Long Term Core Cooling Analysis on Loss of Ultimate Heat Sink for APR1400

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1. Introduction

Nuclear Regulatory Commission (NRC) requires that the reactor core remains cooled, or the containment remains intact in case of aircraft impact [1]. The impact of a large, commercial aircraft is a beyond-design-basis event.

The utility submitted the analysis report [2] to KINS to show that the reactor core can be cooled in case of the Loss Of Ultimate Heat Sink (LOUHS) caused by aircraft impact for Advanced Power Reactor 1400 (APR1400). MAAP (Modular Accident Analysis Program) 5.03 code was used in the analysis. Its input model includes both Reactor Coolant System (RCS) and containment.

This study was performed to check the applicability of RELAP5/Mod3.3 code for the long term core cooling analysis of LOUHS and verify the utility's analysis results. The assumption and assessment methodology are based on the utility's analysis, but not same due to the differences of calculation tool and input model.

2. Nodalization Model

The nodalization models for APR1400 RCS and containment are shown in Fig. 1 and 2.

Containment model based on the referenced model [3] was modified to include sump and IRWST (In-containment Refueling Water Storage Tank), and reflect the heat sink data of APR1400.

RCS is connected to Containment through Reactor Coolant Gas Vent System (RCGVS) and pressurizer Pilot Operated Safety Relief Valve (POSRV). Safety injection from IRWST to Direct Vessel Injection (DVI) is modeled with time dependent volume and valve components. The temperature of the time dependent volume is determined according to the IRWST temperature. The flow corresponding to safety injection is removed from IRWST to properly simulate the containment thermal-hydraulic behavior.

3. Assumption

LOUHS is assumed to happen during full power operation. Reactor Coolant Pump (RCP) and Main FeedWater Pump (MFWP) are assumed to trip at 0 sec. There will be some delay time for RCP and MFWP to trip after LOUHS. But the delay time is not considered in this study.

The operator's manual actions assumed in the analysis are as follows:

- 30 minutes: SG(Steam Generator) Atmospheric Dump Valve (ADV) open / Turbine Driven Auxiliary FeedWater Pump (TDAFWP) start
- 1 day: TDAFWP stop / Secondary external injection start
- 3 days: RCGVS open
- 30 days: Secondary external injection stop / Pressurizer POSRV open / Primary external injection start / Containment drain
- Pressurizer level control using one safety injection pump (~30 days)

Only one safety injection pump is assumed to be available. And the electric power is assumed to be available.

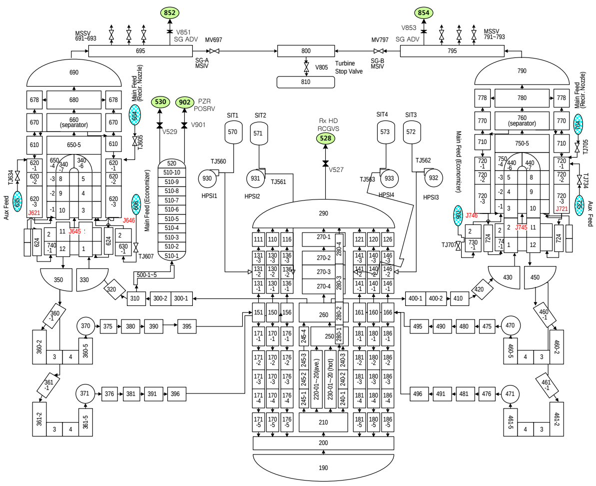

Fig. 1. APR1400 RELAP5 Nodalization Model – Reactor Coolant System

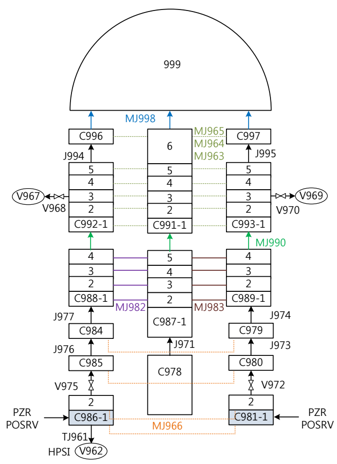

Fig. 2. APR1400 RELAP5 Nodalization Model - Containment

4. Calculation Results

RCP and MFWP trip simultaneously when LOUHS happens. Then reactor trips by low RCS flow alarm.

The operator begins to open SG ADV at 30 minutes and reduces the pressure of SG to 6 bar within RCS cooldown rate of 50°F/hr as shown in Fig. 3 and Fig. 4. And TDAFWP is manually activated by the operator. 6 bar is the pressure guaranteeing TDAFWP operation. The pressure of SG is reduced to the atmospheric pressure and TDAFWP is stopped at 24 hours. And the secondary external injection is initiated.

RCGVS is opened at 72 hours to reduce the primary pressure allowing primary external injection as shown in Fig. 5 and Fig. 6.

The pressurizer level is maintained within 3m~11m by intermittent safety injection pump operation until 30 days as shown in Fig. 7.

The RCS temperature decreases below 177°C (450.15K) (hot shutdown) within 24 hours by TDAFWP operation and SG ADV open. But it doesn't decrease below 99°C (372.15K) (cold shutdown) by secondary external injection as shown in Fig. 8. So feed and bleed operation is required to reduce the RCS temperature below 99°C.

At 30 days, pressurizer POSRV is opened, the secondary external injection is stopped, and the feed and bleed operation by the primary external injection is initiated as shown in Fig. 5. The injected water into DVI is discharged to IRWST through pressurizer POSRV and RCGVS. The flow corresponding to primary external injection is drained from IRWST to the outside of containment to avoid containment flooding. The pressurizer level is increased to full level and maintained. The RCS temperature decreases below 99°C within 24 hours after feed and bleed operation. And it continuously decreases to 82°C (355.15K) until 60 days as shown in Fig. 8.

The containment pressure and temperature (Fig. 9 and Fig. 10) increase slowly until 30 days by coolant discharge through RCGVS into IRWST. The containment pressure and temperature begin to increase rapidly as pressurizer POSRV opens at 30 days. But after 40 days, the containment pressure and temperature decrease slowly. So containment vent is not required.

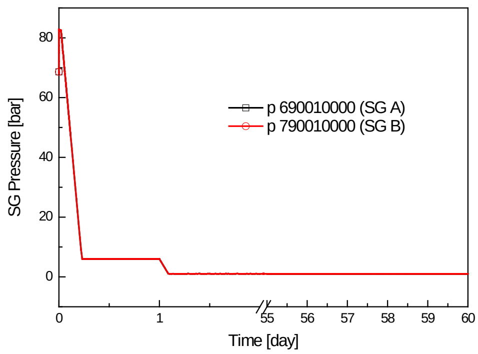

Fig. 3. SG Pressure

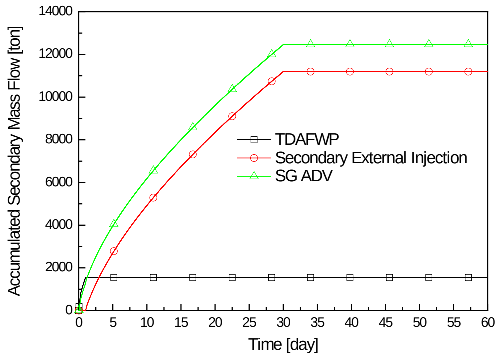

Fig. 4. Accumulated Secondary Mass Flow

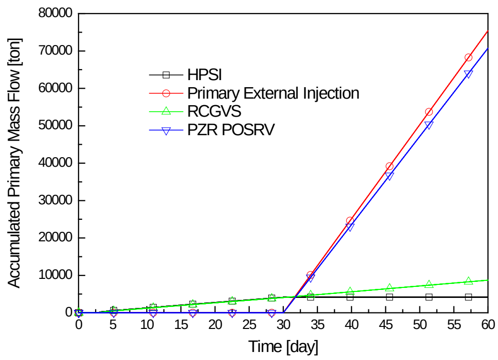

Fig. 5. Accumulated Primary Mass Flow

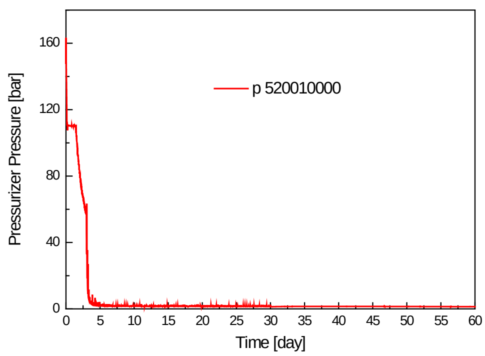

Fig. 6. Pressurizer Pressure

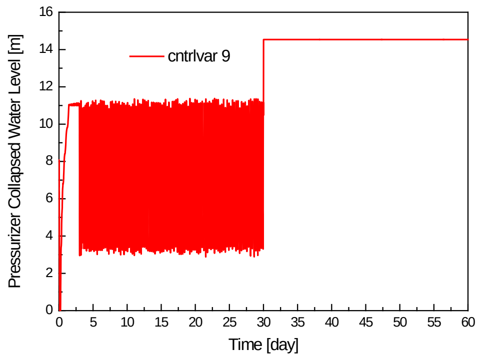

Fig. 7. Pressurizer Level

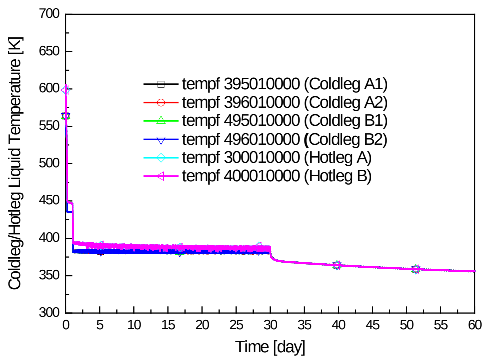

Fig. 8. RCS Temperature

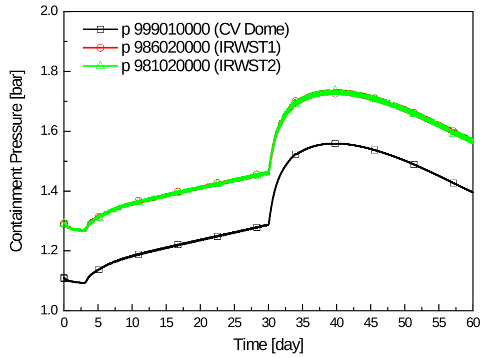

Fig. 9. Containment Pressure

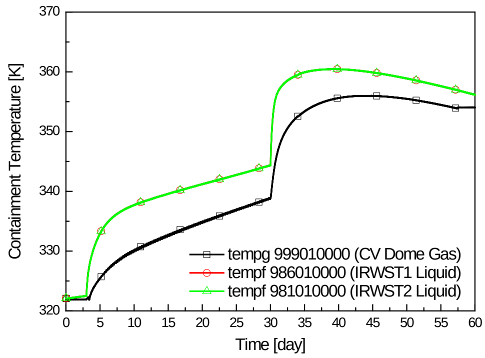

Fig. 10. Containment Temperature

5. Conclusion

The analysis on LOUHS caused by aircraft impact was performed to assess APR1400 coping capability for long term core cooling.

The RCS temperature can be reduced below 177^{o}C (hot shutdown) within 24 hours by TDAFWP operation and SG ADV open. And it can be maintained below 177^{o}C as long as TDAFWP or secondary external injection is available.

But it doesn't decrease below 99^{o}C (cold shutdown) by secondary external injection. So feed and bleed operation is required to reduce the RCS temperature below 99^{o}C.

Consequently, it was verified that the long term core cooling of APR1400 can be maintained by secondary external injection for LOUHS during full power operation.

The further cooling to cold shutdown requires the IRWST drain to the outside of containment. So the IRWST drain strategy should be reviewed carefully considering the radioactivity effects and public acceptance in the future.

REFERENCES

[1] ERIN Engineering & Research, Inc., Methodology for Performing Aircraft Impact Assessments for New Plant Designs, NEI 07-13, Rev.8P, April 2011

[2] KEPCO E&C, Long Term Core Cooling Analysis on Loss of Component Cooling Water System for Shin-Kori Units 5&6, October 2015

[3] Sung Hwan Bae, et.al., Preliminary Analysis of the Thermal-Hydraulic Performance of a Passive Containment Cooling System using the MARS-KS1.3 Code, Journal of Energy Engineering, Vol. 24, No. 3, pp.96~108(2015)