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Development of DEC PIRT for Mid Loop Operation

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1. Introduction

As a result of Fukushima accident in 2011, more people have been worried and concerned about whether each nuclear power plant has enough capability to prevent and mitigate a severe accident even though it is unlikely to occur.

The KOREA regulatory body revised the "Nuclear Safety Regulations [1]" in June 2015, the severe accident management has been included in the existing design basis accident management. Currently, KHNP is pushing for the development of integrated safety analysis codes applicable to multiple failure accident. It is necessary to extend the SPACE code which is developed for thermal hydraulic analysis of domestic PWR, to multiple failure accidents. In order to apply the SPACE code to multiple failure accident, the PIRT (Phenomena Identification and Ranking Table) has to be developed considering the physical phenomena expected in multiple failure accident.

In this paper, "Loss of Residual Heat Removal accident During Mid-Loop Operation[2]" is selected for development of PIRT (Phenomena Identification and Ranking Table) which is considered physical phenomena expected in multiple failure accident.

2. Methods and Results

2.1 Definition of Accident

The Residual Heat Removal (RHR) system is used when the reactor inventory is reduced to mid-water level of the primary loop (mid-loop operation) for a maintenance or inspection of components such as steam generator (SG) U-tubes and reactor coolant pump (RCP) during a plant outage in pressurized water reactor (PWR). The major causes of these events have been found to be a loss of vital ac power, an inadvertent closure of isolation valve in the RHR suction line, and a loss of RHR flow due to air ingestion into the RHR pump. Some of these events resulted in boiling of the reactor vessel coolant and eventually the possibility to uncover the core if the loss of RHR conditions should continue for a long time period.

2.2 Major Scenarios and Characteristics

For PIRT development of loss of RHR event during mid-Loop operation accidents, two typical cases of the geometrical configurations of the plant are analyzed, that is, the cold leg opening (CLO) case with water-filled SGs and pressurizer manway opening (PRO) case with emptied SGs.

For each case, the sequence of two cases for loss of RHR event during mid-Loop operation has shown in the table I and II.

Table I: Sequence of Event for CLO case

Phase	Time(sec)	Event
Phase I	1,000	Loss-of-RHR system
	~1,600	Boiling start
	~1,790	Saturation of upper plenum liquid
	~2,130	Steam discharge into upper head
	~3,840	First loop seal clearing (LSC)
Phase II	~6,400	Condensate accumulating start
	~9,500	Second loop seal clearing (LSC) (Not occurred in code)
	~12,000	Second core heat up start

Table II: Sequence of Event for CLO case

Phase	Time(sec)	Event
Phase I	1,000	Loss-of-RHR system
	~1,600	Boiling start
	~1,800	Saturation of upper plenum liquid
	~2,900	Liquid inflow into pressurizer
	~3,200	Maximum liquid hold up
Phase II	~3,600	Bubbly flow start in surge line
	~3,600	Maximum liquid hold up
	~4,000	Stable liquid hold up
	~6,400	Core heat-up start

2.3 Major Thermal-Hydraulic Phenomena

For each case, the point at which the physical phenomena changes suddenly is used as a phase I and II.

In the CLO case, Figure 1. shows the pressure behavior in hot and cold legs in intact loop after the loss-of-RHR event, which occurred at 1,000 seconds during the mid-loop operation. At about 1,500 seconds, the liquid in core started to boil and the steam migrated toward the hot legs from the core through core upper plenum. Thus, the pressure in the hot leg started increasing rapidly at about 1,600 seconds. The calculated pressure agreed well with the experiment in the early phase. At about 2,100 seconds, the pressurization rate reduced immediately. The calculation showed that the pressurization rate was lower than in the experiment about 3000 seconds. Such a low pressurization rate resulted in delaying an occurrence of loop seal clearing (LSC). This difference could be explained in association with condensation phenomena on SG U-tubes wall during this phase. Actually in the experiment, the steam condensation was not occurred before the LSC, while in the calculation, a significant amount of steam was condensed at the inlet part of the SG U-tubes. As a result, the pressurization became relatively low during this phase.

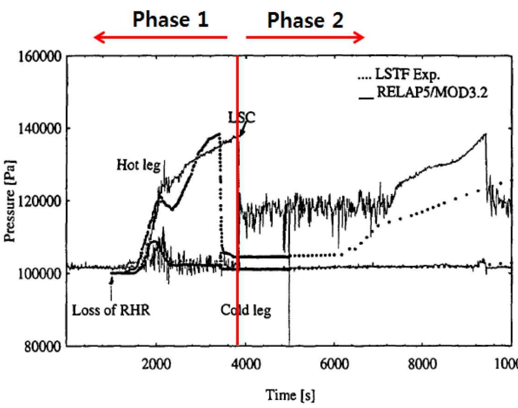

Figure 1. Comparison of Pressures at Hot and Cold legs in CLO case

In the PRO case, Figure 2 shows that the void fraction in the bottom part of the surge line became zero in the rising phase of pressure, i.e., the surge line was rapidly filled with water as the pressure increased to the maximum value. As a result, the overprediction of the water level in hot legs caused an overshooting of the water level in pressurizer. Even after the surge line was completely being emptied from about 4000 seconds, the calculated water level remained higher value, even though the pressure agreed well with the experiment.

Such large water hold up in the pressurizer came from an overprediction of interfacial drag between two phases, because the relative velocities in the pressurizer were calculated very high, although the corresponding experimental data were not available.

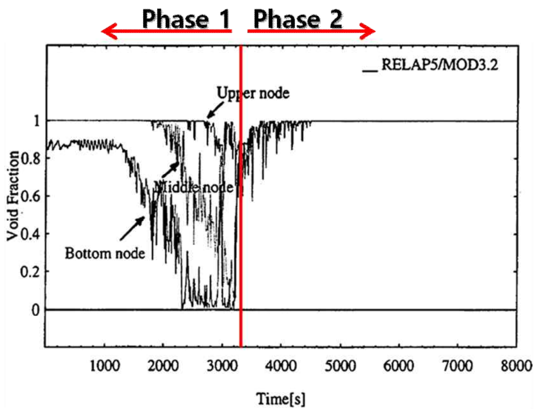

Figure 2. Calculated void fraction in surge line in PRO case

2.4 Development of PIRT

In addition to the accident scenarios and phase distinctions determined in the previous step, system/ structure, and components are categorized to help determined the ranking of major

Table III : Loss of RHR event during mid-Loop operation PIRT

System/structure	component	Phenomena	PIRT			
			PRO		CLO	
			I	II	I	II
Reactor Pressure Vessel	Core (fuel)	Decay heat	H	H	H	H
		Fuel heatup		M	H	M
	Core (fluid)	Voiding	M	H	H	H
		Mixture level		H	H	H
		Wall heat transfer	L	M	H	M
	Downcomer	Mixture level	L	M	H	M
Pressurizer	Vessel	Mixture level (Liquid hold up)		H		
	Open Region (PSV or manwary)	Discharge flow (normal)	L	M		
	Surgeline	CCFL (zero penetration included)		H		
Primary piping	Intermediate leg	Loop seal clearing				H
	Hot Leg	Liquid Entrainment(Off-take)		H		
Steam Generator	U-tube	Reflux condensation			M	M
		NC Gas effect			M	M
		CCFL			M	L
	Secondary side	Wall heat transfer			M	M

In this table, H means high influence on FOM(figure of merit). M means moderate influence on FOM. L means low influence on FOM.

As a result of developing PIRT, the core power was confirmed to be an important phenomenon in the PRO case and the core power, voiding in the core and mixture level in the core were confirmed to be an important phenomenon in the CLO case.

3. Conclusions

Major thermal-hydraulic phenomenon PIRT for loss of RHR accident during mid-Loop operation for expanding the SPACE code to apply to the design extended conditions is developed. The major scenarios and the major thermal-hydraulic phenomenon of the system/structure and the component were derived through the developing the PIRT. PIRT will be to derive the thermal-hydraulic model needed to expand the SPACE code.

Acknowledgements

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