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Development of Operator Guideline for Abnormal Operation Procedure by Using Simulator Validation and Best Estimate Analysis

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1. Introduction

Operator guideline of RHR loss while it is operating at mid-loop condition was developed through the validation performed in Kori Unit 2 simulator in March 2007.

To demonstrate the effectiveness of operator action of the procedure, the validation processes were performed by methods including discussion method and the Kori Unit 2 simulator test. This validation concluded that for RHR loss during mid loop operation, the procedure was effective in restoring the plant to a safe, stable condition. Findings from the validation processes were incorporated in the procedure and guideline.

2. Effectiveness of Procedure

2.1 Cooling Methods

After RHR loss while operating at mid-loop condition, core cooling methods are shown in Table 1. When coolant is not boiling in core and RCS inventory remains at mid-loop level, core cooling methods are secondary heat sink and gravity feed. However these methods are restricted because these require RCS integrity and the availability of gravity feed to core and pumping to RWST respectively. When RCS inventory was leaked to low water level, additional cooling methods is to refill with charging pump. This validation concludes that these core cooling methods are effective as cooling means after RHR loss while operating at mid loop condition as shown Figure 1,2 and 5[1,2].

Table 1. Core Cooling Methods after RHR Loss

Case	Conditions	Cooling Methods
1	RHR loss, no fuel damage, not boiling in core, normal water level	1.Establish available SG 2. Gravity feed
2	RHR loss, no fuel damage, not boiling in core, low water level	1.Establish available SG 2. Refill with charging 3. Gravity feed
3	RHR loss, no fuel damage, not boiling in core, very low water level	1.Establish available SG 2. SI to cold leg 3. Gravity feed
4	RHR loss, fuel damage, initiating to boil in core, any water level	1.Establish available SG 2. SI to hot and cold leg 3. Gravity feed

2.2 Operator Action Time

After RHR loss while operating at mid-loop condition, operator actions are required as shown in Table 2. In this simulator test, operator action time is extracted in step by step. The results showed that operator action time was within the assumed value and the actions lead to appropriate core cooling status. Operator actions to isolate CV need communication between MCR operator and site operators because there are so many isolation valves and several valves are not indicated in the MCR. Therefore, the time to isolate CV is the longest in all the steps. RHR vent time assumes that it will take 10 minutes until voids flow out completely by operator experience.

Table 2. Operator Action Time in Simulator Test

Step	Operator Actions	Time (mm:ss)
1	Stop RHR pump	2:52
2	Isolate letdown	1:00
3	Determine time to boil	0:47
4	Evacuate CV personnel	1:45
5	Isolate CV	11:05
6	Start CV cooling fan	2:13
7	Check core temp.	3:40
8	Check RCS level	0:20
9	Refill RCS with SI	2:01
10	Refill RCS with charging	1:35
11	Isolate leakage	0:30
12	Establish available SG	0:20
13	Vent RHR line	10:00
14	Prepare RHR line	2:10
15	Start RHR pump	5:11
16	Reduce RCS refill	0:20
17	Check RCS temp.	0:31
18	Restore normal state	0:24

2.3 Appropriate Core Cooling through Refilling

After RHR loss while operating at mid-loop condition, core cooling was established by safety injection as shown in Figure 1 and 2. Those results showed that proper flow of safety injection stabilizes core temperature and core collapsed water level.

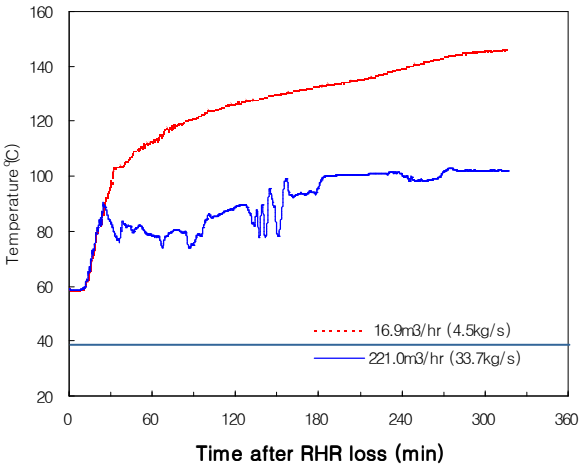

Figure 1. Temperature when refilling SI

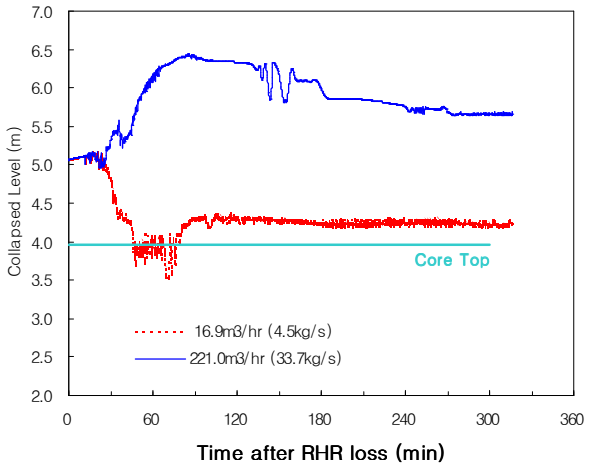

Figure 2. Collapsed Level when Refilling SI

2.4 CV Isolation Time

After RHR loss while operating at mid-loop condition, CV (Containment Vessel) isolation should be required before fuel rod damage occurs and radiation level goes high. Therefore, the procedure was prepared so that CV Isolation should be initiated at 20 minutes before Fuel damage initiated after RHR loss as shown in Figure 3 and 4. In step 3,4 and 5 of this simulator test, operator action time takes about 12 minutes to finish the CV isolation. Results of simulator test showed that it was appropriate to assume the operator action time of 20 minutes.

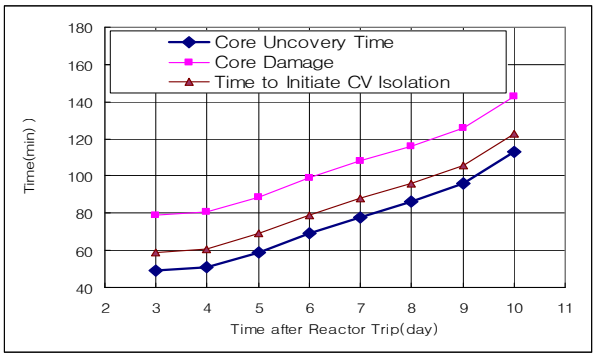

Figure 3. CV Isolation Time after RHR Loss without RCS Hot leg Opening.

When pressurized in the upper head of reactor vessel without RCS hot leg opening, reactor coolant can be swept out to cold leg opening. Therefore core uncovery time in the case is fast than that in case of hot leg opening.

2.5 Cooling with Secondary Heat Sink

RCS pressure remains lower through cooling through reflux and condensation when steam generators are available than when steam generator is not available as shown in Figure 5. Therefore secondary heat sink in this procedure will be applied to cool down RCS when safety injection is not used and steam bubble initiates to generate.

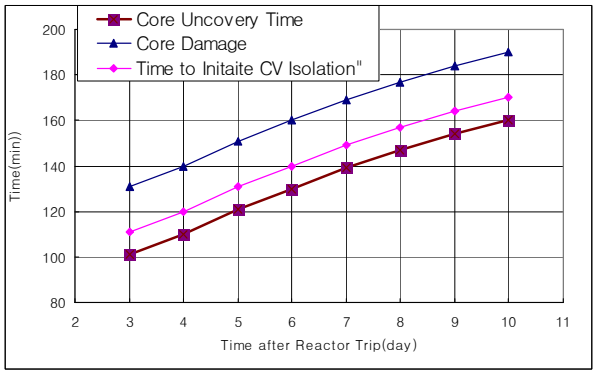

Figure 4. CV Isolation Tome after RHR Loss with Hot leg Opening

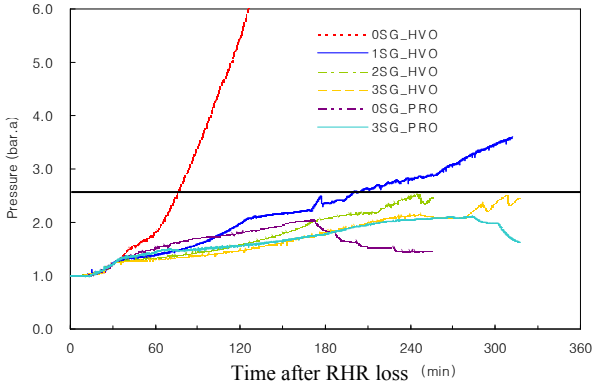

Figure 5. Cooling Effects by Steam Generator

3. Operator Guidelines

After discussing with operators, reviewing analyses report and conducting simulator test, major operator guidelines were deduced as follows; (1) For configurations with hot side opening the time to core damage takes 130 minutes in case of 3 days after reactor trip. Therefore, considering operator action time, CV isolation should be initiated at 110 minutes after RHR loss with RCS hot side vent. (2) While boiling exists in the core region, the water level in the reactor vessel core region indicates incorrectly. Therefore core temperature and pressure indicates symptom of core correctly in this situation. (3) Reflux and condensation is alternate cooling method when RCS integrity remains and steam generator is available. (4) Gravity feed and pumping to RWST is also alternate cooling method when RHR and SI are not available.

4. Conclusions

Operator guideline for procedure of RHR loss while operating at mid-loop condition is developed through validation processes by discussion with operators and KORI Unit 2 simulator test.

REFERENCES

[1] ARG-1, Loss of RHR while operating at mid-loop condition, Westinghouse Co., WCAP-10348, 1983.
[2] Sang-Jun Ha, “Safety Analysis during Mid-loop Operation for Kori 1&2 and YGN 1&2 Units”, KEPRI, 2001.11.