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Evaluation of Long Term Cooling Capability for APR 1400 under Loss of Ultimate Heat Sink Accident during Low Power Shutdown Operation

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1. Introduction

A nuclear power plant should be maintained the cooling capability of reactor core even in the event of an accident. In recent years, it has begun to discuss the possibility of large commercial aircraft impact as a possible accident for nuclear power plant.

The U.S. Nuclear Regulatory Commission (NRC) has issued the rule for aircraft impact assessment to ensure the integrity of containment and the cooling capacity of reactor core in the event of an aircraft impact [1]. The Korean Nuclear Safety Institute (KINS), regulatory in Korea body, published a draft rule about aircraft impact assessment [2] and requested for new nuclear power plants to perform aircraft impact assessment in case of above accident.

This study evaluated the long-term core cooling capacity for APR 1400, new plant design, under Loss of Ultimate Heat Sink (LOUHS) during low power shutdown operation.

2. Scenario and Assumptions

In this study, it is assumed that LOUHS occurs during low power shutdown. The operation status when low power shutdown operation is as follows. The manway of the pressurizer and steam generator is opened at the start of the accident. The refueling pool level is the reactor vessel flange level, and one out of two Shutdown Cooling System (SCS) is in operation. The initial reactor coolant level was conservatively assumed as the reactor vessel flange water level. According to the NEI 07-13 methodology, the decay heat is assumed to be the heat rate generated after 7days of reactor trip. The operator's manual operation was not allowed for 30 minutes after the accident, and the following manual operation was considered after 30 minutes of the accident.

- 30 minutes: the refueling pool is filling by Safety Injection Pump (SIP). / Containment ventilation
- 1 day: Intermittent external injection on the primary side.
- 30 days: Maintain external injection on the primary side / Containment drainage

3. Nodalization Model

Fig. 1 and Fig. 2 show the nodalization model of Reactor Coolant System (RCS) and containment of APR 1400. The nodalization model was developed by modifying the input model of full power operation (Hwang et al.) [3].

Since the manways of the pressurizer and the steam generator are opened at the beginning of refueling pool makeup, the manways are connected to the atmosphere and the containment, respectively. This nodalization includes the containment drain flow path from the refueling pool to the atmosphere through the In-containment Refueling Water Storage Tank (IRWST). The secondary side is deleted because it is not used in this analysis.

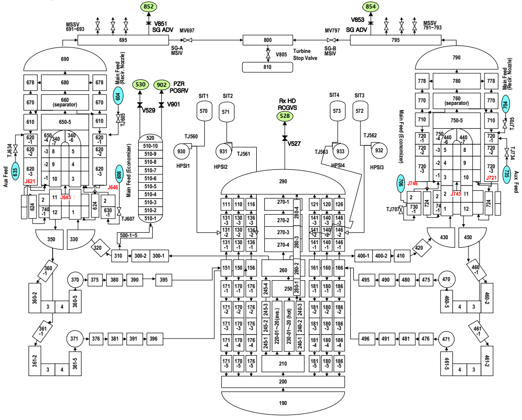

Fig. 1. APR1400 RELAP5 Nodalization Model – Reactor Coolant System

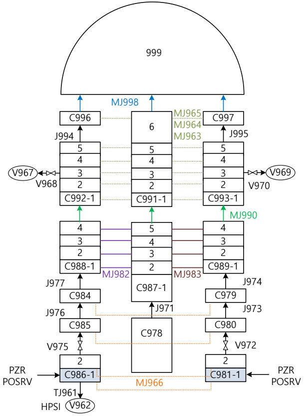

Fig. 2. APR1400 RELAP5 Nodalization Model - Containment

4. Calculation Results

Fig 3 show the safety and external injection flow rates. During the first day, refueling pool is filled by the safety injection pump. After the refueling pool is filled to normal level, the refueling pool is intermittently filled by the external injection through the primary injection flow path. From 30th day after the accident, continuous external injection is made.

The change in the refueling pool level is shown in Fig. 4. The refueling pool level is maintained below 3ft of normal level until 30th days by intermittent external injection. After 30 days, the refueling pool overflows by continuous external injection to perform the injection and ventilation/drainage operation. Therefore, the refueling pool will be maintained to the full level.

Fig. 5 shows pressurizer pressure. Because the pressurizer manway is opened, it remains similar to the containment pressure as shown in Fig. 8.

Containment ventilation flow rate to mitigate the pressurization of the containment is shown in Fig. 6. Fig. 7 shows integrated containment drainage to solve the internal flooding after 30 days.

Fig. 8 and Fig. 9 show containment pressure and temperature changes. After the accident, the temperature and pressure are increased and kept constant by the ventilation. After 30 days, it gradually decreases by injection and ventilation/drainage operation. Most of the non-condensable gas is vented by the containment ventilation, and the steam occupies the containment atmosphere. After 30 days, as the decrease in temperature of containment, the steam is shrunk and the containment is depressurized to less than 1 bar.

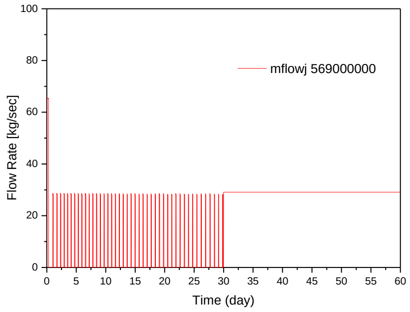

Fig. 3. IRWST and Primary Side External Injection

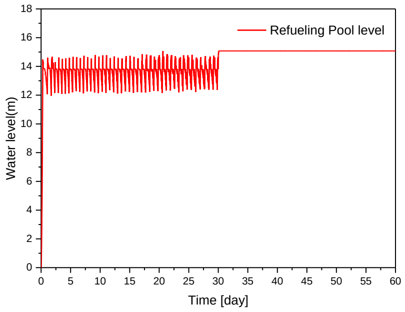

Fig. 4. Refueling Pool Level

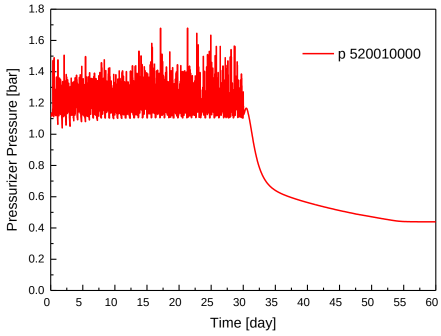

Fig. 5. Pressurizer Pressure

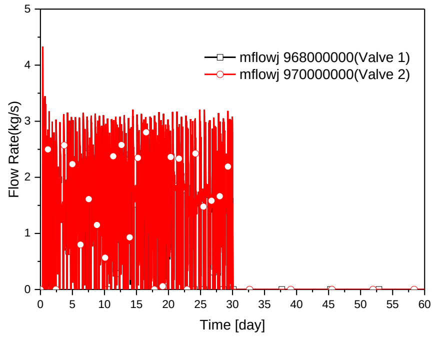

Fig. 6. Containment Purge Flow Rate

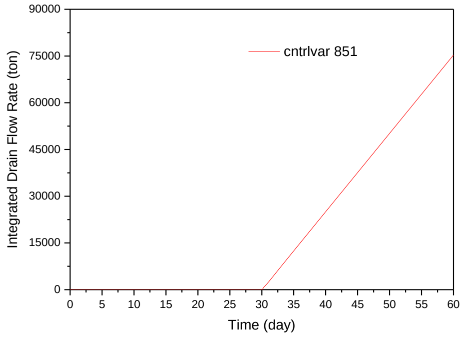

Fig. 7. Integrated Drain Flow Rate of Containment

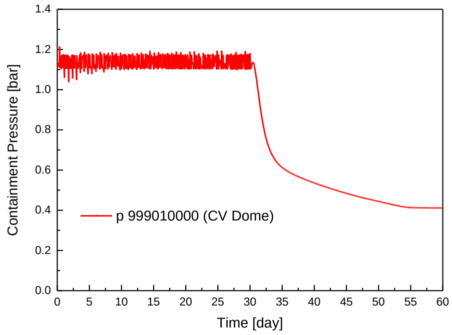

Fig. 8. Containment Pressure

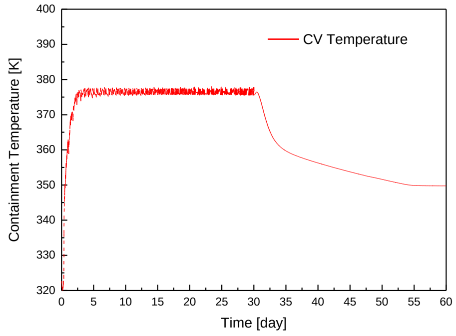

Fig. 9. Containment Temperature

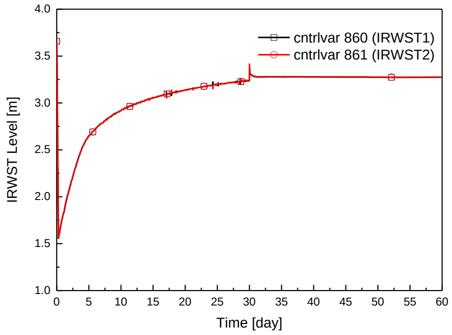

Fig. 10. IRWST Level

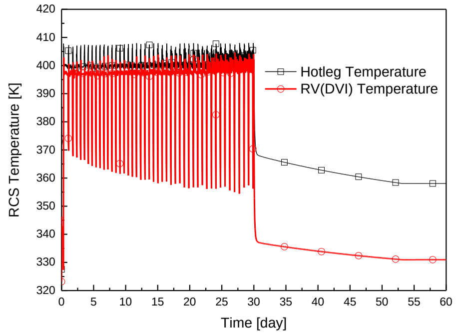

Fig. 11. Cold Leg Temperature

Fig. 10 shows the IRWST level. At the beginning of the accident, since IRWST water is supplied to refueling pool, the IRWST level is decreased. After that, the water level gradually increases because the condensate in the containment is collected in the IRWST and the water source is replaced to external injection. After 30 days, the water is drained as much as it is supplemented, so the IRWST level remains constant.

Fig. 11 shows cold-leg temperature. The initial temperature suddenly rises, and it is constantly kept at about 395K (121 ° C) from 1 day to 30 days because of the cooling by external injection. After 30 days, the cold-leg temperature is gradually decreasing as the containment drainage with external injection is made. It can be seen that reactor core cooling by external injection and containment ventilation/drainage is effective.

5. Conclusion

The analysis was performed to confirm the long term cooling capability of new reactor on LOUHS during low power shutdown operation.

In this study, it is found that injection through the primary side and ventilation and drainage operation of the containment are necessary to maintain the hot shutdown and cold shutdown continuously.

However, since the radiation is released to the environment by ventilation and drainage of the containment, further discussion is needed on injection and ventilation/drainage operation.

REFERENCES

[1] U.S. Code of Federal Regulations, Title 10, Part 50.150, Aircraft Impact Assessment, 2009.

[2] Korea Institute of Nuclear Safety, Safety Assessment for Intentional Impact of Aircraft Impact, KINS/RG-N19.04, 2016.

[3] S. H. Hwang, D. U. Seo, S. I. Jung, N. S. Kim and Y. I. Kim, Long Term Core Cooling Analysis on Loss of Ultimate Heat Sink for APR 1400.