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Investigation of Thermal-hydraulic Variables Affected by the Downstream Effect in the Safety Analysis

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1. Introduction

Since a recirculation sump clogging issue by debris generated from high energy pipe line break (e.g. large break loss of coolant accident; LB LOCA) had been invoked, many researches on this issue have been undertaken [1]. However, they have been mainly focused on the evaluation of debris transport from a location of debris generation to the sump screen. Unfortunately, effect of debris passing the sump screen on the downstream systems, components and piping was not studied much. It has been well known that debris bypassing the sump screen may plug part of core flow or spray nozzles of the containment affecting core or containment cooling in the long-term cooling phase of LOCA. Furthermore, the bypassing debris can generate excessive wear or abrasion on moving parts of pump and valve resulting in inappropriate cooling flow rate or flow balancing. These potential adverse effects by debris are called as the downstream effect. Recently, intensive researches on the downstream effect are performed in the US. Utilities of the US published reports on evaluation methodology for the downstream effect [2, 3] and the US regulatory authority responded a series of safety evaluation reports [4, 5]. Unlike the US, the downstream effect study in Korea is rare except recent one [6] at which effect of partial core blockage and cladding fouling by debris on core cooling was investigated. So, as a preliminary study, a methodology for implementing the downstream effect to a thermal-hydraulic (T-H) safety analysis is studied. Specifically, T-H variables of safety analysis code which are strongly related to the downstream effect are investigated.

2. Development of Methodology

To develop a new methodology, first, typical flow paths of ESFs (Engineering Safety Features) at LB LOCA [7] are reviewed. ESFs considered here are ECCS (Emergency Core Cooling System) and CSS (Containment Spray System). They are safety systems used during LOCA at KSNP (Korean Standard Nuclear Power Plant) plant. Flow paths at various operational modes including standby, injection and recirculation are reviewed. Especially, the recirculation mode is further divided into short-term and long-term for ECCS. This is because the short-term recirculation through cold legs is established first and then the long-term recirculation through cold and hot legs is established later to prevent boron precipitation at top of core. Figure 1 shows the flow paths at long-term recirculation mode. Red solid lines represent the flow paths and small red numbers are pipe size. Note that only part of SI trains is drawn.

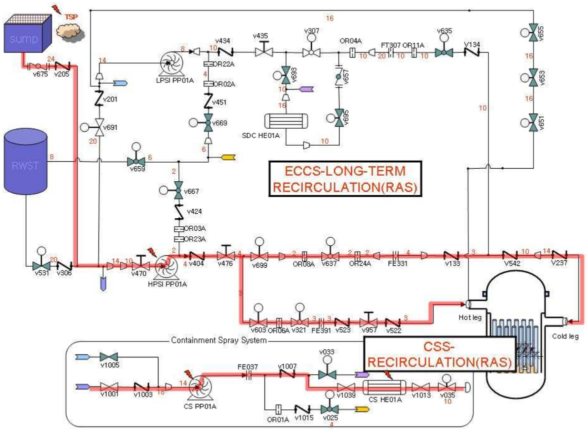

Fig. 1. Typical flow paths at the long-term recirculation mode.

Since typical flow paths are identified, as a next step, we pinpointed locations where the downstream effect is manifested. For this, we identify lists of potential adverse debris effects based on flow paths review result and regulatory references [8-11]. Tables I and II specify potential adverse debris effects at various locations. Note that table I and II separate the debris effect into within a reactor core and outside the core.

Table I: List of IN-vessel debris effects

No.	location		description
IN1	top of core		decrease of safety injection(SI) flow by debris accumulation at top of core during the long-term recirculation mode of ECCS (plugging)
IN2	bottom of core	inlet debris screen	decrease of SI flow by debris accumulation at bottom of core (plugging)
IN3	lower plenum		influence on SI flow/mixing process by debris accumulation in lower plenum
IN4	overall core		decrease of SI flow and occurrence of multi-dimensional effect on SI flow by debris accumulation in core region
IN5	rod bundles	grid support	decrease of SI flow by debris accumulation in rod bundles (plugging)
IN6		mixing vane	
IN7		swelled and ruptured fuel rods	
IN8		rod surface	degradation of heat exchange capacity by debris accumulation on rod surface(fouling,plate-out)

Table II: List of EX-vessel debris effects

No.	location	description
EX1	HPSI pump	increase of wear and vibration of pump by debris accumulation on bearing
EX2		degradation of pump performance by debris accumulation on impeller tip clearance or seal
EX3	HPSI throttle valve	decrease of SI flow by debris accumulation (plugging, V637)
EX4	CS* pump	increase of wear and vibration of pump by debris accumulation on bearing
EX5		degradation of pump performance by debris accumulation on impeller tip clearance or seal
EX6	CSS** heat exchanger	degradation of heat exchange capacity by debris accumulation on heat exchanger(fouling, plugging)
EX7	CSS spray nozzle	decrease of SI flow by debris accumulation in

			spray nozzle
EX8	small flow path	HPSI/LPSI/ CS miniflow lines	decrease of SI flow by leakage through V667/V669/V025 to refueling water storage tank due to debris accumulation these valves
EX9		ECCS common return line	decrease of SI flow by leakage through V659 to refueling water storage tank due to debris accumulation this valve

*CS: Containment Spray, **CSS: Containment Spray System

Red symbols in Fig. 2 represent identified locations of the debris effects based on Table I and II.

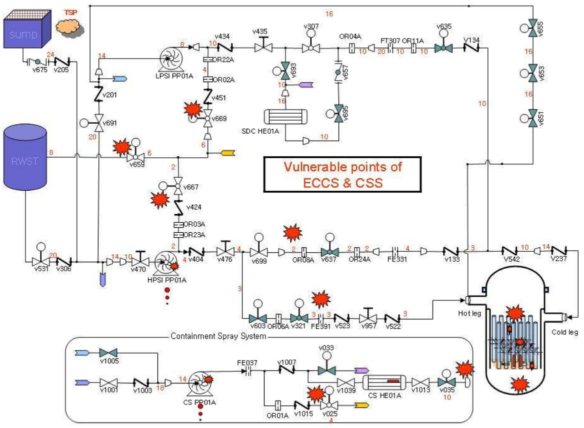

Fig. 2. Vulnerable points to the downstream effect.

Since vulnerable points and their potential adverse effects are identified, now we pick up some of them whose nature is thermal-hydraulic. For ease of selection and a systematic approach for finding T-H variables, each potential adverse effect is analyzed by applicable debris accumulation mechanisms. Three accumulation mechanisms are introduced. (See, table III).

Table III: Applicable debris accumulation mechanisms

types		examples
hydrodynamic induced(HY)		Þmost of EXs and INs vessel potential adverse debris effects
concentration induced(CO)		ÞIN1(precipitation of dissolved boron or debris induced chemicals) ÞIN4(chemical reaction of debris under high temperature and high boron concentration)
adhesiveness induced(AD)	TSP, CalSil, Nukon*	Þmost of EXs and INs vessel potential adverse debris effects (chemical effect)
	fouling	ÞEX6(degradation of heat exchange capacity)
	plate-out	ÞIN8(rod bundle surface)

*TSP, CalSil and Nukon would adhere to solid surfaces [4].

Finally, with reference to the debris generation mechanisms, T-H related potential adverse debris effects are selected and corresponding T-H variables of safety analysis codes such as MARS or CONTAIN are deduced.

Table IV: Determination of T-H related effects and variables

ID	HY	CO *	AD *	Related effect	Related variable
IN1		✖	✖		increase flow resistance
IN2		✖	✖		increase flow resistance
IN3		✖	✖		decrease control volume (lower plenum)
IN4	✖	✖	✖	✖	N/A
IN5		✖	✖		increase flow resistance
IN6		✖	✖		increase flow resistance
IN7		✖	✖		increase flow resistance
IN8	✖	✖			change heat transfer coeff
EX1		✖	✖	✖**	N/A
EX2		✖	✖		decrease HPSI flow
EX3		✖	✖		decrease HPSI flow
EX4		✖	✖	✖**	N/A
EX5		✖	✖		decrease CS flow
EX6		✖			change heat transfer coeff
EX7		✖	✖		decrease CS flow
EX8***	✖	✖	✖	✖	N/A
EX9***	✖	✖	✖	✖	N/A

*Chemical effect related mechanisms which can not be implemented by pure T-H analysis are not considered here.

**Since mechanical effect (i.e. wear and vibration) can not be implemented by pure T-H analysis, they are not considered here.

***Since mini-flow lines are isolated before they are contaminated by debris.

Table IV summarizes our result. Here, a red solid symbol means that a corresponding accumulation mechanism applies and a cross symbol means that corresponding accumulation mechanism does not work. A blue solid symbol denotes a downstream effect which can be implemented by T-H code. Last column of table IV shows that related T-H variables.

3. Conclusions

As a preliminary work for the comprehensive study on the downstream effect, T-H variables pertinent to implementing the downstream effect to the safety analysis of the recirculation cooling phase are determined with reference to operational modes of ESFs, regulatory references and debris accumulation types. Founded variables are flow resistance, HPSI/CS flow rates, lower plenum volume and heat transfer coefficients of fuel rod and CSS heat exchanger. Using these variables, potential adverse debris effects on the long-term core recirculation cooling can be quantified.

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