Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Assessment of a Cryogenic Cooling System Malfunctioning Accident in a CNS

Jonghark Park,a Kyehong Lee, b Donggil Hwang, c
a *KAERI, Research Reactor Analysis Dept., pjh@kaeri.re.kr*
b *KAERI, Dept. of CNS Design and Safety Analysis, khlee@kaeri.re.kr*
c *Decon Engineering, donggil@kaeri.re.kr*

1. Introduction

Hydrogen as a moderator for a cold neutron source is cooled by cryogenic helium gas supplied from a helium refrigerator to make a thermo-siphon loop. If the helium refrigerator can not supply cryogenic helium gas to a moderator cell, the Cold Neutron Source(CNS) can operate no more. While HANARO operates normally, the temperature of the moderator cell made of aluminum will rise by the nuclear heat generation. The temperature of the moderator cell has to be maintained below 150°C, because the material property of aluminum changes above 150°C. So the measures against it are needed to make sure of the safety of the CNS.

It has been considered that the vacuum chamber which is a pressure boundary of an in-pool assembly of the CNS is filled with helium gas when the helium refrigerator is in a malfunctioning condition. The in-pool assembly has a temperature gradient in the longitudinal direction due to the local distribution of nuclear heat generation. The longitudinal temperature gradient of the in-pool assembly may generate the natural circulation of helium gas in the vacuum chamber, which is expected to cool down the in-pool assembly.

A thermal analysis is required to make sure that only the natural circulation of helium gas can maintain the temperature of the moderator cell below 150°C during a HANARO operation. In this study, a 3-dimensional thermal analysis is conducted to establish the feasibility of this idea using a commercial CFD code, CFX-5.7.

2. Modeling and Boundary Condition

Figure 1 shows the in-pool assembly including the moderator cell, a transfer tube and a shell and tube type heat exchanger equipped in a vacuum chamber. The in-pool assembly has a very complex geometry which makes a mesh generation very difficult and it requires massive computational meshes.

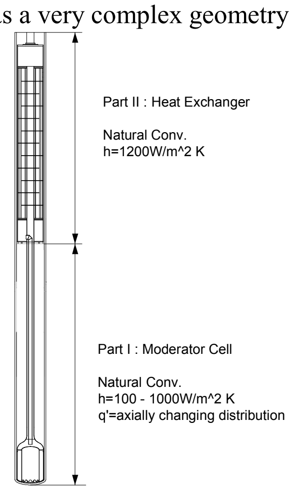


Figure. 1 Schematic of in-pool assembly

The vacuum chamber with a diameter ∅156mm will be installed in a diameter ∅160mm CN irradiation hole. There a 2mm thick light water film between the vacuum chamber and the wall of the CN irradiation hole is located. The CN irradiation hole has five ∅30mm holes, four of them at the lower side wall and one at upper side wall where the reactor pool water flows. To estimate a convective heat transfer coefficient as a boundary condition for the outside of the vacuum chamber, the following equations are employed. It is assumed that the outside surface temperature of the vacuum chamber is 80°C.

$$Nu = 0.10(Gr\,\mathrm{Pr})^{1/3} \quad (1)$$

$$Nu = \left[0.825 + \frac{0.387 Ra^{1/6}}{\left[1+(0.492/\mathrm{Pr})^{9/16}\right]^{8/27}}\right]^2 \quad (2)$$

where

$$Gr = \frac{g\beta(T_w - T_\infty)L^3}{\nu^2}, \quad Ra = Gr\,\mathrm{Pr}$$

Obtained convective heat transfer coefficient by Eq. (1), (2) are 1002W/m^{2}K and 1288W/m^{2}K, respectively. A lower value is taken as a conservative one. From this estimation, the vacuum chamber outside surface has a convective heat transfer coefficient distribution, linearly increasing from the bottom to the top in the range of 100W/m^{2}K to 1000W/m^{2}K.

3. Analysis Results

3.1. step 1 : conduction model

The conduction model means that all heat released from the in-pool assembly is cooled down by only a conduction heat transfer through the gas layers of helium and hydrogen to the outside of the vacuum chamber cooled by the reactor pool water.

Figure 2 shows the temperature distribution of the in-pool assembly including vacuum chamber when HANARO is normally operated at 30MWt. The temperature contour appears in an order which seems like a solid temperature contour by only considering conduction effect. The maximum temperature reaches about 950°C which is located on the inner shell of the moderator cell. The outer shell of the moderator cell also has a very high temperature in the range of 850°C to 650°C which considerably exceeds the melting point of aluminum, 600°C. On the contrary the temperature of the heat exchanger is no more than 80°C due to the lower heat penetration there.

3.2. step 2 : natural circulation model

To find a temperature changes with various the HANARO operation powers, the CFD analyses is performed for four cases, 100%, 50%, 25% and 10% of a full power. Nuclear heat generation rate of the in-pool assembly and a local distribution are obtained by the MCNP code analysis[1] for only a full power. Nuclear heat generation rates of the other cases are obtained from assuming that the nuclear heat generation rate is linearly proportional to the reactor power.

From the CFD analysis results, the temperature distribution of the in-pool assembly is shown in Fig. 3. The maximum temperature is located on the inner shell regardless of the change of the reactor power because it has the maximum heat generation rate and the hydrogen gas trapped inside it, hardly cooled due to a very low heat transfer rate.

The estimated maximum temperature of the moderator cell with a change of the reactor power is graphed in Fig. 4. When the reactor power is 50% of a full power, the maximum temperature is expected to reaches about 390°C, and 220°C at a 25% power, and 100°C at a 10% power. These CFD prediction show that it is hard to maintain the moderator cell temperature below 150°C just by a natural circulation cooling of the helium gas except for a very low power.

Figure 4 shows the helium gas flow field in the vacuum chamber. At a high power (100%, 50%), the helium gas flow around the transfer tube is very active, but around the moderator cell it is weak because the helium gas is heated and rises before reaching the lower side of the moderator cell. When the reactor power becomes low, the descending helium gas penetrates into the bottom side and rises up by the buoyancy. So the flow around the moderator cell looks like more active at a low power.

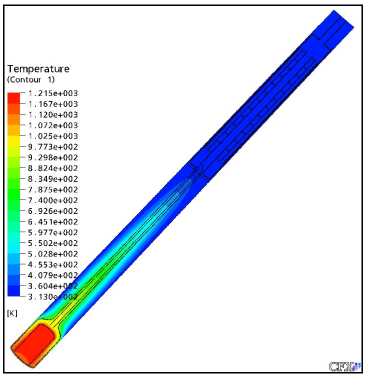


Figure 2. Temperature distribution of conduction model

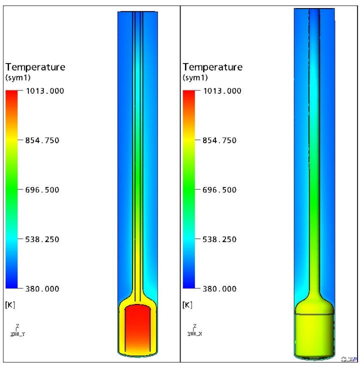


Figure 3. Temperature distribution with HANARO normal operation power(30MWt)

4. Conclusions

Helium gas injection into the vacuum chamber to cause a natural convection for a cooling has been considered as the measures of the abnormal condition when cryogenic helium gas cannot be supplied to the heat exchanger of the CNS for the reason of a helium refrigerator malfunction. CFD method is employed to establish the feasibility of this idea. The prediction results of the CFD analysis suggest that it is impossible to maintain the moderator cell temperature below 150°C only with a natural circulation of helium gas in the vacuum chamber during a HANARO operation. If reactor was to be operated at a low power at less than 10% of the full power, the moderator cell could not exceed the temperature criteria of aluminum. As a consequence, emergency measures must be considered when the hydrogen in the moderator cell is not being cooled by cryogenic helium gas due to a helium refrigerator malfunction.

References

[1] Conceptual Design of the Cold Neutron Research Facility in HANARO, pp. 34-40, HAN-DD-RD-030-04-001, 2004.

Acknowledgement

This research has been carried out as a part of the nuclear R&D program funded by the Ministry of Science and Technology in Korea.

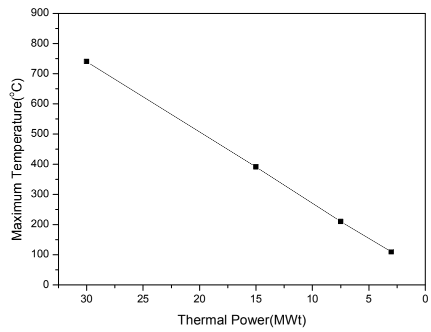
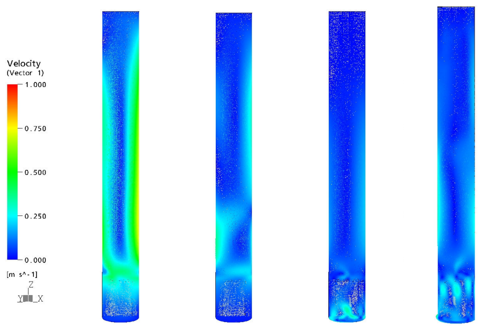


Figure 4. Maximum temperature change with various HANARO operation power



(a) 100% (b) 50% (c) 25% (d) 10%

Figure 5. Velocity vectors distribution in vacuum chamber (helium gas filled region)