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The Numerical Sensitivity Study of Cold Leg Top Slot Break for ATLAS

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1. Introduction

Design certification application for APR1400 is currently in progress by U.S. Nuclear Regulatory Commission (NRC). During the process, NRC expressed concern that core steam pressure during long term cooling period after cold leg top slot break may increase to the point of overcoming static head of the loop seal when four loop seals are reformed by safety injection water. This is because loop seal elevation for the APR1400 is close to the midpoint of the active core height [1], and it might cause cladding temperature to increase due to core uncovery.

In this study, cold leg top slot break calculations are performed by RELAP5/MOD3.3 Patch04 for the ATLAS test which is the scaled down experimental facility for the APR1400 [2]. The test condition for base case is selected as 0.1016 m (4 in.) based on the break size of the APR1400. In addition, sensitivity studies about break size, break distance from vessel, and pressurizer location are performed until the initiation of simultaneous injection of 2.5 hours.

2. Sensitivity Studies and Results

In this section, the evaluation of base case and sensitivity studies are discussed.

2.1 Base Case

Fig. 1 shows the nodalization of cold leg top slot break for the ATLAS facility. The pressurizer is located on Loop 2, and the break for base case is located at the cold leg of the Loop 1B. Four safety injection tanks (SITs), maximum flow rate of four safety injection pumps (SIPs) are credited in order for the ease of the safety injection water refill of loop seals. Initial conditions for this assessment are also scaled down from the APR1400 [2].

Fig. 2 presents the steam mass flow rates at the bottom of each loop seal. As shown in Fig. 2, steam blockage is observed according to safety injection water refill to four loop seals. Loop seal clearing occurs at 513 sec after the break and the four loop seals are blocked and cleared repetitively afterward. The first complete blockage of four loop seals are achieved at 2,109 sec and the condition is released at 2,278 sec. The second and the third blockage occur at 2,904 sec and 3,200 sec. The fourth blockage is continued from 5,843 sec to the time of simultaneous injection.

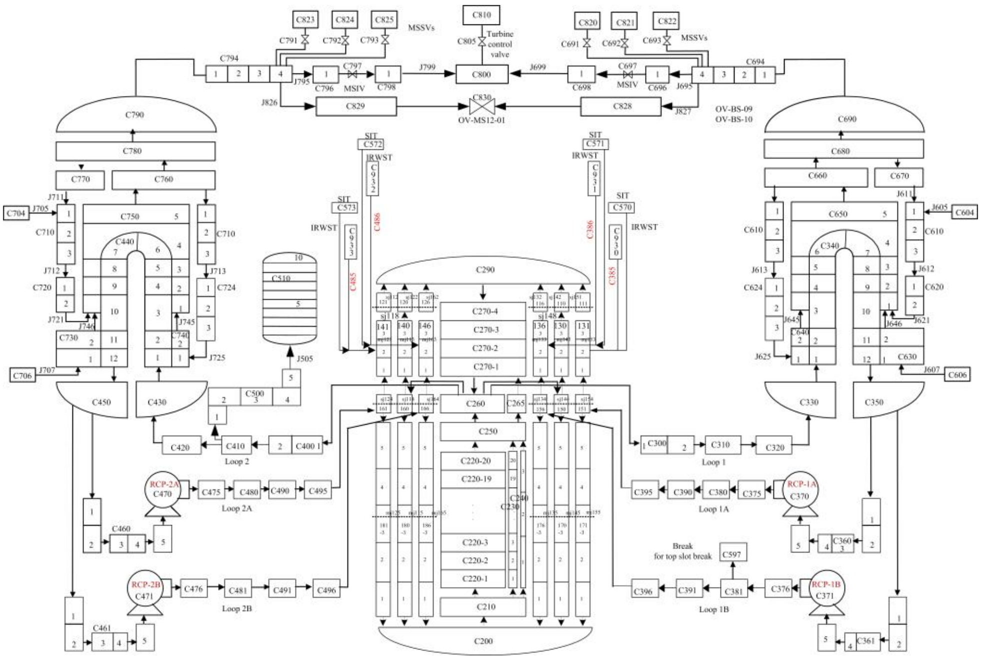

Fig. 1. ATLAS Nodalization for Base Case of Top Slot Break

* Break sizes addressed in the present study are given based on the break size of the APR1400.

Fig. 3 shows the cladding temperature at peak temperature node. The cladding temperature intermittently increases during loop seal reformation until 5,758 sec. However, the cladding temperature is maintained after 7,000 sec even though loop seal is continuously reformed until simultaneous injection. It means that safety injection water is expelled to the break, since cold legs including loop seals are fully covered with excessive safety injection water.

The mass of safety injection water into the core is presented in Fig. 4. According to loop seal reformation issue, accumulated mass into lower plenum is decreased while loop seal is being blocked by safety injection water. However, safety injection water is continuously injected regardless of loop seal reformation.

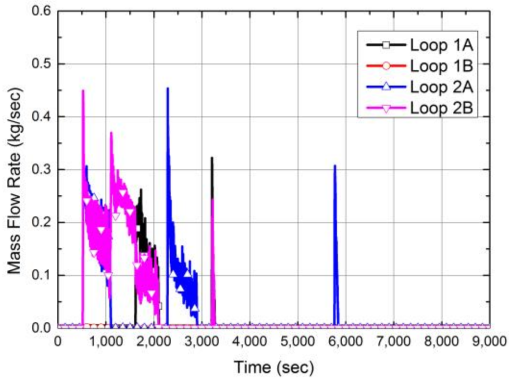

Fig. 2. Steam Mass Flow Rates at Loop Seals

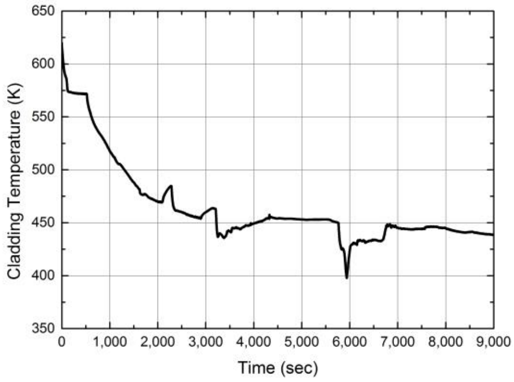

Fig. 3. Cladding Temperature at Peak Temperature Node

2.2 Break Size Sensitivity

Sensitivity study for break size is performed to assess the loop seal reformation phenomena. The results can be categorized into three: 1) no loop seal clearing occurs, 2) loop seal clearing occurs and loop seal is reformed, 3) loop seal clearing occurs but loop seal is not reformed.

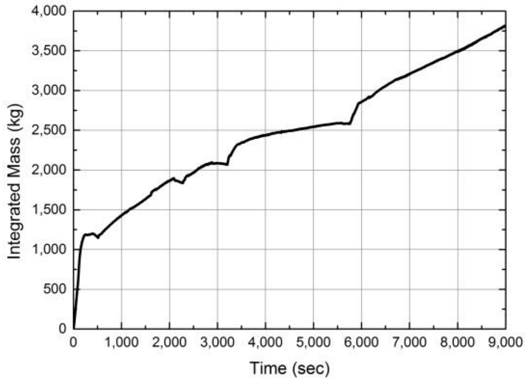

Fig 4. Accumulated Mass into the Lower Plenum

Fig. 5 shows the total steam mass flow rates through four loop seals from 0.0635 m (2.5 in.) to 0.2159 m (8.5 in.) of break size. The total steam mass flow rate of 0.0635 m (2.5 in.) break is 0 kg/sec up to simultaneous injection. Loop seal clearing does not occur on any loop seal when the break size is smaller than 0.0635 m (2.5 in.), since break size is too small to discharge primary water to cold leg level due to SIPs. The loop seal clearing and reformation are intermittently observed with breaks in size from 0.0762 m (3.0 in.) to 0.2159 m (8.5 in.). The blockage of four loop seals is not observed after the size of 0.2286 m (9.0 in.).

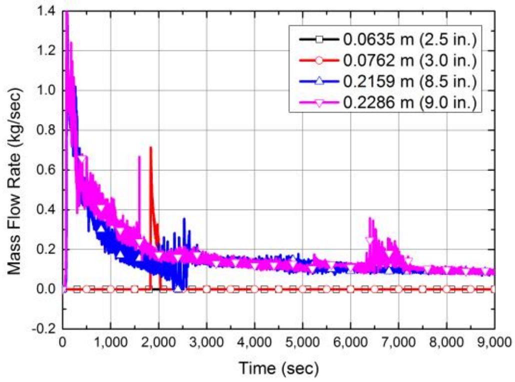

Fig. 5. Summation of Steam Mass Flow Rate of Four Loop Seals

2.3 Sensitivity of Break Distance from Vessel

Sensitivity study of the break distance from the vessel is performed to assess the loop seal phenomena for the break location from the pump discharge line to the vessel inlet nozzle. Table 1 shows the initiation time of loop seal clearing and reformation for sensitivity cases. The result of C376 indicates the break is located adjacent to the RCP pump, and the result of C396 indicates the break is adjacent to vessel. In terms of loop seal reformation, the break which is adjacent to vessel seems conservative since loop seal reformation lasts from 2,393 sec to 9,000 sec. Overcoming static head seems difficult because of friction losses and form losses on the broken cold leg. Nevertheless, the cladding temperature does not exceed 699.82 K (800 °F) as shown in Fig. 6, for liquid volume fraction is over 50 % at the top of core as shown in Fig. 7.

Table 1. Loop Seal Clearing and Reformation Sequences

	C376 (sec)	C381 (sec)	C391 (sec)	C396 (sec)
Loop Seal Clearing (LSC)	500	513	520	529
Loop Seal Reformation (LSR)	1,778	2,109	735	1,703
LSC	2,072	2,278	800	2,290
LSR	2,857	2,904	1,366	2,393
LSC	3,160	3,200	1,709	-
LSR	3,236	3,269	2,380	-
LSC	4,934	5,758	2,920	-
LSR	5,042	5,843	2,990	-
LSC	-	-	3,356	-
LSR	-	-	3,434	-

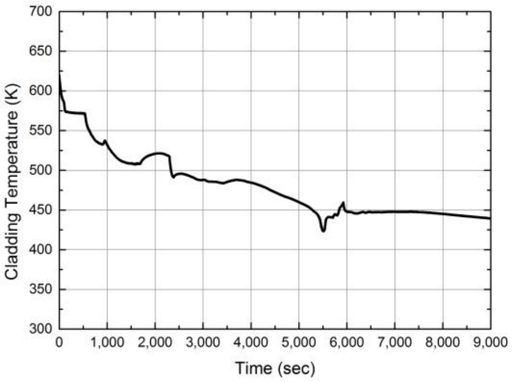

Fig. 6. Cladding Temperature at Peak Temperature Node

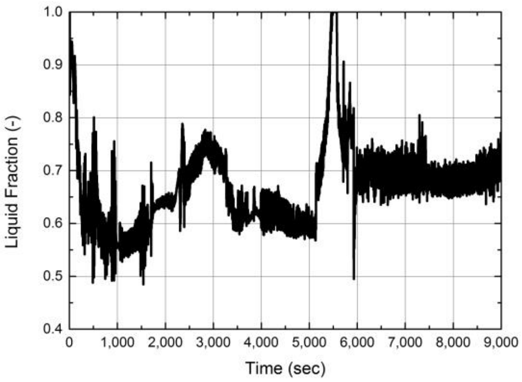

Fig. 7. Liquid Fraction at Active Top Core

2.4 Pressuizer Location Sensitivity

The sensitivity study for pressurizer location is performed by changing cold leg location of the break to 1A, 2A, and 2B. Fig. 8 shows the steam mass flow rates at the loop seal of broken cold leg. The trends of steam mass flow rates and loop seal reformations are similar wherever the break exists. It seems that break location does not have an important impact on the loop seal reformation.

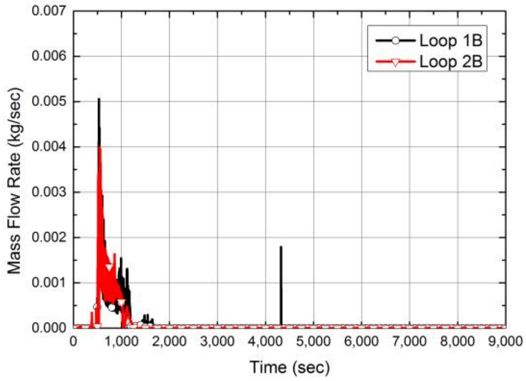

Fig. 8. Steam Mass Flow Rates at Broken Cold Leg Loop Seal

3. Conclusions

The numerical investigation using RELAP5/MOD3.3 Patch04 is performed to evaluate loop seal reformation phenomena and their safety issues related with the ATLAS. Loop seal reformation can be observed for the break sizes ranging from 0.0762 m (3.0 in.) to 0.2159 m (8.5 in.). As break size is larger, loop seal is easy to clear.

The loop seal reformation occurs early, and the duration of final loop seal reformation is longer as the break is close to vessel. Nonetheless, PCT increased by loop seal reformation is not identified since core uncovery does not occur.

In this study, it is confirmed through RELAP5 simulation of the ATLAS test that cold leg top slot break for the APR1400 is not a safety issue in perspective of the loop seal reformation.

REFERENCES

[1] S. Lu, APR-1400 Loop Seal and Its Impact on Long Term Cooling During a Postulated Loss-of-Coolant Accident, ML14134A347.

[2] Y.S. Kim, K. Y. Choi, S. Cho, Second ATLAS Domestic Standard Problem (DSP-02) for a Core Assessment, Nuclear Engineering Technology, Vol 45, p. 871-894, 2013.

ACKNOWLEDGEMENT

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