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Status of UCN source at WWR-M reactor

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

NRC «Kurchatov Institute» – PNPI

Abstract

The WWR-M reactor at PNPI is going to be equipped with an ultacold 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 possibility of maintaining the temperature T = 1.371K with a thermal load of P = 60W was shown experimentally, while the theoretical load is expected to be P=30W. The project envisages the installation on UCN beams the experimental setups of various research projects such as searching for the nEDM, measure the neutron lifetime, and the observation of neutron to antineutron oscillation. In addition to UCN beams, three beams of cold and verycold neutrons are planned. Six experimental setups will be installed on these beams. At present, a vacuum container of the UCN source has been manufactured and the manufacture of low-temperature deuterium and helium parts of the source has been started.

Corresponding Author:
A P Serebrov
serebrov@pnpi.spb.ru

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1. Introduction

At present NRC «Kurchatov Institution» – PNPI has developed the project of a source of ultracold neutrons (UCN) at WWR-M reactor [1]. The technique of obtaining ultracold neutrons employing super fluid He appears to be very promising. It is based on the effect of accumulating ultracold neutrons in super fluid He, due to some peculiar features of this quantum liquid. [2]. This project is supposed to be a successful stage in the program on preserving and further progress of fundamental and applied investigations based on research reactors in Russia. The source will make use of superfluid He, thus making it possible to reach UCN density equal to 10^3–10^4 n/cm^3, which has not yet been achieved anywhere in the world. Reaching such UCN production level is expected to become an essential breakthrough in the progress of fundamental and applied scientific research.

A number of successful experiments have been already performed on the beams of cold neutrons in Japan and France. The principle of obtaining UCN on super fluid He has

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been already confirmed experimentally, hence, the question arises on practical implementation of this effect and engineering solution of this task. Nowadays, UCN sources on superfluid He are primarily elaborated on output neutron beams in scientific centers of Europe, America, Japan and Canada. WWR-M reactor has a unique opportunity to considerably enhance UCN source performance, by placing a source chamber into a thermal reactor column at the distance of 30 cm from the active zone. Such location of a source chamber will provide increasing UCN flux density by 2 orders of magnitude in experimental installations, in comparison with sources at the outlet beams. However, at such a location of UCN source, one must solve a complicated task of taking away 30 W from superfluid He at temperature of 1.2 K. It was successfully done at a full scale model of UCN source [3].

Helium efficiently converts neutrons with wavelength of 9 Å into ultracold neutrons, however, those cold neutrons, which passed through helium without converting into ultracold state, will be released as beams of cold and very cold neutrons. For the source to operate effectively in producing ultracold neutrons, it must be placed into an intensive flow of neutrons with wavelength of 9 Å. Hence, an additional chamber with premoderator should be put into the fore part of UCN source.

Besides, a pre-moderator is a productive source of cold neutrons in wavelengths range over 4 Å, which will be emitted out of the thermal column and effectively used. As a working medium for a pre- moderator liquid deuterium at temperature of 20 K, traditionally applied for cold and ultracold neutrons sources, has been selected. A detailed analysis for choosing a pre-moderator for UCN source is given in the article [4].

2. UCN source neutron guide system layout at WWR-M reactor

UCN source is situated in the northern part of the main hall of WWR-M reactor complex. Fig.1 shows a location scheme of experimental installations for work with UCN source.

Application of a new UCN source is supposed to enhance precision in measurements of neutron EDM by two orders(1) and verify assumptions of supersymmetry theories, which considered to be versions of extension of the Standard Model. Within the framework of these theories, neutron EDM is predicted at a level available for experimental observation. At the same time, supersymmetric theories predict the Universe baryon asymmetry at the observed level, which points to possible validity of the proposed theoretical approach.

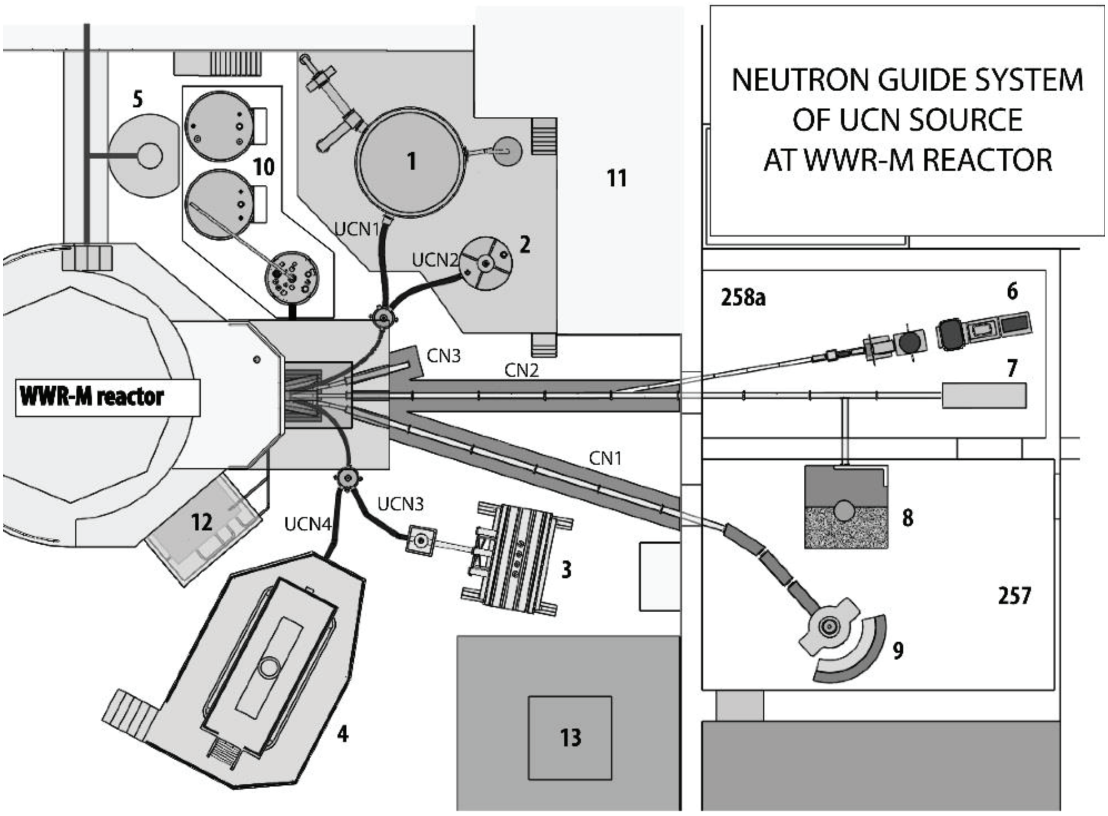

Figure 1: Location scheme of experimental equipment in the main WWR-M reactor hall UCN - beams of ultracold neutrons, CN - beams of cold and very cold neutrons 1 – EDM spectrometer, 2 – UCN magnetic trap, 3 – Experiment n-n′, 4 – UCN gravitational trap, 5 – Diffractometer, 6 – Reflectometer, 7 –Polarimeter, 8 – Powder diffractometer, 9 – Spin-echo spectrometer, 10 – Cryogenic equipment for UCN source, 11 – Technological platform for experimental equipment, 12 – Cooling system for lead screen of UCN source, 13 – Transport entrance.

Two installations for measuring neutron lifetime are presented in addition to the installation for measuring neutron EDM: one - with a magnetic trap (2) and the other one - with a big gravitational trap (4). Neutron lifetime precise measurements are of significance for testing the model of Universe formation at its primordial stage, as well as for search of deviations from the Standard Model. Moreover, an installation for search of mirror dark matter (n–n′) (3) is presented. All these installations have been developed and produced in PNPI, and now they are tested on UCN beams in ILL. They will be transported to a new UCN source in PNPI. Increase in UCN intensity by over two orders of magnitude will enable conducting principally new researches. Finally, for UCN sources of high intensity, one can discuss conducting of an experiment on search for neutron-antineutron oscillations (n-ñ) in order to verify baryon number violation, which is the second condition for Universe origin, according to A.D. Sakharov theorem. Thus, besides the experiment on search for neutron EDM, which is of great significance, there arise possibilities for conducting a series of experiments on physics of fundamental interactions.

The research program on beams of cold neutrons is supposed to be performed on five experimental stations. Four of them have been already constructed: (6), polarimeter (7), powder diffractometer (8) and spin-echo spectrometer (9). Using of the reserved VCN beam (CN3) is also planned for performing further experiments.

Most part of the northern side of the main hall is used for UCN source cryogenic equipment and UCN experimental stations. Thus, CN and VCN installations will be located outside the main hall of the WWR-M reactor complex. The floor level in these premises is higher than that in the main hall by 750 mm. At the height of cold neutron beam of 1000 mm, relative to the main hall floor level, it is necessary to raise the beam by 200 mm at the end point for installing a spin-echo spectrometer, a polarimeter and a reflectometer. Besides all other things, the beam, directed at a spin-echo spectrometer, must bypass a technological aperture for getting into hot chambers. For this purpose, a neutron guide for spin-echo should be deflected by at least 17 degrees relatively to the original beam.

In designing of neutron guides, it is necessary to cut off the total spectrum of gamma quanta and rapid neutrons, going directly from the reactor, by deflecting neutron guides at some angle.

The problem of great importance is concerned with considerable radiation background produced by neutron guides in premises of the main hall of WWR-M reactor. Therefore, all the neutron guides should be provided with sufficient biological shielding for creating favorable conditions for engineering and scientific personal working at experimental stations.

Based on the elaborated scheme, the neutron guide system of ultracold, cold and very cold neutrons has been designed (fig. 2).

3. Neutron flux densities calculations at the outlet of neutron guides

Estimation and optimization of output of ultracold neutrons from the source have been performed with the Monte Carlo method, applying the program [5] developed for neutron calculations in gravitational potential. In modeling, different parameters have been tested with the aim of optimization of UCN output.

As a result of modeling, UCN density has been obtained for traps with 35 l and 350 l volumes. The chosen trap dimensions are typical for experiments on measuring

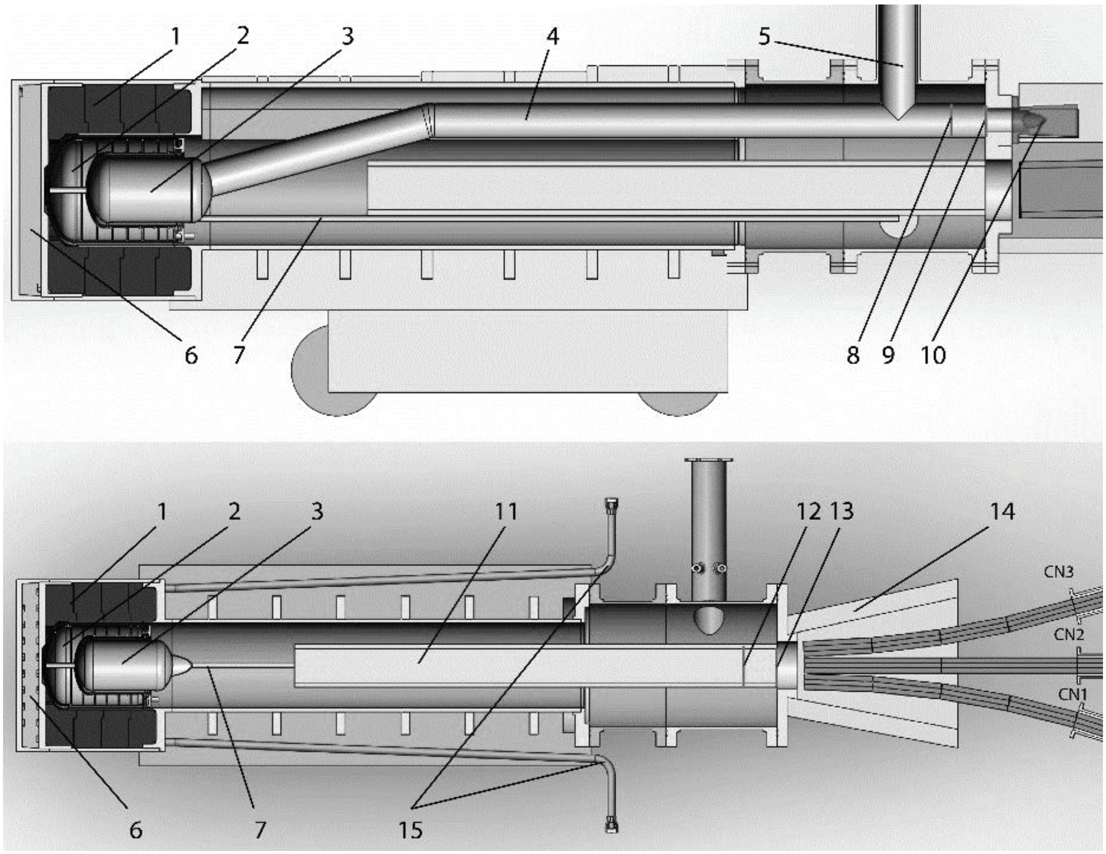

Figure 2: CN and VCN neutron guide system of UCN source at WWR-M reactor 1 – graphite, 2 – liquid deuterium premoderator, 3 – UCN, CN and VCN source, 4 – UCN neutron guide, 5 – pumping out of helium vapors, 6 – lead screen, 7 – supplying tube for superfluid He, 8 – UCN cold membrane, 9 – UCN warm membrane, 10 – splitter of UCN beam, 11 – CN and VCN neutron guide, 12– CN and VCN cold membrane, 13– CN and VCN warm membrane, 14– collimator block, 15– cooling system for lead screen.

neutron electric dipole moment (35 l) [6] and neutron lifetime (350 l) [7]. Fig. 3 shows UCN density depending on HeII temperature in the source chamber.

Thus, as a result of optimization of source parameters, UCN density in the major trap has been obtained equal to $\rho_{35l}= 1.3\cdot10^4$ n/cm^3 (for the trap with volume of 35 l) and equal to $\rho_{350l}= 8.4\cdot10^3$ n/cm^3 (for the trap with volume of 350 l) [8].

The cold neutron guide (CN2) is a direct neutron guide with cross-section of 30x200 mm^2 for releasing cold neutrons. CN2 neutron guide needs to be lifted by 200 mm higher, because of the difference in the floor level. Fig. 4 (left side) presents the neutron flux density $d\Phi/d\lambda$, estimated at the outlet of a direct neutron guide of CN 2, elevated by 200 mm at the outlet point, with 7500 mm length and with cross-section of 30x200 mm^2.

Very cold neutron guide (CN3) is diverged at 16 degrees from the initial beam of CN, by four sections of 400 mm. Hence, it will provide space for installing a scientific station on very cold neutrons in the main hall of WWR-M reactor. Neutron flux density

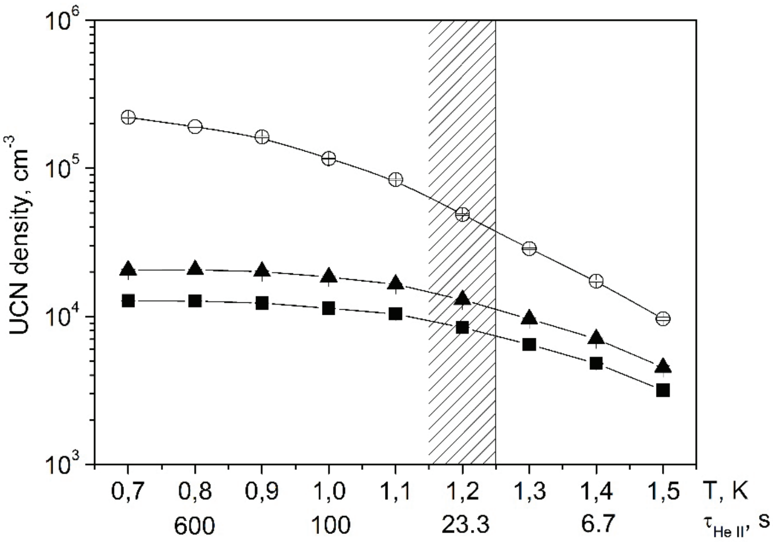

Figure 3: – UCN density dependence on HeII temperature in the source chamber • – in the closed source chamber, ▲ – in the trap of 35l volume, ■ – in the trap of 350l volume .

dΦ/dλ, estimated at the outlet of CN3 neutron guide of 7500 mm length and cross section of 30x200 mm^2, is shown in Fig. 4 (right side) as a wavelength function.

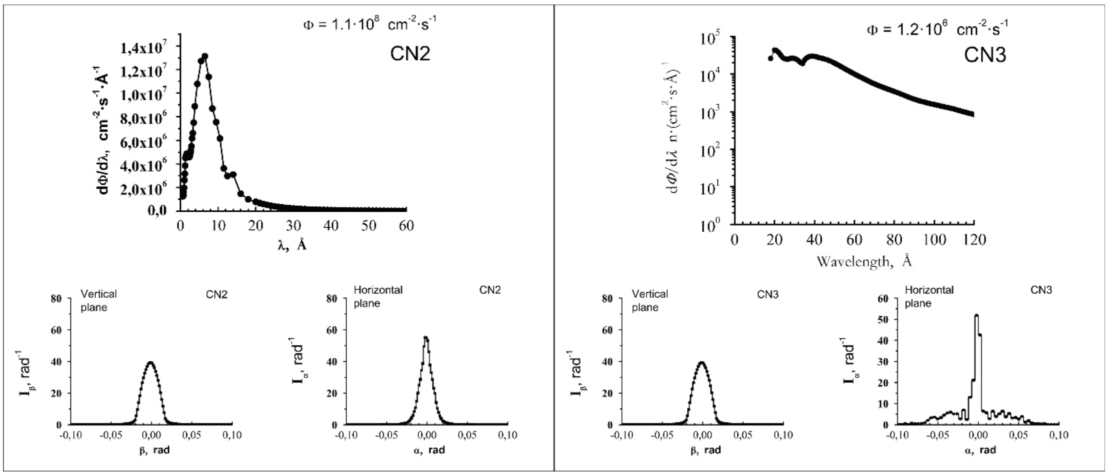

Figure 4: Density of neutron flux dΦ/dλ at the outlet of a direct neutron guide of CN2 and CN3 of 7500 mm length, cross-section of 30x200 mm^2, angular distribution of neutron intensity - I_α and I_β.

Comparative characteristics of UCN sources are shown in table 1.

Thus, the ultracold neutron source of the highest intensity for scientific investigations in fundamental and applied physics will be created in NRC «Kurchatov Institute» - PNPI on the basis of the operating research reactor WWR-M. UCN production will be based on the effect of obtaining UCN in superfluid He owing to peculiarities of this quantum liquid. Implementation of the project on superfluid He at WWR-M reactor will provide an opportunity to create an ultracold neutron source with intensity by 2

Table 1: UCN source model experiment results.

	WWR-M	PIC	ILL
Thermal neutron flux in the source, n $\cdot$ cm^{-2}s^{-1}	$3.2 \cdot 10^{12}$	$2.5 \cdot 10^{14}$	$2.5 \cdot 10^{14}$
Total UCN productivity, n/s	$1 \cdot 10^{8}$	not planned	$1.2 \cdot 10^{6}$
UCN density in EDM spectrometer ρ_{EDM}, cm^{-3}	$1.3 \cdot 10^{4}$	not planned	10
Cold neutrons (2-10 Å), n/(cm^{2}s)$^{-1}$	$1.1 \cdot 10^{8}$	$5.44 \cdot 10^{9}$	$5.5 \cdot 10^{9}$
Very cold neutrons (50-100 Å), n/(cm^{2}s)$^{-1}$	$1.2 \cdot 10^{6}$	not planned	$4 \cdot 10^{6}$

orders of magnitude higher than that at the UCN source in the international neutron center at ILL reactor in Grenoble. Moreover, beams of cold and very cold neutrons are supposed to be created for solid state physics installations, working under low background conditions, in separate premises outside the main hall of WWR-M reactor.

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