Rough Calculation of Heat Loss on Passive Safety System

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1. Introduction

There have been many efforts to develop Passive Safety Systems (PSSs) in the field of nuclear engineering in order to simplify the Nuclear Power Plant (NPP) design and improve the reliability of essential safety functions and eliminate the costs of installation, maintenance, and operation of active systems. PSSs have advantages over active safety systems because it has low dependence on the operator action and the power supply.

However, the driving force is low compared with active safety system because PSSs operates based on natural phenomena such as gravity, density difference, pressure difference, etc. Therefore, the performance of the PSS is likely to change due to various factors called as performance issues of PSS as follows: 1) leakage of working fluid; 2) change of ambient temperature; 3) heat loss; 4) non-condensable gases in the system; 5) pipe and heat exchanger aging; 6) operability of check valve; 7) fire in containment; 8) pipe deformation due to seismic event; 9) thermal-hydraulic model uncertainty of the system analysis code [1].

Among them, heat loss to be covered in this paper affects the driving force and may change the PSS performance as follows. According to Lee et al.[1], for the passive heat removal system such as the Passive Auxiliary Feedwater System (PAFS) and the Passive Containment Cooling System (PCCS) (see Fig. 1[2]), as the heat loss increased, the natural circulation flow rate of the PSS decreases due to the decrease in driving force, and the heat removal rate of the heat exchanger is decreased. For the Passive Emergency Core Cooling System (PECCS) (see H-SIT and connecting pipes in Fig. 1), as the heat loss increased, the wall condensation occurs in the inlet pipe and the injection flow rate may decrease because the resistance of the H-SIT inlet line may increase [3].

It is very important to estimate the impact of heat loss in terms of design and performance analysis of PSSs. Therefore, in this study, the heat loss were briefly and roughly estimated under various assumptions (piping size, length, etc.) for PAFS, PCCS, and PECCS, the three PSSs of iPOWER.

2. Calculation Method

To calculate the heat loss, we used the heat loss coefficient in Fig. 2. This author has the experience to determine the heat loss in the pipes and the vessel in the ATLAS [4]. Based on the heat loss quantification results, this author obtained the graph below by averaging the heat loss in all components. Referentially, all components are surrounded by insulation. At this time, the pipe and the vessel were separated to derive a value. The heat loss rate can be simply estimated by multiplying the difference between the fluid temperature and the atmospheric temperature by the heat loss coefficient and the outer area of the pipe.

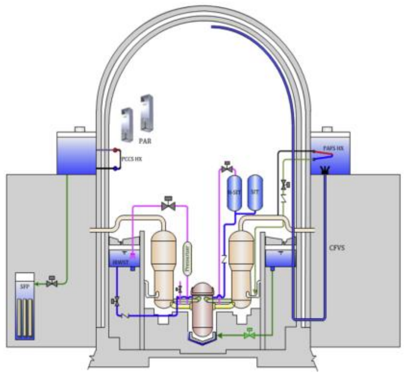

Fig. 1. Schematic of PSSs in iPOWER [2]

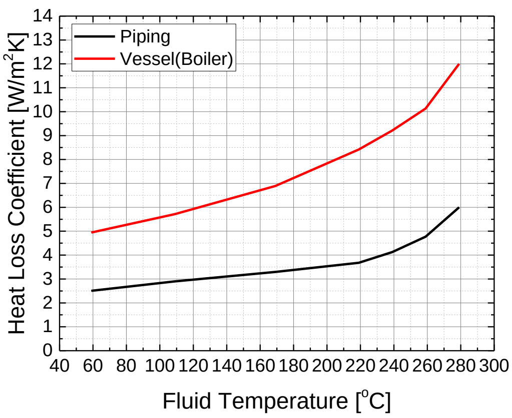

Fig. 2. Heat loss coefficient for rough calculation

3. Rough Calculation of Heat Loss

3.1 PAFS

Fig. 3 shows the configuration of PAFS. To estimate the heat loss in PAFS pipings, we assumed the pipe geometry as follow:

- outer diameter in all pipes : 0.3 m
- length in steam line & condensate line : 100 m

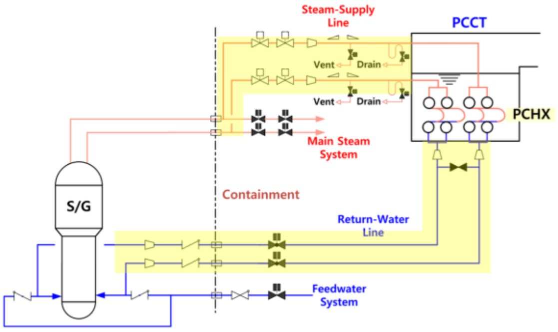

Fig. 3. Configuration of PAFS [5]

If the operating pressure in the PAFS is 10~80 bar, the rough calculation results of heat loss in PAFS is as shown in Table I. This may correspond to the heat removal rate of one or two PAFS tubes. When heat loss is largely considered, it is judged that the designer needs to check the effect.

Table I: Rough Calculation of Heat Loss in PAFS (1 Train)

P [bar]	T_sat [℃]	h [W/m2K]	Q [MW]	Q [MW] (±20%)
80	295	7	1.50	1.20~1.80
70	285	6.5	1.34	1.07~1.61
60	275	5.8	1.15	0.92~1.38
50	265	5.1	0.98	0.78~1.17
40	250	4.5	0.81	0.65~0.97
30	235	4	0.68	0.54~0.81
20	215	3.6	0.55	0.44~0.66
10	180	3.3	0.42	0.34~0.50

3.2 PCCS

To estimate the heat loss in PCCS pipings (see Fig. 1), we assumed the pipe geometry as follow:

- outer diameter in all pipes : 0.3 m
- length in inlet piping & outlet piping : 50 m

If the operating temperature in the PCCS is 50~120 ℃ and the operating pressure is less than 2.5 bar, the rough calculation results of heat loss in the PCCS is as shown in Table II. Considering that the PCCS heat removal rate is several tens of MW, the heat loss in PCCS has little effect on the peak pressure at the beginning of the accident. In terms of long-term cooling, it is recommended to examine its effect.

Table II: Rough Calculation of Heat Loss in PCCS (1 Train)

T_in [℃]	T_out [℃]	h [W/m2K]	Q [MW]	Q [MW] (±20%)
50	70	2.5	0.03	0.02~0.03
60	80	2.6	0.03	0.03~0.04
70	90	2.7	0.04	0.03~0.05
80	100	2.8	0.05	0.04~0.06
100	120	2.9	0.06	0.05~0.07

3.3 PECCS

To estimate the heat loss in PECCS(H-SIT) inlet pipe (see Fig. 1), we assumed the pipe geometry as follow:

- outer diameter in all pipes : 0.3 m
- length in inlet piping of H-SIT : 50 m

Since the effect of heat loss can be large under high pressure conditions at the beginning of accident, steam condensation may occur in the H-SIT inlet pipe, which may hinder the formation of smooth natural circulation flow. This needs to be considered in the design.

Table III: Rough Calculation of Heat Loss in PECCS (1 Train)

P [bar]	T_sat [℃]	h [W/m2K]	Q [MW]	Q [MW] (±20%)
80	295	7	0.10	0.080~0.12
70	285	6.5	0.09	0.07~0.11
60	275	5.8	0.08	0.06~0.09
50	265	5.1	0.07	0.05~0.08
40	250	4.5	0.05	0.04~0.06
30	235	4	0.05	0.04~0.05
20	215	3.6	0.04	0.03~0.04
10	180	3.3	0.03	0.02~0.03

4. Conclusions

The performance of the passive safety system may vary by heat loss. In this study, the heat loss that may occur in PAFS, PCCS, and PECCS was roughly estimated under several assumptions. The impact can be large or relatively negligible depending on the design characteristics of the passive safety system. These calculation results are expected to be used to estimate how much heat loss will affect the performance of the passive safety system.

5. Acknowledgements

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