

Preliminary Evaluation of Time-Dependent Required Flow Rate for a PAFS of an Integral SMR

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1. Introduction

Passive safety systems are adopted in small modular reactors (SMRs) for decay heat removal following reactor shutdown. The Korean innovative SMR (i-SMR) is a 520MWth integral pressurized water reactor equipped with fully passive safety systems [1]. The passive auxiliary feedwater system (PAFS) removes heat from the reactor coolant system (RCS) through the steam generator by natural circulation and provides long-term cooling following reactor shutdown [2,4].

Following reactor shutdown, the heat removal requirement changes with time due to the decrease in decay heat and RCS cooldown. Therefore, the flow rate required for heat removal through the PAFS also varies with time. Estimation of the required flow rate provides a reference for assessing whether the PAFS can provide sufficient heat removal during long-term cooling.

The objective of this study is to estimate the time-dependent required PAFS flow rate for 72 hours after reactor shutdown using a simplified energy balance. The effect of RCS cooldown time on the required flow rate is also examined.

2. Methods and Results

2.1 Analysis Method

The analysis was performed for the i-SMR for 72 hours after reactor shutdown. The major design parameters used in this study are summarized in Table I [1,3]. The average core inlet and outlet temperature, 303.5°C, was used as the initial RCS temperature. Decay heat was calculated using the Way-Wigner correlation [3].

The required PAFS flow was calculated from the decay heat and RCS cooldown heat load. For the preliminary analysis, the RCS coolant inventory was assumed to be 60ton, and the target RCS temperature and PAFS operating pressure were assumed to be 215°C and 5 MPa, respectively. The reference cooldown time was 36h[4].

The total required heat removal rate during the cooldown period was calculated as

$$Q_{req}(t) = Q_{decay}(t) + Q_{cool} \quad (1)$$

Where, the RCS cooldown heat load was calculated by

$$Q_{cool} = M_{RCS} C_p \frac{T_0 - T_{target}}{t_{cool}} \quad (2)$$

The PAFS heat exchanger inlet and outlet were assumed to be saturated steam and saturated liquid, respectively. The required PAFS flow rate was calculated as

$$\dot{m}_{req}(t) = \frac{Q_{req}(t)}{h_g - h_f} \quad (3)$$

Where h_g and h_f are the saturated steam and saturated liquid enthalpies at the assumed PAFS pressure.

The calculated flow rate represents the flow required to remove the heat load through the PAFS and not the actual natural circulation flow in the system.

Table I: Major design parameters of the i-SMR([1], [4])

Parameter	Value
Reactor type	Integral PWR
Rated Power	520 MWth/170MWe
NSSS operating pressure	15.5MPa
Core Temp. in/out	286/321°C
Safety system	Fully passive
Passive core cooling capability	At least 72h without safety grade AC/DC power
Safe-shutdown achievement	Within 36h

2.2 Results and Discussion

The required PAFS flow rate was evaluated for 72 hours after reactor shutdown using the reference conditions described in Section 2.1. The time-dependent behavior was first examined for the reference case. A sensitivity calculation was performed to examine the effect of RCS cooldown time on the required flow rate.

Figure 1 shows the required PAFS flow rate for 72h after reactor shutdown. The required flow rate decreases rapidly during the early period and then decreases gradually as the decay heat decreases. A small decrease appears at 36h because the assumed RCS cooldown is

completed at this time. After 36h, only decay heat is considered in the heat removal requirement.

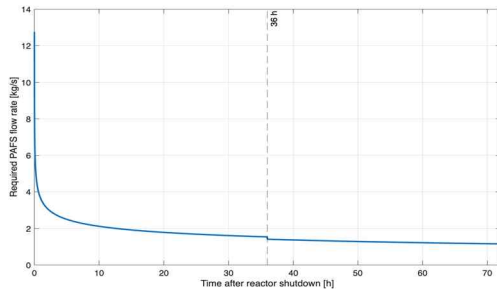


Fig. 1. Time-dependent required PAFS flow rate after reactor shutdown.

Figure 2 compares the required PAFS flow rates for cooldown times of 24, 36, and 48h over the 72-h period. During the cooldown period, a shorter cooldown time requires a higher flow rate because the RCS sensible heat must be removed over a shorter time. The difference among the cases is relatively small at early times but becomes more noticeable as the decay heat decreases. Once the assumed cooldown period is completed, the RCS cooldown load is no longer included in the heat removal requirement. This causes a change in the relative flow rates among the cases around the respective cooldown times. After 48h, all three cases are based only on decay heat removal and therefore give the same required flow rate.

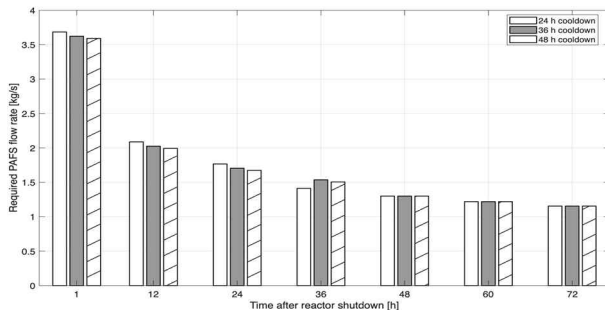


Fig. 2. Effect of cooldown time on the required PAFS flow rate

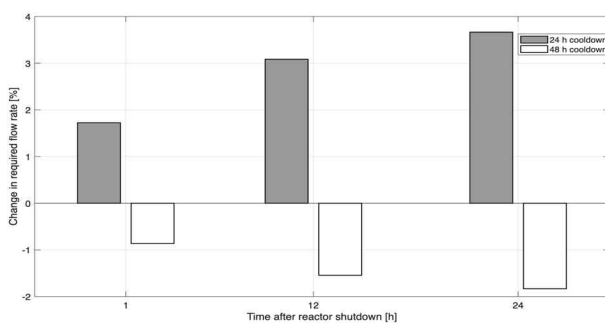


Fig. 3. Sensitivity of the required PAFS flow rate to cooldown time

Figure 3 shows the sensitivity of the required PAFS flow rate to cooldown time, using the 36-h case as the reference. The comparison is limited to 24h so that all three cases are evaluated during the assumed RCS cooldown period. For the 24-h cooldown case, the required flow rate increases from about 1.7% at 1h to 3.7%

at 24h. For the 48-h case, it decreases from about 0.9% to 1.8 %. The increasing relative difference with time results from the decrease in decay heat, which makes the RCS cooldown load a larger fraction of the total heat removal requirement. The results show that the effect of cooldown time remains within about 4% for the range considered.

The present calculation provides a preliminary estimate of the PAFS flow requirement over the 72-h period. The effect of cooldown time is limited within the range considered. The calculated flow can be used as a reference for subsequent comparison with the actual natural circulation flow of the PAFS.

3. Conclusions

The time-dependent PAFS flow requirement was evaluated for a 520 MWth integral SMR for 72h after reactor shutdown. The required flow rate was calculated from the heat removal demand considering both decay heat and RCS cooldown. The 36-h RCS cooldown condition was used as the reference case, consistent with the i-SMR design requirement for reaching the safe shutdown condition.

The required PAFS flow rate decreased continuously with time, mainly following the decrease in decay heat. The effect of RCS cooldown time was examined using 24-, 36-, and 48-h cooldown cases. During the common cooldown period, the effect remained within about 4%, although the relative difference increased with time as the contribution of the cooldown load became larger compared with the decay heat.

The present analysis provides a preliminary estimate of the PAFS flow required to meet the time-dependent heat removal demand. The calculated flow does not represent the actual natural circulation flow of the PAFS. Further analysis of the natural circulation characteristics can be used to compare the available PAFS flow with the required flow obtained in this study.

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