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Effect of Primary Cooling Water on the Hot Water Layer of a Reactor Pool

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1. Introduction

Many research reactors, including HANARO [1], have a hot water layer to reduce the radioactivity level in a pool top area. The hot water layer can keep down the ascending of radio-active matters generated nearby the reactor by the neutron irradiation. The hot water layer is a stratified water layer about 5 ~ 10°C hotter than the lower pool water [2]. The flow in the reactor pool become fierce, the hot water layer may be broken or become thinner due to vigorous mixing between the hot water layer and the pool water. Large amount of cooling water directly dumped into the reactor pool makes the stable water pool move violently that can have a serious effect on the hot water layer. Thus, the preliminary investigation is required to figure out the mass flow dump effect on the hot water layer.

The reactor pool is so gigantic that it is hard to conduct this study by an experimental method, whereas CFD method is relatively easy to simulate even such a very large structure. In this paper when a mass flow of cooling water is dumped into the reactor pool, flow behaviors of pool water are studied by CFD method.

2. Modeling and Computation

In order to establish a computational model for CFD analysis, a simplified geometric model, a reactor immerged in a pool, is prepared as shown in Fig. 1.

The height of a reactor pool is about 11 m. Top end of upper guide structure (hereafter UGS), sucking water from the pool is at an elevation of about 4.8 m from the pool bottom. Because large amount injection of cooling water leads to be in a mess, an injection header is employed to make its effect as small as possible. The circular shape injection header located on near the pool bottom has many exhaust holes along the center line. The direction of exhaust holes is changed from upward to downward to find out its effect.

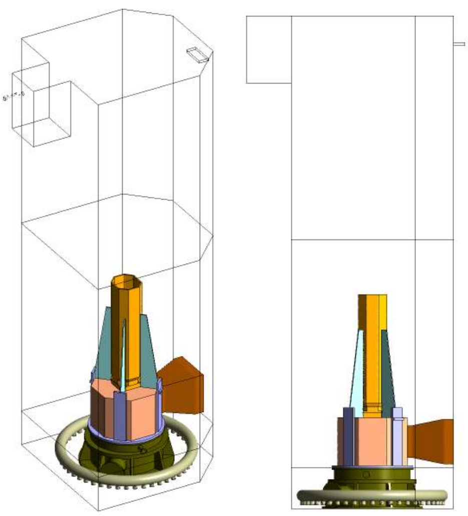


Fig. 1. Geometric model for CFD analysis.

The conditions of the pool dumped water flow rate are 70 kg/s, 153 kg/s and 306 kg/s. The temperature of water dumped into the pool is set as 35°C.

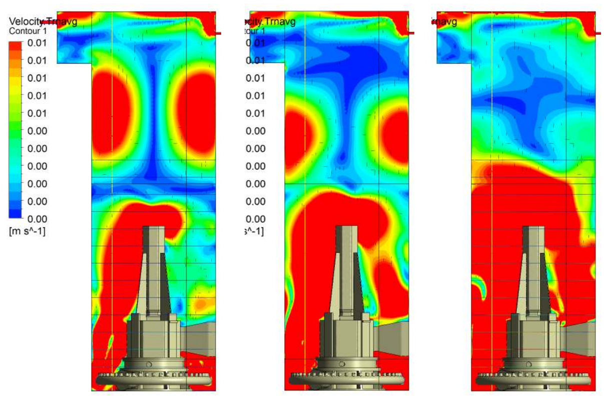
In order to develop a hot water layer on the upper area of the pool, 2.5 kg/s of hot water with 45°C is injected from a one side wall of the pool, and sucked from the opposite wall. The pool top surface and pool walls are specified as an adiabatic condition to easily meet the energy balance in the computational domain.

In order to simulate the turbulence effect, the k-ω based shear stress transport (SST) model is employed. The convergence criteria of the iterative calculation is specified as the normalized RMS residual values of all equations fall below 1×10^{-4} at every time step.

Pre-calculation was conducted on the steady state condition to be used as an initial condition of the unsteady calculation for an hour of simulation time. All results are obtained by time averaging for a simulation time.

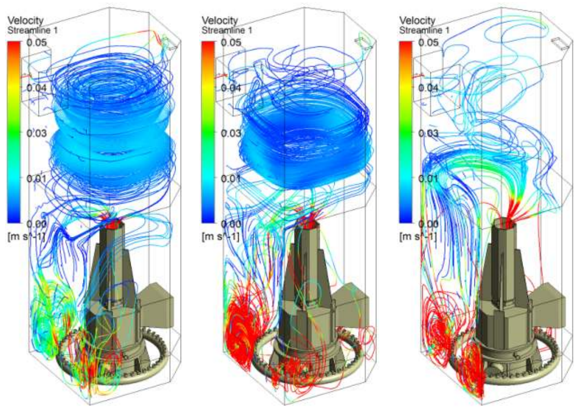
3. Results and Discussions

Fig. 2 shows the flow rate effect of the pool dumped primary cooling water that is exhausted upward from the injection header. Dumped water from the header goes up toward the top of USG where the cooling water is sucked into the reactor core. The velocity contours in the Fig. 2 mean the area where is directly influenced by



(a) 70 kg/s (b) 153 kg/s (c) 306 kg/s

Fig. 2. Velocity distribution in the reactor pool (0 - 0.01 m/s, upward injection)



(a) 70 kg/s (b) 153 kg/s (c) 306 kg/s
Fig. 3. Streamlines at upper region of reactor pool

the primary cooling water dumped into the pool. For 70 kg/s of flow rate, the pool dumped flow seems to reach about 5.4 m from the pool bottom. For 153 kg/s and 304 kg/s, it rises up to about 5.8 m and 6.7 m, respectively. Increase of flow rate results in area extension to be affected by the pool dumped flow as expected.

At low flow rate of 70 kg/s and 153 kg/s, a fair of flow fields are seen at the upper side of pool. In order to figure out the flow field, streamlines are depicted near the above of the reactor as shown in Fig. 3. According to this figures, those flow fields are turned out a whirlpool. This is very similar to the flow pattern to be seen in the vicinity of a drain hole, which accounts for the reason why the whirlpool is generated on the top side of UGS. The effect of the whirlpool on the mixing and diffusion between the hot water layer and the lower pool side cannot be accounted for up to now.

As previously mentioned, 2.5 kg/s of hot water with 45°C is infused into the pool top area to generate a hot water layer by thermal stratification. Fig. 4 shows the temperature of pool water at a center cross-section. It can be seen that the temperature boundary moves up with increase of flow rate, because the influenced area of pool dumped flow extends toward the upper side of pool with the flow rate. This movement of temperature boundary up to pool top area shortens the distance from the lower pool area to the pool top surface, which may results in the increase of radioactivity at the pool top the

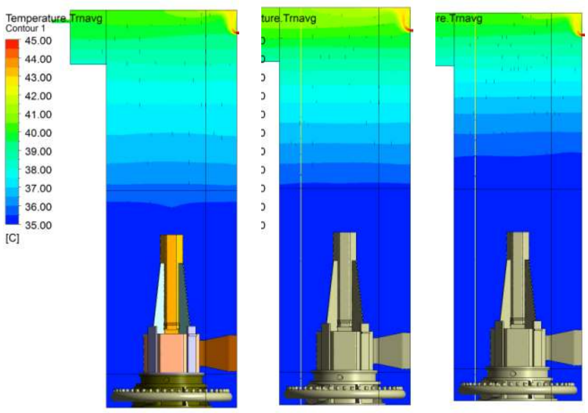


Fig. 4. Temperature distribution in the reactor pool for upward injection.

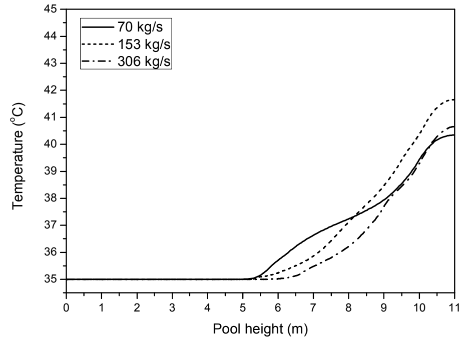


Fig. 5. Temperature variation from pool bottom to top surface

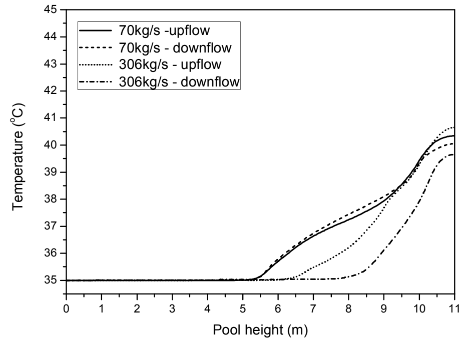


Fig. 6. Effect of the injection direction of pool dumped water

lower pool area to the pool top surface, which may results in the increase of radioactivity at the pool top surface. The temperature variation from the pool bottom to top surface is drawn in the graph of Fig. 5.

If the direction of header exhaust holes is changed to bottom side, there seems to be a notable change of pool dumped flow behaviors. The temperature boundary goes up much higher than that of the upward injection case as shown in Fig.6. This is an opposite result than we expected. It can be seen that the temperature boundary goes up to 9 m from the pool bottom for downward injection of 304 kg/s. This is because the injected water bounces off the pool bottom and ascends along the pool wall without suction effect by the UGS. Consequently pool water injection toward the pool bottom makes the hot water layer thin.

4. Conclusions

The effect of primary cooling water flow dumped into the pool on the hot water layer and flow behaviors is studied by CFD method. The hot water layer thickness is reduced as the pool dumped flow rate increases. Thin hot water layer may lead to the increase of radioactivity at pool top surface. If the pool dumped flow is exhausted toward the pool bottom, the hot water thickness become thinner than that of upward exhausting.

REFERENCES

[1] HANARO SAR, KAERI/TR-710/96, 1996.
[2] Jongharh Park et al, The performance Evaluation of a Hot Water Layer using a Numerical Simulation, 2009 KNS Spring Meeting, 2009.