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Accident Effects Analysis of SBO during Mid-Loop Operation for Framatome Nuclear Power Plant

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1. Introduction

Since the Fukushima accidents, the mitigation strategies against Station Black Out (SBO) have been emphasized. The release of massive radioactive materials would be 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 power plants.

The purpose of this study is to check the strategies for maintaining core cooling, protecting the reactor core, the accident effects dose analysis and the safety in the event of complete loss of all AC power while on mid-loop operation.

For the purpose, RHR cooling and external feeding water strategy during mid loop operation are introduced.

The accident effects analysis is performed by RADTRAD 3.03 and ARCON 96.[1]

The transient analysis is carried out to get the insight into mitigating strategies for SBO(ELAP) while on mid-loop operation using the RELAP5/MOD3.3 code.[2-3]

2. Methodology

Fig.1 is the modeling concept of RADTRAD 3.03 for the accident effects analysis.

Fig.2 is the nodalization model of RELAP5/MOD3.3 for transient analysis.

The key point of the nodes of reactor modeling are consists of down-comer, plenums (lower part and upper part), core, and each junctions.

And the components are connected with the hot leg.

The secondary part of Steam Generator (SG) includes the main feed-water system, evaporator, riser, separator, dome, time dependent junctions and time dependent volumes.

2.1 Transient Case and Analysis Assumptions

Plant shutdown state has five categories as below[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

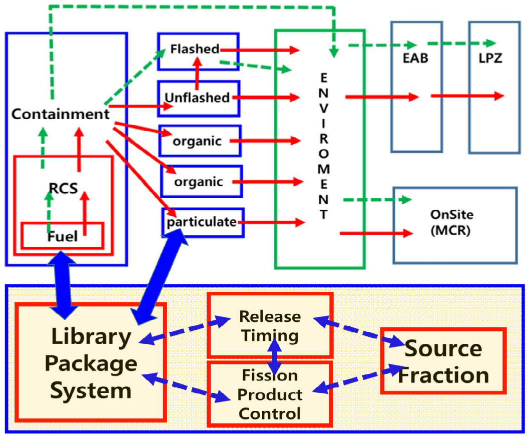

Fig.1. Modeling Concept of RADTRAD 3.03

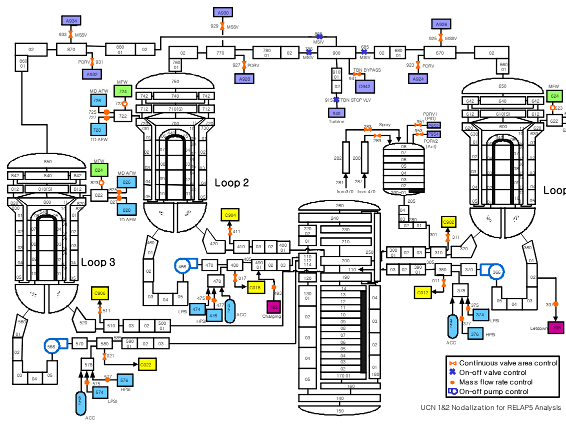

Fig.2. Nodalization Model of Hanul Unit 1&2

These categories are based on the plant design, the operation availability and equipment performance including RCS intactness, SG availability, and RCS level.

In five categories of shutdown state, the limiting case is the shutdown state C.

In shutdown state C, RCS is vented and drained up to the mid-level of the hot leg. The RHR system is the only equipment to remove the decay heat.

Also, no SGs are available to provide core cooling.

So the shutdown SBO transient analysis is selected only for Shutdown State C.

Here, the only available items are the gravity feed water 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:

Case-C1
· No operator actions
Case-C2
· Gravity feed from PTR to the primary by operator (4,000 sec)
Case-C3
· Gravity feed from PTR to the primary by operator (4,000 sec)
· Primary external injection by operator (14,000 sec)

2.2 Accident Effects Analysis and Assumptions

In accident effects analysis, the optimized strategy "Case-C3 is selected for RADTRAD modeling with assumptions as below:

- Reactor Coolant System (RCS) fission product's activity is equilibrium state with Technical Specification limitation.
- Technical Specification limitation is based on the FSAR 11's source term
- Iodine activity is 1.0uCi/gram and Iodine spiking is considered.
- The release of noble gas is based on FSAR 11 in equilibrium state.
- Conservatively, RCS specific activity is not diluted by refueling cavity flooded water

2.3 ARCON96 Modeling for Accident Effects Analysis

In order to analysis the effects of Casce-C3, on-site atmospheric dispersion factor is calculated by ARCON 96.

Basic calculation conditions are below:

- Methodological date is ranged from 2017 to 2018 in hanul site.
- Application during time is within 24 hours.
- Time duration is 8hours and 24hours.
- ARCON 96 calculation results are applied by limiting atmospheric dispersion factor.
- Modeling distance is MCR left side, MCR right side and MCR centerline
- Initial sigma-y and initial sigma-z are used to calculated.

3. Results and Discussions

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 5,088 sec and core damage occurs at 8,712 sec during SBO as shown in Fig.3 and 4. 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 31,243 sec and the core damage occurs at 41,175 sec as shown in Fig.5 and 6. 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.7 and 8. However, the core region maintains the form of bubbles and two-phase flow.

Finally, Fig. 8 shows the peak cladding temperature is always under the criteria of fuel cladding temperature.

From Fig.3 ~ Fig.8, the accident effects evaluation is carried out. The On-site atmospheric dispersion factors and the dose effect of the accident are shown in Fig. 9 and Fig.10.

The On-site atmospheric dispersion factors is MCR-centerline case and Fig.9 shows the trend.

Fig. 10 is the accumulated dose results from starting point to 86400sec in Case-C3.

In the condition of the suitable operator action, fission products effects is within 2.5mSv in Fig. 10.

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	466 sec (0.13 hr)	466 sec (0.13 hr)	466 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	5,088 sec (1.41 hr)	31,243 sec (8.68 hr)	-
Core damage	8,712 sec (2.42 hr)	41,175 sec (11.44 hr)	-

Table. 2. Source Terms and Conditions

Input Items	Equivalent I-131 values
Equilibrium Concentration (uCi/gram)	- I-131 : 0.809 - I-132 : 0.195 - I-133 : 0.828 - I-134 : 0.077 - I-135 : 0.390
RCS mass (gram)	- 270,000,000
Iodine Activity (Ci)	- I-131 : 218.43 - I-132 : 52.65 - I-133 : 223.56 - I-134 : 20.79 - I-135 : 105.3
Total Removal Constant (min^{-1})	- λ131 : 0.001015 - λ132 : 0.005900 - λ133 : 0.001431 - λ134 : 0.015200 - λ135 : 0.002630

Table.3. On-Site Atmospheric Dispersion Factors

Time (hours)	MCR-left (sec/m^3)	MCR-Right (sec/m^3)	MCR-Center (sec/m^3)
0~8	1.88E-03	1.91E-03	2.10E-03
8~24	8.5E-04	9.00E-04	9.73E-04
24~96	6.88E-04	6.9E-04	7.6E-04
96~720	4.82E-04	4.7E-04	5.5E-04

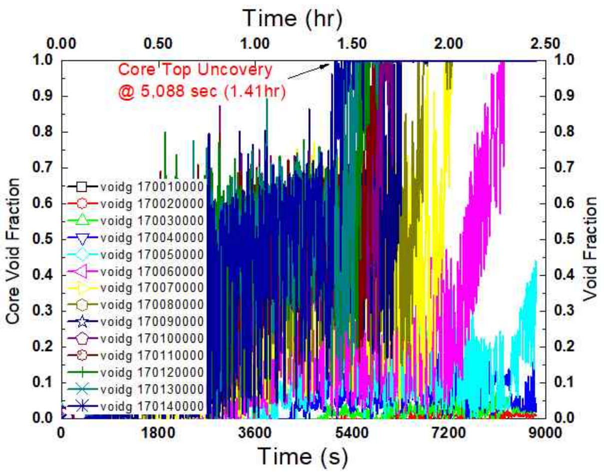

Fig.3. Core void fraction (Case-C1)

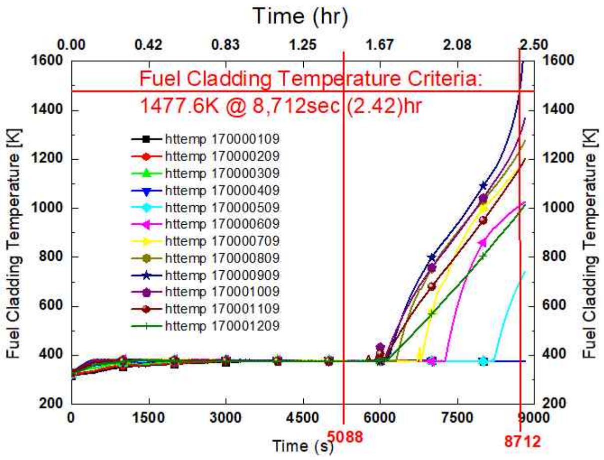

Fig.4. Fuel cladding temperature (Case-C1)

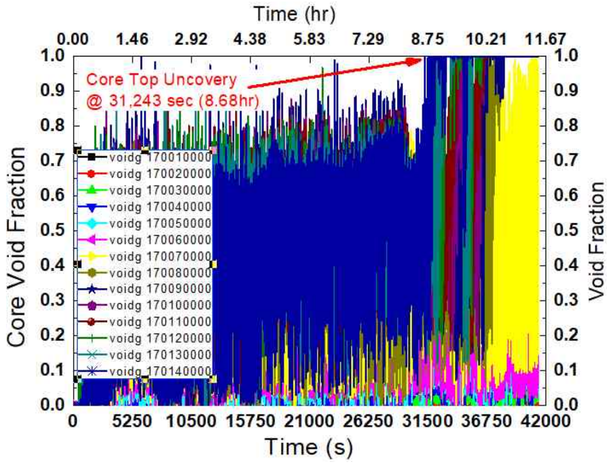

Fig.5. Core void fraction (Case-C2)

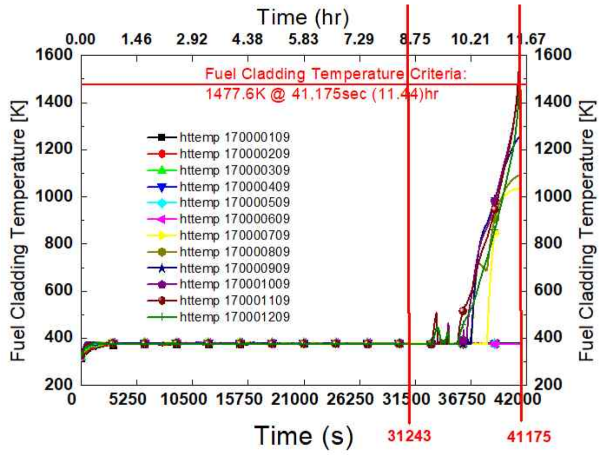

Fig.6. Fuel cladding temperature (Case-C2)

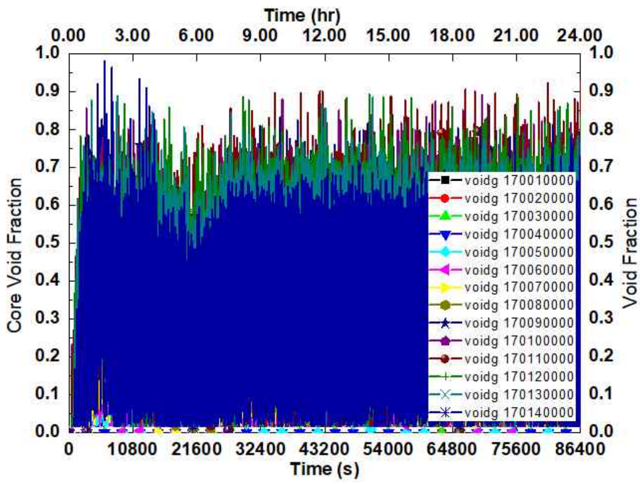

Fig.7. Core void fraction (Case-C3)

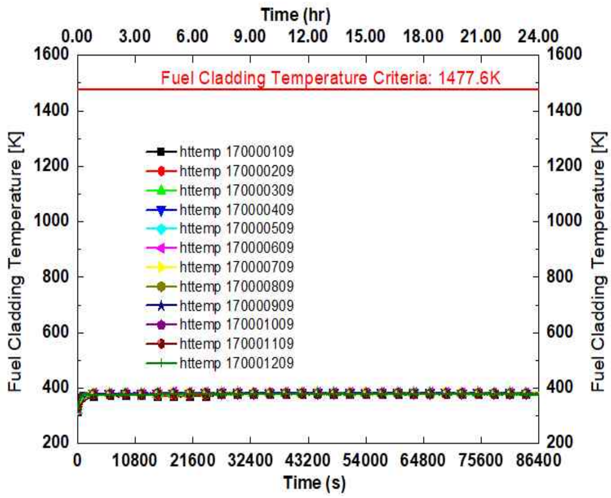

Fig.8. Fuel cladding temperature (Case-C3)

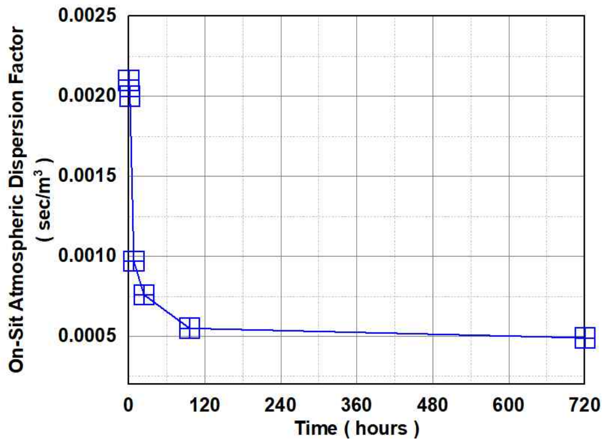

Fig.9. On-Site Dispersion Factors from ARCON 96

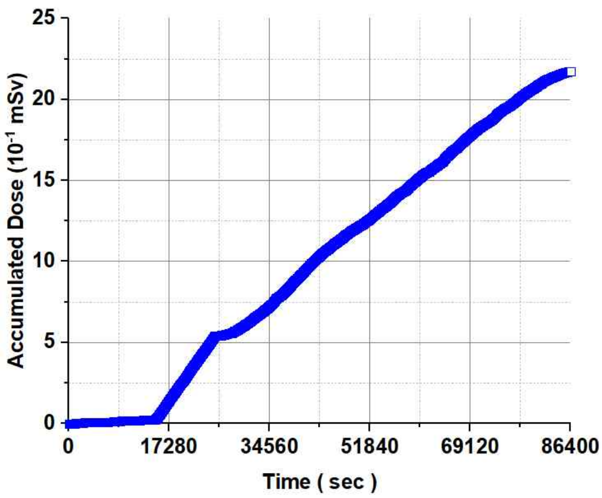

Fig.10. Accumulated Dose from RADTRAD 3.03

4. 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 purpose, RHR cooling and external feeding water strategy during mid loop operation were introduced.

And the accident effects analysis was performed including dose estimation and on-site atmospheric dispersion factor evaluation.

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.

Considering the specific activity and RCS evaporation, the accident effects is under 2.7mSv dose.

In the conclusion, the long-term cooling strategy should be established by primary external injection or PTR refill.

This study would be useful for the dose effect mitigation and the response strategy improvement in condition of loss of all AC power during mid-loop operation

Fig.3~Fig.10 are useful for improving a strategy to cope with SBO while on mid-loop operation in the Framatome NPP.

REFERENCES

[1] NUREG-6604, RADTRAD 3.03 CODE MANUAL.

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

[3] 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.