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Transient Analysis of Station Black Out during Mid-Loop Operation for Framatome Nuclear Power Plant

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1. Introduction

After the Fukushima accidents from an earthquake followed by a tsunami, the mitigation strategies against Station Black Out (SBO) have been emphasized. The reactor core melt-down and release of massive radioactive materials occurred due to the accident. After the accident, the equipment and strategies against the Extended Loss of All AC Power (ELAP) were recommended strongly in the nuclear industry.

The purpose of this study is to provide strategies for maintaining core cooling and protecting the reactor core in the event of complete loss of all AC power while on mid-loop operation.

The transient analysis was performed to comprehend the Fukushima accident, and to provide insights into mitigating strategies for SBO while on mid-loop operation using the RELAP5/MOD3.3 code.

2. Modeling for Analysis

The RELAP5/MOD3.3 code has been developed for best-estimate transient simulation of reactor coolant system during accident. This code is a tool that allows users to model the coupled behavior of the reactor coolant system and reactor core during accidents. The reactor coolant system behavior is calculated using a two-phase model, which allows unequal temperatures and velocities for the two phase flow [1].

The modeling of the Framatome NPP has been developed using Hanul Unit 1&2 design data. Fig.1 shows the nodalization model of Framatome NPP for the analysis. The nodes of reactor are composed of the down-comer, lower plenum, upper plenum, core, and junction to connect with the hot leg.

The secondary side of Steam Generator (SG) includes the nodes of the main feed-water system, evaporator, riser, separator, and dome.

3. Analysis Cases and Assumption

Plant shutdown state can be divided into the following five categories [2]:

- A: Reactor Coolant System (RCS) intact and full with SGs available
- B: RCS intact but not full
- C: RCS vented with reactor vessel head installed
- D: RCS drained below reactor vessel flange with the upper head removed
- E: Refueling cavity flooded with the upper head removed

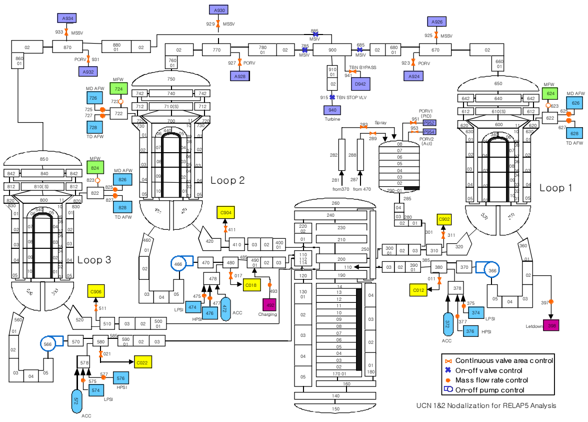

Fig.1. Nodalization Model of Hanul Unit 1&2

These categories are selected based on plant configuration such as RCS intactness, SG availability, and RCS level.

In Shutdown State C, the reactor coolant system is vented and drained to the mid-plane of the hot leg. The RHR system is the only means of decay heat removal. There are no SGs available to provide core cooling. This Shutdown State is the most limiting case of the five configurations [2]. So the shutdown SBO transient analysis is performed here only for Shutdown State C. In Shutdown State C, the only available systems are Low Temperature Over Pressurization (LTOP), gravity feed from Refueling Water Storage Tank (PTR), to the primary by operator and external injection to the primary by operator.

Assumptions in the analysis are as follows:

<u>Case-C1</u>
ĀNo operator actions
<u>Case-C2</u>
ĀGravity feed from PTR to the primary by operator (4,000 sec)
<u>Case-C3</u>
ĀGravity feed from PTR to the primary by operator (4,000 sec)
ĀPrimary external injection by operator (14,000 sec)

It is assumed that gravity feed from PTR to the primary by operator is available at 4,000 sec after SBO occurs. 4,000 sec is reasonable time for operator to initiate PTR gravity feed manually in shutdown SBO situation.

4. Results

The sequence of events is provided in Table 1. In Case-C1, there are no operator actions so that the upper core is uncovered at 5,080 sec and core damage occurs at 8,710 sec during SBO as shown in Fig.2 and 3. In order to prevent completely uncovered of the upper core, the injecting into RCS should be initiated at least 5,400 sec. The core uncovery time is defined as the point when the fuel rods are no longer covered with coolant and begin to heat up.

In Case-C2 of that the gravity feed into RCS from PTR by operator is initiated at 4,000 sec, the core is uncovered at 31,240 sec and the core damage occurs at 41,170 sec as shown in Fig.4 and 5. The PTR gravity feed flow is decreased as the water level in PTR is lowered. So PTR refill or primary external injection is required to maintain core cooling and prevent core damage.

Case-C3 shows the same sequence of events as Case-C2 before the initiation of the primary external injection. In Case-C3 the gravity feed is initiated into RCS from PTR at 4,000 sec and primary external injection was provided at 14,400 sec. The core uncovery do not occurred and the integrity of core is also maintained as shown in Fig.6 and 7. However, the core region maintains the form of bubbles and two-phase flow.

Table.1. Event Sequences for Shutdown State C

Event	Case-C1	Case-C2	Case-C3
SBO occurs	0 sec	0 sec	0 sec
Core boiling begins	460 sec (0.13 hr)	460 sec (0.13 hr)	460 sec (0.13 hr)
Gravity feed from PTR	-	4,000 sec (1.11 hr)	4,000 sec (1.11 hr)
Primary external injection	-	-	14,400 sec (4.00 hr)
Core uncovery	5,080 sec (1.41 hr)	31,240 sec (8.68 hr)	-
Core damage	8,710 sec (2.42 hr)	41,170 sec (11.44 hr)	-

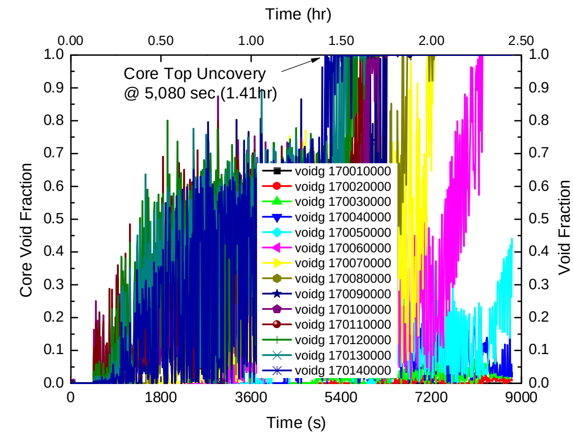

Fig.2. Core void fraction (Case-C1)

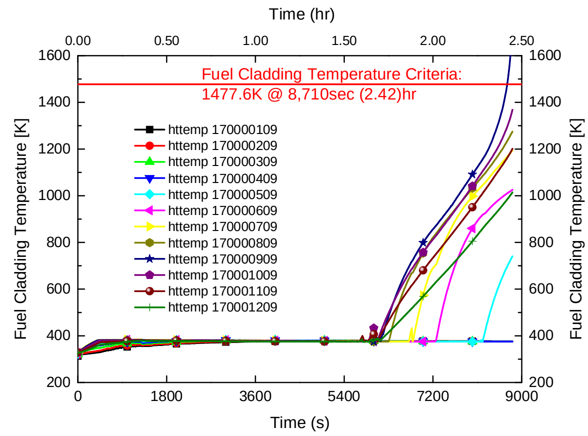

Fig.3. Fuel cladding temperature (Case-C1)

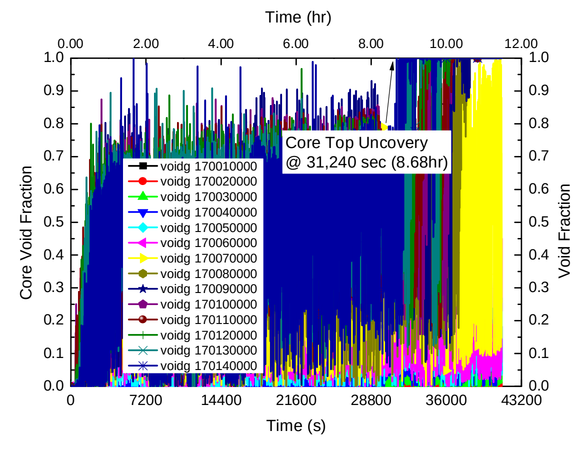

Fig.4. Core void fraction (Case-C2)

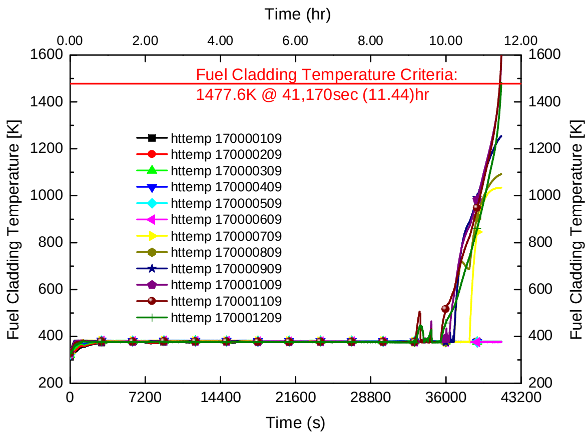

Fig.5. Fuel cladding temperature (Case-C2)

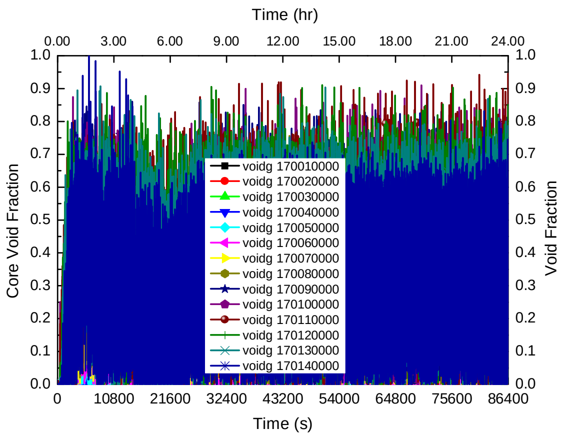

Fig.6. Core void fraction (Case-C3)

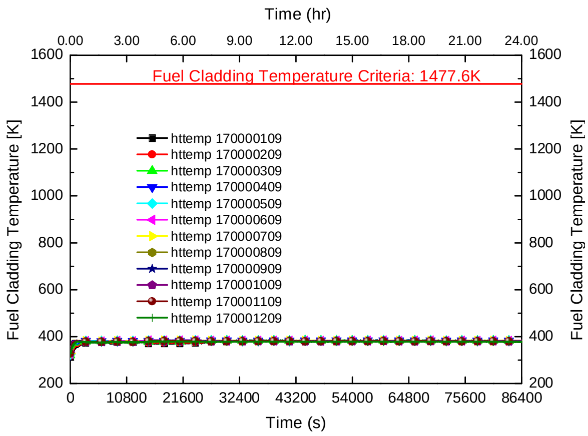

Fig.7. Fuel cladding temperature (Case-C3)

5. Conclusions

The transient analysis was performed to provide useful insights for operator guidelines to maintain critical safety functions during SBO for shutdown modes.

For the shutdown state C, the PTR gravity feed flow decreases as the water level in PTR is lowered. So, PTR should be refilled or primary external injection is required at 14,400 sec. If PTR gravity feed is provided at 4,000 sec and primary external injection is provided at 14,400 sec, the core is covered with coolant and cooled well. In the conclusion, the long-term cooling strategy should be established by primary external injection or PTR refill.

This study would be useful for improving a strategy to cope with loss of all AC power while on mid-loop operation in the Framatome NPP.

REFERENCES

[1] NUREG/CR-6150, ñSCDAP/RELAP5/MOD 3.3 CODE MANUAL,ò Rev.2, Vol.3, Jan, 2001.

[2] Westinghouse, Supplemental Information for Operator Response to Extended Loss of AC Power in Modes 4, 5 and 6, PWROG-14073-P, Revision 0, March 2015.