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Preliminary Sensitivity Analysis of APR1400 IBLOCA Scenario using SPACE code

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1. Introduction

Recently, proposals to replace the existing design basis accident (DBA) of the double-ended guillotine break loss of coolant accident (DEGB LOCA) with a new design basis accident of the intermediate break (IB) LOCA have been proposed in the U.S. and French nuclear industry [1,2].

Similarly, the domestic nuclear industry is attempting to reclassify LOCA by incorporating IBLOCA as a new DBA instead of DEGB LOCA through pipe rupture probability assessment. This requires both a new safety analysis methodology and a new safety analysis code. The existing SPACE code is already licensed for the safety analysis of small-break (SB) and large-break (LB) LOCAs, but it has not been validated for IBLOCA. To apply the SPACE code to the IBLOCA safety analysis methodology, a phenomenon identification and ranking table (PIRT) for IBLOCA in domestic pressurized water reactors (PWRs) is being developed, and preliminary IBLOCA scenarios have been selected through several PIRT meetings composed of expert panels.

Based on the preliminary accident scenarios of the IBLOCA PIRT developed to date, this paper presents the results of IBLOCA sensitivity analysis of APR1400 for initial events such as reactor coolant pump (RCP) trip and secondary system isolation.

2. Overview of IBLOCA

2.1 Characteristics of IBLOCA

In the IBLOCA PIRT currently under development, IBLOCA is defined as a pipeline rupture event with a break size in the range of 10 to 25% of the cold leg cross-sectional area. The break size for IBLOCA was determined based on a full spectrum LOCA analysis performed by Westinghouse (WH) [3]. In general, a break of 10% is equivalent to the maximum break size for SBLOCA.

The main characteristics of IBLOCA from the WH analysis are as follows [3]:

- A single, prolonged core uncover that may uncover all or nearly all of the active core
- A plug of water that remains in the lower plenum that prevents reverse steam flow through the downcomer to the break. Without an upward flow of steam in the downcomer, bypass does not occur, and accumulator water falls freely into the downcomer.
- All of the loops clear and vent steam to the break. Flashing in the primary system makes the increase in steam flow through the loop seals continuous, and loop seal clearance is no longer determined only on the hydrodynamic balance between the uphill and downhill sides of the pump suction piping.

2.2 Preliminary Temporal Phase of IBLOCA

The major phenomena and processes during an IBLOCA transient can be categorized into three temporal phases as follows:

<u>Phase 1: blowdown and rapid depressurization</u>

A critical flow occurs through the break and primary system is depressurized rapidly due to inventory loss. The reactor power starts to decrease by negative moderator density feedback reactivity as void fraction of the core fluid increases due to drastic depressurization prior to reactor scram. Reactor trip is activated by low pressurizer pressure signal and reactor power decreases to decay heat after all control rods are inserted into the core.

Loss of offsite power (LOOP) should be considered as a postulated initial events (PIEs) during an IBLOCA and as a result of LOOP, turbine and RCPs are tripped simultaneously.

It is noted that the first peak cladding temperature (PCT) due to departure from nucleate boiling (DNB) might occur at high power region before reactor scram, especially when trip of all RCPs coincident with break and top-skewed power shape are assumed.

<u>Phase 2: Crossover of pressure and core boil-off</u>

Phase 2 begins when the primary system pressure decreases below the 2nd system pressure. In this phase, makeup water for compensating coolant inventory loss is delivered into the reactor coolant system (RCS) by safety injection pumps (SIPs) of emergency core cooling system (ECCS). 2 out of 4 SIPs are failed because one emergency diesel generator (EDG) is assumed to fail according to single failure criteria. Loop seals are formed at the RCP suction but all of them are cleared by flashing and never formed again. Depending on the break size, boil-off or 2nd PCT starts to increase as core water level decrease due to continuous boil-off in the core.

<u>Phase 3: Core recovery and long-term cooling</u>

Phase 3 begins with actuation of safety injection tanks (SITs) or accumulators (ACCs). As a result of SIT/ACC injection, core is reflooded quickly and PCT turns around. Flow balance between discharge and safety injection is established and primary system pressure is stabilized at high pressure around 1 MPa. Shutdown cooling system (SCS) or low pressure safety injection (LPSI) is actuated for long-term core cooling after termination of SIT/ACC injection.

3. Sensitivity Analysis of APR1400

3.1 SPACE Input Model

Reference SPACE input model of IBLOCA sensitivity analysis is based on the APR1400 LBLOCA safety analysis model as shown in Fig. 1. The axial power shape is slightly top-skewed with the maximum power peaking, F_Q of 2.38. Several modeling features of SBLOCA analysis such as credit for reactor trip and actuation of main steamline safety valves (MSSVs) to prevent the overpressure of the 2nd system after a turbine trip are also added into the LBLOCA input model.

As mentioned earlier, RCP trip occurs coincident with turbine trip as a result of LOOP. In this study, however, RCP trip and the 2nd system isolation due to turbine trip are treated as independent events to estimate the effect of each event on the PCT which is the first safety criterion for an IBLOCA scenario. The time of occurrence of each event is summarized in Table I.

The break sizes of each analysis case are set to 10%, 15%, 20% and 25% at the pump discharge side of the cold leg. Therefore, total number of sensitivity analysis cases is 16.

Table I: Analysis cases of sensitivity parameters

Case	Occurrence timing		Remark
	RCP trip	**2nd isolation**	
1	at break	at break	RX is tripped by low PZR pressure
2	at break	at RX trip	
3	at RX trip	at break	
4	at RX trip	at RX trip	

3.2 Results of Sensitivity Analysis

Table II summarizes the results of sensitivity analysis. It shows the event occurring time for reactor trip, ECC water delivery to the RCS and start of each phase, and maximum PCTs in each analysis case.

As the isolation of the secondary is delayed, the reactor shutdown following a low pressurizer pressure signal occurs earlier because the turbine operation removes the core power continuously without any obstacles to depressurization of the primary. This effect of delayed isolation of the secondary system is greater for smaller break sizes.

Since all events in the IBLCOA scenario are dependent on the depressurization of the primary system, the timing of each event is accelerated when the primary system is depressurized quickly. Therefore, the overall IBLOCA scenario tends to progress faster when secondary system isolation is delayed.

The secondary system isolation event is the most significant factor affecting primary pressure, while RCP trips are the most significant factor affecting the 1st PCT rather than primary pressure are. In addition, if the break size is relatively large, the RCP trip affects not only the 1st PCT but also the 2nd PCT to some extent.

RCP trips do not have a significant impact on the timing of reactor shutdown because they mainly affect core coolant flow and heat transfer to the SG secondary.

Comparing the impact on the 1st PCT caused by DNB, the RCP trip from a mass flux perspective is more important than the secondary system isolation from a pressure and inlet superheat perspective, and the RCP trip also has a greater impact on the 2nd PCT, the boil-off PCT.

In general, the 1st PCT occurs under the condition that the RCP trips simultaneously with the break. For small break sizes, it also occurs when secondary isolation is delayed with an early RCP trip, but the maximum value of the PCT in this case is smaller than when secondary isolation occurs earlier.

Comparing the trends of the 1st and 2nd PCTs according to the break size, the 1st PCT tends to decrease and the 2nd PCT tends to increase as the break size increases. For small break cases with relatively high core coolant inventory, the above trend is due to the high core power determined by the negative coolant density feedback reactivity.

In conclusion, the maximum 1st PCT (691.2 K) occurs for the smallest break size (10%) under conditions where the RCP trip and secondary isolation occur early. The maximum 2nd PCT (696.2 K) also occurs for the largest break size (25%) under the same condition. However, the effect of the difference in the timing of the secondary isolation on the 2nd PCT is not as large as the difference in the timing of the RCP trip.

4. Conclusions

To evaluate the impact of RCP tripping and secondary isolation due to LOOP on the PCT during a ARP1400 IBLOCA transient, a sensitivity analysis was performed varying the timing of each event for four break sizes. The sensitivity analysis based on the APR1400 LBLOCA model using the SPACE code with the addition of the SBLOCA model including MSSV operation and reactor shutdown.

The results showed that when the RCP trip and secondary isolation occurred simultaneously with the rupture, the 1st PCT due to DNB occurred for all break sizes. The RCP trip also had some influence on the 2nd PCT due to boil-off. However, the impact of RCP trip on primary depressurization was negligible. Isolation of the secondary system suppresses the primary system depressurization, so if the secondary system isolation is delayed, the reactor shutdown by the low PZR pressure signal will occur earlier.

In conclusion, the combination of initial events representing the highest PCT is the case of both RCP trip and secondary isolation coincident with break, which is likely to occur when LOOP and break occur simultaneously.

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REFERENCES

[1] Alternative Licensing Approaches for Higher Burnup Fuel, technical report, EPRI, 2020.

[2] Sandrine Boutin, Audrey Buiron, Stéphanie Graff, "A New Method Taking into Account Physical Phenomena Related to Fuel Behaviour during LOCA", EUROSAFE 2016.

[3] Stephen M. Bajorek, Nikolay Petkov, Katsuhiro Ohkawa, Robert M. Kemper & Arthur P. Ginsberg, "Realistic Small- and Intermediate-Break Loss-of-Coolant Accident Analysis Using WCOBRA/TRAC," Nuclear Technology, Vol.136, 50-62p, 2001.

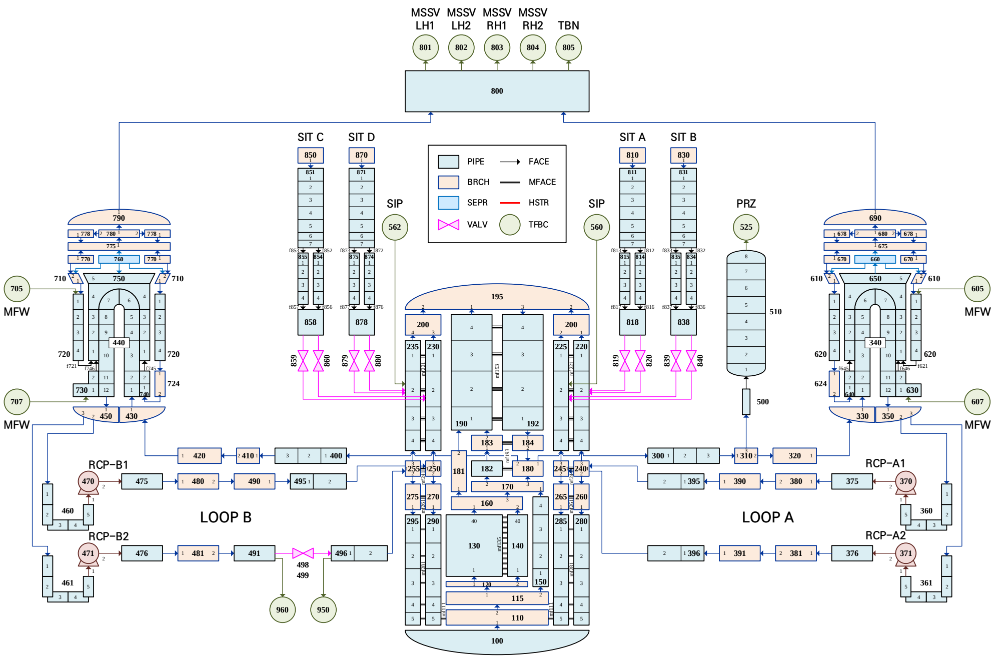

Fig. 1. SPACE input model for APR1400 IBLOCA analysis

Table II: Summary of APR1400 IBLOCA sensitivity analysis

Break size	Sensitivity parameters		Event time (s)				PCT (K)
	RCP trip	2nd sys. isol.	RX trip	Phase 2	SI delivery	Phase 3	(1st / 2nd)
10%	at break	at break	20.3	69.9	59.2	166.2	**691.2** / -
		at RX trip	16.6	63.5	55.4	167.9	677.3 / -
	at RX trip	at break	20.8	69.5	59.6	173.3	-
		at RX trip	15.4	67.7	54.2	173.2	-
15%	at break	at break	16.6	54.9	55.5	131.9	674.2 / -
		at RX trip	14.5	41.8	53.3	132.5	666.5 / -
	at RX trip	at break	16.5	55.9	55.4	136.9	-
		at RX trip	13.9	53.9	52.8	137.4	-
20%	at break	at break	13.4	36.2	52.3	87.6	660.9 / 670.0
		at RX trip	12.4	29.9	51.3	87.2	- / 646.5
	at RX trip	at break	13.4	38.2	52.2	91.0	- / 644.0
		at RX trip	12.3	32.7	51.2	90.7	- / 641.8
25%	at break	at break	12.6	30.1	51.4	72.0	660.4 / **696.2**
		at RX trip	11.8	26.2	50.7	71.0	- / 694.6
	at RX trip	at break	12.6	31.8	51.4	74.3	- / 686.6
		at RX trip	11.8	27.8	50.6	73.6	- / 684.3