Development of IBLOCA PIRT for Domestic Operating PWRs

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1. Introduction

Similar to recent trends in the United States and France [1,2], the domestic nuclear industry is also attempting to reclassify LOCA by incorporating intermediate-break (IB) LOCA as a new design basis accident (DBA) instead of double-ended guillotine break (DEGB) LOCA, through pipe rupture probability analysis.

This necessitates the development of both a new analysis methodology and a new analysis code appropriate for IBLOCA safety analysis. For this purpose, the existing SPACE code, licensed for the safety analysis of small-break (SB) and large-break (LB) LOCAs, should be improved at IBLOCA analysis. In order to enhance the SPACE code, a phenomena identification and ranking table (PIRT) for IBLOCA is required for the better understanding of the major thermal-hydraulic phenomena and processes during such a transient.

Conducted were a total of ten PIRT expert meetings, composed of 25 domestic thermal-hydraulic experts for the development of the IBLOCA PIRT. Through these meetings, key safety criteria, temporal phase, major phenomena and processes, and importance rankings and knowledge level corresponding to each phenomenon and process during IBLOCA transient have been determined.

The IBLOCA PIRT will be used to develop a validation matrix for enhancing the SPACE code, aimed at improving its capability for IBLOCA analysis.

2. Development of IBLOCA PIRT

The development methodology and process for IBLOCA PIRT are based on the references [1~3]. The development process of the IBLOCA PIRT consists of 11 steps as shown in Fig. 1 and each step will be briefly described as below.

2.1 Definition of Problems & Objectives

There are two types of PIRT problems, research oriented for code development and resolution of licensing issues, respectively. Currently, there is no licensing issues for the IBLOCA, so that IBLOCA PIRT is developed for the code improvement and guidance of validation experiments.

2.2 Collecting Available exp. and analytical data

Four kinds of integral effect tests (IETs) data simulating cold leg break LOCA were selected for the PIRT development (LSTF, ATLAS, PKL, LOFT).

2.3 Important Plant Design Features

IBLOCA PIRT deals with the domestic pressurized water reactors (PWRs) such as Westinghouse (WH) 3-loop plants, OPR1000 and APR1400.

2.4 Identifying Important Scenario Features

Based on the research results for the probability of pipe rupture by the U.S. NRC [4] and the previous study [5], break of branch pipes connected to the cold side pipes of reactor coolant system (RCS) is considered as a base scenario of IBLOCA. The break size of IBLOCA corresponds to 10% ~ 25% of the cross-sectional area of a cold leg.

2.5 Primary Safety Criteria

The peak cladding temperature (PCT) was selected as primary safety criteria or figure of merit (FOM) during an IBLOCA. In addition, the core water level was also selected as secondary safety criteria.

2.6 Partitioning Scenario into Temporal Phases

The major phenomena and processes during an IBLOCA transient were categorized into three temporal phases as described in the previous study [5].

- Phase 1: blowdown and rapid depressurization

- Phase 2: Crossover of sys. pressure & core boil-off
- Phase 3: Core recovery and long-term cooling

2.7 Defining System and Components

The major systems and components involved in IBLOCA transient were described in PIRT tables (Table I).

2.8 Rank phenomena/process and knowledge level

The results of the IBLOCA PIRT, as finalized through expert meetings, have been summarized in Table I. The rank and level of knowledge for each major phenomenon were determined using a 3-point scale (High, Middle, Low).

3. Conclusions

To develop the IBLOCA safety analysis methodology and an appropriate analysis code, the IBLOCA PIRT was developed through discussions with a domestic thermal-hydraulic experts. In the IBLOCA scenarios, PCT was selected as a key safety factor, and the transient progress was divided into three phases: 1) blowdown and rapid depressurization, 2) crossover of primary and secondary system pressures and core boil-off, and 3) core recovery by actuation of the safety injection tanks and long-term cooling. Major thermal-hydraulic phenomena and processes occurring within each phase were identified, and after evaluating the importance of each phenomenon on key safety factors and determining knowledge levels, the development of the IBLOCA PIRT was finally completed. This IBLOCA PIRT is intended to be utilized for the development of a validation matrix necessary for safety analysis code development and the establishment of an experimental database. The final report for IBLOCA PIRT is currently being prepared and is expected to be completed by the end of this year.

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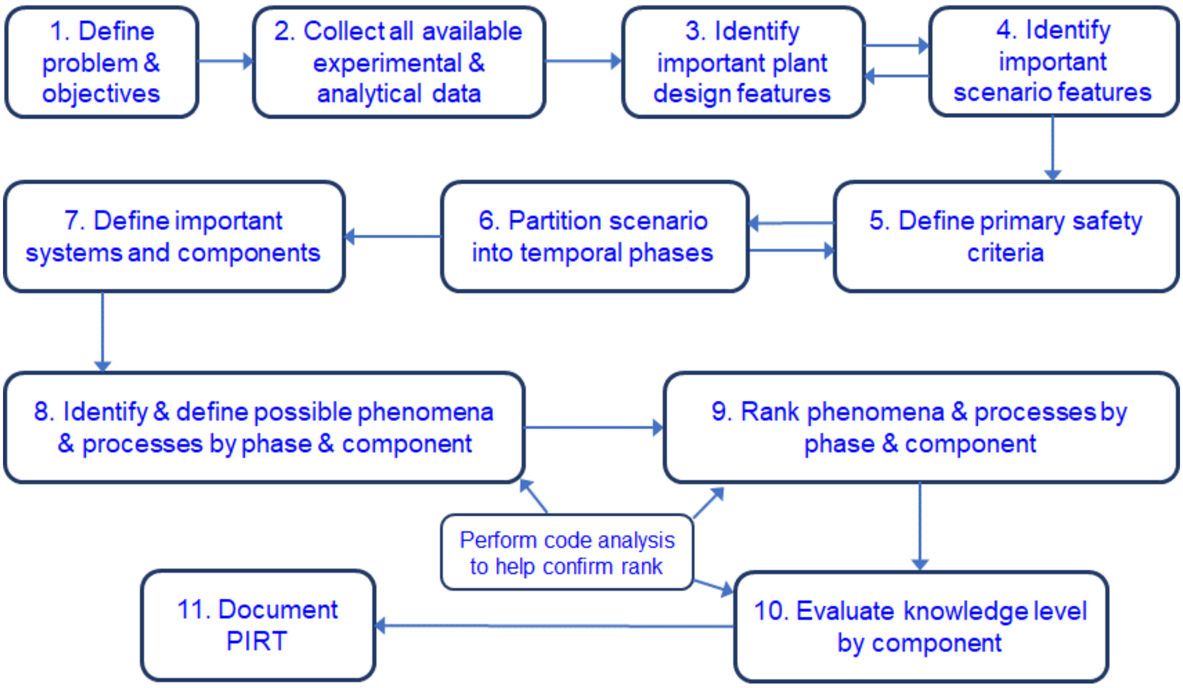

Fig. 1. Process of IBLOCA PIRT development

Table I: Summary of IBLOCA PIRT

System	Components	Phenomena / Process	Phase			K. L.
			1	2	3	
RPV	Core(fuel)	fission power (including distribution)	H	-	-	H
		decay heat (including distribution)	M	H	H	H
		oxidation/hydrogen generation	-	L	M	H
		stored energy release	M	L	L	H
		pellet heat transfer (including TCD[1])	M	M	L	H
		gap conductance	M	M	H	H
		rod surface heat transfer				
		- nucleate boiling	H	H	M	H
		- critical heat flux	H	L	H	H
		- rewet (min. film boiling temperature)	H	-	H	H
		- stable film boiling	H	-	H	H
		- transition boiling	H	L	H	H
		- single phase convection to vapor	-	H	H	H
		- radiation to surface, vapor, liquid	L	L	L	H
		reactivity				
		- void/moderator feedback reactivity	H	-	-	H
		- doppler feedback	M	-	-	H
		- boron mixing and reactivity effects	-	L	L	H
		- scram reactivity	H	-	-	H
		clad ballooning	-	L	M	H
		flow blockage	-	L	M	H
		fuel relocation into ballooned region	-	L	M	M
		clad burst	-	-	L	M
	Core(fluid)	flashing & boiling	H	H	H	H
		phase separation	-	H	H	H
		entrainment in core	L	L	M	H
		de-entrainment in core	L	L	M	H
		(core-wise) multidimensional flow	L	M	M	M
		subchannel (turbulent) mixing	M	L	L	H
		vapor superheat (SP vapor convection)	-	H	H	H
		interfacial heat transfer	M	M	H	H
		interfacial drag	M	M	H	H
		CCF (counter-current flow)	L	L	L	H
	Guide tube thimbles	fuel rod radiation heat transfer	L	L	L	H
	Spacer grid	grid heat transfer effects - droplet deentrainment & breakup - grid downstream mixing enhancement - clad-to-Grid direct conduction	L	L	M	H
	Downcomer	level change	-	M	H	H
		level oscillation due to N.C gas	-	-	L	H
		bulk condensation	-	L	M	M
		liquid entrainment (off-take, bypass)	-	L	L	M
		ECC bypass incl. sweep-out	-	L	M	H
		de-entrainment	-	L	L	M
		vessel stored energy release (DC boiling in LTC)	L	L	M	H
		flashing	L	M	-	H
		multidimensional flow	-	L	L	M
		bulk mixing of flow stream w/ temp. difference	-	L	L	H
		subcooled boiling in DC	-	-	L	H
	Lower plenum	stored energy release	L	L	L	H
		flashing in the fluid volume	L	M	-	H
	Upper plenum	flashing	H	L	L	H
		level (change)	M	L	M	M
		deentrainment on structures	L	L	M	M
		multidimensional flow	L	L	L	M
		entrainment (incl. loop flow distribution)	L	L	M	M
		complex flow through plate/GTs	M	L	L	M

[1] TCD: Thermal conductivity degradation

		CCF at fuel assembly top nozzle	-	L	-	M
	Upper head	flashing including level decrease (affected by initial liquid temperature)	H	-	-	H
		stored energy release	L	-	-	H
		complex flow through plate/GTs	L	-	-	M
RCS	Hot leg	liquid entrainment	-	-	L	M
		CCF	L	-	-	H
		de-entrainment (SG inlet plenum)	-	-	L	M
		flow stratification	L	L	L	H
		flashing	H	L	L	H
	Cold leg	stored energy release	-	L	-	H
		flashing	L	M	-	H
		flow stratification	M	M	L	H
		steam condensation by ECC (including mixing)	-	L	M	M
		non-condensable gas effects (level effect)	-	-	L	H
	Intermediate leg	(partial) loop seal clearing (seal & clear)	M	M	-	M
		flashing	M	M	-	H
	Break	critical flow	H	H	H	H
		film offtake, vapor pull-through	M	M	L	M
	RCP	flow coast-down	H	-	-	H
		stored energy release	-	L	L	H
		pump performance (1P/2P)	H	-	-	H
PRZ	Vessel	stored energy release	L	-	-	H
		level decrease with flashing	H	-	-	H
	Surge line	Flashing	H	-	-	H
SIS	SIT	wall heat transfer (tank wall)	-	-	-	-
		N2 gas release after tank empty	-	-	-	-
		gas pull-through by vortex (FD only)	-	-	-	-
		liquid temperature and change	-	-	M	H
		gas temperature and change (H/T through interface)	-	-	L	H
		water level and change	-	-	L	M
		FD resistance in high flow	-	-	L	H
		FD resistance in low flow	-	-	H	M
		flow oscillation (stepwise injection)	-	-	H	H
	SIP	SIP flow (including flow resistance)	-	-	H	H
	IRWST	temperature change by recirculation / steam condensation (thermal stratification)	-	-	H	M
SG	U-tubes	CCFL (or CCF)	L	-	-	H
		steam binding				
		- vapor superheating	-	L	M	H
		- 2^{nd} to primary heat transfer	-	L	M	H
		primary to 2^{nd} heat transfer	M	-	-	H
		U-tube flowrate (reflux, condensation)	L	-	-	M
	2^{nd} side	wall heat transfer (boiling)	M	-	-	H
		pressure build-up by isolation	L	-	-	H
	MSSV	critical flow (auto open)	L	-	-	H
Containment		Pressure change - containment spray - containment wall condensation - IRWST direct condensation	L	L	M	M