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Numerical Investigation of APR1400 Loop Seal Reformation and Clearing Phenomena during Post-LOCA Long-term Cooling Period using RELAP5

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1. Introduction

The KEPCO led consortium applied a design certification for APR1400 to USNRC. During the application process, it is confirmed that the staff's concern also lies on the loop seal reformation and clearing (LSRC) phenomena during post-LOCA (loss of coolant accident) long-term cooling (LTC) period[1]. Simple hand calculations had been tried to show that the loop seal reformation does not degrade the LTC performance of the APR1400, but the result was unclear[2]. Therefore, the code assessments of the phenomena for APR1400 are required to guarantee the performance of LTC. In the present study, RELAP5/MOD3.3 patch04 (3.3iy) is used for the assessments.

The safety degradation, e.g., possible cladding temperature rise due to LSRC during LTC period would be stronger when the safety injection (SI) is larger, while the core uncovery is more probable when the SI is smaller. In other words, it is not easy to determine the limiting condition of safety injection as two or four safety injection pumps (SIPs) in APR1400. In the present study, both the minimum SI condition with two SIPs and the maximum SI condition with four SIPs are considered.

The study focuses only on the top slot break condition due to its highest possibility of LSRC phenomena.

2. Methods and Results

2.1 Conservative Assumptions and Analysis Method

Several conservative assumptions are made in the study; 102 % power, Appendix K decay heat and Moody critical flow model. In addition to these, the steam generator (SG) cooldown operation, which is the operator's action, is not credited. Thus, the only possible secondary heat removal mechanism is steam release through safety valves.

A break spectrum analysis is performed to investigate the possible condition of the loop seal reformation and the effect of the loop seal blockage on the cladding temperature behavior.

2.2 RELAP5 model

In order to simulate the LTC behavior of APR1400, almost the same noding with that of the short term cooling analysis, such as large break (LB) or small break (SB) LOCA analysis can be employed. Only the major differences are the trip logics to simulate SI during the LTC period are different from those of the short term cooling analysis and that the break size to be simulated ranges from almost 0% to 100% of cold leg cross sectional area. Some minor modifications should be followed in accordance with those described in section 2.1. The noding diagrams of the study are shown in Fig. 1 and 2, where some of noding is hidden with box marked with trade security (TS).

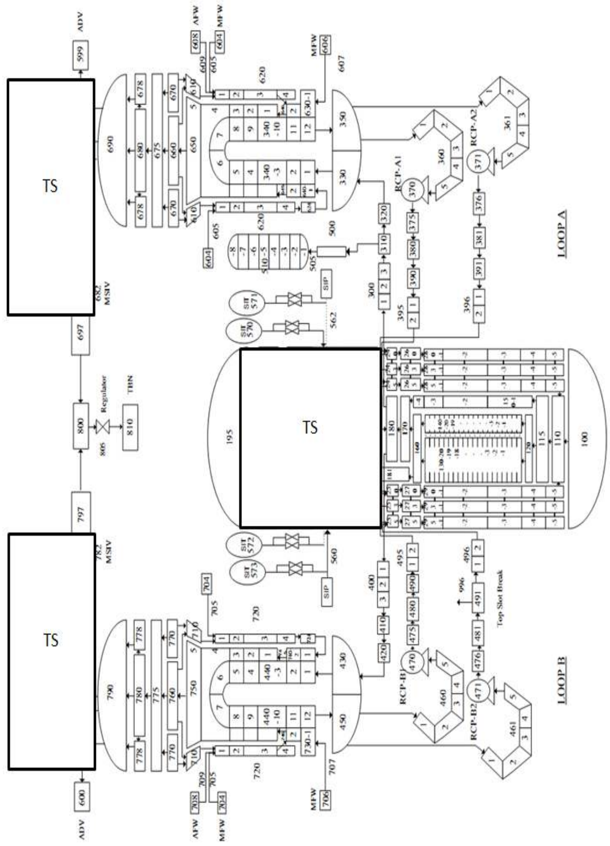

Fig. 1. Noding diagram for the study

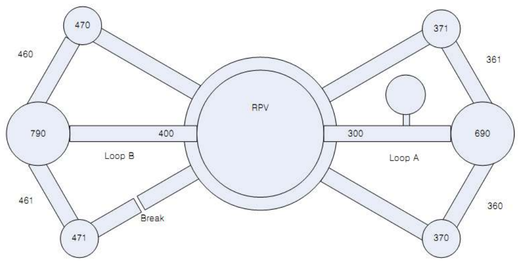

Fig. 2. Noding diagram for the present study (top view)

2.3 Calculation results

The most worried situation by the LSRC may occur when the four loop seals are blocked simultaneously. The situation would result in the highest pressure difference between the upper core and the downcomer, which can make the core uncovery take place. After the change into the simultaneous injection mode, the concerns would be less important due to the SI provision through hot leg; the cladding temperature rise due to the possible core uncovery is prohibited by the direct supply of liquid through hot legs.

Break spectrum analyses as listed in Tab. 1 are performed for both two SIP and four SIP cases. The break sizes in the analyses ranges from 0.6 inch diameter to 30.0 inch diameter, thus break sizes having almost 0% through 100% of cold leg cross-sectional area are investigated. In the break spectrum, upward break only is considered due to the easy coolant movement toward the broken side loop seal. Cases with red boxes represent the cases shown in the following figures. When two SIPs are assumed in the analysis, no occurrence of four loop seal blockage before the simultaneous injection is found. On the other hand, four loop seal blockage conditions are obtained at break size of 3.5 and 4 inch diameter in the case of 4 SIPs.

The cladding temperatures at the top of the active core for investigated cases with two SIPs are shown in Fig. 3 for relatively larger break sizes and Fig. 4 for smaller break sizes. There are no temperature rises before the simultaneous injection change at 10,800 sec for all cases. However, some oscillations are observed after ~25,000 sec for cases 02 and 03, which come from the four loop seal reformation conditions. The condition of four loop seal reformation in these cases is not the safety concern because the direct SI through the hot legs, thus core uncovery cannot be significant.

The cladding temperatures at the top of the active core for all investigated cases with four SIPs are summarized in Fig. 5 and 6 for larger break sizes and for smaller break sizes, respectively. Severe temperature oscillations are found at cases 17 and 18, where the four loop seal reformations take place as shown in Fig. 7 and 8. The LSRCs are observed during the time interval between 5,000 and 10,000 s in case 17, 3,000 ~ 5,000 s and 7,000 ~ 9,000 s in case 18. However, the temperature rises are not significant even in these cases and an adequate long term cooling is achieved.

Tab. 1. Cases analyzed in the break spectrum analysis

	break diameter(in)	break Area(m^2)
case00	6.055518	0.018581
case01	2.70811	0.003716
case02	2.345292	0.002787
case03	1.914923	0.001858
case04	1.354055	0.000929
case05	0.957461	0.000465
case06	0.85638	0.000372
case07	0.741646	0.000279
case08	0.605552	0.000186
case09	3	0.00456
case10	30.00001	0.456037
case11	25.09981	0.319226
case12	21.21328	0.22802
case13	9.486834	0.045604
case14	6.708232	0.022802
case15	5.5	0.015328
case16	5	0.012668
case17	4	0.008107
case18	3.5	0.006207

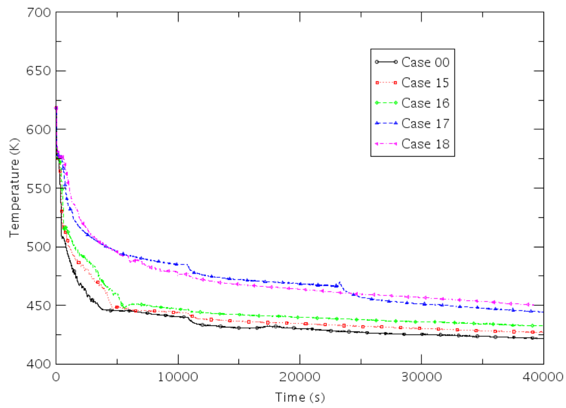

Fig. 3. Cladding temperature at the top of the active core – case 00 ~ case 18 (two SIPs)

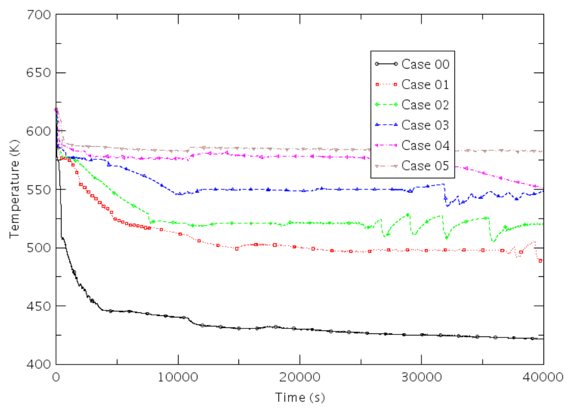

Fig. 4. Cladding temperature at the top of the active core – case 00 ~ case 05 (two SIPs)

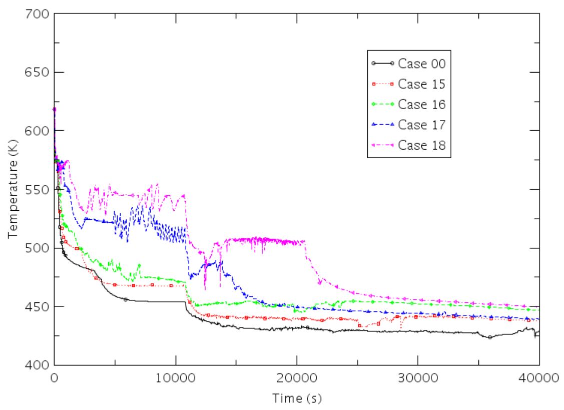

Fig. 5. Cladding temperature at the top of the active core - case 00 ~ case 18 (four SIPs)

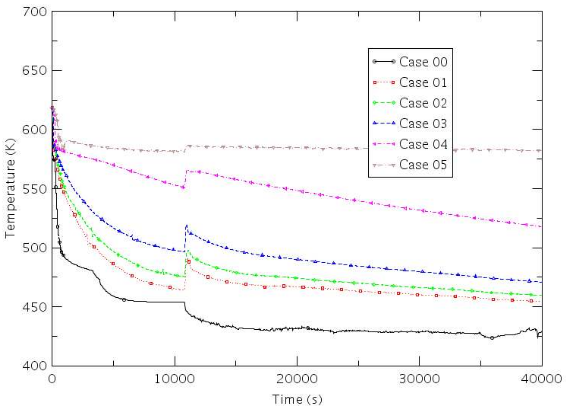

Fig. 6. Cladding temperature at the top of the active core - case 00 ~ case 05 (four SIPs)

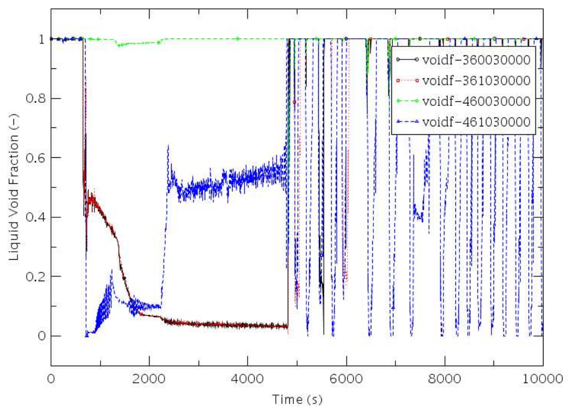

Fig. 7. Loop seal liquid fraction – Case 17

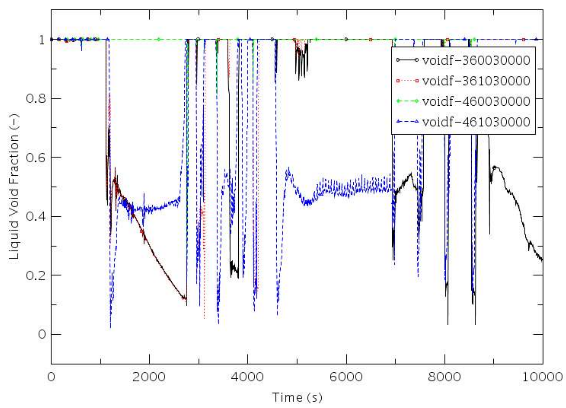

Fig. 8. Loop seal liquid fraction – Case 18

3. Conclusions

The LSRC issues for APR1400 are discussed and investigated through numerical investigation using RELAP5MOD3.3 patch04 for top-slot cold leg (pump discharge line) breaks. The major items investigated are whether the simultaneous four loop seal reformation is possible and whether there is any possible violation of the long term coolability criteria in 10 CFR 50.46.

Safety injection with two SIPs and four SIPs are investigated to find that the four loop seal reformation condition before the simultaneous injection may occur only with four SIPs. However, even when the loop seal reformation is made, no significant cladding temperature rise is observed and it is concluded that there is no violation of the 10 CFR 50.46 criteria in LTC perspective.

REFERENCES

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[2] H. J. Sung, et al., A simple hand calculation of possible pressure drop assuming loop seal reformation in APR1400, Internal discussion, 2015.