INSTALLATION OF COLD NEUTRON SOURCE AT HANARO

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Abstract

The development and installation of Cold Neutron Source (CNS) is intended to enhance the neutron science research area and utilization of HANARO as a research reactor. The system design for the CNS was completed in October of 2006. The installation and modification permit at the existing HANARO facility was successfully issued in August of 2007. After that, the structures, systems and components for the CNS had been installed inside and outside the reactor building since 2008. The system performance tests were started from the October, 2008 to the end of April, 2009, during the scheduled reactor shutdown. It is confirmed that the first cold neutron beam is successfully produced at 23:30 on 3rd Sep. 2009. HANARO CNS and its system is being operated at an extremely low temperature, 18~21 K, along with the normal operation of HANARO since just after the completion of commissioning on September 2009. The successful completion of the development of the cold neutron source is a meaningful achievement enhancing national nuclear engineering capability.

1. INTRODUCTION

This paper is to introduce the development and installation of Cold Neutron Source (CNS) at HANARO (High-flux Advance Neutron Application ReactOr), which is a research reactor with a thermal power of 30 MW. It has been operating for 16 years since its initial criticality in February of 1995 and has been designed for multi-purpose use in various science and engineering fields such as material irradiation, nuclear fuel irradiation, neutron scattering, neutron radiography as well as neutron transmutation doping for silicon. All the aforementioned purposes, except for the CNS, have been developed successfully for their inherent aims. The installation of the CNS is a final project to complete the overall design purposes of HANARO. In order to implement the final goal, the CNS project has been launched since 2003. It was also intended to enhance the neutron science research area and utilization of HANARO as a research reactor.

2. COLD NEUTRON SOURCE

The cold neutron source is a hydrogen-moderated vertical type, of which the in-reactor component, called In-Pool Assembly (IPA) consists of a moderator cell and heat exchanger, a vacuum chamber and connecting pipes as shown in Figure 1. The 6061-T6 Al alloy has been selected for the moderator cell and the vacuum chamber based on the structural analysis and its competitive mechanical properties at cryogenic and radiation environment. Through a considerate special welding test and analysis for the moderator cell, a detail and practical design and specification have been implemented and the manufacturing contract was made in last April, 2008. Major components of IPA were respectively designed according to requirements of ASME below:

— Vacuum Chamber: ASME Sec. III, ND, 1998, 2000 addenda;

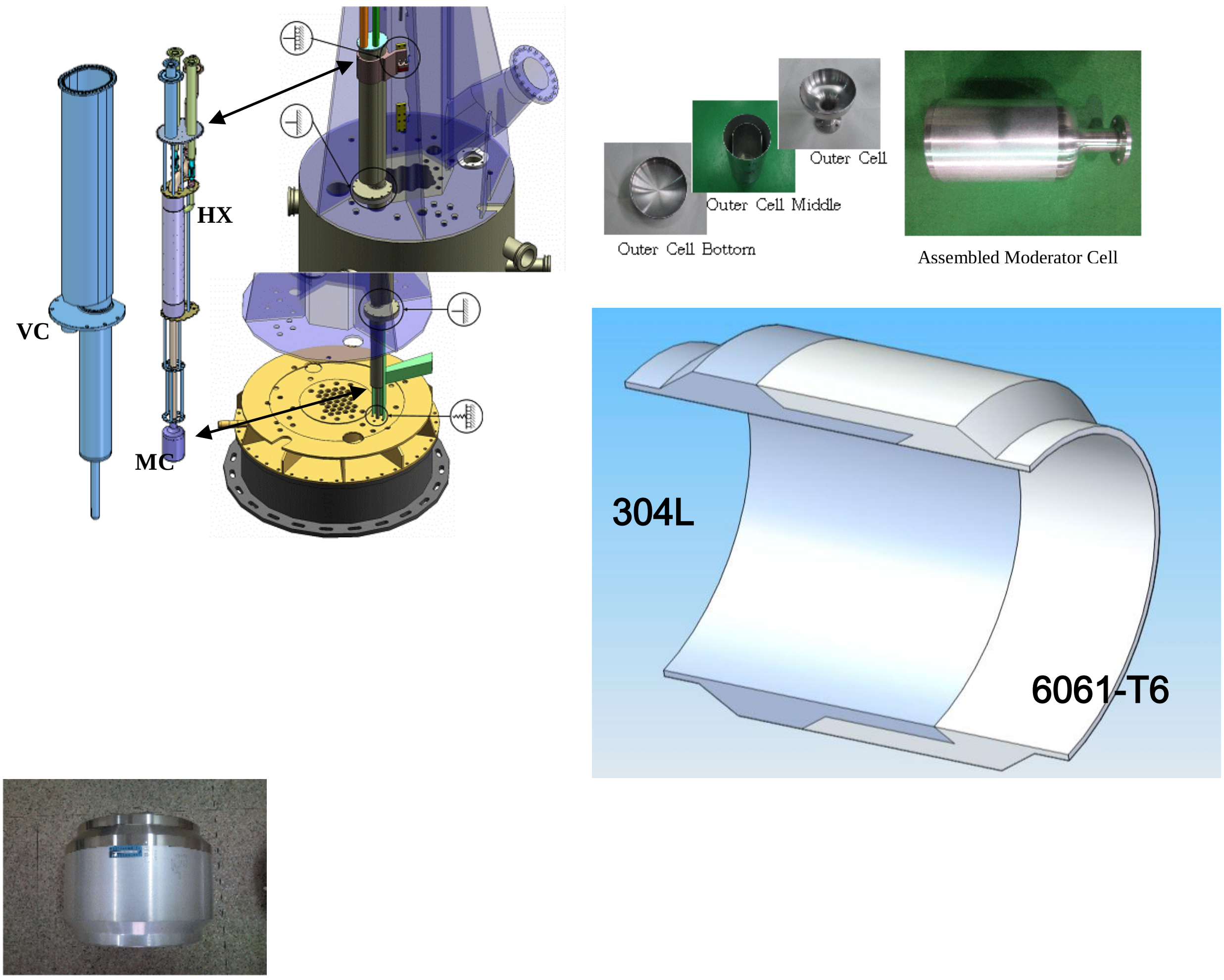
— Moderator Cell: ASME Sec. III, NB, 1998, 2000 addenda;

— (NB is applied to consider the fatigue corresponding to thermal stress due to the normal operation.);

— -Heat Exchanger: ASME Sec. VIII, Division I, 2004 Edition, 2004 Addenda

— -Hydrogen Transfer Piping: ASME B31.3, Power Piping.

The vacuum chamber accommodates the moderator cell and heat exchanger under high vacuum environment. As a pressure boundary, the vacuum chamber is designed to withstand 30 bar against the hydrogen-oxygen reaction. The moderator cell design is one of the most important parts in the CNS design, which governs the performance of cold neutrons. The MCNP calculation was conducted with various possible options. It’s been decided that a double cylinder with an open cavity is the best option for the HANARO CNS. The manufacturing of the IPA was completed within February, 2009 then installed in the reactor in the May, 2009. Once the IPA has been connected to the outside systems, an integral system commissioning was started with reactor operating.



Bi-Metal Transition Joint with AL-6061(T6) and STS-316(L)

Fig. 1. IPA installed in reactor, Detailed Moderator Cell and Bi-Metal Transition Joint.

Liquid hydrogen is adopted as a moderator to transform thermal neutrons into cold neutrons in the reflector tank of a reactor. The liquid hydrogen contained in the moderator cell evaporates due to gamma heating. The hydrogen vaporizes up to the condenser, where it is reliquefied then it returns down to the moderator cell. This thermo-siphon loop can only be established under a very low temperature environment, which requires a method for thermal insulation. In order to implement the above mentioned physical phenomenon, the system for the CNS is composed of a Hydrogen System, a Vacuum System, a Gas Blanketing System, a Helium Refrigeration System, Control System, and an Auxiliary System. [1]

3. SYSTEM AND FACILITY CHARACTERISTICS

The overall design concept of the CNS is to ensure that the reactor safety systems and the on-site personnel and equipment are not adversely affected by the hydrogen-oxygen reaction caused by hydrogen gas leaking from related pipe lines and components of system for the CNS. The safety design criteria of the CNS adhere to the defence-in-depth approach that provides several means to avoid any accidental contact between the hydrogen in the system and the air. Therefore, the principles of conservatism, simplicity, redundancy, fail-safe design, and passive safety features are included in the design to enhanced safety and efficiency [2]. According to the safety classification based on ANSI N51.1, the in-pile assembly which contained the moderator cell and heat exchanger is classified in nuclear safety class 3 same as the HANARO reactor assembly. [3]

The hydrogen is only stored in the closed loop consisting of the thermo-siphon loop in the IPA, hydrogen buffer tank through adequate piping and valve manifold. The hydrogen buffer tank maintained at room temperature has sufficient volume to accommodate the entire gaseous hydrogen inventory. The hydrogen boundary is surrounded by the blanketing gas, helium or nitrogen gas for safety. A commercial movable metal hydride unit is adopted to store the hydrogen gas for system repair. The hydrogen gas in the metal hydride unit will be back to the system easily. The vacuum level for the cryogenic insulation shall be at least lower than 1×10^{-5} torr during the CNS normal operation. The vacuum system has two trains of vacuum pumping system. The standby train will automatically start when the main train is failed or vacuum performance is not good enough for the thermal insulation. The vacuum system adopts a guided venting concept using a gas collection tank with hydrogen detector. [4]

The helium refrigeration system (HRS), manufactured by Linde Kryotechnik AG, has been designed to produce refrigeration capacity of 1500 W at 14 K. Since the oil-injected screw compressor is equipped with the variant frequency driver, its cooling capacity can be controlled in several steps along the balance with the reactor power in terms of the electric power saving. The self-activated gas bearing turbines inside the cold box do not require a separate gas supply system; therefore, there is no danger of contamination of the process gas. In the beginning of this year, the factory acceptance test of the HRS was performed at the vendor’s workshop to check not only the maximum cooling capacity but also its control scheme. The HRS was timely delivered at KAERI in April of 2008 and successfully installed in a CNS equipment island inside reactor hall and an auxiliary building in upcoming September. Figure 2 is showing all the systems abovementioned and their layout at HANARO.

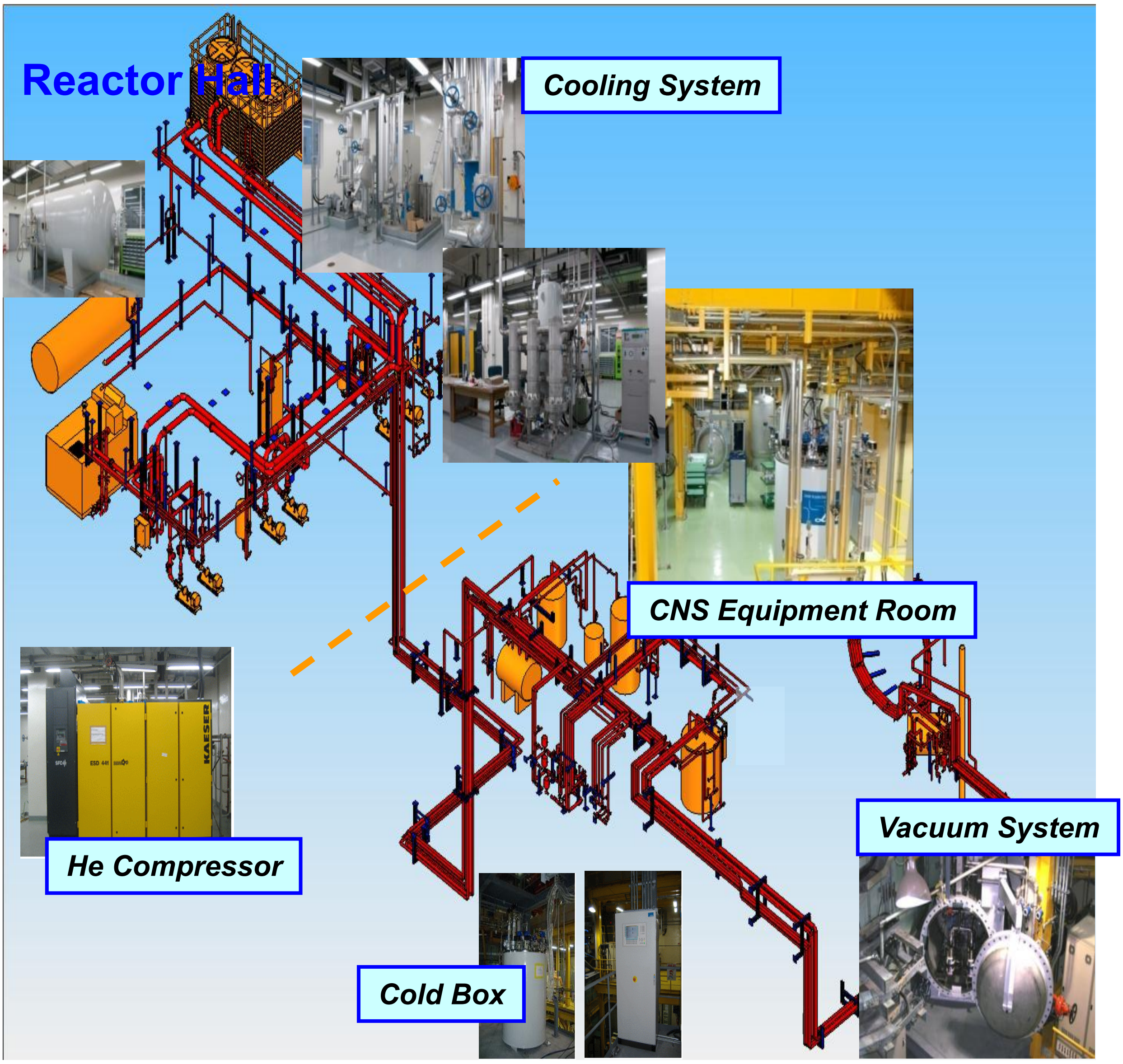


Fig. 2. Layout of Systems installed in HANARO.

The systems and components for the cold neutron research facility are located at four different places based on their dedicated functions. While the in-pool assembly is located in the reactor pool, the helium compressor station is placed in the auxiliary building outside the reactor building, by considering that it produces a vibration and a big noise during an operation. The remaining parts, which have a limitation in the length of their connecting pipe for the required performances, were installed in the CNS Equipment Island (CEI) in the reactor building. The hydrogen buffer tank, vacuum pumps and valves, helium cold box and instrumentation and control systems etc., are accommodated in this CNS equipment island. As shown in the Figure 3, the CEI is located in the north-west area of the reactor building.

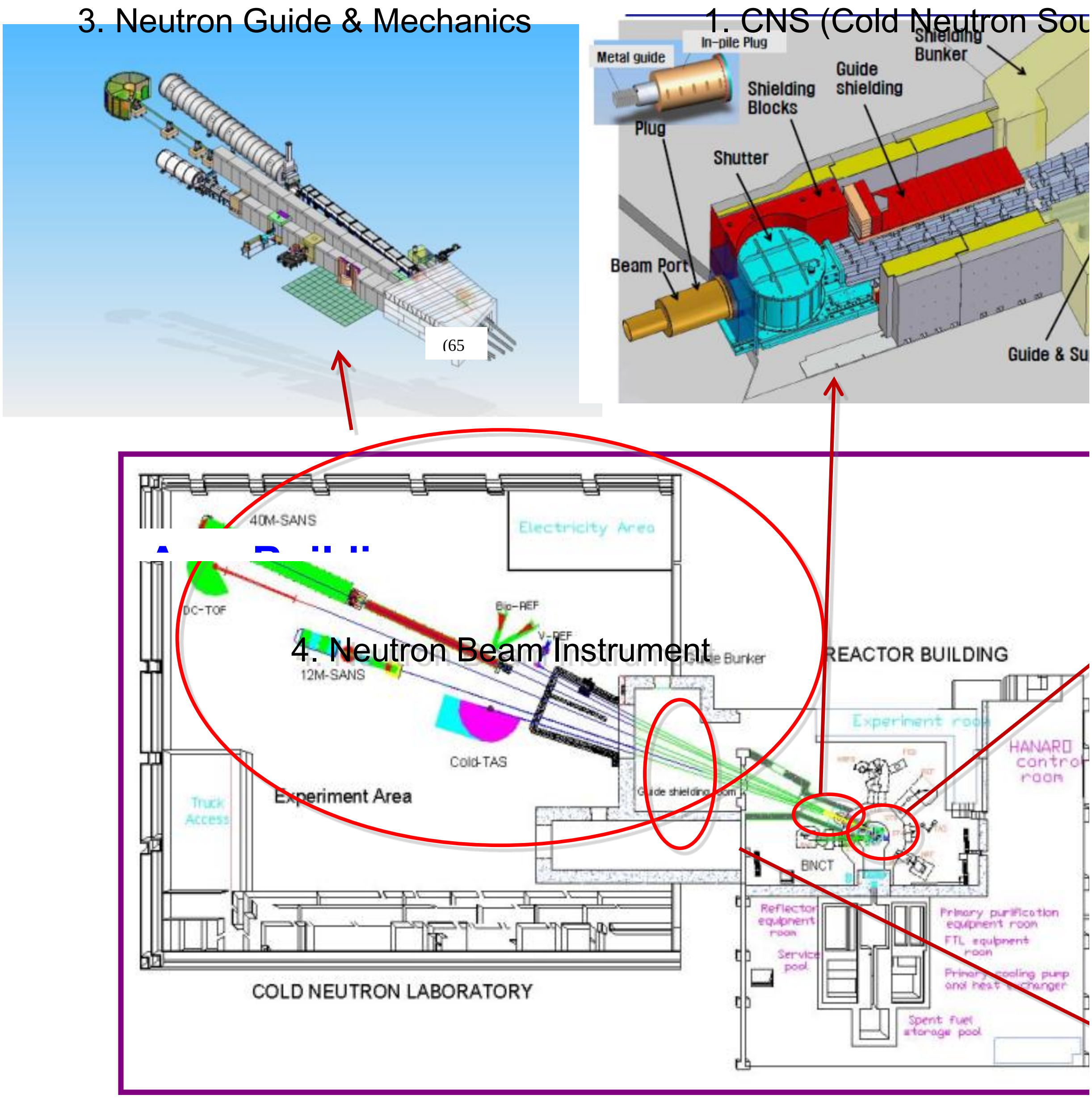


Fig. 3. Cold Neutron Research Facilities at HANARO Site.

The CEI was seismically qualified and designed to optimize the interferences with the existing structures or facilities in the reactor hall. An appropriate height and space of each floor were reflected for the structural design to avoid any problem in installation or maintenance work. The ground floor occupied by the concrete shielding have an enough space to maintain the primary shutter of the neutron guide system. The second floor is reserved for electrical and instrumentation equipment. The third floor was designed as a fire-free zone. Physical barrier or proper measures was designed to block a propagation of any fire originating outside into the room for the hydrogen equipment.

4. INSTALLATION AND COMMISSIONING

The system design for the CNS was completed in October of 2006. The three design phases, which were normally defined in engineering terms like as a conceptual, basic, and detailed design, have been completely every year depending on its available budget from the Government. Finally, the Safety Analysis Report (SAR) was prepared based on the detailed results and has been submitted to the Korean regulatory body to get an installation permit of the CNS. It was intended to reflect the design concept into the Final Safety Analysis Report (FSAR) of HANARO. The installation and modification permit at the HANARO facility was successfully issued in August of 2007. After that, the structures, systems and components for the CNS have installed inside and outside the reactor building since 2008. As the reactor had to be operated according to normal operation schedules, the installation works were only available during the scheduled shutdown period, totally 8 months over two year period. Even though the installation time was not adequate, all the entire system for CNS including a moderator cell has been successfully installed by our own technology on schedule. Figure 4 is showing the inside view of HANARO enhanced by the installation of CNS and its processing system.

Fig. 4. HANARO, enhanced by the Installation of Cold Neutron Source and its Processing System.

5. PROJECT SCHEDULE

All of the CNS equipment and systems except for the IPA were installed within September, 2008. The system performance tests were started from the October, 2008 to the end of April, 2009. The IPA was installed during the scheduled reactor shutdown from May to August, 2009. It is confirmed that the first cold neutron beam was produced at 23:30 on 3rd Sep. 2009. The time schedule of CNS project is below.

— 2003: Conceptual Design
— 2004: Thermo-siphon Mock-up Test
— 2005: Basic Design
— 2006: Detailed Design and Licensing
— 2007 : Construction Permit, Fabrication and Installation
— September 2008: Installation of components and systems

— April 2009: System performance test without the reactor operating
— May–August 2009: Installation of In-Pile Assembly into the reactor
— September–December 2009: Integrated system performance test with the reactor
— January–April 2010: Commission & Preparation of CNS normal operation
— December 2010: Project completed with Normal Operation Scheme
— January 2011: Cold Neutron Research Facility opens to users

6. CONCLUSION

The CNS and its system is being operated at an extremely low temperature, 18~21 K, along with the normal operation of HANARO since just after the completion of commissioning on September 2009. The successful completion of the development of the cold neutron source is a meaningful achievement enhancing national nuclear engineering capability. The purpose of the cold neutron source was to increase the available neutron flux delivered to the instruments in the cold neutron range from 4 to 12Å. The essential needs of the user groups were to obtain a maximum gain in the cold neutron flux and a good operational reliability. As results, the cold neutron flux level measured during the commissioning is indicated about 1.47×10^9 $s^{-1}cm^{-2}$. Conclusively, the target of the CNS project is successfully satisfied by the high level requirements of users.

ACKNOWLEDGEMENTS

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