Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Effect on the HANARO CNS under a HRS Malfunction

Jungwoon Choi, Dong-gil Hwang*, Kye Hong Lee, and Hark Rho Kim
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseng-gu, Daejeon 305-353, Korea
**GNEC, 150 Deokjin-dong, Yuseng-gu, Daejeon 305-353, Korea*
ex-jwchoi@kaeri.re.kr

1. Introduction

Owing to national research demands on a cold neutron beam utilization [1], the Cold Neutron Research Facility project has been carried out since July 2003 and is now at the completion stage of the detail design for the HANARO cold neutron source. The cold neutron source (CNS) facility, one of the main parts of the CNRF, includes the in-pool assembly (IPA) and related systems to moderate thermal neutrons through a cryogenic moderator, liquid hydrogen, into cold neutrons with the generation of a nuclear heat load, about 500 W. In order to acquire the information about the IPA integrity under a helium refrigeration system (HRS) malfunction, a thermo-siphon mock-up test has been performed using liquid hydrogen as a working fluid. Of the pressure and temperature in the IPA, the experimental results are reported in this paper to determine whether the integrity of the IPA is maintained under an abnormal condition.

2. Malfunction of the helium refrigeration system

During a normal operation of the CNS as well as the reactor, the two-phase thermo-siphon is no longer working properly if the HRS has a malfunction, because the evaporated hydrogen by the heat load breaks the balance with the liquefied hydrogen at the heat exchanger. In this case, the hydrogen pressure rises because the reactor is still running under a normal operation. Even though all the liquid in the moderator cell evaporates, the temperature of the moderator cell is increasing continuously by the applied heat load. If the reactor does not shut down at this time, the temperature of the moderator cell, Al 6061-T6, will exceed the phase transition temperature, 423 K, of the aluminum alloy [1]; accordingly, the integrity of the moderator cell is no longer sound. To avoid such a situation, the pressure and temperature behaviors in the IPA should be checked in a thermo-siphon mock-up test under the assumed conditions as follows: firstly, sudden stop of the helium compressor and turbo-expander caused by the loss of electric power, the break down of its component, or the shortage of the cooling water or compressed air; lastly, the vacuum loss in the cold box through an intrusion of air. These situations are simulated in the mock-up test by cutting off the helium flow into the heat exchanger for the 1st case and by injecting nitrogen gas into the cold box for the 2nd case.

3. Experimental facility

The full scaled mock-up test facility is manufactured for the thermo-siphon test in terms of the same geometry of the IPA. In addition, the test is performed under as same operating condition in the hydrogen system, approx. 22K at 152 kPa(a) at the cold state and the room temperature at 305 kPa(a), as well as the vacuum system, below $1x10^{-5}$ torr, as the HANARO CNS. In order to simulate the nuclear heat load on the moderator cell, two types of heaters are installed in the moderator and moderator cell: the cartridge type for granting the heat load in the liquid hydrogen and the Ni wire type in the outer surface of the moderator cell and its cavity. Moreover, the instruments are installed in the facility to acquire the values of the operating parameters in the IPA such as a silicone diode, a pressure transmitter with the accuracy of a 1% full range, and a vacuum gauge. Of the total eight temperature sensors with an accuracy of ± 1K, four are installed in the inner and outer moderator cell and another four are in the heat exchanger. The helium refrigeration system (Cryogenic Plants and Service, model 1620 refrigerator) produces the cooling power with a maximum 540 W without a liquid nitrogen pre-cooling.

4. Results and discussions

4.1. Sudden breakdown of the compressor or turbine

When the heat load applied by the heaters is 422W in the moderator cell, the helium flow is diverted to the heat exchanger. The pressure and temperature behaviors are shown in Figure 1. For approx. 2 min from the point of a helium flow interruption (pointed out with an arrow in the figure), the temperature of the moderator cell remains constant at the cold normal operation temperature because the applied heat load compensates for the latent heat of the liquid hydrogen by an evaporation. Then, the temperature of the moderator cell increases as the time elapses. After 9 min from that point, the hydrogen pressure approaches almost the warm normal operation condition. However, the hydrogen pressure can not reach over 305 kPa(a) during the full experiment time since the heated gas, transferred into the buffer tank, becomes the warm gas by the heat transfer to the buffer tank gas although the hydrogen gas heated by the heat load contributes locally to an increase in the pressure of the IPA. The high pressure set point of the hydrogen system that was determined at 400 kPa(a) for protecting the integrity of CNS against the abnormal condition has been necessarily decreased to 200 kPa(a) based on the experimental results. This new set point considered by the operation margin is fixed at a value at the time when no liquid hydrogen exists in the moderator cell so the hydrogen gas temperature is about to increase.

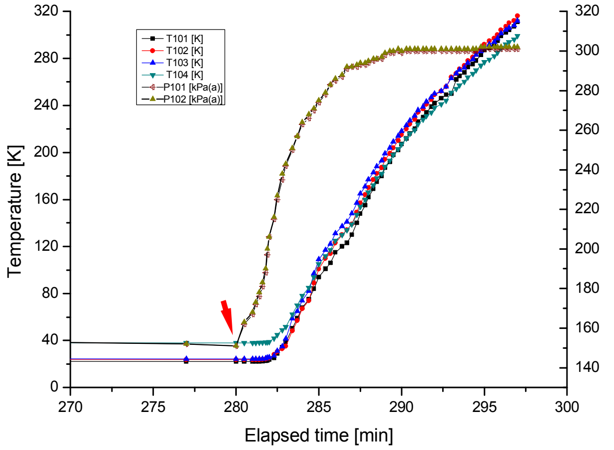

Figure 1. Operating parameter profiles under the breakdown of turbine expander of compressor

4.2. Vacuum loss in the cold box

The hydrogen pressure behaviors represented in Figure 2 along the deteriorated vacuum inside the cold box by means of a dry nitrogen injection. The leakage rate in the cold box is approx 0.1torr/min for the initial 30 min from the injection (pointed out with an arrow in the figure), less than 1 torr/min for the next 12 min and about 2 torr/min for the rest of experiment time. In the beginning of a vacuum loss, the hydrogen pressure is almost constant because of the cryo-pumping effect [2]. Since the intruded nitrogen gas in the cold box is solidified on the cold surface while moving and colliding against the surface, the vacuum deteriorates slowly.

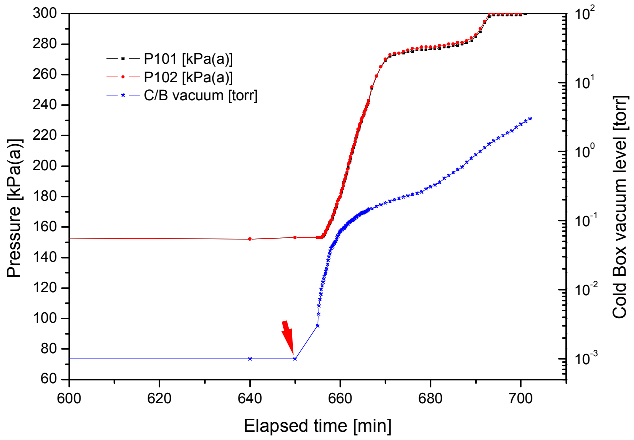

Figure 2. Pressure transition under the leakage in the cold box

For the moderator cell temperature shown in Figure 3, the starting time for a rise takes almost 13 min after injecting the gas into the cold box because the helium flows continuously into the heat exchanger even if its temperature becomes higher owing to a worse vacuum. In addition, it takes 50 min until the pressure rises up to approx. 300 kPa(a). In a comparison with the effect by the first case, this case has a relatively smaller influence on the CNS in terms of its integrity although the effect on the CNS depends on the leakage rate.

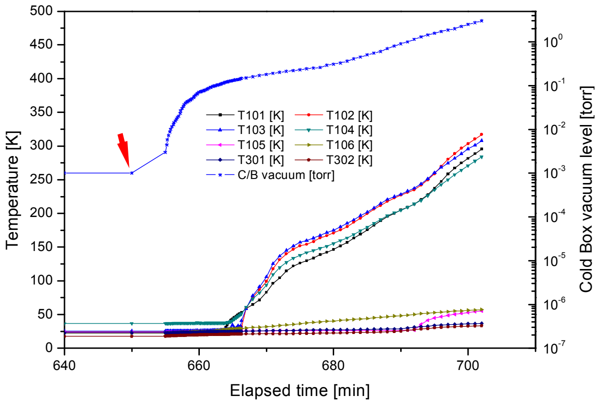

Figure 3. Temperature profiles on the IPA under the vacuum loss in the cold box

5. Conclusion

The two phase thermo-siphon mock-up test has been performed to confirm whether the integrity of the CNS is sound against the abnormal conditions of the helium refrigeration system: sudden breakdown of the compressor and the turbo expander; a vacuum loss in the cold box. As time elapses, the temperature of the moderator cell could rise up to the material's phase transition temperature under the abnormal condition. From the experimental data, the hydrogen high pressure set point has been resettled from 400 kPa(a) down to 200 kPa(a) with the operating margin for the CNS integrity. The first case brought out a much severer influence on the CNS than the other case.

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. Moreover, the authors especially appreciate the Korea Electric Power Research Institute because the thermo-siphon mock-up test has been successively performed using his helium refrigerator.

REFERENCES

[1] Hark-rho Kim et al., Basic Design of the Cold Neutron Research Facility in HANARO, KAERI Report, KAERI/TR-3051/2005, September 2005.
[2] Sangkwon Jeong et al., Investigation on the development of the cryogenic thermo-siphon for the cold neutron source, KAERI report, KAERI/CM-770/2004.