for the sequence of events can be identified by each three phases: pre-trip, depressurization, post SG dryout phases. Phenomena of highly importance in the phases of more than two divisions and the phase of one division were confirmed.

4.2. Steam Generator Tube Rupture

Two cases were investigated from the SAR review:

1) SGTR at hot full power, assuming coincident reactor trip and LOOP
2) SGTR at hot full power, reactor trip by actual protection signal followed by LOOP

Focusing on the RCS pressure affecting break flow at the SG tube, the sequence of events was divided into two phases: depressurization and decay heat removal phases. Phenomena of highly importance in the phases of more than two divisions and the phase of one division were confirmed.

4.3. Loss of Normal Feedwater without Scram

The two phases are distinguished from the TR review: pressurization and depressurization, and phenomena of highly importance were identified.

5. Results and Recommendations

For LOCA, including LBLOCA and SBLOCA, the previous PIRT results were fully utilized to draw the important phenomena and processes. Especially, consolidation of the LBLOCA PIRTs was made through cross-correlations among the PIRTs, adjusted by the KNGR PIRT scheme. In non-LOCA case, the three accidents were selected, MSLB, SGTR and LONFWS, where there are likely to be some phenomena to be regarded as less important and omitted in the LBLOCA PIRT. Further study is needed to utilize the present results for MARS V&V application: a) deduction of the components of highly important phenomena and b) determination of highly important sub-phenomena, supported by the knowledge level of the phenomena. Further work is planned to develop the identification and ranking of the highly important sub-phenomena, and to draw what is to be supplemented to the V&V results performed by KAERI, the developer of MARS.

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