# Passive Decay Heat Removal Performance Analysis with the MARS-LMR Code

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## 1. Introduction

The passive decay heat removal circuit (PDRC) is a key safety design feature of a Generation IV sodium-cooled fast reactor under development at the Korea Atomic Energy Research Institute (KAERI). The PDRC removes the decay heat from the primary pool to the ambient atmosphere via a natural circulation of sodium flow in a closed loop when the primary temperature increases deviating from normal operating ranges. Therefore, an evaluation of natural circulation performance is remarkably important because it determines the decay heat removal function of an SFR, thus, it forms the basis of accurate safety evaluation at various transients.

In the present study, the performance of the PDRC loop at a steady state and at a transient condition are analyzed with the MARS-LMR code, [1] which is developed for the system analysis of a liquid metal-cooled fast reactor. The main purposes of the study are to test the appropriateness of the thermal-hydraulic models for liquid metal flow implemented in the MARS-LMR code and to confirm the design parameters of PDRC for KALIMER-600.

## 2. Modeling of a PDRC Loop

The important modeling features for the evaluation of natural circulation characteristics include a correct description of pressure drop and a heat transfer models for various situations. For a description of the pressure drop in a wire-wrapped rod bundle the correlation by S.C. Cheng and N. E. Todreas [2] has been implemented in the MARS-LMR code. The heat transfer by a liquid metal flow in nuclear fuel bundles is described by the modified Schad's correlation.[3] For the liquid metal heat transfer in a heat exchanger tube the correlation by Aoki [4] is selected and it is found that the Graber-Rieger model [5] is best for a shell side heat transfer.

The PDRC system in KALIMER-600 is simulated to evaluate the feasibility of the PDRC concept and to investigate the performance of the PDRC design. At a 100% power operation condition, the heat of 2.33 MWt is transported to the atmosphere via the PDRC loop whose flow rate is about 25.45 kg/s. The cooling air flow rate due to a buoyancy effect amounts to about 26 kg/s.

The essential driving force for the natural circulation in the PDRC loop is caused by the density difference between the heat input to the sodium-sodium decay heat exchanger (DHX) tube via radiation from the hot pool and the heat output to the atmosphere from the sodium-air heat exchanger (AHX) shell side. The evaluation of the PDRC performance is the main purposes of the present study, thus, the primary heat transport system (PHTS) and the complicated flow path between the hot pool and the DHX are eliminated to simplify the numerical simulation. Fig. 1 depicts the nodalization of a KALIMER-600 PDRC loop generated for a simulation with the MARS-LMR code.

The expansion tank is modeled as a time-dependent volume filled with liquid sodium to reach a fast convergence for the simulation, which was derived from previous simple test simulations. The heat transfer area of the DHX and the AHX is calculated based on the real design data supplied by the fluidic system designers for KALIMER-600. The flow resistance coefficients of the friction and form loss in the PDRC loop have been evaluated independently and not by using the data supplied by the design team.

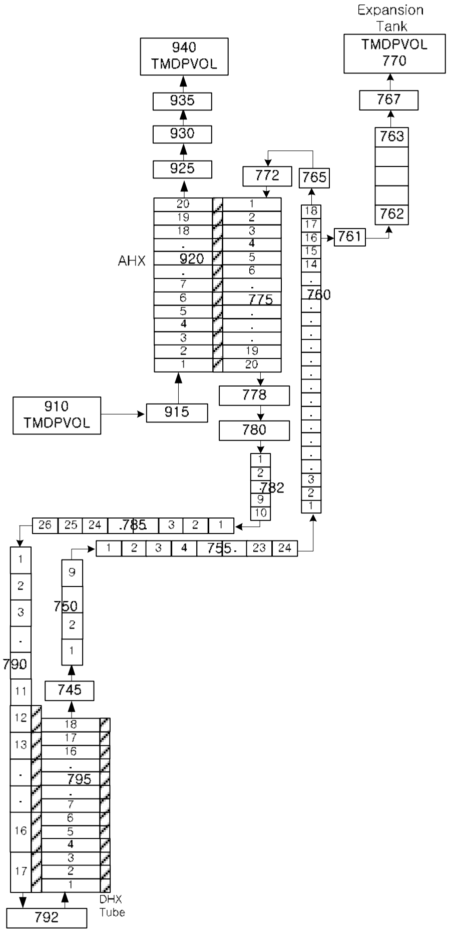

Fig. 1. Nodalization of a PDRC loop for MARS-LMR Code.

## 3. PDRC Performance Analysis

The numerical simulation is performed for two different stages of operational conditions. Up to the time of 500 second, the DHX is heated with 2.33 MW and the AHX is forced cooled with an air flow rate of 26.18 kg/s, which is the operating condition for a 100% power level in KALIMER-600. In the second stage, the forced air flow is stopped and the air flow rate is formed by the buoyancy effect in the AHX. The heat rate transported to the DHX is maintained at 2.33 MW until 1,000 second and from that time the heat rate is increased stepwise to 3.0 MW.

Fig. 2 shows the natural circulation flow rate in the PDRC loop. The thermal-hydraulic state reaches an almost equilibrium state even though there is some mismatch between the heating rate and cooling rate. Therefore, it can be said that a quasi-static steady state in the PDRC loop is achieved with the PDRC design data provided for KALIMER-600. This difference could have resulted from the difference in heat transfer correlation, and the loss coefficient.

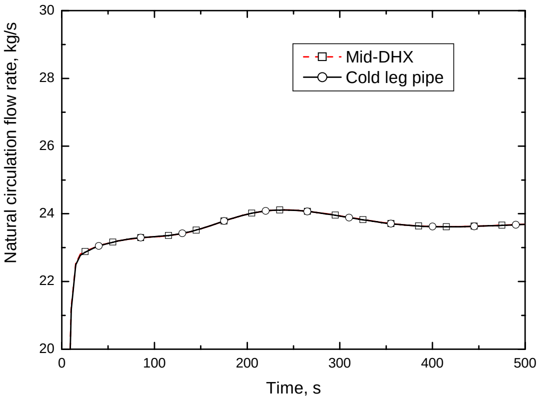

Fig. 2. Natural circulation flow with a forced air flow.

At 500 second, the forced air flow into the AHX air stack is stopped and the heat into the DHX is transported by pure passive natural circulation in a PDRC loop and by pure buoyancy force in AHX air side. The natural circulation flow increases just after stopping the forced air flow, then it decreases up to 1,000 second. When the heater power is increased to 3.0 MW at 1,000 second, the circulation flow in PDRC loop start to increase and it approaches to a stable value after experiencing some oscillatory behavior. This means another quasi-state condition is reached by the balance between the increased power and the cooling.

With the elevated power level in the DHX the sodium temperature in the PDRC loop and the temperature of the air flowing through the AHX tube are increased. Fig. 3 shows the temperature trends in the second simulation stage. From these temperature distributions, it is re-confirmed that a quasi-state condition is obtained after an increase in the power. It is noted that the temperature increase in the AHX side is delayed by about 200 seconds, which means the propagation of an increased temperature through a natural circulation in the PDRC takes some time. The temperature increase in the DHX downcomer pipe seems to be over-estimated. It is necessary to modify the DHX heat structure modeling between the downcomer and the DHX tubes.

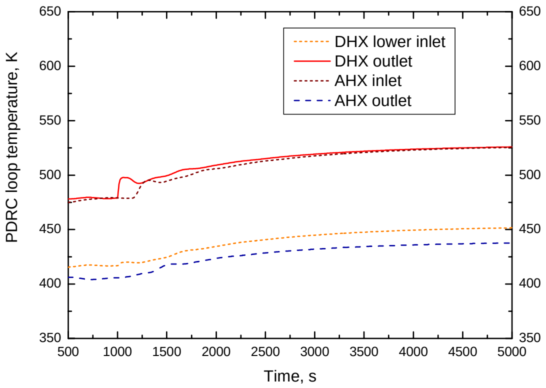

Fig. 3. Sodium temperatures in a PDRC loop with a power increase.

## 4. Conclusions

The performance of natural circulation in a PDRC loop has been numerically evaluated for the PDRC design of KALIMER-600. A complete passive operation of a natural circulation heat removal system is modeled and simulated successfully with the MARS-LMR code. It is found that the thermal-hydraulics models in MARS-LMR code are suitably implemented for the description of PDRC loop characteristics. This information will be utilized for a future whole system modeling and a transient analysis of a Gen IV SFR.

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