Development of the Phenomena Identification Ranking Table (PIRT) for the Passive Auxiliary Feedwater System (PAFS) of the APR+

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1. Introduction

The APR+ (Advanced Power Reactor plus) is a Gen-III+ pressurized water reactor (PWR) of which the standard design is currently being developed in Korea. This reactor adopts new design features which are believed to contribute not only to enhancement in nuclear safety but also to improvement in economic competitiveness. While the conventional nuclear power plants have utilized the active cooling systems, the APR+ adopts two types of passive safety features; an advanced fluidic device (FD+) and a passive auxiliary feedwater system (PAFS).

The PAFS is one of the passive cooling systems of the APR+ which can replace an active system for auxiliary feedwater injection to a steam generator [1]. A schematic diagram of the PAFS is shown in Fig. 1. It cools down the secondary system by heat transfer at horizontal heat exchangers in a PCCT (Passive Condensation Cooling Tank). High pressure steam flow from the steam generator is condensed in the horizontal heat exchanger, and the water in the PCCT pool is evaporated by a boiling heat transfer at the outside wall of the heat exchanger. With an aim of validating the cooling and operational performance of the PAFS, a separate effect test, PASCAL (PAFS Condensing heat removal Assessment Loop) is being performed at KAERI (Korea Atomic Energy Research Institute) [2].

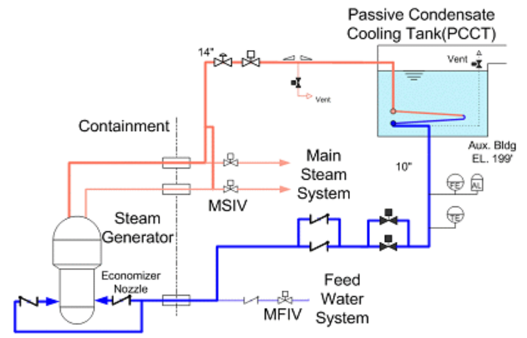

Fig. 1. A schematic diagram of the APR+ PAFS.

In this study, Phenomena Identification and Ranking Table (PIRT) has been developed for identifying the major parameters affecting the thermal-hydraulic phenomena which originate from the adoption of the PAFS in the APR+. The PIRT process can be widely used to improve a safety analysis code for a new application and to establish experimental programs and to support the resolution of the licensing issues [3]. The PIRT process used in this study follows the methodology previously applied in the APR1400 (Advanced Power Reactor 1400 MWe) PIRTs for large break loss of coolant accident (LBLOCA) and direct vessel injection (DVI) line break events [4].

2. Generation Process of the PIRT

The PIRT can serve as guides to planning a cost-effective experimental program and code improvement and also to developing test and validation matrix. Typical PIRT process is shown in Fig. 2. In this study, based on the general process of the PIRT development, the PIRT has been developed by consensus of Korean expert panellists from industry, regulatory commission, and research institute, etc.

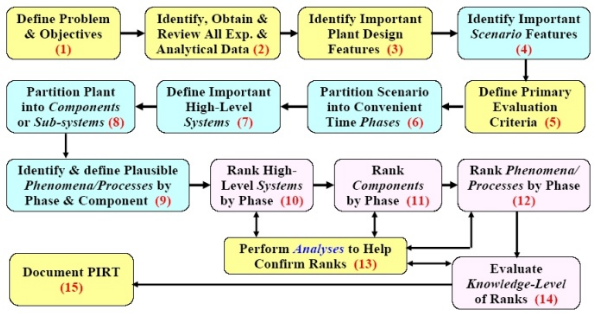

Fig. 2. Typical process of the PIRT development.

Among the various transients, the feedwater line break (FLB) event was selected for the PIRT analysis of the thermal-hydraulic phenomena related with the PAFS in the APR+. From the viewpoint of the heat removal capacity through the PAFS, the FLB was considered to be most important design basis accident (DBA) in the APR+.

It was agreed by the expert panellists that the main objective of the present PIRT development is to validate the heat removal capacity of the PAFS in the APR+. Therefore, principle safety criterion (PSC) of the PIRT was determined to be the cooling rate resulting from an actuation of the PAFS. The PSC, used for judging the relative importance of the phenomena in the plant behaviour of interest, are generally based on regulatory safety requirements or on key parameters that affect major safety issues. The rank of a system, component, process or phenomena is a measure of its relative influence on the PSC [5].

The relative importance of the phenomena is time-dependent as an accident proceeds. For the convenience of the determination on the dominant phenomena, FLB scenario was partitioned into four temporal phases of pre-actuation, initial transient, before saturated boiling in PCCT, and after saturated boiling in PCCT. With the same reason, the plant was partitioned into smaller elements of system, component, and subcomponent. Finally, the importance and the knowledge level were ranked for the individual phenomena in the specific temporal phases.

3. Development of the PIRT

The final PIRT for the heat removal capacity of the PAFS is presented in Table 1. As for the major components of the APR+, the rank of the importance and the knowledge level were summarized for each of the four temporal phases. The following phenomena were determined to be important to clearly define the heat removal capacity during an actuation of the PAFS.

- Condensation heat transfer inside the horizontal heat exchanger
- Subcooled boiling and convection heat transfer in the water pool of the PCCT
- Pool boiling in the water pool of the PCCT
- Single and two phase natural circulation in the water pool of the PCCT
- Natural circulation inside the condensate recovery pipe

4. Conclusions

The PIRT has been developed for identifying the major parameters affecting the thermal-hydraulic phenomena which originate from the adoption of the PAFS in the APR+. It was agreed by the expert panellists that the main objective of the present PIRT development is to validate the heat removal capacity of the PAFS in the APR+. Therefore, principle safety criterion (PSC) of the PIRT was determined to be the cooling rate resulting from the actuation of the PAFS. As for the major components of the APR+, the rank of the importance and the knowledge level were summarized for each of the four temporal phases. And the important phenomena were determined to clearly define the heat removal capacity during an actuation of the PAFS. The present PIRT can serve as a guide to planning cost effective experimental programs, code improvement efforts, and guidance for resolving relevant safety issues which originate from the adoption of the PAFS in the APR+.

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Table 1: Result of the PIRT for the heat removal capacity of the PAFS

System	Component	Sub-component	Phenomenon	Importance Rank				Knowledge Level Rank
				Pre-actuation	Initial Transient	Before Saturated Boiling in PCCT	After Saturated Boiling in PCCT	
PAFS	Condensing Heat Exchanger	Inlet header	Condensation	N/A	N/A	2	2	4
			Flow distribution			3	3	3
		Tubes	Condensation Heat Transfer	N/A	N/A	5	5	4
			Flow Stratification			4	4	3
			NC gas behavior			3	3	3
			Flow Instability			4	4	2
			Flow regime of bending elbow			4	4	2
		Outlet header	NC gas behavior	N/A	N/A	3	3	3
			Condensation (Upper part)			1	1	4
	PCCT		Subcooled boiling & Convection heat transfer	N/A	N/A	5	5	5
			Pool boiling			N/A	5	5
			1 Phase Natural Circulation			5	N/A	5
			2 Phase Natural Circulation			N/A	5	3
			Bundle effect			4	4	2
			Flashing (static head effect)			N/A	3	5
	Steam Supply Pipe		Natural Circulation	N/A	N/A	4	4	5
			Flow Oscillation	N/A	N/A	4	4	3
	Condensate Recovery Pipe		Natural Circulation	N/A	N/A	5	5	5
			Flow Oscillation	N/A	4	4	4	3