# Negative Buoyancy Phenomenon in the LMFR Hot Pool during Scrammed Transient

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## 1. Introduction

In pool-type liquid metal fast reactors (LMFR), the core flow entering the hot pool in the form of a turbulent jet plume is characterized by the sodium temperatures at the core exit and in the hot pool. The jet plume leaving the core goes to the top of the hot pool when the core outlet temperature is hotter than the bulk hot pool temperature. In the opposite condition, a full penetration of the jet is prevented by the negative buoyancy and, therefore, the fluid mixing is limited to a smaller region in the hot pool.

As a result of flow stratification due to buoyancy during scram transients, a hot-cold interface is created within the hot pool. Component structures located in the neighborhood of the hot-cold interface may be adversely affected by thermal discontinuity stresses. Another potential thermal design problem may be presented whenever the hot pool flow configuration becomes unstable and produces a sudden inversion of the hot and cold regions.

## 2. Analytical Models and Results

### *2.1 Analytical Models*

A simple lumped-parameter mixing model can be used to predict the transient thermal response under the conditions of a flow stratification. The penetration distance of the core outlet flow is first determined by an experimental correlation. The calculation of a fluid mixing in the region of a penetration is then performed. A schematic of the hot pool above the core outlet is shown in Fig. 1. The upper mixing zone is denoted as zone A and the lower zone as zone B.

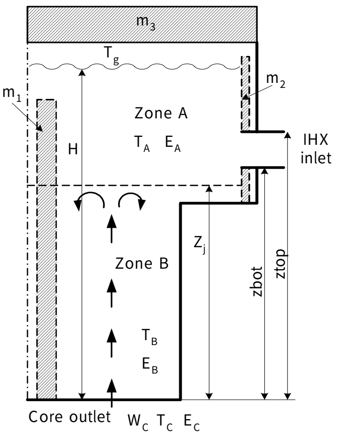
The following assumptions are basis of the model. Core flows from different channels into the hot pool are represented by a single equivalent flow. This flow has the mass-average enthalpy of the different channel flows. The maximum penetration distance divides the upper plenum into two mixing zones. Full penetration is assumed for flow with positive buoyancy. The mixing process in both zones is assumed to be an instantaneous complete mixing. The cover gas obeys the perfect gas law.

The maximum penetration height is determined from an experimental correlation developed by Yang [1] Based on his analysis the penetration distance is a function of a single initial parameter, the Froude number. When the average Froude number at the exit of core is less than 10, the analytical results can be approximated by the following correlation with a maximum deviation of 6%.

$$Z_j(t) = 1.0484 Fr^{0.785} r_o \qquad (1)$$

For the jet with negative buoyancy in uniform environment, the local Froude number, Fr, is defined as $Fr = U_C^2 \rho_B / g r_o (\rho_C - \rho_B)$.

Figure 1. Schematic of the Simple Hot Pool Model




A detailed two-dimensional model calculates more accurately the coolant temperature and velocity profiles in the hot pool than the simple lumped-parameter model. The κ-ε model is based on the eddy viscosity concept in which κ is the turbulence kinetic energy and ε is the turbulence eddy dissipation rate.

The spatial calculation domain is discretized into finite control volumes and the governing discretization equations are integrated over each control volume. The convection terms are approximated using the HLPA high resolution scheme by Zhu [2] and the transient terms are treated by a first order backward differencing scheme. Two velocity components, turbulent kinetic energy, and the rate of turbulent kinetic energy dissipation at the core inlet are given as the inlet boundary condition. No-slip condition is assumed at the wall and a wall-function approach is used to model near-wall flow. The SIMPLEC algorithm developed by Van Doormal and Raithby [3] is used for the treatment of the pressure-velocity coupling.

### *2.2 Analysis Results*

Under the condition of an overpower transient (TOP) with reactor scram for KALIMER-150, the core outlet flow is characterized by a negative buoyancy and low momentum. As soon as the reactor core is scrammed, the reactor power rapidly drops to the decay heat level but the core flow rate follows the coastdown characteristics of the pumps. The mismatch in the power-to-flow ratio results in a negative buoyancy condition in which the core outlet flow is colder than the fluid in the hot pool above the core. The simple lumped-parameter model calculated almost the same power and flow transients compared with the two-dimensional model. The reactor is automatically scrammed by a high level power signal (116% power) at 5.7 seconds and all primary pumps begin coastdown operation at the same time.

The various sodium temperatures in the hot pool predicted by the simple model are indicated in Fig. 2. Two temperatures of the upper and the lower hot pool are also presented and they correspond to the temperatures of zone A and zone B in Fig. 1, respectively. The upper hot pool temperature and the IHX inlet temperatures remain at a steady-state temperature until 65 seconds and this represents that the IHX inlet nozzle is above the lower hot pool region.

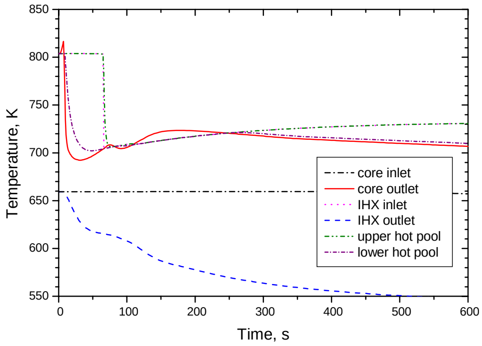



Figure 2. Temperatures predicted by the simple model

The hot pool temperatures predicted by the two hot pool models are shown in Fig. 3. The core outlet temperature behaviors by the two models are very close until 70 seconds. The IHX inlet temperatures predicted by the two models are also close until 65 seconds when the core outlet jet plume reaches to the top of the hot pool in the simple model calculation. The difference of the IHX inlet temperature behavior after the core jet plume reaching the IHX inlet nozzle was expected because of the significantly different approach.

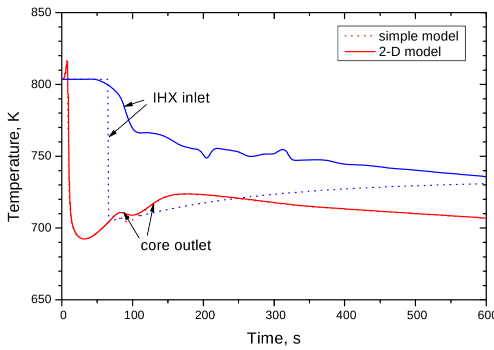



Figure 3. Pool temperatures predicted by two models

The temperature contours of the hot pool predicted by the two-dimensional model are shown in Fig. 4. The unit of temperature in the plots is in $^{o}$C. The sodium temperature in the upper hot pool remains at a steady-state value during the early period of the transient due to the large volume of the hot pool. Thus the core outlet flow entering the hot pool in the form of turbulent plume is characterized by the negative buoyancy. The analysis result indicates that the Yang's correlation expressed in Eq. (1) properly calculates the penetration distance of the core jet plume in the hot pool under the negative buoyancy condition.

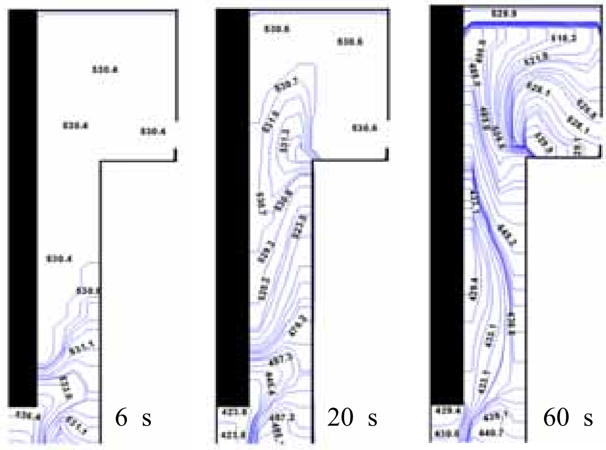



Figure 4. Temperature contours of the hot pool predicted by the two-dimensional model

### 3. Conclusion

The simple lumped-parameter model as well as the two-dimensional model predicts well the thermal response of the hot pool for the safety analysis of the KALIMER-150 plant. The analysis results indicate that Yang's correlation can be used to determine the penetration distance of the core jet plume within the hot pool. The simple correlation in the function of Froude number can be incorporated in the large-scale computer code for the analysis of transient thermal-hydraulic behavior of the hot pool in LMFR systems.


Acknowledgement

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### REFERENCES


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