

Preliminary Simulation for Thermal Flow Phenomena in a Large Pool of Passive Safety Systems Using CUPID Code

Minseok Choi^a, Seong-su Jeon^{a*}, Seok-jong Yun^b, Ji-su Kim^b

^aFNC Technology CO., LTD, Heungdeok IT Valley Bldg. 32F, 13, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 16954, Republic of Korea

^bKorea Hydro and Nuclear Power Central Research Institute, 70, Yuseong-daero 1312beon-gil, Yuseong-gu, Daejeon, Republic of Korea

*Corresponding author: ssjeon@fnctech.com

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1. Introduction

Advanced small modular reactors (SMRs) employ passive safety systems to ensure long-term core and containment cooling without active components or off-site power. In the i-SMR, the Passive Auxiliary Feedwater System (PAFS) and the Passive Containment Cooling System (PCCS) both reject heat to a common large water pool, the Emergency Cooling Tank (ECT), which functions as a heat sink and inventory during loss-of-coolant accidents.

Because the PAFS heat exchangers and PCCS inlet/outlet pipes are immersed in the same pool, complex three-dimensional phenomena such as natural convection and thermal stratification can affect system performance. Simultaneous operation of PAFS and PCCS therefore necessitates a detailed assessment of the thermal-hydraulic behavior in the ECT. Before simulating complex thermal flow phenomena in the i-SMR ECT, a conceptual problem was devised and a preliminary simulation of thermal flow behavior in a large passive safety pool was performed with the CUPID code.

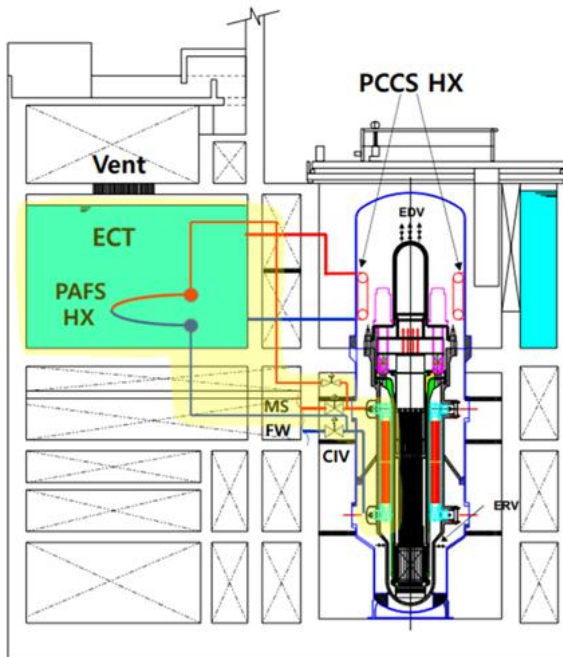


Fig. 1. Passive safety systems of i-SMR

2. CUPID Modeling of Large Pool

The CUPID code[1] is used as a three-dimensional two-phase finite-volume solver that solves the mass, momentum, and energy conservation equations for liquid and vapor. The large passive safety pool is idealized as a narrow rectangular tank that captures the key geometric and thermal-hydraulic features of the i-SMR ECT including the pool, the overlying atmosphere, and simplified representations of the PAFS heat exchangers and PCCS inlet/outlet connections. The PAFS heat exchanger region is modeled as an equivalent porous medium with a volumetric heat source, and the PCCS connections are represented as flow rate boundaries on opposite sides of the tank with prescribed mass flow and temperature boundary conditions, approximating the natural circulation operation.

Fig. 2 shows the computational mesh and boundary conditions. A structured hexahedral mesh discretizes the entire analysis domain. The adiabatic wall condition is applied bottom, back and side walls.

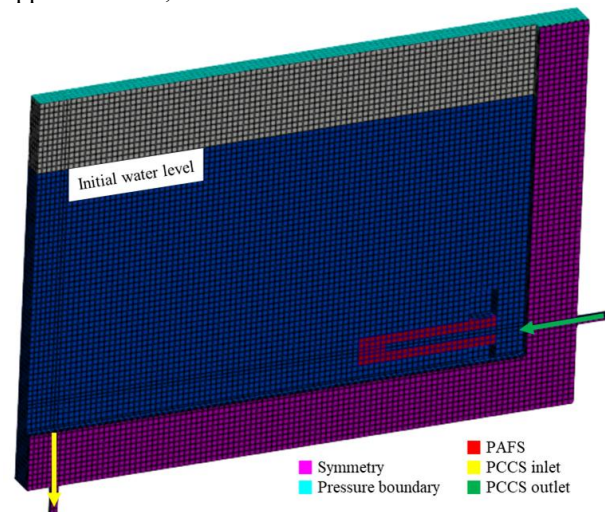


Fig. 2. Computational grid and boundary conditions

The pool is initially quiescent at a uniform subcooled temperature of 80 °C with a fixed water level, and during the transient, heat input through the PAFS region and hot-water injection from the PCCS outlet drive natural convection and stratification. The detailed CUPID models used for this research are summarized in table 1.

Table I: The list of applied model.

Items	Models
Interface Topology Map	Bubbly, mist and sharp interface[2][3]
Interfacial Heat Transfer	Ranz & Marshall[4]
Interfacial Drag Force	Linear model (User defined)
Turbulent Model	k-ε

3. Simulation Results

The CUPID simulation was performed for a transient in which heat is continuously supplied through the PAFS heat-exchanger region and hot water is injected from the PCCS outlet. The results indicate that buoyancy-driven natural convection develops in the pool and a circulation loop is established. Warm water generated near the PAFS region and the PCCS outlet rises along the side wall, impinges on the upper part of the pool, and then spreads horizontally, while cooler water in the lower region moves toward the PAFS and PCCS outlet, closing the recirculation. This behavior is clearly visible in the combined temperature and velocity fields, where an upward jet forms near the outlet and relatively slow return flow occupies the lower part of the pool.

Fig. 3 shows that the strongest motion occurs in the plume rising from the PCCS outlet, where the injected hot water accelerates upward and enhances thermal mixing in the upper part of the pool. Away from this plume, velocities are lower but still sufficient to sustain the global circulation and to transport heat laterally across the pool. Near the bottom, the flow is slower and more uniform, consistent with its role as the return path of the circulation loop. Overall, the conceptual CUPID model successfully reproduces key large-pool phenomena such as buoyant plumes, and natural circulation. The result provides a useful preliminary basis for extending the methodology to the full-scale i-SMR ECT.

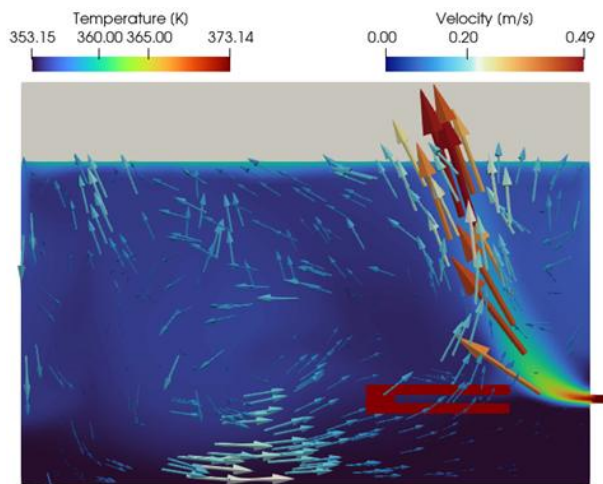


Fig. 3. The vector and temperature field of calculation result.

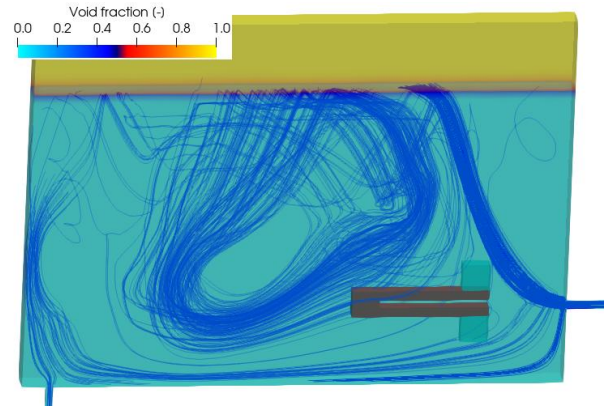


Fig. 4. The streamlines of calculation result.

4. Conclusion

A conceptual CUPID analysis was performed for a ideal pool representative of a large passive safety tank in the i-SMR. The simulation showed that buoyancy-driven circulation and plume formation are reasonably captured, while relatively cool water continues to feed the passive heat-removal components. These results indicate that the present CUPID modeling approach can reproduce key large-pool thermal flow features and provide a useful first step toward a more detailed methodology for the full-scale ECT.

ACKNOWLEDGEMENT

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