COLD NEUTRON SOURCE AT CMRR

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ABSTRACT

As an effective means to study structure of many materials and law of microscopic movements on atomic or molecular scale, neutron scattering technique is paid more and more attention by many countries. To promote its development in China, a set of advanced Neutron Scattering Experimental Facilities (NSEF) will be installed at China Mianyang Research Reactor (CMRR), currently under construction.

The cold neutron source (CNS) on CMRR, one of the most important components of NSEF, is of vertical thermosiphon type, and uses single-phase liquid hydrogen moderator. Nice working capacity and safety are the benefit features of CNS on CMRR. Cooling helium from refrigerator removes the total heat load from CNS in the heat exchanger.

In this paper, the in-pile parts, parameters and safety features of CNS are given in detail. At the same time, the utilization of the CNS is briefly described.

Keywords: CNS, liquid hydrogen moderator, CNS parameters, CNS utilization

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1 INTRODUCTION

CMRR under construction is a new pool-type research reactor with light water as coolant and moderator, and beryllium and heavy water as reflectors. The rated thermal power is 20MW. The reactor will achieve its initial criticality in 2004 with thermal and fast neutron flux of 1.9×10^{14}n/cm^2 s and 3.4×10^{14}n/cm^2 s, respectively, at full power, then it will become a powerful instrument in various research fields such as nuclear physics, radioisotope production, neutron activation analysis, neutron scattering, neutron photography, and radiobiology, etc.

A liquid hydrogen moderator will be located close to the reactor core to produce cold neutrons to a level at which it can be transported through neutron guides into Neutron Beam Hall, where experimental facilities will be located.

Single phase, self-regulation, nice working capacity and safety are the benefit features of CNS with a sub-cooled liquid hydrogen thermosiphon. The thermosiphon between the moderator chamber and the heat exchanger makes the hydrogen at a few degrees below the boiling point. Cooling helium from refrigerator removes the total heat load from CNS in the heat exchanger.

CNS at CMRR is a turn-key project being designed and constructed by Petersburg Nuclear Physics Institute of Russian Academy of Science. Up to now, the conceptual design has completed, and detailed engineering design is in progress.

2 COLD NEUTRON SOURCE AT CMRR

2.1 CNS ARRANGEMENT

The CNS is placed in a vertical support tube on the top of the heavy water tank (See Figure 1). The support tube keeps the vacuum containment, which contains the thermosiphon loop. The lower part of the thermosiphon loop is the moderator chamber. The chamber contains sub-cooled liquid hydrogen without bubbles due to the thermosiphon operation.

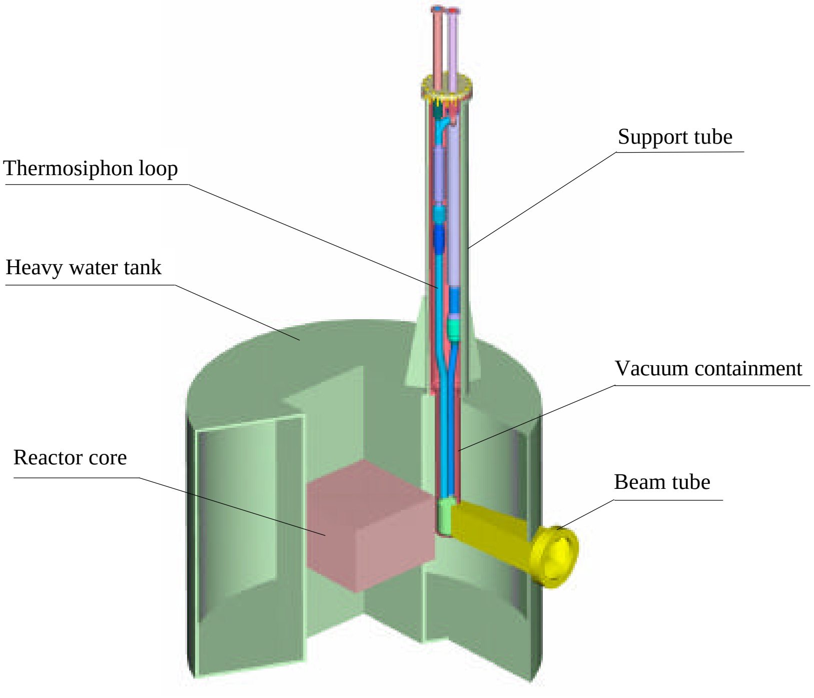

Fig 1. CNS at CMRR

2.2 MODERATOR CHAMBER

Cylindrical moderator chamber, with 126mm outside diameter and 246mm height respectively, as the key part of CNS, has a double wall construction. It consists of moderator cell, moderator cell jacket and short parts of supply tubes (See Figure 2). Hydrogen supply tubes in the chamber have inner diameter of 20 mm. The moderator chamber is made of aluminum alloy.

Liquid hydrogen comes into the bottom part of the cell through the tube and spreads in the cylindrical gap. Heated hydrogen is removed by thermosiphon driving force to the outlet tube on the top of the cell. The flow of the cooling helium comes in the middle part of the chamber and spreads around the moderator cell via a hole in the bottom part of the cell. Helium flow exits from the top of the chamber. Cooling helium removes the heat that is generated by reactor radiation in the chamber material.

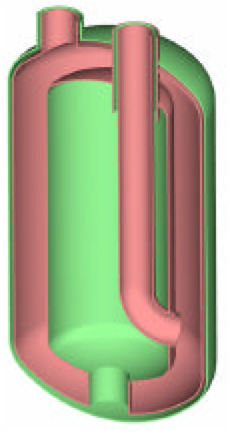

Fig 2. Cylindrical Moderator chamber

2.3 THERMOSIPHON

The thermosiphon consists of four elements integrated in a loop: heat exchanger, moderator chamber and two connecting tubes (See Figure 1). Natural circulation of liquid hydrogen occurs due to a temperature difference in the loop. The cold helium from the refrigerator removes the heat from liquid hydrogen in the heat exchanger. There is a thermal balance between heat release and heat removal in the thermosiphon.

The moderator chamber is placed at the bottom part of the thermosiphon. The heat exchanger and the chamber are connected with a downward 30mm tube and an upward 32mm tube. Total thermosiphon length from the bottom of the chamber to the top of the heat exchanger is 2.44 m.

The lower and upper parts of the thermosiphon are made of aluminum alloy and stainless steel, respectively. There are transient junctions on the tubes to connect different materials.

2.4 VACUUM CONTAINMENT

The vacuum containment, made of aluminum alloy, is placed in the CNS support tube. The containment with 2910mm total length consists of a top flange, two tubes with different diameters and a bottom. The upper tube has inner diameter 218mm and 4mm wall thickness. The lower tube has outer diameter 144mm and 3mm wall thickness. The bottom part has 4.5mm thickness. The upper and the lower tubes are welded together with an intermediate flange.

2.5 HYDROGEN BUFFER TANK

The hydrogen buffer tank with a double wall construction is made of stainless steel. The inner vessel contains gaseous hydrogen while blanketing helium is kept in the gap between the walls. There is a double wall manifold between the buffer tank and the hydrogen box. The inner vessel of the buffer tank has a volume of 4 m^3. Hydrogen pressure in the tank and the helium pressure in the blanket are 0.25 MPa and 0.13 MPa, respectively, while CNS is in operation.

3 CNS PARAMETERS

The liquid hydrogen thermosiphon was designed for 1 kW radiation heat load and can remove easily lower load. Taking into account heat sinks from ambient on the CNS and on the cryogenic feeding lines, reactor heating excursion and some reserve of cooling capacity, the available cryogenic capacity of the refrigerator should be 1.5 kW.

Temperature difference of hydrogen in the thermosiphon legs is 2.5 K at 1 kW radiation heat load. The hydrogen flow rate is 20.8 g/s due to the driving force existing in the thermosiphon while CNS is in normal operation. Hydrogen changes its temperature in the moderator chamber from 16.4 K to 18.9 K and remains in a sub-cooled state. Helium flow rate is equal to 40 g/s. Helium temperatures into the heat exchanger and after moderator cell are 14K and 18.8K, respectively.

Neutron spectrum and gain factors are shown in Figure 3, Figure 4 and Figure 5. Liquid moderator under irradiation consists usually of the mixture of 50% para- and 50% ortho-hydrogen.

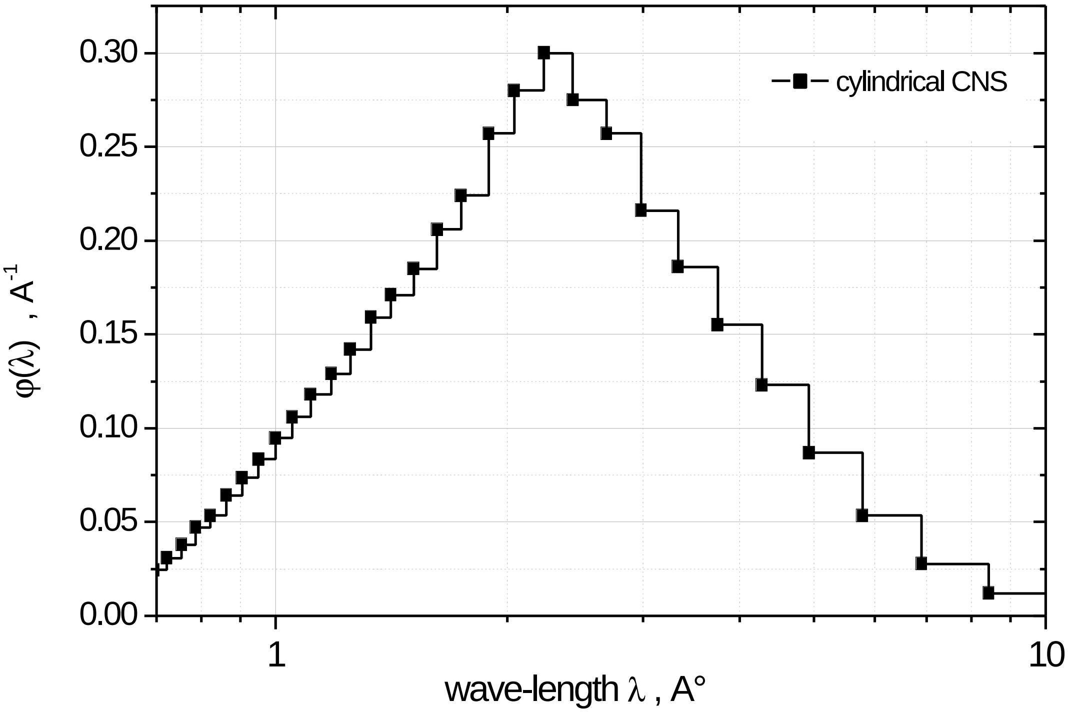

Fig. 3 Neutron spectrum in CNS for neutrons scattered in the direction to the beam tube

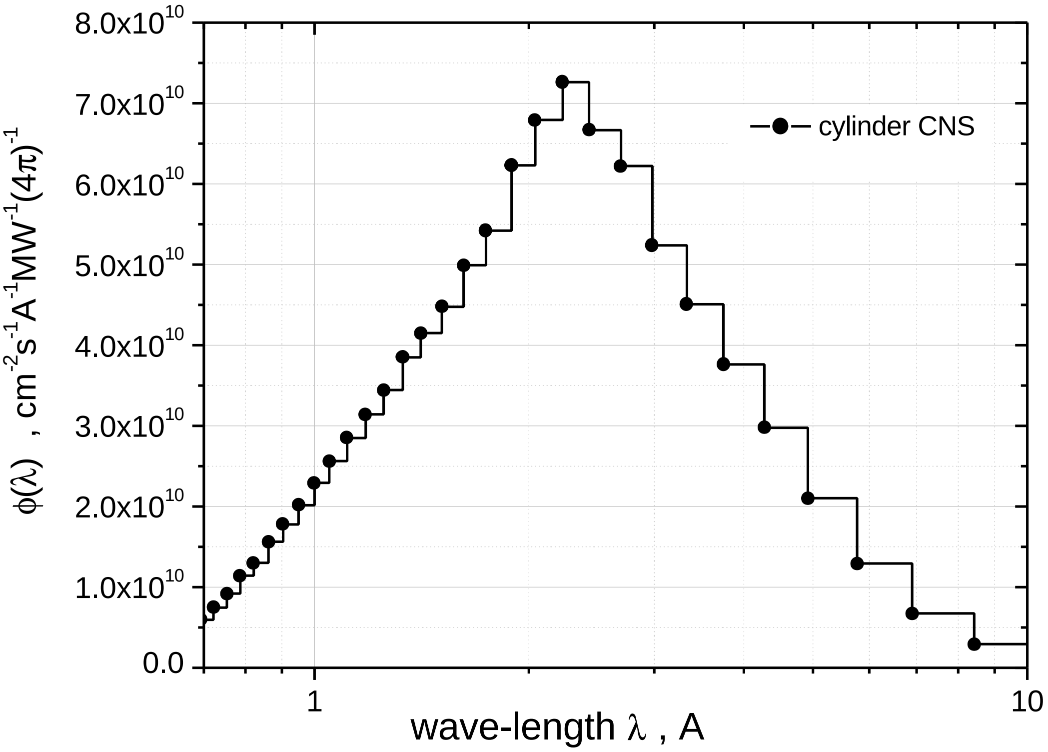

Fig. 4 Neutron brightness in CNS for neutrons scattered into the direction of C-N channel.

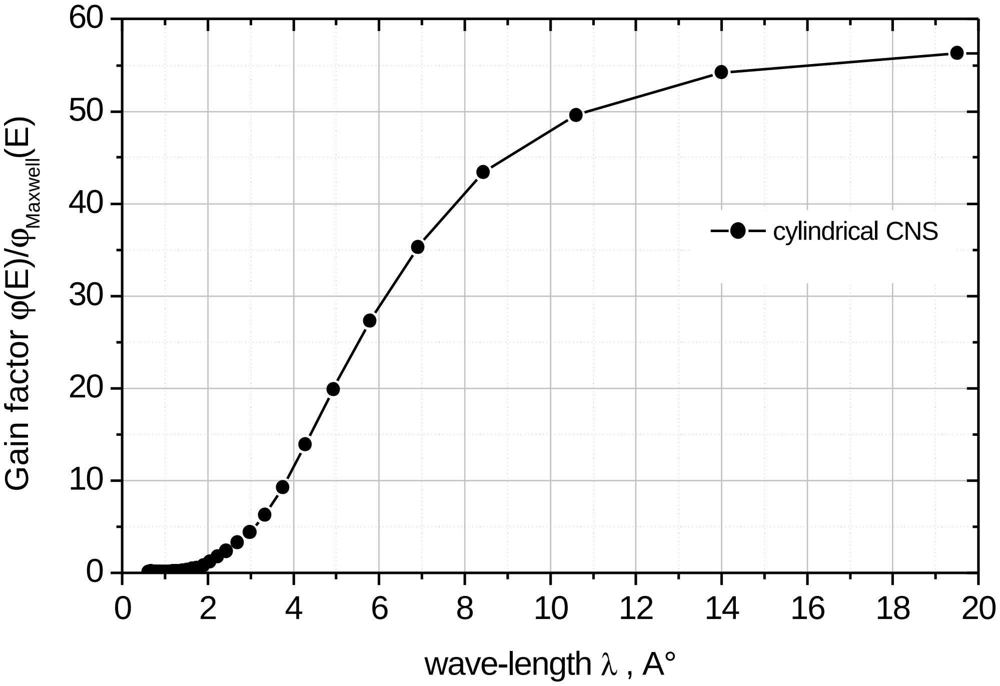

Fig. 5 Cold neutron gain factors for CNS

4 CNS OPERATION AND SAFETY FEATURE

4.1 OPERATION MODE

CNS system is equipped with backup cooling system to allow reactor operation at full power in case of helium refrigerator failure. Construction of the moderator chamber allows removal of radiation heat from the chamber material by warm helium flow. The cooling system supplies two operation modes for CNS:

- Cold mode to keep liquid hydrogen in the moderator cell at full reactor power;
- Standby mode to remove radiation heat from material when liquid hydrogen is absent in the moderator cell.

The safety of the reactor and CNS operation under possible influence on each other is ensured by independent operation for both facilities. The reactor can operate when CNS has no liquid hydrogen (CNS Standby Operation), and CNS facility can operate when reactor is shutdown.

4.2 SAFETY FEATURE

The safety of the reactor is ensured by impossibility of nuclear accident in case of any breakdowns in CNS. The Vacuum Containment is designed to keep the explosion of air-hydrogen mixture. CNS facility has an inert gas blanket system for a safety reason. Helium blanket system exists for three purposes:

- Insulation of hydrogen from the possible contact with air;
- Monitoring of the possible hydrogen leakage;
- Preventing air from penetration into the CNS containment.

The well tested “multiple barriers” concept is fully applied to the present design. The entire moderator system is double-walled to maintain an inert gas blanket constantly monitored to provide early leak warnings. In addition, the thermosiphon loop is fully contained by the Vacuum Containment, which acts as the boundary between the reactor and CNS systems. This vessel is designed to withstand explosion energy from a hypothetical hydrogen-oxygen stoichiometric explosion reaction within it. Therefore, the moderator system is isolated from the reactor core boundary by three successive passive barriers and an active constant early leak detection system between them. In consequence, although close to the core, the CNS system can be considered effectively “outside” the reactor system.

5 CNS UTILIZATION

As cold neutrons have wavelengths comparable with the inter-atomic and intermolecular distances and energies of the same order of magnitudes as that of the thermal motion of atoms, they are ideal tools to understand the structure and arrangement of atoms. So CNS at CMRR will significantly enhance the research and development activities of the reactor. The neutron scattering experiment facility at CMRR will mainly focus in material research fields such as:

- Crystallography,
- Chemical physics of materials,
- Surface and interfacial studies
- Macromolecular and microstructure studies,
- Residual stress, texture and radiography,
- Neutron physics and metrology,
- Irradiation.

Cold neutrons provided by the liquid hydrogen source are transported into the neutron beam hall. The hall with 21.6m width x 57.6m length is located east of the reactor building (See Fig 6). Three cold neutron guides, namely C1, C2, C3 coming from CNS with 2Å, 4Å and 6Å cold neutron characteristic wavelength respectively, extend into the guide hall. After the constructions of cold neutron source system and neutron guide tube system, a few neutron spectrometers will be installed in the beam hall step by step. At the first stage, these instruments below will be installed before 2006.

- Small angle neutron scattering instrument,
- Reflectometer,
- Trip axis spectrometer.
- High intensity powder diffractometer.

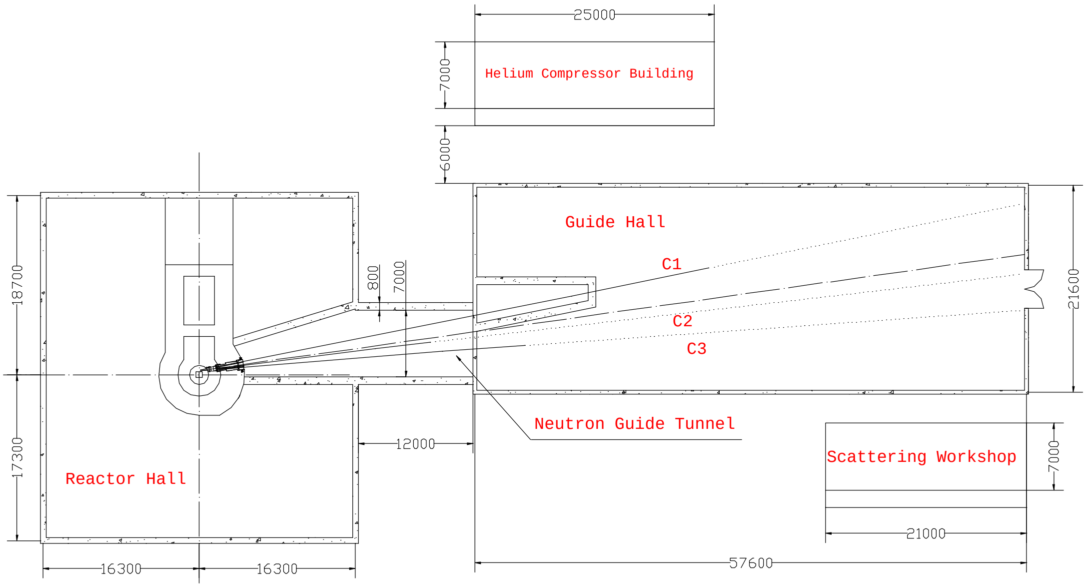

Fig. 6 Layout of cold neutron scattering facility at CMRR

6 CONCLUSION

Nice working capacity and safety are the benefit features of CNS at CMRR with a sub-cooled liquid hydrogen thermosiphon, so the CNS under construction will be one of the most advanced cold neutron sources in the world.

When the cold neutron source system and other experimental facilities are completely installed, There is not much doubt that they will contribute to developing the state-of-the-art technology in polymer science, biology, colloidal chemistry, metallurgy and condensed matter physics in our country.