UCN source with superfluid helium at WWR-M reactor

A P Serebrov, V A Lyamkin, A K Fomin, D V Prudnikov, O Yu Samodurov and A S Kanin

Petersburg Nuclear Physics Institute NRC KI, Gatchina, Leningrad region, 188300, Russia

E-mail: serebrov@pnpi.spb.ru

Abstract. The WWR-M reactor at PNPI is going to be equipped with an ultracold neutron source of high density. Method of UCN production is based on their accumulation in the super fluid helium due to particular qualities of that quantum liquid. The satisfying storage time of UCN at WWR-M reactor in the super fluid helium exists at a temperature below 1.2 K. Our source aims at obtaining a density of UCN equals to 10^4 n/cm^3, two orders of magnitude exceeding that in existing sources presently available in the world. Increase in the density of UCN will raise the accuracy of the measurement of the neutron electric dipole moment (EDM) of an order of magnitude, which is fundamentally important for the problem of CP violation. The most intense sources of UCN allows PNPI become the centre of fundamental researches with ultracold neutrons.

1. Development of UCN sources

Ultracold neutrons (UCN) are successfully used in fundamental research: for the search of the neutron electric dipole moment, for neutron lifetime measurements, for measurement of neutron decay asymmetries and other studies. The accuracy one may reach in these experiments is limited by counting statistics. Therefore there is a strong activity in the development of more intense UCN sources.

UCN density has been increased by eight orders of magnitude due to using of more powerful reactor and cold neutron sources in Gatchina (PNPI) [1] and in Grenoble (ILL) [2]. These sources were placed in extremely high neutron fluxes and used liquid hydrogen (PNPI) or liquid deuterium (ILL). In 90s this line of UCN sources development came to saturation. Development of alternative branches of UCN sources is connected with using of superfluid He^4 at the temperature about 1 K and solid deuterium at the temperature 4 K. We aim at obtaining a density of UCN equals to 10^4 n/cm^3 using superfluid helium technology.

2. Scientific program with UCN

We are going to install facility to measure the neutron electric dipole moment (nEDM) and two facilities for the measurement of the neutron lifetime: a large gravitational trap and a magnetic trap [3]. The neutron lifetime measurements are important to check the model of the formation of the universe in its early stages, as well as to search for deviations from the Standard Model. In addition, the installation to search for mirror dark matter (n - n') is presented. All these installations are established and have been or are being tested in beams of ultracold neutrons at ILL. They will be transferred to new UCN source at PNPI. Increasing UCN intensity by more than two orders of magnitude will give us new research accuracy levels. Finally, for the high-intensity UCN source, we

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can discuss an experiment to search for neutron-antineutron oscillations (n-ñ) to check the violation of baryon number, the second condition of the Universe by Sakharov theorem.

Thus, in addition to a major experiment to search for the neutron EDM we have an opportunities for a series of experiments on the physics of fundamental interactions.

3. Scheme of UCN source

The thermal column with diameter 1 m, situated close to the reactor core, offers a unique opportunity to prepare a source for ultracold neutrons (UCN) in an environment of high neutron flux (about $3{\cdot}10^{12}$ n/cm^2/s) at still acceptable radiation heat release (about $4{\cdot}10^{-3}$ W/g). In order to reduce the heat release from γ-rays from the reactor core a lead shielding will be installed. The external diameter of this lead shielding will be 990 mm with a thickness of 100 mm. The lead is enclosed in a water-cooled aluminum shell (35 mm thick). Behind the lead shielding a liquid deuterium moderator with thickness 96 mm will be installed. It will be cooled down to 20 K using a helium refrigerator. This construction is placed in a vacuum jacket. Inside the deuterium moderator a cylindrical vessel with superfluid helium at a temperature of 1.2 K is placed. Its diameter is 300 mm, and the length is 500 mm. The thickness of the aluminum walls is 2 mm. The internal surface of Al walls is coated by (3-5)$\cdot 10^3$ Å of ^{58}NiMo alloy with critical velocity 7.8 m/s. UCN can be extracted from the source by means of a UCN guide coated by ^{58}NiMo, too. UCN guide and source volume will be separated by a 100 μm thick Al membrane with support grid. The thickness of lead shielding and deuterium premoderator has been chosen to obtain the maximal possible neutron flux with wave length 9 Å [4].

Calculations of neutron fluxes and the heat release were done using the MCNP code (figure 1). The total heat releases at 15 MW reactor power are: 16 kW in the lead shielding, 750 W in the graphite moderator, 13 W in the aluminum shell of the helium source, and 6 W in the superfluid helium. Hence the total heat load at temperature level 1.2 K is 19 W.

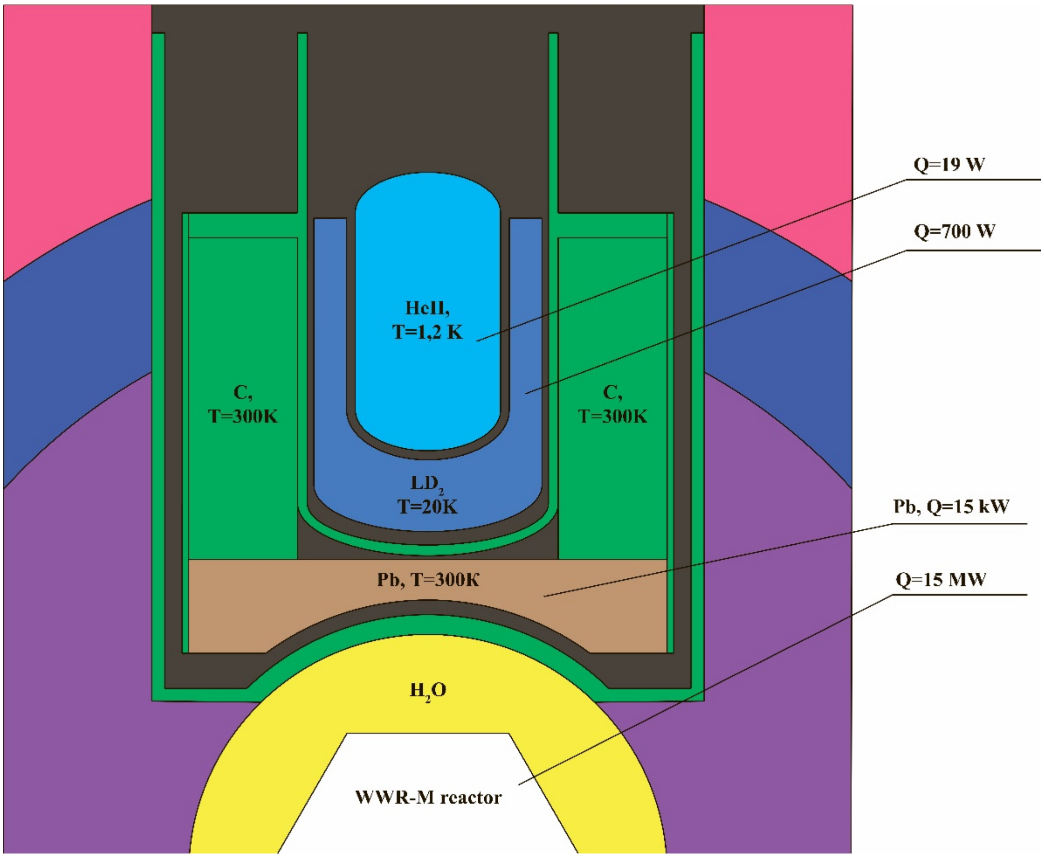

Figure 1. Temperature and heat load distribution in the UCNS.

4. First cryogenic experiment

4.1. Full-scale UCN source model
Presently the first steps for the realization of this project have been done. All cryogenic and vacuum equipment for the UCN facility, as well as for obtaining isotopically pure He4, has been launched. It includes: 3 kW refrigerator with a temperature of 20 K for the cooling of the deuterium moderator, helium liquefier and vacuum pumping system for producing enough amount of superfluid helium [5].

4.2. UCN source model experiment results
As a result, during experiments with full-scale model of UCN source with superfluid helium were obtained real temperature of helium with the heat load up to 60W while the calculated value of the heat load on the reactor WWR-M estimates at 20W. The highest helium temperature T = 1.371K was recorded at 60W thermal load. Even at such high loads on the model of the UCN source, helium remains in the superfluid phase. It was experimentally demonstrated the possibility of installing UCN source inside the reactor WWR-M thermal column.

Table 1. UCN source model experiment results.

Helium heat load (W)	Temperature (K)	Vacuum pump performance (%)
0	1.064	13
15	1.282	24.5
30	1.325	36.4
60	1.371	58.8

5. UCNS technological complex at the WWR-M reactor
After successful experiments on a full-scale model of the UCN source was demonstrated the possibility of keeping helium at superfluid state with thermal load P = 60W (Estimated heat load is calculated to be P=20W). Thus the start for the design of the technological complex in the main hall of the WWR-M reactor was started.

At the moment, the project of accommodation of cryogenic and vacuum equipment at WWR-M reactor hall is designed. This project includes: installation of platforms for cryogenic and equipment, installation of pipelines and cryopipelines, installation of technical water and air communication, installation of electrical equipment etc. The preparation of the northern part of the reactor WWR-M for installation liquefier and refrigerator is started right now.

Moreover, we are in process of manufacturing of the WWR-M UCN source. In particular, the 100mm lead shield and the vacuum module are ready for installation inside the thermal column. The thickness of the vacuum module (22 mm) is designed for the localization of the theoretical explosion of deuterium.

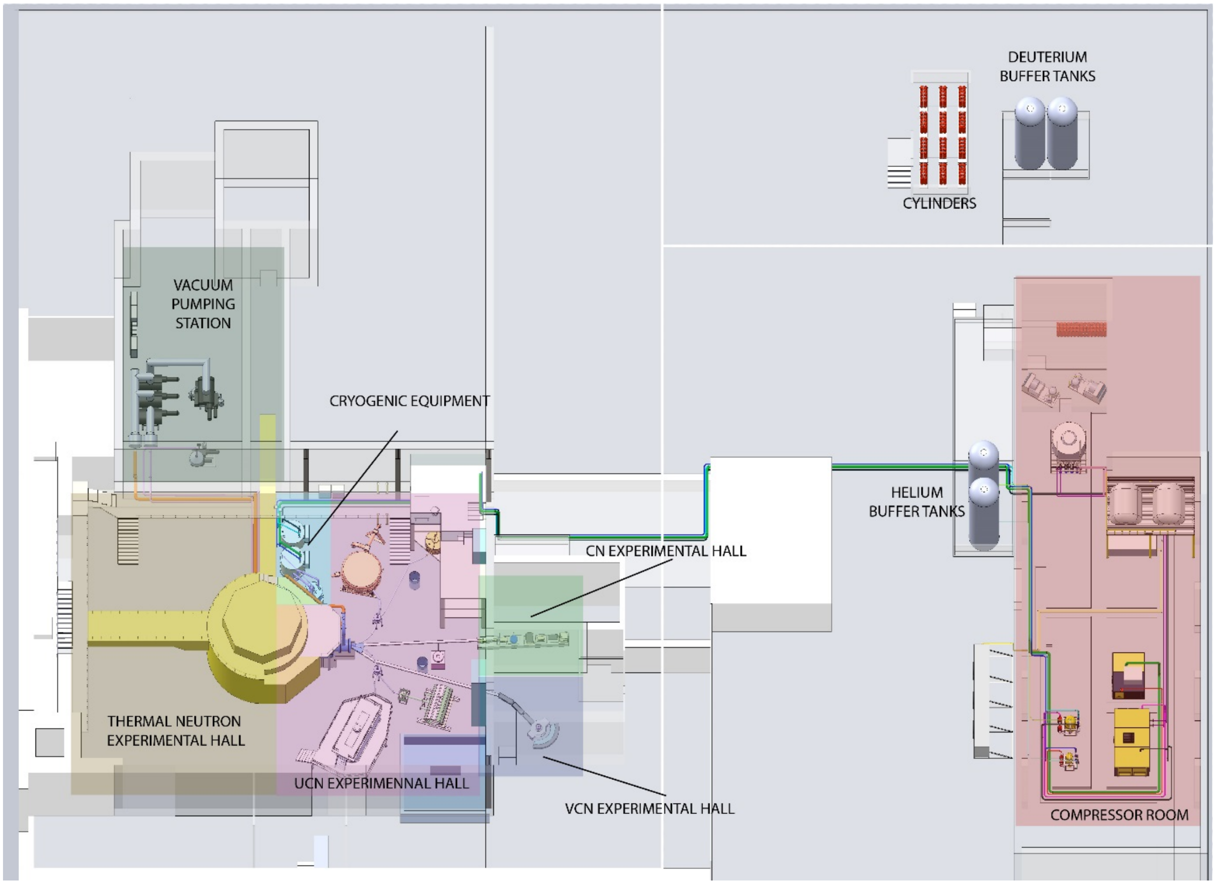

Figure 2. UCNS facility layout.

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