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Heat Loss Determination of ATLAS Facility and System Code Application

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) has been operating an integral effect test facility, the Advanced Thermal-Hydraulic Test Loop for Accident Simulation (ATLAS) for transient and accident simulations of advanced pressurized water reactors (PWRs) as shown in Figure 1 [1]. By using the ATLAS, an integral effect test database has been established for major design basis accidents of the APR1400.

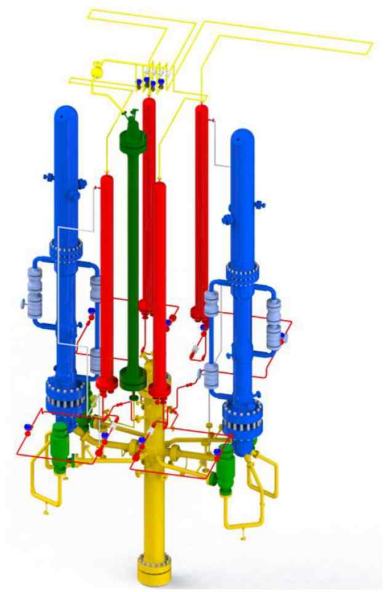

Fig. 1. Schematic diagram of ATLAS Facility [1]

There have been many efforts to improve the prediction capability of the system codes such as RELAP5, MARS-KS, and SPACE using ATLAS experimental data. However, since the heat loss of the ATLAS has not been reflected correctly in the system code input model, there have been differences between the experimental data and the code prediction results. This difference can induce a distortion in maximum cladding temperature, natural circulation flow rate in primary system, cooling and de-pressurizing rate of the system [2].

To improve the prediction capability of the system code input model for the ATLAS, this study performed followings: 1) determination of the ATLAS heat loss (total heat loss of Reactor Coolant System (RCS), component heat loss such as Reactor Pressure Vessel (RPV), hot leg, cold leg, intermediate leg, Reactor Coolant Pump (RCP), Steam Generator (SG) lower plenum) using the experimental data, 2) modeling and application of the heat loss results to the MARS-KS 1.4 input model of ATLAS facility, 3) steady-state simulations with heat loss, and 4) comparison with the experimental data.

2. Determination of Heat Loss in ATLAS

The heat loss test was performed to determine the heat loss of the primary-side of the ATLAS. SG secondary-side was isolated and empty. It enabled to exclude the heat transfer at the U-tubes. The heat losses were determined in two separate and different ways as follows [3].

2.1 Total Heat Loss

In the integral approach [3], the total heat loss of the entire system was evaluated by adjusting the core heater power to maintain constant temperature. By running four reactor coolant pumps (RCPs), the temperature difference between the core inlet and outlet remains below 2 °C. Since the heat transfer to the SG is ignored, the primary-side heat loss is almost same with the core heater power. This approach has the merit to easily grasp the total heat loss of the entire system according to the fluid temperature [2]. Figure 2 shows the total heat loss in RCS determined from the integral approach. If the ambient temperature is 11 °C and the temperature distribution in the RCS is almost uniform, and the RCS average temperature is 294 °C, it can be seen that a heat loss of about 85 kW occurs. The total heat loss of the RCS increased as the coolant temperature increased.

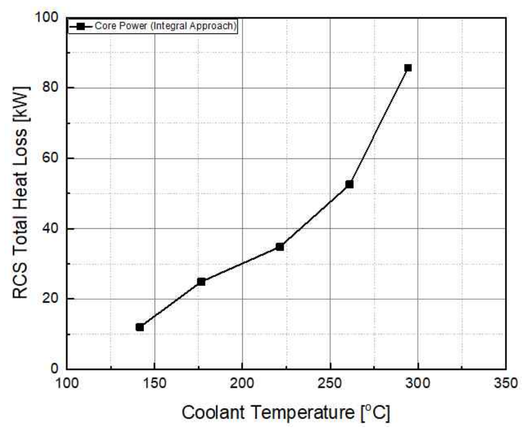

Fig. 2. Total heat loss in RCS

2.2 Local Heat Loss

In the differential approach [3], the individual heat loss of primary-side components was derived from local temperature evolution during a cool-down transient by using Equation (1). This approach has the merit to grasp approximately the local heat loss of the component according to the fluid temperature [2].

$$\dot{Q} = \left(mc_{p,fluid} \frac{\partial T}{\partial t} \right)_{fluid} + \left(mc_{p} \frac{\partial T}{\partial t} \right)_{structure} \qquad (1)$$

To determine the local heat loss, this study divided all components in RCS based on the MARS nodalization of ATLAS (see Fig. 3). The heat loss of zone ‘C’ is determined by applying the representative temperatures (see Fig. 4) measured in the location ② for the fluid, steel, and insulator to Eq. (1).

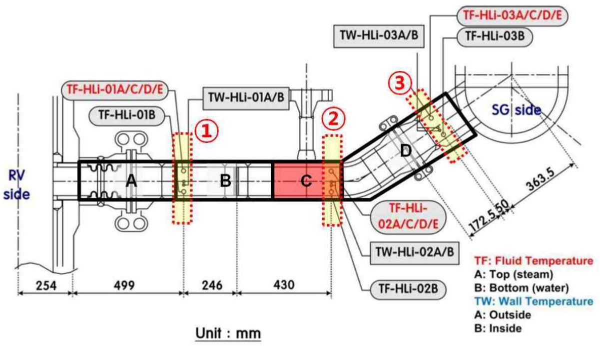

Fig. 3. Sectionalization of RCS piping

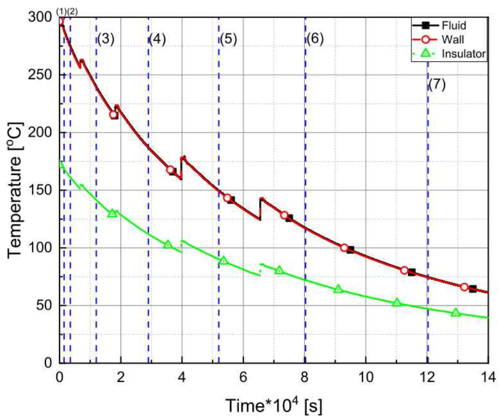

Fig. 4. Hot leg temperature in zone ‘C’

Figure 5 shows the heat loss in zone ‘C’ determined from the differential approach. As the fluid temperature increases, the heat loss was increased. Heat loss quantification was performed in the same manner for the remaining sections in Fig. 3.

Figure 6 shows the heat loss on the entire hot legs. This is the result of summing the local heat loss on each zone in the hot leg. It can be seen that the heat loss increased as the coolant temperature increased, and the total heat loss is about 2.4 kW at 290 °C.

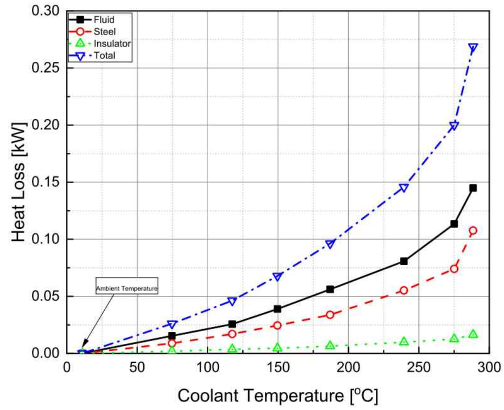

Fig. 5. Heat loss in zone ‘C’

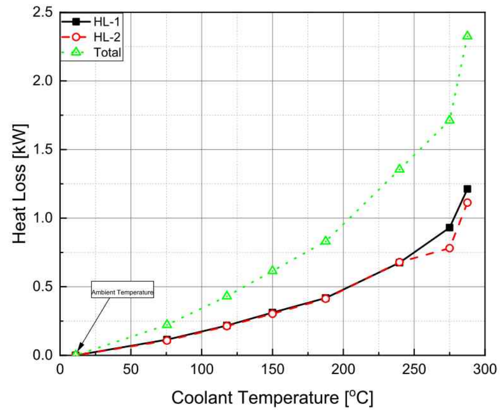

Fig. 6. Heat loss in hot legs

2.3 Heat Loss Distribution

Figure 7 shows the heat loss distribution for each component of the RCS in the ATLAS under normal operating conditions. It can be seen that under normal operating conditions, the total heat loss from the RCS is about 88 kW, and about 45% of the heat loss occurs in the reactor vessel.

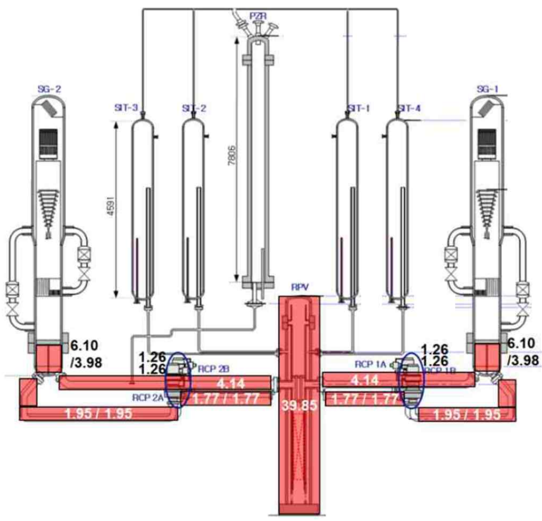

Fig. 7. Heat loss distribution in RCS

3. Heat Loss Modeling of ATLAS Facility

For the heat loss analysis, this study used the MARS-KS1.4 code [4]. Figure 8 illustrates the MARS-KS nodalization of ATLAS facility. The red lines indicate the primary-side heat structures except the U-tubes. To simulate the heat loss of the ATLAS facility, this study applied the local heat loss data (refer Fig. 5) from various locations to each heat structure considering the measurement point. The heat loss is modeled with the heat transfer coefficient boundary condition according to the wall temperature [2].

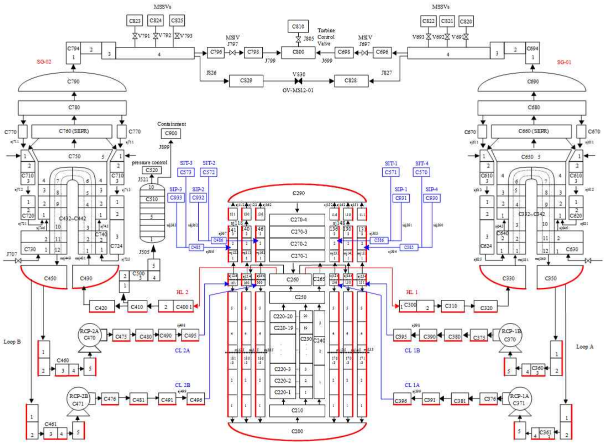

Fig. 8. Schematic diagram of ATLAS Facility

4. ATLAS Steady-State Calculation

Using the ATLAS heat loss input model, steady-state simulation was performed for the core power of 1.654 MW considering the RCS total heat loss of 88 kW. Table I shows the steady-state calculation results. Overall, it can be seen that the input model reflecting heat loss provides satisfactory results in terms of heat loss as well as temperature distribution in the RCS.

Table I: Steady-state Calculation Result

Parameter	Unit	Target Value	Experiment	Original Input Model	Heal Loss Input Model
Core Power	[MWth]	1.560	1.639	1.566	1.654
Pressurizer Pressure	[MPa]	15.5	15.5	15.5	15.5
Core Inlet Temperature	[K]	563.9	563.9	563.8	563.8
Core Exit Temperature	[K]	597.4	599.5	597.3	598.9
Hot Leg Temperature	[K]	–	598.7	596.9	598.4
Cold Leg Temperature	[K]	–	564.4	562.8	563.5
Cold Leg Flow Rate	[kg/sec]	2.0	2.0	2.0	2.0
SG Total Heat Removal Rate	[MWth]	1.560	1.500	1.565	1.567
SG Water Level	[m]	–	5.0	4.9	4.9
Steam Pressure	[MPa]	7.83	7.83	7.82	7.99
Steam Temperature	[K]	566.7	566.1	566.6	565.9
Feedwater Temperature	[K]	505.4	–	505.4	505.4
Feedwater FlowRate	[kg/sec]	0.444	0.414	0.444	0.444
Total Heat Loss	[MWth]	–	–	0.000	0.088

5. Conclusions

To improve the prediction capability of the system analysis code for the ATLAS, this study performed followings: 1) determination of the ATLAS heat loss (RCS total heat loss, RCS component heat loss using the experimental data, 2) modeling/application of the heat loss results to the ATLAS input model, 3) steady-state simulations with heat loss. From the MARS code simulation results, it was found that the heat loss was modeled in the ATLAS input model appropriately and the MARS predicted the experimental steady-state condition well. It is expected that the results of this study could improve the system analysis code prediction capability of the various ATLAS transient tests.

ACKNOWLEDGMENTS

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