The Performance Evaluation of a Hot Water Layer using a Numerical Simulation

Jonghark Park,a Heetaek Chae,a Heonil Kim,a Byungjin Jun,a, Cheol Park,a
a Korea Atomic Energy Research Institute, Daedeokdaero 1045, Yuseong-gu, Deajeon, Korea
pjh@kaeri.re.kr, htchae@kaeri.re.kr, hkim@kaeri.re.kr, bjjun@kaeri.re.kr, cpark@kaeri.re.kr

1. Introduction

Most of all research reactors are immerged in the deep water pool to be a ultimate heat sink[1]. At the neighbor of the reactor, some radio-active matters, such as Na-24, Ar-41, Mg-27, Al-28 and etc, may be generated by the neutron irradiation. Those radio-active isotopes may rise up to the pool water surface through the natural convection flow, which can make the radioactivity in the reactor hall rise high enough to concern about the health of people working in the reactor hall. When the irradiation test facilities are loaded or unloaded during a normal operation, the highly radio-activated primary coolant may flow out through the irradiation test holes on the top of the reactor. This also may be a main hazard source to make the working environment of the reactor hall bad.

Making a hot water layer 1.5 ~ 2.0 m thick at the top of reactor pool would be a good measure to resolve that problem. The hot water layer is formed by a thermal stratification of pool water, which can effectively suppress the ascending of the radio-active matters and primary coolant flowing out from the IR holes.

In this study a performance evaluation of the hot water layer is conducted by a computational fluid dynamics technique. According to the results of the prediction the hot water layer is formed well about 1.5 m thick, and can suppress the flows containing radio-active matters ascending from the neighbor of the reactor.

2. Modeling for CFD Analysis

2.1 Geometry

To carry out the performance evaluation of the hot water layer, the reactor pool containing a reactor vessel is modeled as shown in Fig. 1. The dimension of the reactor pool is 9 m long, 4.5 m wide and 12 m deep. The 5.2 m tall reactor vessel is located on the bottom of the pool with 2.25 m distance from the adjacent walls. 8 nozzles for discharging of pool cooling water are located at the lower side of reactor vessel. 4 IR holes also are shown at the top of reactor vessel. The suction of the pool cooling water locates at 8.5 m above the pool bottom. 8 nozzles for hot water discharge/suction are located 0.5 m below from the pool surface.

2.2 Modeling set-up

In the computation model the water density in the pool was assumed as 994 kg/m^3 at 35°C. To simulate the natural convection and the thermal stratification, the buoyancy model was adopted. The reference pressure at

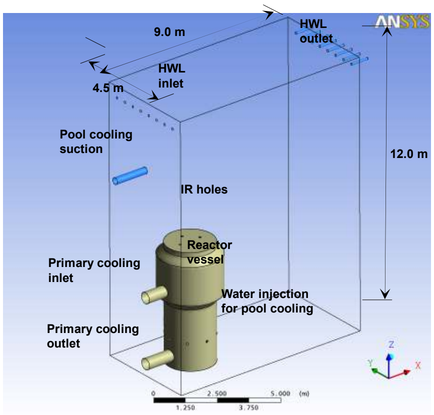

Figure 1. Schematic of a reactor and a reactor pool

the pool top was set as 1 atmospheric pressure. The pressure at the bottom would be almost 2 atmospheric pressures due to the hydrostatic head by the pool water.

The surface temperature of the reactor vessel is assumed as 58°C for conservative prediction. The hot surface would generate an ascending flow. The wall temperature of the pool is assumed to maintain at 35°C. For the hot water layer, the hot water of 50°C, 20 kg/s, is discharged from the 8 nozzles near the pool top. On the counter side of pool 8 other nozzles are provided to suck the water from the hot water layer. For pool cooling, 70 kg/s of water with 30°C is injected to the pool through the 8 nozzles on the low side wall of the reactor vessel. The same amount of pool water is suck out through the pool suction pipe located on the upper region of pool. The pool surface facing to the air is set as a free-slip wall with 600 W/m^2 of heat loss by the convection and the evaporation to the air of the reactor hall.

To simulate the core coolant flowing out from the IR holes, it was assumed that the flow rate from the IR holes would be 1 kg/s of 58°C water, and it includes suspended particles of 10 kg/m^3 mass concentration. Those would be spread out by diffusion and convection into the pool with time.

The k-ω based shear stress transport (SST) model[2] was adopted as a turbulence model. The convergence criteria of the iterative calculation is laid down when the normalized RMS residual values of all the equations for the momentum and mass conservation reach under 1×10^{-4} at each time step.

2.3 Solution Procedures

The aim of this study is to inquire out the development of the hot water layer by thermal stratification, and to evaluate the performance of hot water layer whether it can function well as we expects

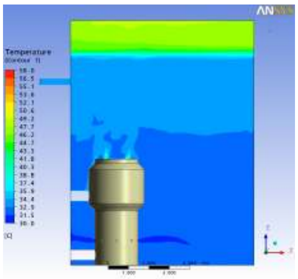

Figure 2. Thermal stratification in the reactor pool

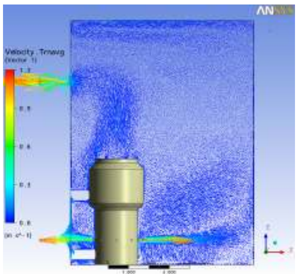

Figure 3. Flows in the reactor pool

or not. At first a steady state calculation without leak flow of primary coolant from the IR holes was done. The second calculation was a transient simulation to find out the flow behaviors of core coolant after flowing out from the IR holes. The steady state calculation result was used as the initial condition of transient calculation. The very moment of core coolant flow out from the IR holes was set as an initial time 0 second.

The time step for transient simulation was set 0.05 second in early stage after the calculation started, and then it was increased more and more to 1 second. Total simulation time was 2 hours. The transient calculation simulated the flow behaviors during that period.

3. Simulation Results and Discussions

Figure 2 shows the temperature distribution in the reactor pool. The pool water is thermally stratified with its temperature. It can be seen that the hot water layer about 1.2 m thick is well developed at the pool top. CFD analysis predicts that the hot water layer can keep the temperature of 7°C ~ 10°C higher than the bulk pool water. In case of HANARO in KAERI, it was 5°C. As the temperature of hot water layer becomes high, evaporation to the reactor building increases and also the heat loss, the hot water layer temperature may have to be decreased to about 5°C differences like HANARO.

To understand a flow stream in the water pool, velocity vectors are shown in figure 3. The primary coolant flowing out from the IR holes on the top of the reactor vessel moves upward by natural circulation flow from the reactor vessel surface, but most of the floating coolant is suppressed below the hot water layer. This is sucked at the upper side of pool.

The behavior of the small amount of primary coolant running out from the IR holes is shown in figure 4. It rises up and is sucked out through the pool water suction pipe, but not reach to the pool top by passing

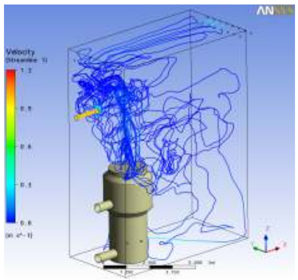

Figure 4. Flow behaviors of primary coolant flowing out from the IR holes of the reactor vessel top

through the hot water layer.

During on-power loading or unloading of irradiation facilities, highly radiated core coolant may rise to the pool top. Figure 5 shows how the primary coolant from IR holes spreads through the reactor pool with time. The iso-surfaces in the figure mean the same mass concentration per unit volume. The mass concentration of the iso-surface is 0.05 kg/m^3 (5% of the maximum value). As you can see in the figure, it seems that the flow is substantially stabilized in 45 minutes after the first inflow of the primary coolant flowing out from the IR holes to the pool. The primary coolant from IR holes rise upward, but it can not penetrate the hot water layer and seems to be suppressed below the hot water layer.

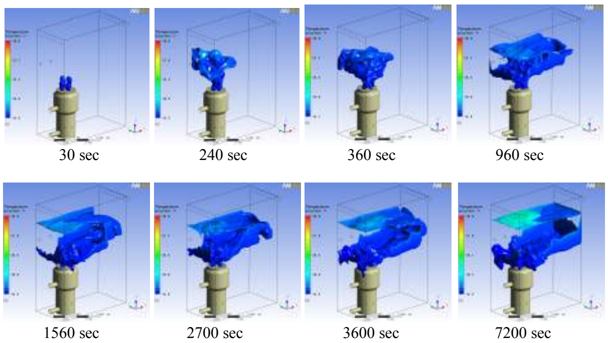

Figure 5. Diffusion and convection of primary coolant flowing out from the IR holes

4. Conclusions

In the prediction results, about a 1.2m ~1.5m thick hot water layer is developed by a thermal stratification at the pool top. During on-power loading/unloading of irradiation facilities, highly radiated primary coolant may flow out to the pool and rise to the pool top. But it is expected that the rising core coolant flowing out from the IR holes can not reach to the pool water surface by the hot water layer. Therefore the hot water layer must be installed in order to maintain the reactor hall radiation low enough for workers

REFERENCES

[1] HANARO SAR, KAERI/TR-710/96, 1996.
[2] ANSYS CFX-11 Solver modeling guide, ANSYS Inc. 2006.