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Evaluation of a Design Concept for the Combined Air-water Passive Cooling PAFS+

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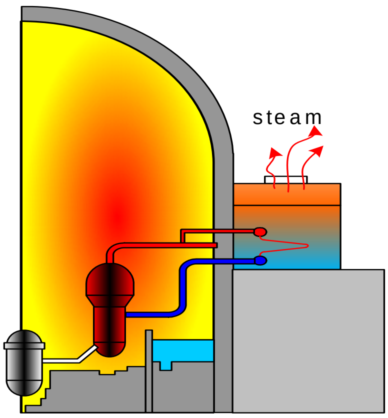
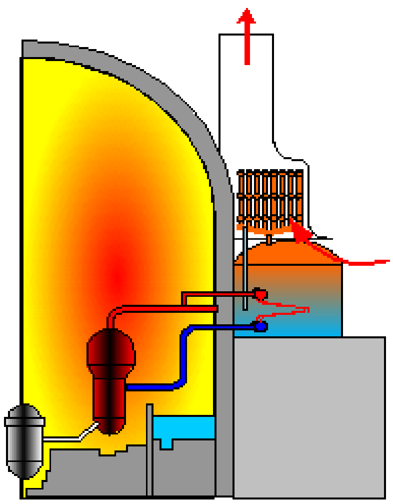
1. Introduction

After the Fukushima Daiichi nuclear power plant accident, a long term passive cooling capability is a key important design change issue in the nuclear safety concerns. Because the Emergency Diesel Generation (EDG) system is supposed to be out of work under the assumption of Station Black-Out (SBO), the conventional active pump driven safety injection and auxiliary feed-water supply system are not affordable. In this situation, the ultimate cooling of reactor decay power inevitably depends on the natural circulation and convection.



(a) PAFS



(b) Combined cooling system

Fig. 1 Conceptual design of passive air-water combined cooling systems

The APR+ system provides the Passive Auxiliary Feed-water System (PAFS) for the passive cooling capability. However, the current design requirement for working time for the PAFS is about 8 hours only. Thus, current working time of PAFS can not meet the required 72 hours cooling capability for the long term SBO situation. To meet the 72 hours cooling, the pool capacity should be almost 3~4 times larger than that of current water cooling tank.

In order to continue the PAFS operation for 72 hours, a new passive air-water combined cooling system is proposed. This paper provides the feasibility study on the combined passive air-water cooling system. Figure 1 and 2 show the conceptual difference of the PAFS and combined passive air-water cooling system, respectively.

2. Concept of Passive Combined Air-Water Cooling System

2.1 Current PAFS Design

The heat generation of APR1400 is assumed to be 3983MWt. The PAFS has been designed to remove the total decay heat of APR1400 for 8 hours without any safety injection and auxiliary feed water supply. Total of 4 heat exchangers and two Passive Condensate Cooling Tanks (PCCTs) are installed for 2 steam generators. The PCCT is also used as the source of containment cooling. The size of PCCT is 2916 m^3 and the pool level is 10.75 m.

From the previous studies on the PAFS system [1,2], it is found that the Loss of Condenser Vacuum (LOCV) and Feed Line Break (FLB) accidents are most limiting. For the FLB, the break side steam generator loses the feed water inventory within itself. Consequently, the PAFS system of the break side does not work.

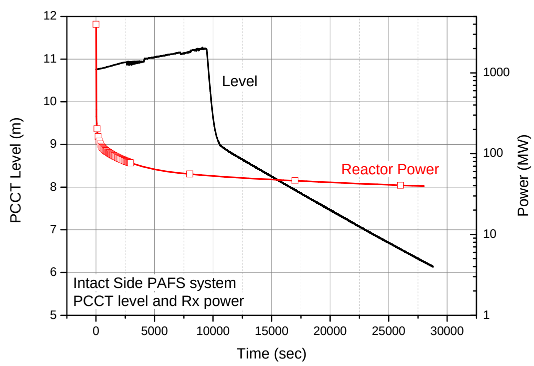


Fig. 2 PCCT collapsed water level for the FLB

Figure 2 shows the PCCT collapsed water level during a FLB accident. On the right axes, scram reactor power is plotted. The PCCT level is monitored at the intact side only. At the beginning of the accident, the

PCCT level is slightly increasing due to the thermal expansion of subcooled pool water. At about 9200 s, the pool level reaches up to 11.2 m from 10.8 m.

Right after the maximum pool level, the vaporization on the PAFS heat exchanger surface rapidly decreases the pool level. At that moment, steam flow rate is up to 56 kg/s, as shown in Fig. 3. The vapor flow rate from the PCCT is maintaining 40 kg/s for the remained calculation time. During the linear water level decreasing period, the water level decreasing rate is 0.77 m per 5000 seconds. With that dry-out speed, it takes 19 hours to zero inventory of the PCCT. Note that the reactor decay power is about 50 MW.

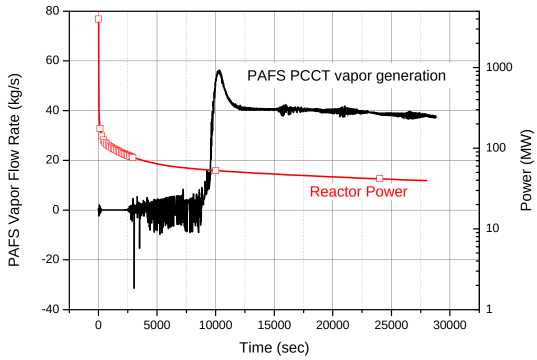


Fig. 3 PCCT steam flow rate for the FLB

2.2. Air-Water Passive Cooling Heat Exchanger

In order to condense the steam from the PCCT, an air cooling heat exchanger system is installed at the top of the PCCT. The steam gathers to the inlet head of the air cooling heat exchanger. The heat exchanger tubes are 2 inch diameter and 6 m long. The steam flowing area of a tube is 2.554×10^{-3} m^2. On the tube outer surface, heat enhancing fins are attached with the pitch of 7 fins per inch. The fin height is 12.7 mm and thickness is 1 mm. For the performance evaluation, 600 tubes are considered as a basic unit.

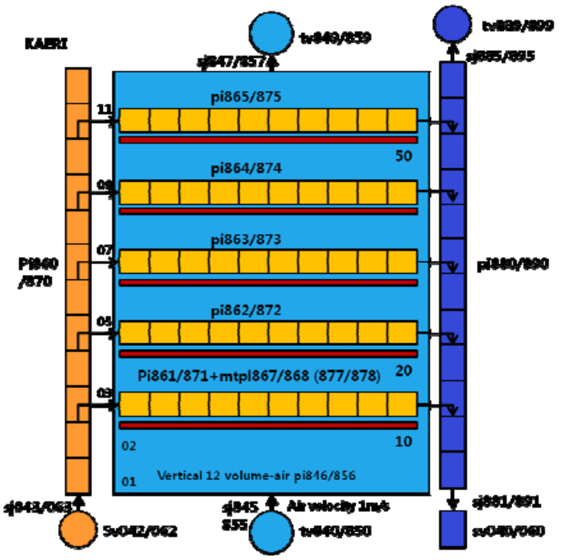


Fig. 4 MARS model for the air cooling heat exchanger system

Figure 4 shows the MARS model for the air cooling heat exchanger system. The 600 heat exchanger tubes are divided to 5 groups, connected at different levels of the inlet header. As like the PAFS tubes, the air cooling heat exchanger tubes are 3^{o} inclined so that the help the water drainage. The heat structures are divided into 10 nodes for each tube. For the evaluation of the design concept of passive air cooling heat exchanger system, the steam flow rate obtained from the previous PAFS FLB analysis is used as the boundary conditions.

3. Evaluation of Condensation Capability

A sensitivity study was performed by varying 2 effective parameters of the design: 1) number of heat exchanger tubes and 2) air velocity. A total of 8 cases were calculated.

Figure 5 shows the calculation results of the performance of an air cooling heat exchanger. The heat exchanger condensate flow rates are much dependent on the air velocity than tube number. Between 2400 to 4800 heat exchanger tubes, the condensate flow rate does not increase as much.

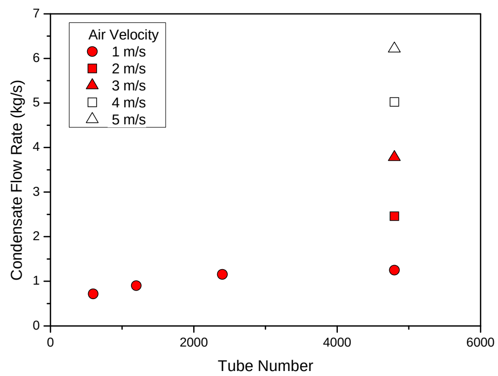


Fig. 5 HX condensate flow rate for the tube number and air velocity.

The condensate flow rate for the 4800 tubes and 5 m/s air velocity conditions is 6.2 kg/s. Considering the saturated water density and pool area, water level increase rate is equivalent to 0.435 m per 5000 second. Consequently, the level decrease rate is reduced to 0.335 m per 5000 second. With this level decrease rate, it takes about 40 hours to empty the PCCT.

4. Conclusions

Simple performance evaluation of the passive air cooling heat exchanger has been conducted by the MARS calculation. For the postulated FLB scenario, 4800 heat exchanger tubes and 5 m/s air velocity are not sufficient to sustain the PCCT pool level for 72 hour cooling. Further works on the system design and performance enhancing plan are required to fulfill the 72 hours long term passive cooling.

ACKNOWLEDGEMENT

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