Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Pre-test analysis of ATLAS SBO with RCP seal leakage scenario using MARS code

Quang Huy Pham, Sang Young Lee, Seung Jong Oh*
KEPCO International Nuclear Graduate School, 1456-1 Shinam-ri, Seosaeng-myeon,
Ulju-gun, Ulsan, Korea
*Corresponding author: *sj.oh@kings.ac.kr*

1. Introduction

After Fukushima nuclear accident, the capability of coping with the extended station blackout (SBO) becomes important. Many NPPs are applying FLEX approach as main coping strategies for extended SBO scenarios. In FLEX strategies, outside cooling water injection to reactor cooling system (RCS) and steam generators (SGs) is considered as an effective method to remove residual heat and maintain the inventory of the systems during the accident [1]. It is worthwhile to examine the soundness of outside cooling water injection method for extended SBO mitigation by both calculation and experimental demonstration. This study presents a pre-test calculation for the Advanced Thermal-hydraulic Test Loop for Accident Simulation (ATLAS) SBO experiment with RCP seal leakage scenario. Initially, turbine-driven auxfeed water pumps are used. Then, outside cooling water injection method is used for long term cooling. The analysis results would be useful for conducting the experiment to verify the APR 1400 extended SBO optimum mitigation strategy using outside cooling water injection in future.

2. Model and Calculation Conditions

2.1 ATLAS Facility and Scaling Parameters

The ATLAS is a thermal-hydraulic integral effect test facility, which was designed to simulate thermal-hydraulic phenomena of OPR1000 and APR1400 operational/abnormal transients [2]. The three-level scaling methodology developed by Ishii et al. [3] was applied to design the facility.

Table 1. ATLAS major scaling parameters [4]

Parameters	Scaling ratio	ATLAS design
Length	l_{0R}	1/2
Diameter	d_{OR}	1/12
Area	d_{0R}^{2}	1/144
Volume	$l_{OR}\, d_{OR}^{2}$	1/288
Core temperature	T_{0R}	1
Velocity	$l_{0R}^{1/2}$	1/1.414
Time	$l_{0R}^{1/2}$	1/1.414
Power/volume	$l_{0R}^{-1/2}$	1.414
Core power	$l_{0R}^{1/2} d_{0R}^{2}$	1/203.6
Flow rate	$l_{0R}^{1/2} d_{0R}^{2}$	1/203.6
Pressure drop	l_{0R}	1/2

The ATLAS primary side has the same two-loop features, 1/2 on height, 1/288 on volume, and full pressure simulation in comparison with APR1400. Due to 1/2-height model, the time for the event progression of ATLAS is a squared root 2 times faster than APR1400. The ATLAS secondary side is simplified with a circulating loop-type. The steam from SGs is condensed in a condenser tank and pumped back into the SGs [4]. The ATLAS major scaling parameters compared with APR 1400 are listed in Table 1.

2.2 MARS KS Code

For the pre-test calculation, the Multi-dimensional Analysis of Reactor Safety code (MARS) is used. The code was developed by Korea Atomic Energy Research Institute (KAERI). The code’s backbones are the RELAP5/MOD3.2 and COBRA-TF codes of USNRC [5]. The ATLAS input nodalization diagram used in the pre-test calculation is shown in Fig.1.

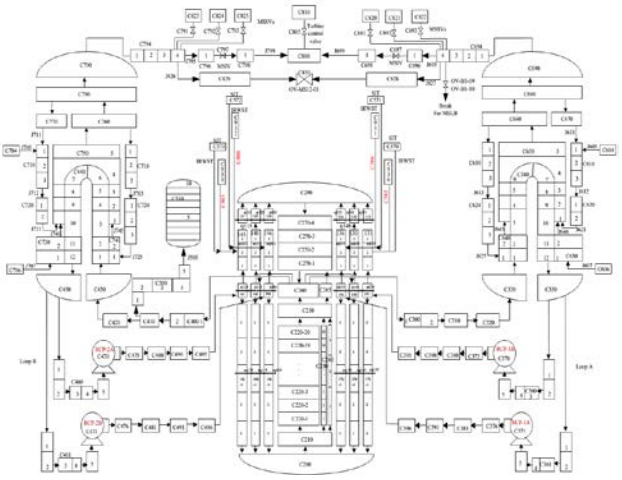

Fig. 1. MARS nodalization diagram of ATLAS.

2.3 Steady state calculation

The ATLAS input deck developed by KAERI is used for the steady state calculation, in which all important components and thermal hydraulic parameters of the ATLAS are described. Since the ATLAS facility is a scaled-down test facility of APR1400, the initial and boundary conditions for ATLAS calculation is based on the scaled-down values of the corresponding conditions of the APR1400. Y.S. Kim et al. [6] has studied the steady state conditions for ATLAS SBO scenario without RCP seal leakage. In this study, the most important parameters used in steady state calculation of this study are checked with the above calculation to confirm its validity. The steady state conditions of ATLAS can be archived by running the input file for a couple of minutes. The ATLAS calculated steady state conditions in comparison with the APR 1400 are shown in Table 2.

Table 2. Steady state conditions of APR1400 and ATLAS

Major parameter	**APR1400**	**ATLAS Design**	**Atlas Steady State Cal.**
Primary system			
Power (MWt)	3983	1.56	1.56
Pressurizer pressure (MPa)	15.50	15.50	15.55
Core inlet temp. (K)	564.45	563.85	563.80
Core outlet temp. (K)	597.35	597.35	597.30
Secondary system			
SG pressure (MPa)	6.90	7.83	7.82
Steam temp. (K)	558.05	566.65	565.80
Feedwater temp. (K)	505.35	505.35	505.37
Feedwater flow rate (kg/sec)	1152.4	0.44	0.44

2.4 Transient calculation

The transient calculation conditions of this study are obtained by scaling down the corresponding conditions which have been calculated by J.R. Hwang and S.J. Oh for APR1400 [7]. Due to SBO, core and RCS heat removal relies on SGs safety relief valves and turbine driven auxiliary feedwater pump (TDAFP). The ATLAS secondary side has no turbine driven auxiliary feedwater (TDAFW) trains. However, the TDAFW behavior can be simulated by using ATLAS's feedwater system. The main assumption regarding installed equipment is that TD AFP should be working until 5 hours 40 minutes after the SBO initiation (8 hours in APR1400). During that period, the repetitive atmospheric dump valves (ADV) and TDAFW flow control is not desirable since operators need to focus on various difficult tasks. Therefore, SGs ADV opening ratio and AFW flow were investigated to have a suitable value in order to minimize operator actions and satisfy requirements of current APR1400 emergency operation procedure (EOP) [9].

After 5 hours 40 minutes, the station battery is assumed to be exhausted and TDAFW stops working. Then the maintaining primary and secondary inventory should be relied on outside injection sources. The extended SBO main events from transient calculation are shown in the Table 3.

In the ATLAS transient input file, the RCPs seal leakage positions were modelled by the valves located on the discharge pipelines of 4 RCPs. The valve flow area was investigated in order to get seal leakage flow rate of 0.036 kg/sec/pump at 15.5 MPa, which is corresponding to 7.3 kg/sec (116.2gpm) in the RCP technical manual [8]. The Henry-Fauske choke flow model and default discharge coefficients in MARS are applied to calculate the seal leakage flow. In addition, a conservative 1973 ANS decay heat curve with a 1.2 multiplication factor is used in the transient calculation.

Table 3. Extended SBO main events

Time (hh:mm:ss)	**Main Event**
00:00:00	SBO accident starts, reactor trip, RCPs coast-down, TD AFPs supply feedwater to SGs (assumed value 0.45kg/sec)
00:02:08	RCP seal leakage starts (0.036kg/sec/pump at 15.5 MPa)
00:19:07	Reducing AFW flow rate of SGs to 0.07kg/sec (to avoid SG solid state)
01:03:40	Start cooldown and depressurization process by opening ADV(25% equivalent area of MSSV)
01:12:50	SITs start injection (set point 4.02 MPa)
05:40:00	TD AFPs stop, full opening of ADV Start outside water injection to RCS and SGs.
12:00:00	End of calculation

The transient calculation starts with SBO event, the RCP seal leakage is initiated at 128 seconds after SBO initiation (3 minutes in APR1400). The RCP seal leakage flow rate is shown in Fig.2. Primary pressure starts decreasing after reactor trip and RCP seal leakage initiation. Meanwhile, SGs inventory is maintained by TDAFP. The SGs MSSVs are cycling open/close to release pressure from SGs before cooldown process is performed. Primary and secondary pressure behaviors are shown in Fig. 3.

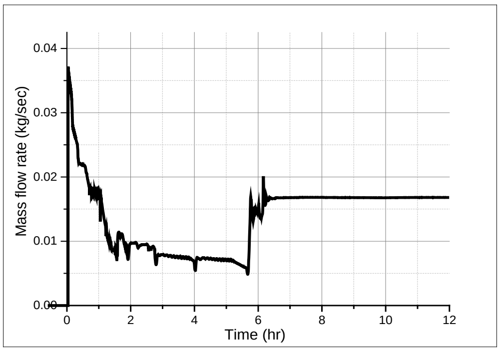

Fig. 2. RCP seal leakage flow rate (1RCP)

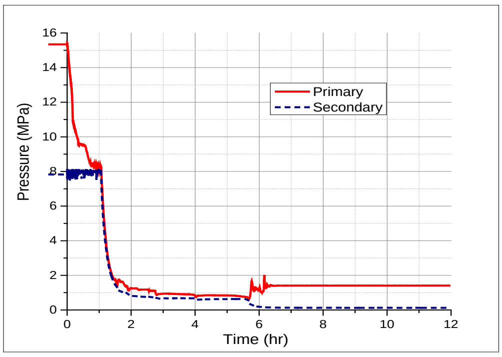

Fig. 3. Primary and secondary pressure

The core water level is gradually decreased due to RCP seal leakage. However, the water level is still kept above top of fuels before SITs injection. The core residual heat is mainly removed via secondary side by natural circulation and depressurization process. The calculation results for core collapsed level and cladding temperature are shown in Fig.4.

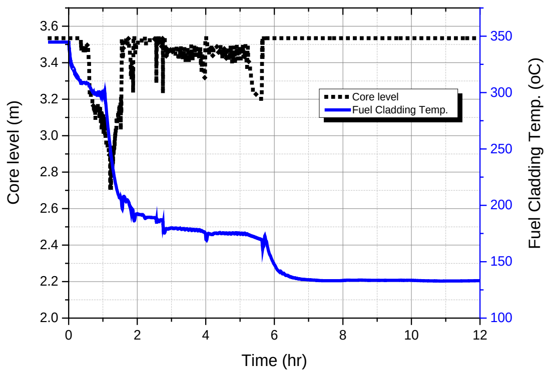

Fig. 4. Core collapsed level and fuel cladding temperature

At 5 hours 40 minutes, the pre-test calculated results for SG pressure and temperature were 0.63 MPa and 162^{o}C, respectively. These conditions are satisfied the TDAFP operation condition [9]. After 5 hours 40 minutes, outside water injection starts for long term cooling with injection flow rate of 0.19kg/sec at 0.78 MPa for primary side and 0.05kg/sec at 0.63MPa for secondary side, respectively. With these outside injection flow rates, the inventory of RCS and SG are maintained until 12 hours without any injection flow adjustment performed by operator. Fig.5 shows the behavior of SG levels during the transient calculation.

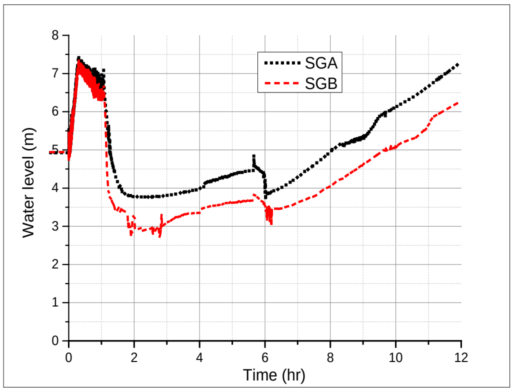

Fig. 5. SGs water level

3. Conclusions

The pre-test calculation for ATLAS extended SBO with RCP seal leakage and outside cooling water injection scenario is performed. From the calculation results, outside cooling water injection into RCS and SGs is verified as an effective method during extended SBO when RCS and SGs depressurization is sufficiently performed. The pre-test calculation is expected to be useful for conducting the experiment in future to produce the optimal emergency operation and mitigation strategy for APR 1400 to cope with the extended SBO accident scenarios.

ACKNOWLEDGEMENTS

This research was supported by the 2015 research fund of the KEPCO International Nuclear Graduate School (KINGS), Republic of Korea.

REFERENCES

[1] NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," Rev. 0, (2012).

[2] Y. S. Kim et al, "Commissioning of the ATLAS Thermal Hydraulic Integral Test Facility," Annals of Nuclear Energy, 35, 1791 (2008).

[3] M. Ishii, et al., "The three level scaling approach with application to the Purdue University multi-dimensional integral test assembly (PUMA)," Nuclear Engineering and Design, 186, 177–211 (1998).

[4] K.H. Kang, et al., "Detailed Description Report of ATLAS Facility and Instrumentation," KAERI/TR-4316/2011, Korea Atomic Energy Research Institute, (2011).

[5]KAERI, MARS code manual, KAERI/TR-2812/2004, (2009).

[6] Y.S. Kim et al., "Analysis of a Station Blackout Scenario with an ATLAS Test," Nuclear Engineering and Technology, 45, 205–220,(2013)

[7] J.R. Hwang, S.J. Oh, "Developing Optimal Procedure of Emergency Outside Cooling Water Injection for APR1400 Extended SBO Scenario Using MARS Code," KNS, (2013).

[8] Westinghouse Electric Company LLC, "Reactor Coolant Pump Type R01 Technical Manual," Volume 1, 9-181 -Z-431 -N01C (2011).

[9] Korea Hydro & Nuclear Power Co., Ltd., Shin-Kori Unit 3,4 NPP, "Station Blackout Emergency Operation Procedure, EOP-07, Rev. 0 (2011).