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Model Development for Condensate Collection from Passive Containment Cooling System and Return to In-Containment Refueling Water Storage Tank

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1. Introduction

After Fukushima accident, there have been many studies on alternative design based on the passive system to replace the active safety system such as Containment Spray System (CSS) and Emergency Core Cooling System (ECCS) to passive safety system such as Passive Containment Cooling System (PCCS) and Passive Emergency Core Cooling System (PECCS).

The PCCS is installed with the heat exchanger in inside containment building, thus removes the heat sources contained in containment atmosphere through the effect of condensation on the outside surface of heat exchanger tube and convection in the inside of heat exchanger tube. The absorbed heat from the containment atmosphere is transferred to the Passive Condensate Cooling Tank (PCCT) by natural circulation and finally exhausted to the environment.

The Passive Emergency Core Cooling System (PECCS) replaces two Safety Injection Tanks (SITs) with two Hybrid Safety Injection Tanks (Hybrid SITs) to supply cooling water to the reactor vessel to protect the core during design basis accident, and the In-Containment Refueling Water Storage Tank (IRWST) provides cooling water when the Reactor Coolant System (RCS) pressure is depressed to a certain level. And all of the condensates on heat exchanger surface of the PCCS are designed to be collected and supplied to the IRWST to provide the cooling water to the reactor vessel as safety injection during long-term period.

In this study, the GOTHIC 8.2 (QA) model for the collection of condensate from the PCCS and return it to IRWST is developed, and results of containment pressure and temperature and condensate rates using the analysis model are presented.

2. System Description and Analysis Model

2.1 PCCS Design Description

The heat removal capacity of the PCCS is determined from estimation of heat released from the RCS at design basis accident. The break flow from the RCS includes the decay energy, RCS metal and coolant energies and all energies in the SGs secondary side.

The PCCS is composed of 4 trains and its capacity for each train is having 33% of heat removal capacity as shown Figure 1. The two trains of PCCSs are physically separated each other and are connected to one PCCT. There are eight heat exchanger modules and upper and lower common header is placed in each train of PCCS. Each heat exchanger module consists of 42 x 8 array tubes and one upper and lower module header [1].

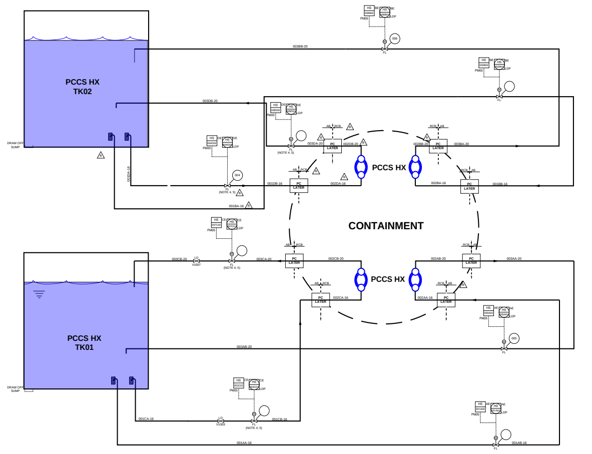

Fig. 1. PCCS Schematic Drawing

2.2 PECCS Design Description

The PECCS is aimed to maintain core cooling, thus to prevent failure of nuclear fuel. It is composed of Hybrid SITs, SITs, IRWST and depression system as shown in Figure 2 [2].

The high pressure injection to reactor vessel is provided by Hybrid SITs and mid pressure injection is performed by SITs. At the point of the reactor vessel pressure decreases by break and depression system and eventually reaches the pressure of the containment atmosphere by depression system actuation, the low pressure injection to reactor vessel begin to provide the cooling water from the IRWST by head difference between IRWST and reactor vessel. During long-term cooling phase, the condensate on PCCS heat exchanger surface is collected and supplied to IRWST and used as safety injection water for the reactor vessel cooling. In direct IRWST injection system has two isolation valves on the injection path, those are opened at the open signal of Automatic Depressurization Valve (ADV) in depression system is generated [2].

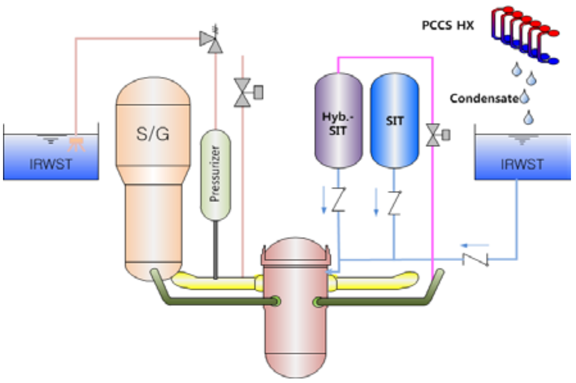

Fig. 2. PECCS Schematic Drawing

2.3 Containment P/T Analysis Model

The containment P/T analysis model including the collection of the condensate from the PCCS heat exchanger and return to the IRWST is developed by GOTHIC 8.2 (QA) code as described in Figure 3. It contains containment building, RCS, PCCS with heat exchanger, PCCT and IRWST. The design data for the containment model are based on the APR+ Standard Safety Analysis Report (SSAR) and the mass & energy release at the break point modeled as a flow boundary condition in GOTHIC model are obtained from the SHN 3,4 Preliminary Safety Analysis Report (PSAR) [3-4].

The containment volume is divided into 3 parts of volume such as containment atmosphere, the PCCS installed area and lower containment. To maintain the same thermal equilibrium between containment atmosphere and PCCS installed area, the volumetric fan is modeled with two flow paths. The containment atmosphere volume includes 18 heat conductor models to model the passive heat sinks groups and two flow boundary conditions to represents the mass and energy release from the RCS through the break at the design basis accidents. As a heat transfer model for 18 conductors, the TAGAMI and UCHIDA model options are chosen for blowdown and post-blowdown period to model the condensing effect on the containment inner surfaces including wall, floor and surface of structures and equipment [3, 5-6].

The SIT volume is modeled to consider the effect of pressurization by N_2 gas release during Loss Of Coolant Accident (LOCA). The IRWST volume, modeled as a lumped volume, is placed at EL. 135'-0" for gravity injection of water during long-term cooling phase [2-3].

The PCCS model is composed of 4 trains and one train of the PCCS is assumed to be insulated on heat exchanger surface to consider a single failure. The heat exchanger of the PCCS is modeled as one volume by combining all tubes in one module. As a heat transfer model, the basis model in GOTHIC codes such as Built-in Heat Transfer Package is applied and additional Condensation and Convection model of DLM-FM model is applied on the outside tube surface and UCHIDA model on the inside tube surface is considered. All parts of the PCCS except the module header are modeled as 1-D sub-divided volume. The PCCTs are considered the lumped volume and connected to environment volume [3-4, 7].

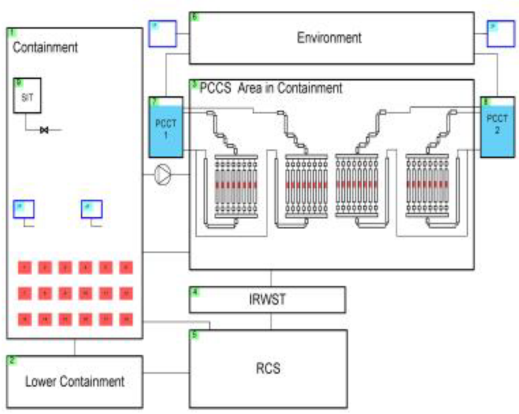

Fig. 3. Containment P/T Analysis Model

3. Results and Discussions

3.1 Sensitivity Analysis and Results

The sensitivity analysis are performed to determine the containment P/T analysis model as shown in Table I and II because the pressure and temperature between containment volume and PCCS installed area volume are maintained the same conditions. According to the analysis results, the peak pressure difference between each volume is similar results on all cases but there are different results on the peak temperature difference between each volume. The case 7 (PCCS installed volume: 20,000 m^3) has minimum peak temperature difference and there is lower peak temperature difference in the model of No Forced Convection Flow option because it is effect to heat transfer by volumetric fan flow rate. Also, it is possible to identify that if the lower volumetric fan flow rate is considered, the higher difference of temperature is occurred.

Table I: Sensitivity Analysis Cases

Case No.	PCCS Volume, (m^3)	Volumetric Fan Flow (m^3/s)	Forced Convection Option
1	1,000	2,000	ON
2	1,000	2,000	OFF
3	1,000	500	ON
4	1,000	1,000	ON
5	5,000	2,000	ON
6	10,000	2,000	ON
7	20,000	2,000	ON
8	40,000	2,000	ON

Table II: Sensitivity Analysis Results

Case No.	Peak Pressure Difference, kPa	Peak Pressure Difference, ^{o}C
1	0.15286	4.26171
2	0.15228	3.69547
3	0.17861	13.55947
4	0.16283	7.32962
5	0.15344	3.37726
6	0.15605	2.32256
7	0.16341	-1.43253
8	0.17070	-7.55666

3.2 Containment Pressure and Temperature

The final containment P/T analysis model including the collection of the condensate from the PCCS heat exchanger and return to IRWST is determined as PCCS installed area volume of 20,000 m^3, volumetric fan flow rate of 4,000 m^3/s and the Forced Convection Option on PCCS heat exchanger outside surface is off. As a result of analysis, containment peak pressure is 384 kPa-A and peak temperature is 169.31 ^{o}C, the difference peak pressure and temperature between containment volume and PCCS installed area volume are 0.136 kPa and 1.2 ^{o}C as described in Figure 4 and 5.

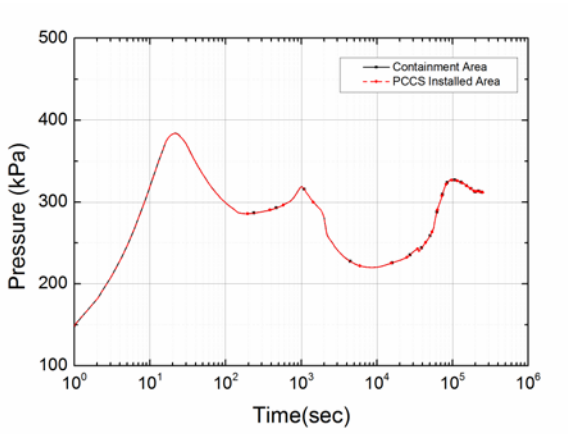

Fig. 4. Containment Pressure Responses

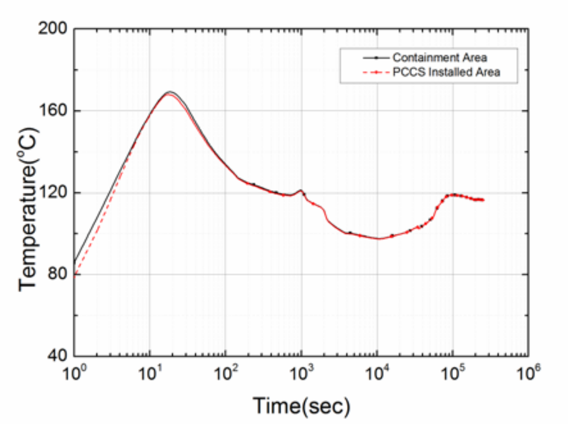

Fig. 5. Containment Temperature Responses

3.3 PCCS Condensates

The condensate rate on the PCCS heat exchanger surface is identified as described in Figure 6. As a result of the analysis, there are a lot of condensates generated in the early stage of the accident because of higher difference between containment atmosphere and PCCS cooling water including PCCT. The condensation water is decreases as the temperature of PCCT reaches to saturation condition over time and it remains constant.

Also, all of condensates generated on PCCS installed volume are discharged to IRWST volume.

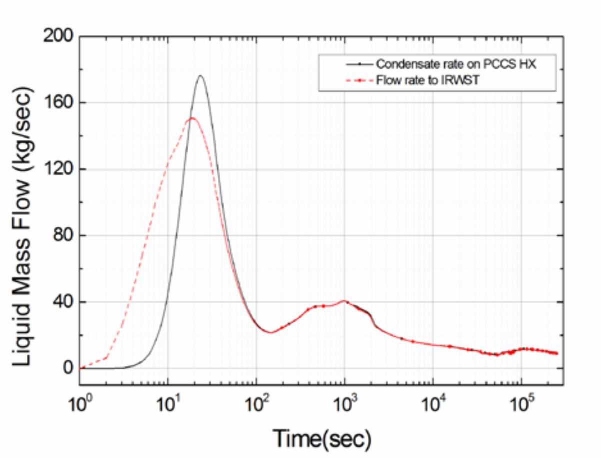

Fig. 6. Condensates on PCCS Heat Exchanger

4. Conclusions

In this study, the containment P/T analysis model including PCCS condensates collection and return to IRWST is developed using GOTHIC 8.2 (QA). It is verified that the containment volume maintains its two divided volumes in a thermally equilibrium during entire transient by the volumetric fan equipped in the containment. Also, it is identified the pressure and temperature difference between each volume are effected by the ratio of each volume, volumetric fan flow rate and convection model due to sensitivity analysis. As a result of the analysis, there are peak pressure and temperature difference range between each volume are as 0.136 kPa and 1.2 ^{o}C.

From the study, the containment model developed for the PCCS can be used for the containment pressure and temperature responses to the mass and energy releases from RCS following design basis accidents LOCA for iPOWER plant.

ACKNOWLEDGEMENTS

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