

# Performance verification of Passive Accident Mitigation Scheme (PAMS) under feedwater line break (FLB) accident



Shi Er-bing<sup>a,\*</sup>, Wang Chang<sup>a,\*</sup>, Hao Rui<sup>a</sup>, Fang Chengyue<sup>a</sup>, Xia Genglei<sup>b</sup>

<sup>a</sup> China Ship Development and Design Centre, Wuhan 430000, China

<sup>b</sup> Harbin Engineering University, Harbin 150001, China

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## ABSTRACT

An innovative secondary circuit passive residual heat removal scheme, termed as Passive Accident Mitigation Scheme (PAMS), is investigated in our work. PAMS aims at removing core residual heat and ensuring reactor safety for Pressurized Water Reactor (PWR) Nuclear Power Plant (NPP), which consists of two parts: the first part is Passive Auxiliary Feedwater System (PAFS), and the other part is Passive Residual Heat Removal System (PRHRS).

Shi et al. (2015) analyzed the PAMS operation characteristics under Station Blackout (SBO) accident using RELAP5. In order to assess the ability of PAMS, more analyses should be carried out. This paper takes the Westinghouse-designed Advanced Passive PWR (AP1000) as research object and proposes the simulation performance verification of PAMS under FLB accident with the help of RELAP5. Moreover, the comparative analysis is also conducted between PAMS and traditional secondary circuit PRHRS with different design capacities under FLB accident. Results show that: during the whole accident process, the key parameters' performances of primary system could meet acceptance criteria requirements, which proves PAMS can cope with FLB accident; moreover, since only the PAMS train connected to intact circuit can operate to mitigate FLB accident, the analysis results prove that PAMS design satisfies single failure criterion; the primary system cooling process with PAMS operation is quite close to primary system cooling process with 4% of Full Power (FP) design capacity PRHRS operation, and both of them can remove core residual heat significantly under FLB accident.

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## 1. Introduction

To enhance inherent safety features of NPP, the advanced PWR implements a series of passive safety systems. PRHRS is of great significance for passive safety design. Secondary circuit PRHRS is one type of PRHRS, which is installed on the secondary side of steam generator (SG). A Heat Exchanger (HX) connecting steam line and feedwater line is cooled by cold source. Under loss of heat sink accidents, the steam generated in SG would form a natural circulation and is condensed in HX, and then flowed back into SG, through which the core residual heat is removed to cold source. Secondary circuit PRHRS design can be classified into two types by cold sources. APR+ in Korea equips Cooling Tank (CT) (Cho et al., 2012), in which the low-temperature water is used as cold source; a similar design is adopted in SMART (Kim et al., 2016) in Korea, KLT-40S (Balunov et al., 2011) in Russia, IRIS (Carelli

et al., 2004) in America. HI-SMUR, designed by Holtec Company, equips air-cooling tower as cold source (Singh et al., 2011); a similar design is adopted in AC600 (Yan and Zang, 2002) in China. For some small scale PWR NPP, the water of SG secondary side is relatively little in inventory, for which when it comes to secondary circuit PRHRS design, it is necessary to add SG water makeup tank in case of SG evaporation to dryness. This design concept has been applied to SMART in Korea, IRIS in America, and KLT-40S in Russia.

As a passive safety system, secondary circuit PRHRS should satisfy single failure criterion (Kim et al., 2013), for which secondary circuit PRHRS capacity of a single train should be designed to be large enough to remove the total decay heat during an accident. However, the large design capacity would lead to a rapid cooling rate, which causes adverse impact on Reactor Coolant System (RCS) material. In China, the heat removal cooling rate is limited to be less than 28 °C/h.

Research related to secondary circuit PRHRS heat removal cooling rate has been performed. Kim et al. (2015) conducted PAFS-CIV-01 test on ATLAS-PAFS test facility to regulate core cooling rate by adjusting Condensate Isolation Valve (CIV) opening stroke. The

\* Corresponding authors.

E-mail addresses: [erbing\\_shi@qq.com](mailto:erbing_shi@qq.com) (E.-b. Shi), [wangchang\\_csddc@163.com](mailto:wangchang_csddc@163.com) (C. Wang).

pressure and the temperature gradients of primary system are reduced as the stroke of the CIV is decreased during passive heat removal process.

To solve the cooling rate problem and improve the operation performance of secondary circuit PRHRS, an innovative secondary circuit passive residual heat removal scheme, termed as PAMS, is investigated in our work. Shi et al. (2015) analyzed PAMS operation characteristics under SBO accident using RELAP5. The results show that PAMS can remove core residual heat significantly. Moreover, due to the strong load-following capability, the cooling rate is much more reasonable compared to traditional secondary circuit PRHRS.

Compared to SBO accident, when FLB accident happens, the PAMS train of broken feedwater line circuit cannot operate because of corresponding SG evacuation, for which FLB accident is much more severe than SBO accident. For AP1000, FLB accident under full power would lead to the most severe condition for reactor core (Sun, 2010). In order to assess the ability of PAMS, the simulation performance verification of PAMS under FLB accident is conducted using RELAP5 in this paper. Moreover, the comparative analysis is also conducted between PAMS and traditional secondary circuit PRHRS with different design capacities under FLB accident. The advanced PWR NPP AP1000 is taken as research object in this work.

## 2. PAMS design concept description

Traditional Secondary circuit PRHRS only involves HX, connecting pipes, isolation valves and cold source. Based on traditional Secondary circuit PRHRS design, PAMS consists of two parts: the first part is PAFS, and the other part is PRHRS. The design schematic diagram is shown in Fig. 1.

AP1000 is a two-circuit PWR. One SG, one hot leg, two cold legs, and two Reactor Coolant Pumps (RCP) are arranged for each circuit. The Pressurizer (PRZ) is connected to the hot leg of one of the circuits through surge line. To satisfy single failure criterion, two identical PAMS trains are designed. Each PAMS train is connected to the corresponding SG.

The core equipment of PAFS are Auxiliary Turbine (ATur), and steam-driven Auxiliary Feedwater Pump (AFWP). The core equipment of PRHRS are HX and CT.

For PAFS, the high parameterized steam flows into ATur through Steam Isolation Valve 1 (SIV1) and Rotation Speed Control Valve (RSCV). Exhaust steam is collected in Exhaust Steam System (ESS). RSCV is used to regulate the rotational speed of ATur, as well as AFWP connected to ATur through shaft component. Auxiliary feedwater is pumped from Emergency Feedwater Tank (EFWT) into secondary side of SG. Check valve 1 (CV1) on return water line is to prevent auxiliary feedwater from flowing backward. The pressure of SG decreases with the operation of PAFS. PAFS stops when the SG pressure decreases to the minimum allowable pressure value of ATur.

For PRHRS, steam generated in SG flows into HX through SIV2 and is condensed in HX. The condensed water flows back to the secondary side of SG through Condensed-water Isolation Valve 1 (CIV1). Driving force of PRHRS is density difference and height difference between steam and condensed-water. The cold source used to cool down steam in HX is water in CT.

Compared to traditional secondary circuit PRHRS, the PAFS is added, while the design capacity requirement of PRHRS is decreased. According to our previous work, the control method of steam flowrate flowing into ATur makes PAFS strong load-following, for which the cooling rate is much more reasonable compared to traditional secondary circuit PRHRS. Strong load-

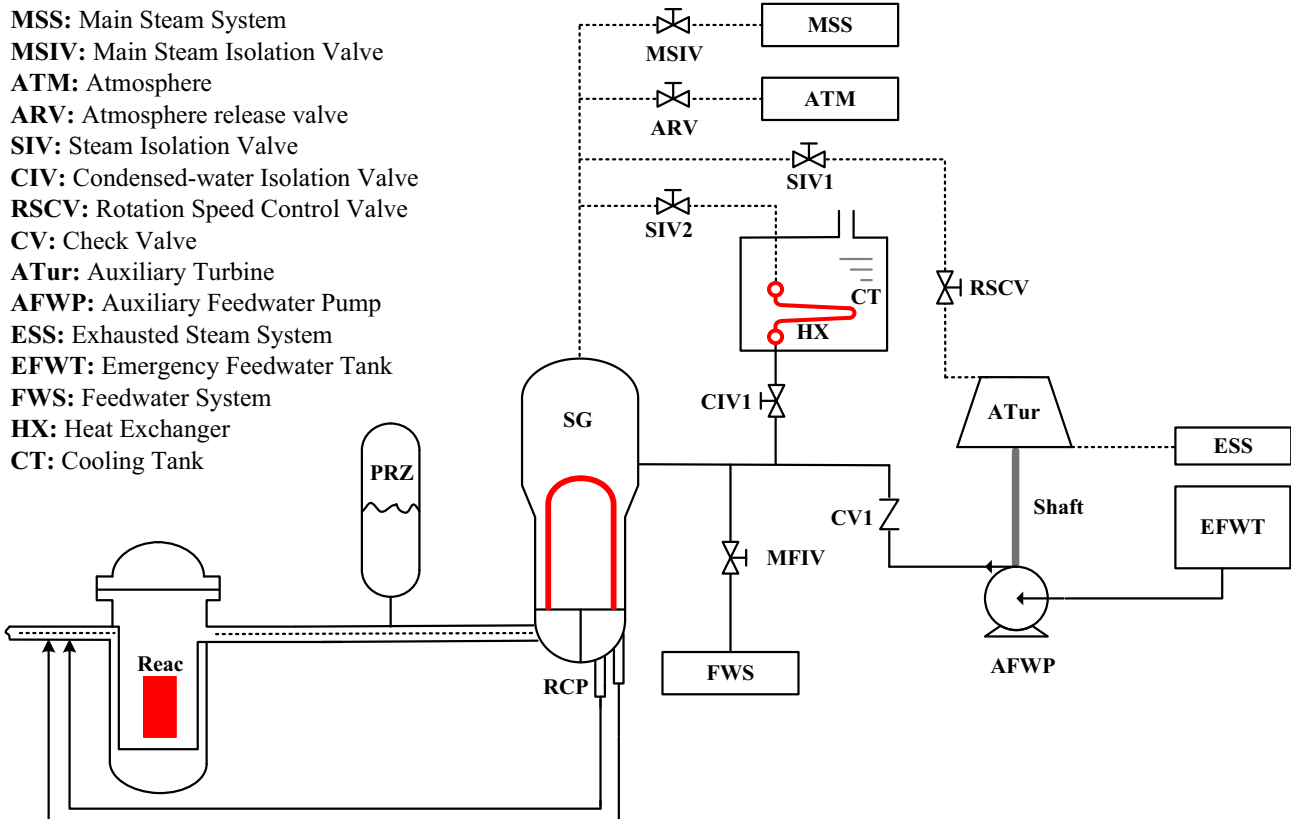


Fig. 1. PAMS design schematic diagram.

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