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Design Characteristics of the Passive Auxiliary Feedwater System in APR+

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1. Introduction

The passive auxiliary feedwater system (PAFS) is a typical passive safety system implemented for the APR+. The auxiliary feedwater system (AFWS) in the APR1400, which is the reference plant of the APR+, consists of two motor driven pumps, two turbine driven pumps, two water storage tanks, and related pipes and valves. The AFWS feeds emergency water to steam generators to cool down the reactor coolant system when the main feedwater is lost. To enhance the safety, the PAFS replaces the AFWS with a passive condensation heat exchanger (PCHX), a passive condensation cooling tank (PCCT), and a few valves and pipes in the APR+ design.

In this paper, we propose the design requirements and conceptual design of the PAFS in order to evaluate the operability of the PAFS, to develop the APR+'s general arrangements for the auxiliary building, and to identify the important parameters to be quantified by experiments.

2. The Design Requirements of the PAFS

The target of the PAFS is to replace the function of the current AFWS. To meet this target, the following design requirements are selected:

- The PAFS must be capable of bringing the reactor to a shutdown cooling entry condition under all design basis accidents (DBAs) which are related to loss of the secondary heat sink.
- The PAFS must be capable of performing the intended function by natural phenomena, such as condensation, two phase natural circulation, pool boiling, and direct current (DC) battery power source.
- In order to prevent core damage, the capacity of the PAFS must be sufficient to maintain a hot shutdown condition for at least eight hours without any operator action in the case of station black out (SBO).
- The required condensate flow for heat removal has to be sufficient to maintain the predetermined steam generator (S/G) water level..
- To perform their safety functions, all the PAFS's components and piping have to be designed to withstand the effects of natural phenomena, such as earthquakes, tornadoes, hurricanes, floods, and tsunami, without loss of capability.
- The PAFS must be capable of receiving an actuation signal from the engineered safety Feature system (ESF) and the diverse protection system (DPS).
- The PCCT must be designed to have water capacity sufficient to permit eight hours of operation so that a shutdown cooling entry condition can be achieved within that time without the need for refill when both trains are operating.

3. Design of the PAFS

The APR+ has two S/Gs, two main steam lines and two main feedwater lines for each S/G. Two independent and identical PAFS loops are installed. The major equipment and piping diagram are illustrated in Fig. 1.

Each PAFS loop consists of a PCCT, four U-tube bundles, which is submerged in the PCCT, containment isolation valves (CIVs) on the steam supply line and system actuation valves (condensate return line isolation valves), check valves, non-condensable gas purge/vent valves, normal and emergency makeup valves, and associated piping and instrumentation.

The PAFS condensate return line isolation and check valves are arranged in parallel so that single valve failure does not prevent the PAFS's actuation. In the PAFS, we assume the common cause failure for valves. To avoid this problem, there are two distinct types of condensate return line isolation valves: a motor-operated valve (MOV) and an electro hydraulic valve (EHV).

Each PCCT is located at the top of the auxiliary building, considering connection to the main steam line and feed-water line within the MSVH and the gravity head relative to the S/G water level and the economizer feedwater nozzle.

A schematic diagram is illustrated in Fig. 2. The PCCT capacity has to be determined based on the mission time of the PAFS, which is defined by the duration of the cooling down of the RCS from the initial conditions by PAFS actuation to the shut down cooling entry condition for all design basis accidents.

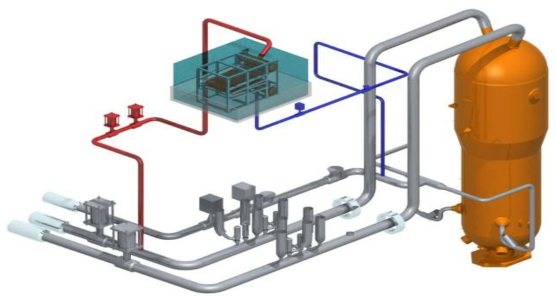

Fig. 1 Major equipment and piping of the PAFS in the APR+

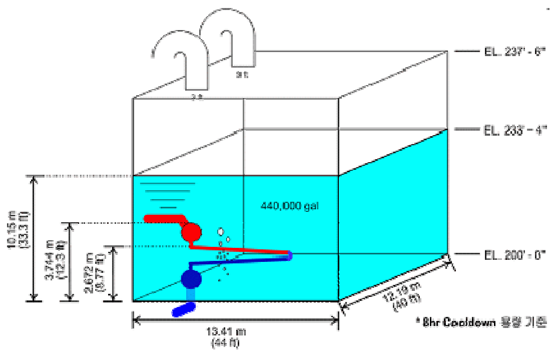

Fig. 2. Schematic diagram of PCCT in PAFS

4. Operation of the PAFS

The PAFS has a two-phase natural circulation loop. There are two major driving forces: one is the density difference between its liquid and vapor phase and the other is water head between the S/G water elevation and the PCCT elevation. When the PAFS is in standby mode, the steam supply isolation valves are opened and the condensate return line isolation valves are closed to maintain the PCHX in the pressurized condition in order to reduce dynamic load during the PAFS's startup while minimizing the effect of a possible high energy line break downstream of the valves. When the PAFS is actuated, the steam generated in the S/G enters into the PCHX through the main steam line and the steam supply line. The steam is condensed inside the PCHX due to the temperature difference between the steam and the water in the PCCT, and eventually the condensate returns to the S/G through the condensate return line and the main feed-water line. The heat of the steam is transferred to PCCT water by condensation between the steam and tube wall, conduction in the tube wall, and convection between the tube wall and PCCT water. The steam generated in the PCCT drives out to the atmosphere, the final heat sink. The PCCT retains a sufficient amount of water to remove the decay heat until the shutdown cooling system (SCS) can operate or the make-up system recovers and is able to remove the decay heat of the reactor core.

For the preliminary performance analyses, we are analyzed the loss of condenser vacuum accident (LOCV) of the PAFS limiting event using RELAP5/Mod3.3 code. As shown in the figure 3, the S/G water level is maintained at a normal level before the reactor trip. After the reactor trip, the SG secondary water level is continuously decreased and the PAFS is actuated, at which point the SG water level is leached to PAFS actuation level. During this period, the heat generated in the reactor core is vented through the MSSV by vaporization of the SG secondary water. After PAFS is actuated, the SG water level is maintained at a constant level.

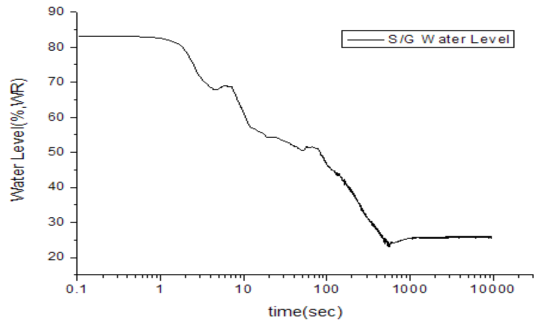

Fig3. Steam generator Water level (LOCV)

5. Conclusions and Further Studies

According to the PSA and preliminary cost analysis, core damage frequency is reduced more than 26% and the construction cost is reduced to half of the current AFWS by the adoption of PAFS. We have developed the preliminary design of the PAFS. It was found that PAFS has sufficient capacity to remove the decay heat of the reactor core and the sensible heat of the reactor coolant in the event of transients.

The major design parameters of the PAFS are pressure loss, the heat transfer coefficient, flow stability, and transient response. Throughout the detailed design process of the APR+, these parameters will be finalized through numerical code analysis, separate effect tests and integral effect tests. Based on these efforts, the PAFS design will be optimized by 2012.

ACKNOWLEDGMENT

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REFERENCE

[1] KHNP, Technology Development on the Application of Passive Safety Features, 2010, 9-018-K-462-004].