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Investigation of Safety Margins Associated with the KALIMER Station Blackout Accident

Won-Pyo Chang, Yong-Bum Lee
Korea Atomic Energy Research Institute
P.O.Box 105, Yusung, Taejon, 305-600, Korea
**Corresponding author: wpchang@kaeri.re.kr*

1. Introduction

The station blackout accident is one of the most concerning scenarios for the KALIMER design. It is a limiting scenario in a loss of heat removal, and the scenario also provides a measure for the effectiveness of the passive safety system which ultimately secures the KALIMER safety. When the accident occurs, all the pumps in both the primary and intermediate systems are tripped, and thereby the normal heat removal path through the IHX is not available. The path for the heat removal, therefore, is made only through the PDRC (Passive Decay Heat Removal Circuit), while the core cooling becomes solely dependent on the natural circulation in the primary system. Since the PDRC does not come into normal operation before sodium begins over-flowing from the hot pool into the cold poor, the safety analysis in the early stage before the PDRC activation is of great concern in order to assess the timing of the PDRC engagement. The most dominant factor affecting the transient is natural circulation, and the core flow is determined from the friction and heat transfer of the core wire-wrapped rods. For this reason, they should be evaluation objects in this study. The safety margins obtained in the study will provide a quantitative basis for the KALIMER safety assurance.

2. Analyses and Results

In this section an input modeling for the analysis with MARS-LMR[1], a steady state calculation, a transient scenario, and the calculation results are described.

2.1 Input description

Figure 1 represents a nodalization for the MARS-LMR analysis.[1] Heat transfer is not allowed through the IHX(Intermediate Heat Exchanger) because no natural circulation is assumed inside the IHX for conservatism. The shell side of the IHX, however, is taken into account in the nodalization for the pressure drop calculation in the primary system. The PHTS(Primary Heat Transport System) is simulated with the cold pool, 2 pumps, the lower plenum, 7 regional channels with 10 axial nodes each for the core, the hot pool, and the shell sides of 4 IHX's.

2.2 Steady State Calculation

The steady state calculation with MARS-LMR gives the core power of 1523.4 MWt with the primary flow rate of 7731 kg/s. The flow calculation is accurate enough to give 0.02 % of the designed value of each channel in the core. The core inlet and outlet coolant temperatures in the calculation show a difference from those of the design values, and it is likely to come from a fine difference of sodium property tables used in the analysis and design. The core inlet and outlet pressures are calculated at 4.6 and 2.1 bars, respectively, with the pressure drop of 2.5 bars over the wire-wrap. So the cover gas pressure reaches 1.0245 bars and it is slightly higher than the atmospheric pressure. The hot and cold pool levels agree well with the design values. Considering the results, it is said that a successful steady state is obtained for the transient analysis.

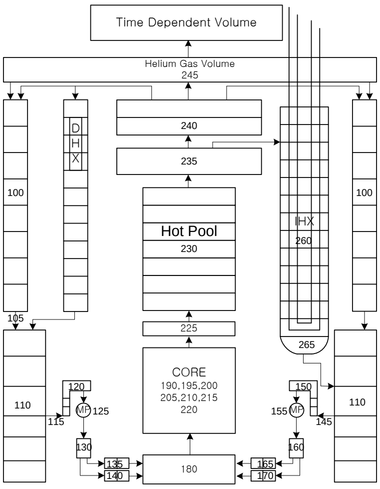

Fig. 1 Nodalization of the primary side for KALIMER-600

2.3 Transient Scenario

The transient is initiated by trips of all the primary and IHX pumps. The reactor is tripped by the normal protection system. No heat transfer is allowed through the IHX for a conservative assumption.

The transient begins with a reactor trip signal at 0.0 s, and the reactor actually trips at 0.2 s. The IHX pumps are tripped immediately after the trip. So no heat transfer is available through the IHX, while the primary pumps undergo a coast-down operation. It is also assumed that the heat removal by the PDRC is absent at early transient. It is very conservative assumption. A sensitivity study has already conducted to find out the effects of such parameters as the heat transfer coefficient and friction factor on the transient.[2]

2.4 Results

Figure 2 reveals the variation of the maximum cladding temperature with time. For the friction factor investigation, ± 25 % of the nominal value is chosen as a bounding value, since 96 % of the experimental data on pressure drop lie within ± 25 % of the prediction by Cheng and Todreas model[3] which is used for the calculation. The effect of the heat transfer coefficient is not noticed, but +25 % of the nominal friction factor reduces the safety margin by 8 ^oC from 105 to 97 ^oC. This result indicates that the upper bound of the friction factor must be taken into account in the analyses in order to gain a conservative safety margin.

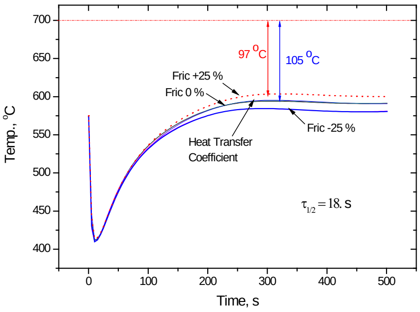

Fig. 2 Effect of the friction factor in the hot channel for $\tau_{1/2}$ = 18.0 s

The effect of the pump halving time ($\tau_{1/2}$) is more distinctive in the safety margin as seen in Fig 3. For the reduced pump halving time from 18.0 s to 10.0 s pump, a 25 % increase of the nominal friction factor gives 25 ^oC reduction in the safety margin, compared with 10 ^oC reduction when the nominal friction factor is applied. Figure 4 shows that the flow rate in the hot channel is not sensitive to the friction factor relatively but to pump halving time.

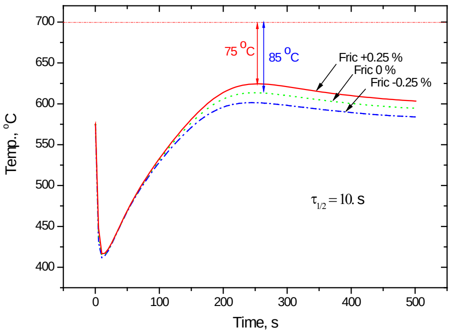

Fig. 3 Effect of the friction factor in the hot channel for $\tau_{1/2}$ = 18.0 s

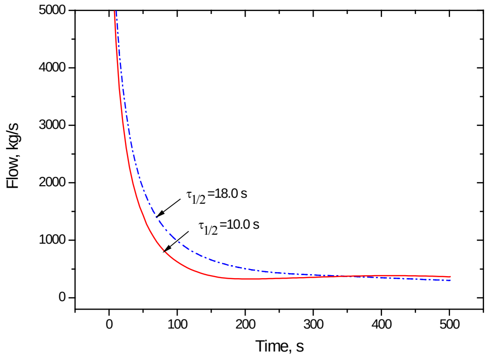

Fig. 4 Pump halving time effect on core outlet flow

3. Conclusions

The heat transfer coefficient is not sensitive to the safety margin, however, the effect of the friction factor is clear. The 25 % increase of the friction factor gives rise to 8 ^oC reduction from the nominal value in the safety margin.

The friction factor effect is more distinctive when the pump inertia is reduced from $\tau_{1/2}$ = 18.0 s to 10.0 s. As a result, a 10 ^oC decrease in the safety margin is observed by reducing the pump halving time to $\tau_{1/2}$ = 10.0 s.

Besides, a flow reversal does not occur near 300 s for $\tau_{1/2}$ = 18.0 s, but it is observed for $\tau_{1/2}$ = 10.0 s.

Therefore, about 10 ^oC reduction of the safety margin is anticipated due to a friction factor uncertainty, and the reduction of the pump halving time brings about 22 ^oC difference in the safety margin. Further more, a longer pump halving time than 10.0 s is required in order to avoid the flow reversal in the core.

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