Thermal Hydraulic Similarity Analysis of the ATLAS for Main Steam Line Break Accidents

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1. Introduction

A thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation), is being constructed at the Korea Atomic Energy Research Institute (KAERI). The ATLAS is a 1/2-height and 1/288-volume scaled test facility based on the design features of the APR1400, an evolutionary pressurized water reactor developed by the Korean industry. [1] In this paper, thermal hydraulic similarity between the ATLAS and the APR1400 during MSLB events is assessed by using a multi-dimensional best-estimate thermal hydraulic code MARS 3.0 with the same control logics, transient scenarios and nodalization scheme for the two systems. [2] The analysis result provides an insight into the unique design features of the ATLAS and will be used for developing optimized experimental operation procedure and control logics.

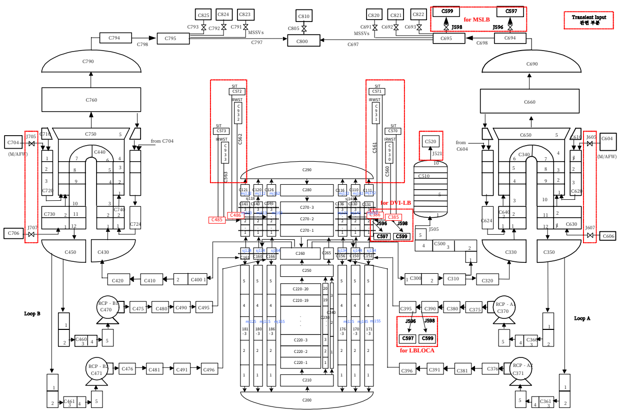


Figure 1 MARS-1D Nodalization for the APR1400 and the ATLAS

2. MARS Modeling

Among the several spectrums of MSLB accidents, the SLBFPLOOP (Steam Line Break at Full Power with Loss Of Offsite Power) is selected as a basic test case to examine the thermal-hydraulic similarity between the APR1400 and the ATLAS. Two cases of the MSLB simulations for the ATLAS were carried out. One (ATLAS-8%) has the same control logic as the APR1400 and the other (ATLAS-8%-new) has modified control logics in the early phase of the transient. In the "ATLAS-8%-new" case, we increased the main feedwater flow rate from 8% to 100% before a main feedwater isolation. In addition to that, the RCP speed is raised up to 100% before the RCP trip. The RCP speed is 8% lower to have the 8% RCS flow rate at an initial steady state condition. It seems to be too low to remove the decay core power through the broken steam generator. The former modification has an effect of increasing the heat removal from the broken steam generator to the break system. The latter has an effect of increasing the heat transfer from the primary system to the secondary system. Both cases are compared with the APR1400.

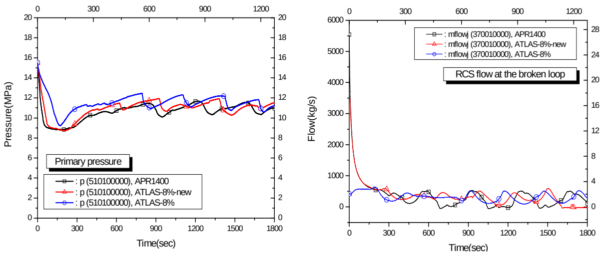
3. Results and Discussion

Table 1 Major sequence of events for SLBFPLOOP

Event description	Time (sec) APR1400	Time (sec) ATLAS-8%	Time (sec) ATLAS-8%-new
MSLB begins	0.002	0.01	5.0
Reactor trips	0.002	0.01	5.0
RCP trips	0.002	0.01	5.0
Aux. feed starts (broken loop only)	0.002	0.01	5.0
Turbine trips (1.3sec delay)	1.302	0.93	5.9
MSIS on	13.604	6.86	14.6
MSIV close with 5.0 sec delay	18.606	10.39	18.1
MFIV close with 10sec delay	23.606	13.93	21.7
HPSI on	72.315	115.42	67.2
Transient stops	1800.0	1300	1300

Table 1 lists the major sequence of events observed during the MSLB transient. The transient begins with a simultaneous opening of the break valves of the break model. But, the "ATLAS-8%-new" transient begins with a delay of 5sec for an implementation of the modified controls. All the delay times of the APR1400 are converted in the ATLAS model according to the time scale ratio. The delayed core power trip is used to preserve the heat addition to the system.

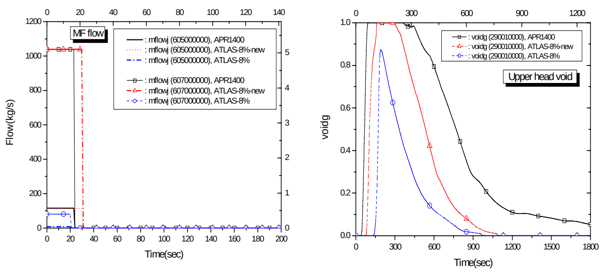
Figure 1(a) shows the primary pressure variation. After a steam line break, the primary pressure rapidly decreases due to the rapid cooling caused by the secondary mass inventory loss through the break nozzle. The "ATLAS-8%-new" result shows a more rapid pressure drop compared with the "ATLAS-8%" case. It is due to the RCP speed up in the early phase of the transient. The increased RCS flow rate is plotted in Figure 1(b). As seen in Figure 1(b), when we follow the same RCS flow rate as the APR1400, a similar reducing trend of the primary pressure as the APR1400 can be obtained.



(a) (b)

Figure 1 Calculation results – (a) Primary pressure (b) RCS flow rate

Figure 2(a) shows a comparison of the main feed water flow rate. In order to get the steady state conditions, the main feed water flow rate was reduced to an 8% scaled flow rate. As seen in Figure 2(a), the "ATLAS-8%" initially has about an 8% scaled flow rate before an isolation, while the "ATLAS-8%-new" has an 100% scaled flow rate before an isolation. Figure 2(b) shows a comparison of the core upper head void fraction. The "ATLAS-8%-new" has an earlier voiding and later collapsing of the void in the core upper head than the "ATLAS-8%" case and shows a better agreement with the APR1400 case. It is mainly due to the better agreement of the primary pressure as shown in Figure 1(a).

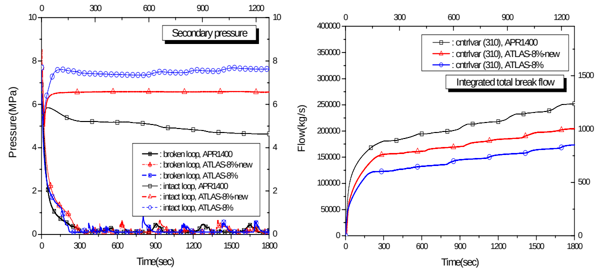


(a) (b)

Figure 2 Calculation results – (a) Main feedwater flow rate (b) Void fraction at core upper plenum

The secondary pressure trend is shown in Figure 3(a). As regarding the steam pressure in the broken loop, both ATLAS results show a similar pressure trend as the APR1400. On the other hand, as for the steam pressure in the intact loop, both the "ATLAS-8%" and the "ATLAS-8%-new" show a higher pressure than that of APR1400. In particular, in the case of the "ATLAS-8%" the steam pressure almost approaches the main steam safety valve (MSSV) set point. It is attributed to the low heat transfer rate from the intact to the broken steam generator caused by a low RCS flow rate.

One of the most important thermal hydraulic parameters is the break flow rate in a break nozzle. It directly impacts on the cooling behavior in the primary and secondary system. The small integrated break flow rate is obtained as shown in Figures 3(b). The distortion of the break flow would result in a distortion in the thermal hydraulic similarity between the ATLAS and the APR1400. More detailed investigations on the secondary side such as the steam line and steam header are required to account for the difference in the break flow.



(a) (b)

Figure 3 Calculation results - (a) Secondary pressure (b) Integrated break flow rate

4. Conclusion

The simulation capability of the ATLAS for a typical non-LOCA accident, a main steam line break (MSLB) accident is evaluated by the best-estimate system code, MARS, assuming a loss of offsite power. The neutronic effects such as the moderator temperature coefficients and doppler reactivity in APR1400 are not considered. Most thermal hydraulic parameters of the ATLAS showed a good agreement with the design parameters of the APR1400. However, a distortion in the secondary pressure seems to be inevitable to preserve the same temperature distribution in the primary system at a steady state condition of 8% power level. Also, a large inconsistency in the secondary pressure and break flow were obtained when we used the same control logics as the APR1400. However, the inconsistency becomes small if we increase the initial main feedwater flow rate and RCP speed to 100%. The present similarity analysis provides us with a good insight into the unique design features of the ATLAS. Further analyses are being performed to reduce the distortions and to set up an optimized experimental procedure.

REFERENCES

[1] Baek, W. P. 2004. "The KAERI Thermal Hydraulic Integral Effect Test Program for Advanced PWRs: Program Overview and the ATLAS Design", NTHAS4, Sapporo, Japan.
[2] Jeong, J.J. et al. 1999. "Development of a Multi-Dimensional Thermal-Hydraulic System Code, MARS 1.3.1." Annals of Nuclear Energy. 26(18), pp.1611-1642.