Current Status of the HANARO CNS Moderator Cell Design

Yeong Jin Yu, Kye Hong Lee, Hark Rho Kim
Korea Atomic Energy Research Institute
Daejeon, Korea

yjyu@kaeri.re.kr

The detail design of the HANARO cold neutron source (CNS) is in progress. The nuclear design of the CNS moderator cell was optimized using the MCNP-4C code. The CN hole is located in the D_2O reflector tank 51.93 cm away from the core center. The in-pool assembly consists of a two-phase thermosiphon loop and a vacuum chamber, which will be installed in the CN hole. The liquid hydrogen is selected as the moderator and Al 6061-T6 is the material for whole in-pool assembly. The type of moderator cell is a double cylinder with open cavity. The maximum radial thickness of the moderator is 3 cm. The void fraction in the moderator cell will be maintained at less than 20% and the ortho/para ratio is assumed to be in the range from 50% ortho to 65% ortho hydrogen. The brightness gain factor is about 31.7 in the energy range of less than 5meV at the entrance of the guide. The nuclear heat load of the CNS moderator cell is calculated as 629 Watt. The 1st fabrication test of the moderator cell and the mock-up test have been done successfully and the 2nd fabrication test and the mock-up test with detail design are in progress.

1. **Introduction**

The HANARO, an open-tank-in-pool type research reactor of a 30MW$_{th}$ power in Korea, has been operated for 10 years since its initial criticality in February 1995. The cold neutron source project for HANARO was launched from July 2003. HANARO Cold Neutron Research Facility (CNRF) Project includes a cold neutron source which shifts neutrons from a short wavelength range to a long wavelength, the related systems for an operation of a cold neutron source, neutron guides to be able to send neutrons to the spectrometers located over a long distance, instruments and a cold neutron laboratory. The cold neutron laboratory will be located at the west side of the reactor building.

The detail design is in progress now and this paper summarizes the status of the moderator cell design and the in-pool assembly design.

2. Moderator and Material Selection

Although there are several choices of a cold moderator in principle, only liquid hydrogen and liquid deuterium are used for a research reactor [1]. A large volume of liquid deuterium is usually used as a cold moderator due to the small absorption cross section. The necessary volume of liquid hydrogen for reducing the neutron energy is less than that of liquid deuterium because of the higher total cross-section of liquid hydrogen. For the HANARO CNS, considering the mean free paths of hydrogen and deuterium and the diameter of the CN hole, hydrogen is appropriate as a cold neutron moderator.

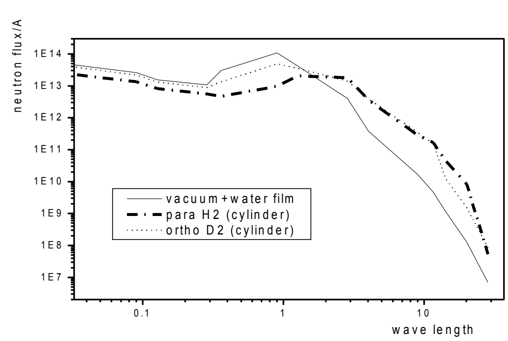

Fig. 1 Neutron spectrums for vacuum, H_2 and D_2

The moderator diameter has been selected as 130 mm to maximize the moderator surface area and to see more thermal neutrons. It was found that the spectrum peak was shifted to the cold neutron region in case of the liquid hydrogen but not in case of the liquid deuterium as shown in Fig. 1.

The in-pool assembly (IPA) of the cold source consists of a moderator cell containing the liquid hydrogen, transfer tube, heat exchanger and a vacuum chamber. The materials of the IPA are required to have good mechanical, nuclear, and thermal properties. Most of the moderator cell materials are 5xxx and 6xxx Al alloys, and stainless steel (A286) is used in the other facilities [2]. Al alloys and Zircaloy are mainly used as vacuum chamber materials. Considering the mechanical properties at cryogenic temperatures, neutron physical properties and a weldability, Al 6061-T6 was selected as both a moderator cell and a vacuum chamber.

3. Moderator Cell Design

The reflector tank containing D_2O surrounds the reactor core and various vertical and horizontal experimental holes as shown in Fig. 2. The cold neutron moderator cell will be placed in a vertical CN hole. The CN hole is positioned in 51.93cm apart from the core center.

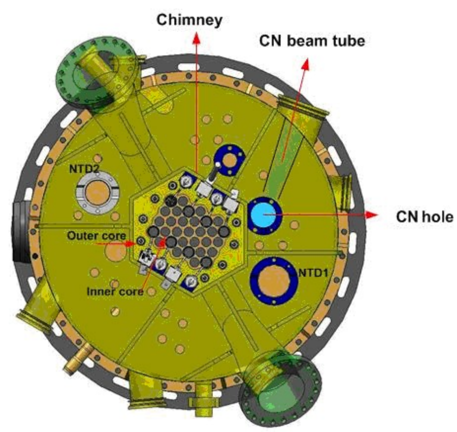

Fig. 2 HANARO core and reflector tank

During the full power operation, the peak flux in the CN hole is about 1.25×10^{14} n/cm^2/sec and it is 44% of the outer core thermal neutron peak when the CN hole is in vacuum. At that time the control rods are in the middle, the axial thermal neutron peak appears at 10cm below the middle. Considering the axial thermal peak, the CN beam tube has been installed at 10cm below the middle. The diameter of the CN hole has been measured as 156.7mm.

The basic design philosophy of the moderator cell is to have a lower heat load and a higher brightness. The various shapes are considered as a moderator cell such as ellipsoidal, cylinder, sphere, double cylinder and double cylinder with open cavity. As shown in Fig. 3, it was found that the cold neutron brightness increased by about 22% when the moderator shape is changed from double cylinder to double cylinder with open cavity. It seems that the cavity reduces the possibility of the up-scattering and the absorption.

The ortho/para ratio is important to the moderator performance because the neutron inelastic scattering cross-section of the othro-hydrogen is one order of a magnitude larger than that of the para-hydrogen. The results of the simulation indicated that the ortho/para ratio had an obvious influence on the cold neutron brightness. The ortho/para ratio during the CNS operation is assumed to be in the range of 50% ortho and 65% ortho hydrogen from the experience of other institutes [3].

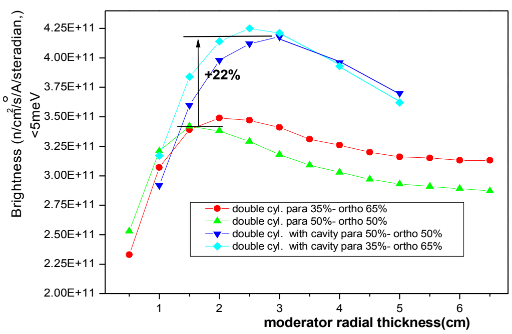

Fig. 3 Effect of the ortho/para ratio and the moderator cell shape

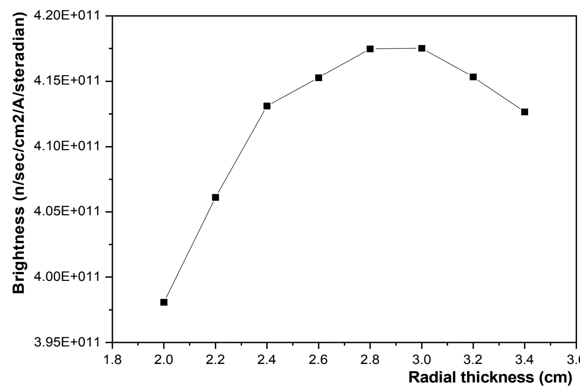

Fig. 4 Radial thickness optimization

To find the optimum point of the radial thickness for the double cylinder with open cavity, the case study has been conducted as shown in Fig. 4. The optimum thickness of the liquid hydrogen is 3cm. However, the brightness difference between 2.5cm and 3cm is less than just 2% despite about 6% hydrogen mass increase. To reduce the hydrogen mass considering the heat load, the center of the open cavity is shifted toward the CN beam tube by 0.5cm under a 2.5cm thickness as shown in Fig. 5.

The height of the moderator cell is 232 mm and the wall thickness is 1 mm. The thickness of the vacuum chamber made of Al 6061-T6 has been selected as a thickness of 5 mm. The inner cylinder has an open bottom and is filled with hydrogen vapor.

HANARO CNS thermosiphon loop consists of a hydrogen buffer tank, condenser, moderator transfer tube, and a moderator cell. HANARO CNS adopts a two-phase thermosiphon loop driven by a natural circulation. The boiling by a radiation in the moderator cell is allowed and the void fraction will be less than 20%. The 20% void fraction provides only a 2.7 percent cold neutron flux reduction.

The gain factor is defined as the ratio of the brightness with a cold neutron moderator cell to the one without it (hence only pool water is there). The calculated gain factor is shown in Fig. 6. The calculated gain factor is about 31.7 below 5meV. The maximum gain factor is 42 at about 11.8 Å.

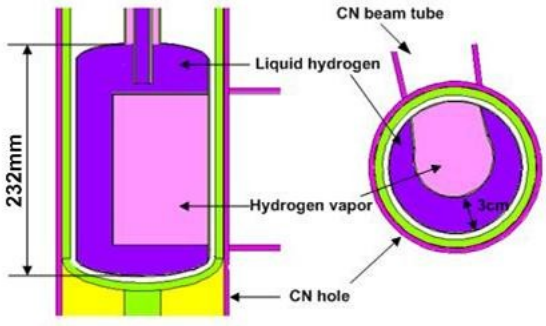

Fig. 5 Double cylinder with open cavity

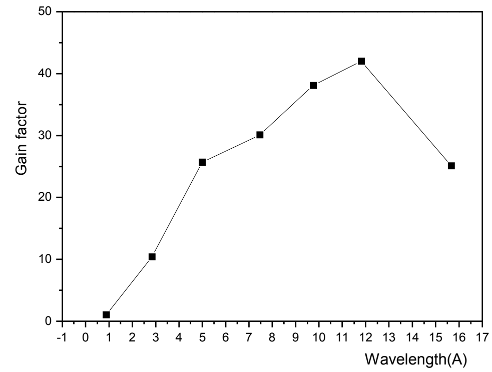

Fig. 6 Gain factor

The heat load estimation of the CNS is calculated by MCNP code. The total nuclear heating to be removed is 629 Watt [4]. The heating generated at Al 6061 is 68.8%; the gamma is dominant over the nuclear heating. The nuclear heating rate is summarized in Table 1.

Talbe 1 Nuclear heating rate

	Specific heating rate (Watt/g)				Heating rate (Watt)	
	Neutron	Gamma	Beta	Sum	Mass	Heating
Outer cyl. Al	0.0034	0.4238	0.1503	0.58	360.6	208.2
Cavity Al	0.0039	0.4786	0.2389	0.72	127.1	91.7
Tube Al	0.0019	0.2264	0.0857	0.31	422.2	132.6
Outer cyl. H_2	0.9828	0.9482		1.93	87.5	168.9
Cavity H_2	0.8607	0.7782		1.64	2.4	4.0
Tube H_2	0.5243	0.4580		0.98	9.8	9.6
others					661.4	13.9
Total (Watt)	95.7	398.6	120.7	614.0	1670.9	629

4. Mock up and Fabrication Test

The small-scale thermo-siphon mock-up test has been performed using liquid argon as a working fluid in a pyrex glass. Liquid argon is chosen because it exists as in liquid phase within a small temperature range like liquid hydrogen. The main purpose of this test is the visual observation of the thermal hydraulic phenomena. This test provides an understanding on the IPA design, cryogenic phenomena, void fraction measurement and self-regulation [5]. The full-scale mock-up test using liquid hydrogen as a working fluid is in progress. The 2^{nd} mock-up test will provide a confirmation on a stable operation of the CNS as well as the manufacturing capability.

The 1st fabrication test of the moderator cell was done successfully. The welding and manufacturing capability for a 1.2 mm thickness Al 6061 was confirmed. The 1.2 mm thick moderator cell was successfully manufactured by 6061 T6 alloy. The product shows good results at the visual and dimension inspection including welding part and non destructive test, leak test, tensile test of welding part. Following this result, the 2nd fabrication test for a 1 mm thickness is in progress according to same fabrication procedure.

5. Conclusion

For the optimization of the cold neutron moderator cell, the brightness was analyzed at the entrance of the CN guide using the MCNP 4C code [6]. From the results, a double cylinder with open cavity is chosen for the HANARO CNS.

The 2nd fabrication test and 2nd mock-up test is the main part of the 3rd year of the cold neutron research facility project. The CNS system design is in the detail design stage.

Reference

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