Simulation of Flow Behavior in the HANARO Reactor Pool by Using the MARS Code

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Abstract

In the HANARO, around 10% of the primary cooling flow rate is fed into the reactor pool through a bypass line and returned to the primary cooling system through a chimney. From operational and safety view points, an understanding of the 3-D flow characteristics in the reactor pool due to the bypass flow is necessary. Here, the 3-D flow behaviour in the HANARO reactor pool was reviewed and simulated by using the 3-D model of the MARS code which was applied to the thermal hydraulic analysis of the HANARO.

1. Introduction

The HANARO (High Flux Advanced Neutron Application Reactor) is an open-tank-in-pool type research reactor with 30 MWth [1], and the reactor structure is submerged in a large cylindrical pool of 4 m in a diameter and 12.2 m in depth. Fig. 1 shows the schematics of the primary cooling system (PCS) of the HANARO. At a normal operation, the core heat is removed by a forced convection cooling through two pumps and two heat exchangers. 90% of the total PCS flow passing the core meets 10% of the downward bypass flow at the lower part of the chimney and flows to the pumps

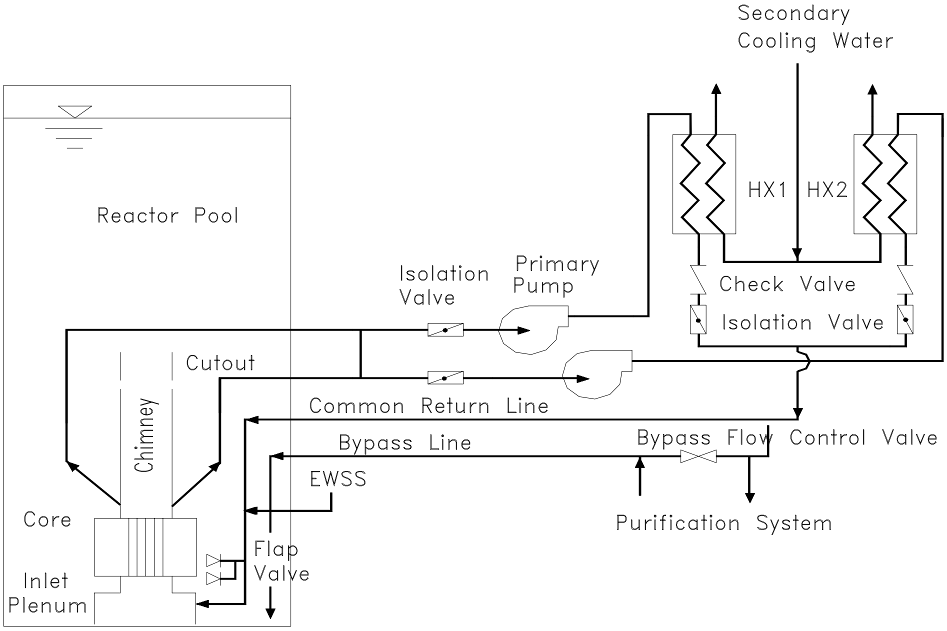


Fig. 1 A schematic Diagram of HANARO Primary Cooling System

through two chimney outlet nozzles. The main function of the bypass flow is to prevent the core flow containing the activated N^{16} and other radioactivity from escaping out of chimney to the pool and to cool the pool water as well. At the top of the reactor pool, a hot water layer (HWL) is formed to prevent the activated pool water from reaching the pool surface. During a reactor shutdown, the core decay heat is removed by a natural circulation by a gravity driven recirculating flow via flap valves inside the pool or by the primary cooling system with the same path as that of the forced convection flow.

For a safe design and operation of research reactors, we often need to fully understand the 3-D flow characteristics in some locations. Major concerned areas for 3-D flow behaviours in the PCS of the HANARO are; 1) inlet plenum where a vortex, a possible cause of a fuel wearing, is generated, 2) chimney inside where the upward core jet flow is suppressed, and 3) reactor pool where the bypass flow may rises up to the pool surface, which is related to the radiation level near a working place.

On the other hand, it is generally said that no robust computer codes such as RELAP5, RETRAN, and MARS are available for the analysis of research reactors, and these computer codes are recommended to be applied carefully to a specific research reactor after assessing the applicability. The MARS code [2] is a realistic system transient analysis code that can be used for the simulation of a wide variety of PWR system transients. This code is a unified version of 1-D reactor system analysis code, RELAP5/MOD3 and a 3-D reactor vessel analysis code, COBRA-TF coupled with a 3-D reactor kinetics code, MASTER and a containment code, CONTEMPT4. The MARS code is being used for the analysis of the HANARO through some modifications and assessment calculations [3].

In this paper, the 3-D flow behaviour in the HANARO reactor pool was reviewed and simulated by using the 3-D model of the MARS code from the practical analysis view point.

2. Flow behavior in the HANARO Reactor Pool

2.1. Estimation from measurements

During the commissioning tests, it was confirmed by the experiments that the core jet flow passing the core was suppressed within the chimney if the bypass flow was larger than 5% of the total PCS flow [4, 5]. Nevertheless, the radiation level at the pool surface was much higher than that calculated for the design. One of the reasons was rising up of some bypass flow to near the pool surface, which was not expected in the design. Hence, in order to reduce a pool surface radiation level, a hot water layer (HWL) system was installed together with other necessary measures which were found to have effect on the pool water flow behaviour.

Fig. 2 shows the temperature and the Na-24 activity distributions in the reactor pool with the operation of the HWL system, which were measured at 7 hours operation of the HANARO. The reason of Na-24 measurement is that most of the radioactivity in the pool water was revealed to be from Na-24 (around 60%). Fig. 2 shows that the thickness of the HWL is around 1.2 m and there are 3 regions with different temperatures. It is thought from the firgure that most of the bypass flow is sucked into the chimney near the chimney top level. Horizontal distribution of Na-24 activity measured at 3 m and 6 m below the pool surface is shown in Fig. 3. Up to 3m, the activity is similar with each other, while there appear some different distributions at 6m. It implies that there may be an asymmetric flow below this depth.

From the thermal hydraulic aspect, the temperature distribution due to 3-D flow characteristics can affect the analysis results such as the establishment of a natural circulation flow and the corresponding core thermal margin. The effect, however, might generally be very small in a pool type research reactor. Anyhow, a 1-D analysis has some limitations in dealing with a 3-D flow behavior like this. So, the results by measurements or 3-D analyses should be reflected in a 1-D analysis in order to give more accurate predictions.

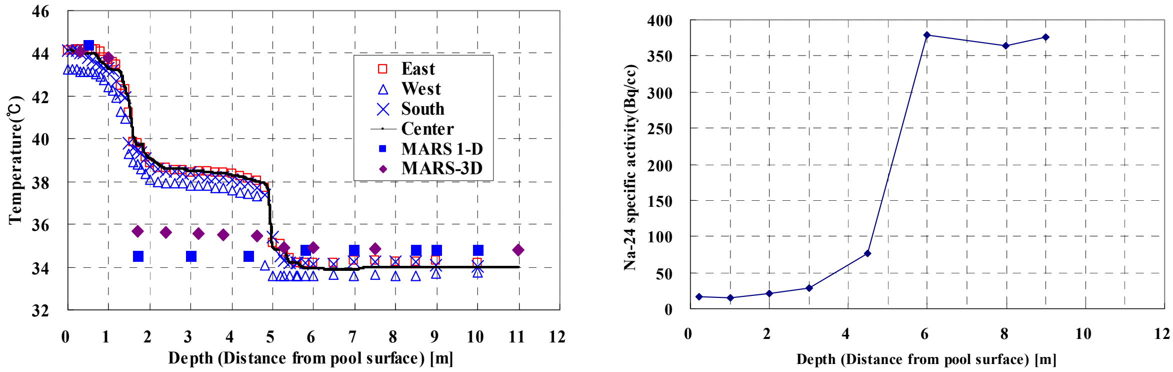


Fig. 2 Temperature and Na-24 Activity Distributions in the HANARO Reactor Pool

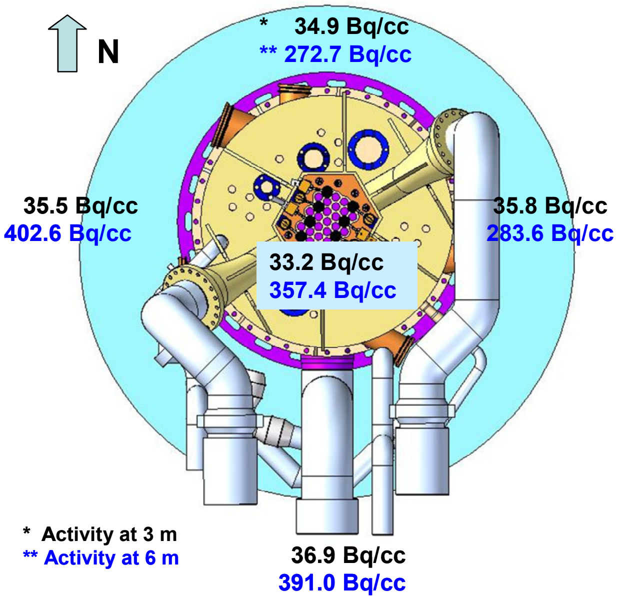


Fig. 3 Na-24 Activity Distributions at 3m and 6m below the Reactor Pool

2.2. CFD simulation results

Flow behaviour in the HANARO reactor pool was predicted by a commercial CFD code [6]. The total number of cells used in the calculation was 17,620 and the result was judged to be converged because the result was the same for the larger cell numbers of 28,600. The flow split at the end of the bypass line was assumed to be 1 vs 1.5.

The prediction results of Fig. 3 showed that most of the bypass flow is sucked into the chimney near the chimney top level but some of the outer circulating flow upwards to the pool surface. As shown in a figure (middle) depicting an iso-surface with a 0.1 m/s upward velocity, a counter clockwise circulating flow exists in the entire reactor pool if one looks into the pool from the top. It may be caused by an unsymmetrical pouring of the bypass flow into the bottom of the reactor pool. A large swirl flow rises up slowly toward the pool surface, but it soon turns downward again at near the bottom of the hot water layer and then it flows downward to the core through the chimney. The hot water layer (HWL) is well maintained and the temperature distribution in the pool also the similar pattern to that of the measurements in Fig. 4.

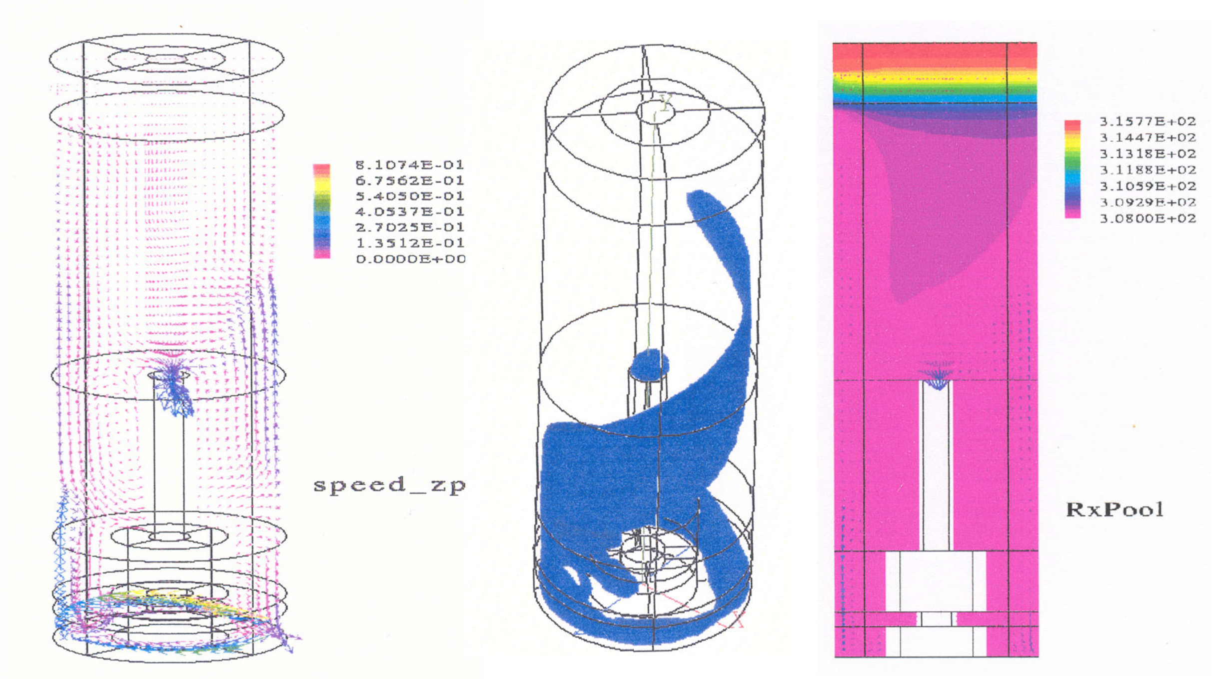


Fig. 4 Flow Behaviors in the HANARO Reactor Pool

3. MARS simulation of flow behavior in the HANARO reactor pool

3.1. Modeling

The 3-dimensional flow behaviours in the HANARO reactor pool described above were simulated by using the 3-D model of the MARS code in order to inquire into the applicability of the MARS code to such a case. The nodalization of the HANARO reactor pool and systems for the MARS simulation is shown in Fig. 5. The reactor pool was modelled by the multi-dimensional model of the MARS code. The number of Z, R, and θcells are 19, 8 and 8, respectively. So, the total number of volumes for the reactor pool is 1216, which is about 1/15 of that of the CFD analysis. It is noted that the number of nodes is limited in the MARS code. The reactor assembly was modelled as a 1-D part. The reactor pool surface is connected to a time dependant volume as a boundary condition of the atmosphere, and the depth of the hot water layer was assumed to be 1.3m. Other components such as the piping, pumps and heat exchangers were modelled with proper components in the code.

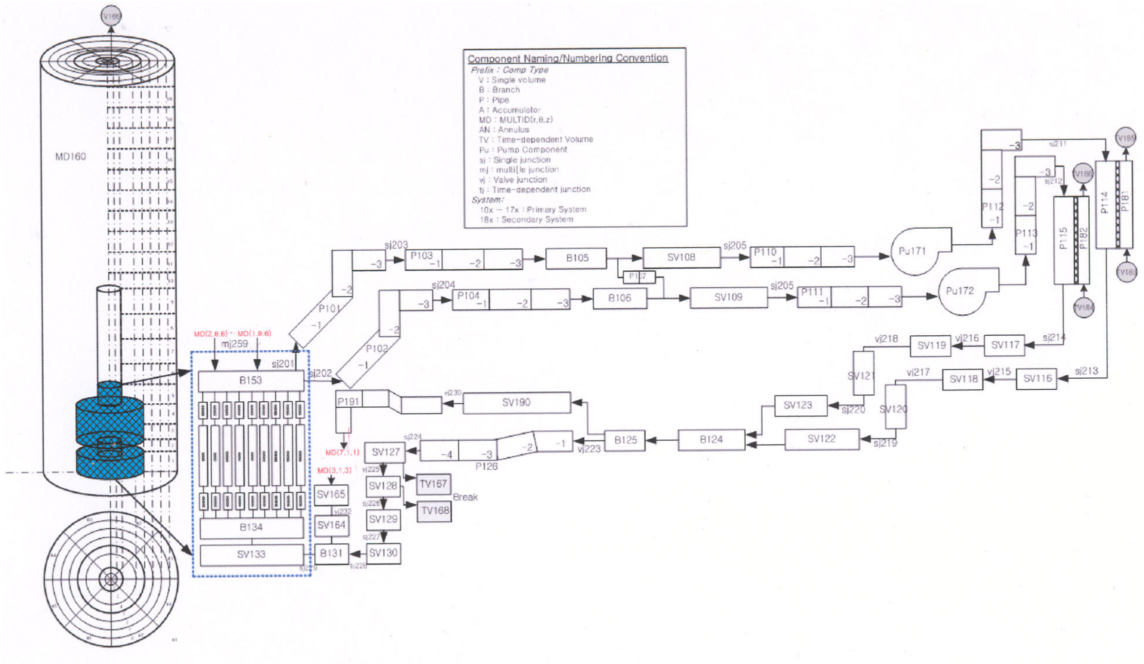


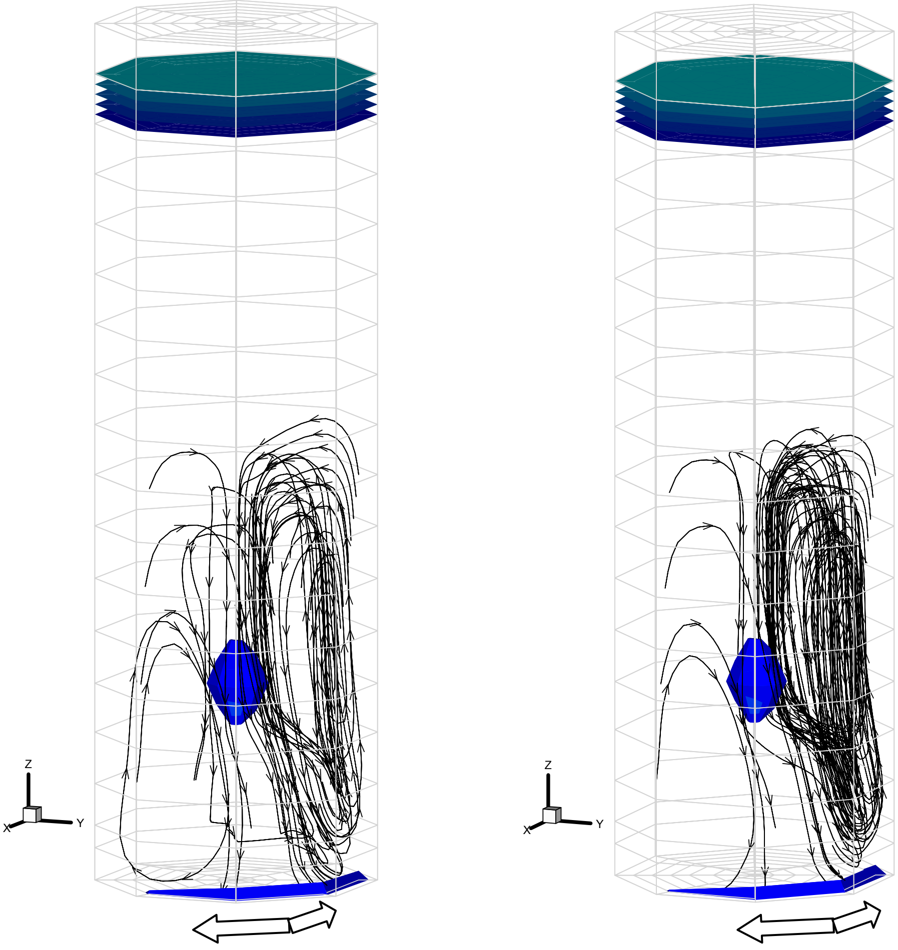
Fig. 5 Nodalization of the Reactor Pool and the System of the HANARO

3.2. Simulation results

Firstly, a measurement condition described in section 2.1 was simulated by using the MARS code with a typical 1-D nodalization for the reactor pool for comparison. The result showed that almost bypass flow was sucked into the chimney near its top and the pool water above it was almost stagnant. So, the temperature distribution, as shown in Fig. 2, indicated that the middle temperature region due to local mixing of the HWL and the pool water beneath it was not predicted because 1-D nodalization could not properly done to deal with the mixing of hot water layer and the pool water.

The flow behavior calculated by the MARS code with the 3-D nodalization of Fig. 5 is shown in Fig. 6. It shows the streamline which flows into the chimney. Less flows into the chimney in left side implies that the upward flow is more than the right side. It may cause the unsymmetric distribution of Na-24 activity below 6 m in the reactor pool. Although a very weak large circulating flow along the pool liner was predicted in the code, it is not clearly shown in the figure because the upward flow is calculated to be much more than the swirl flow and is predicted to be the dominant flow. In this calculation, the temperature distribution at the reactor pool, as shown in Fig. 2, indicates that the temperature between HWL and the chimney is increased a little comparining the result by 1-D, which means that a flow mixing in the 3-D appears more than in the 1-D calculation.

The flow pattern was not that affected by the different ration of the flow split. When comparing MARS results with the CFD results, the circulating flow is weaker than that by CFX. It may be caused by the relatively longer axial (Z) node than the radial (R) and the azimuthal (θ) nodes, and the 1D biased solution method of the code. It is noted that the MARS code provides information at a volume center, while the CFD code provides information at a volume surface.



(a)1.5:1 (b)2:1

Fig. 6 Flow Behavior Predicted by the MARS Code

4. Concluding Remarks

Through the measurements and CFD analysis on the 3-D flow pattern in the HANARO reactor pool, it was concluded that the most of the bypass flow, even if it showed asymtric flow pattern below chimney top, was sucked into the chimney near the chimney top level. And a part flows upwards to the pool surface and returns downwards near the bottom of the HWL which plays its role to prevent the rising of the activated pool water.

The 3-D behaviour in the HANARO reactor pool has been simulated by using the 3-D model of the MARS code. It is noted thta this calculation was done from a practical aspect, not from a safety aspect. The results showed a possibility that the MARS code can provide reasonable predictions for the 3-D flow behaviour in the HANARO pool. For a practical calculation with 1-D nodlaization, the flow behavior should be considered in the nodalization.

This capability for a 3-D calculation in an accident analysis codes may be useful to predict the effect of 3D flow phenomena on a core thermal margin during a flow reversal transient in research reactors and the establishment of a natural circulation cooling flow as well, from the practical poinit of view.

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