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# STATUS OF THE ULTRACOLD NEUTRON SOURCE AT PSI

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on behalf of the UCN Project (http://ucn.web.psi.ch/people.html)

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## ABSTRACT

Construction of the new ultracold neutron (UCN) source at the Paul Scherrer Institut (PSI), Switzerland, is nearing completion. The facility will deliver the highest UCN density worldwide, almost 100 times higher than the currently strongest UCN source PF2 at ILL. The key features are a very intense ($I_p$ > 2.2 mA) pulsed proton beam with a low duty cycle (1%), a lead/Zircaloy spallation target, a 3.6 $m^3$ heavy water moderator and a 30 liter solid Deuterium ($sD_2$) converter system. Spallation neutrons are thermalized in the $D_2O$, further cooled and partially downscattered into the ultracold energy regime (E < 300 neV) in the $sD_2$ crystal. The source is expected to deliver densities of more than 1000 UCN/$cm^3$ into two experimental areas. Commissioning of the facility will be finished within the next few months. User operation will start directly afterwards. An overview of the final design of all essential components of the source is reported as well as the current status of construction and commissioning.

In December 2009, the PSI Ultracold Neutron (UCN) Source received the first proton beam on the spallation target. The beam was delivered in a well elaborated sequence of 5 ms pulses from 100 $\mu$A up to a full beam current of 2 mA. This test run successfully confirmed the beam-line and system integrity for beam-on operation and neutron production. The installation will be completed with the cold source in summer 2010.

## 1. Introduction

Over the last years the efforts to set up new, more powerful sources for ultracold neutrons increased. The scientific drivers for this development are to measure fundamental properties of the neutron in order to test the Standard Model (SM) of particle physics and suitable extensions and the use of UCN as a probe for solid state, surface and biological studies. All applications would benefit from an intensity gain compared to the presently most powerful UCN user facility at ILL with about 50 n/$cm^3$.

Principally the source concepts under investigation differ by the choice of the converter material for the UCN production, superfluid helium at temperatures of 0.5 K and solid Deuterium ($sD_2$) with a temperature around 5 K. The PSI UCN source is based on the solid Deuterium ($sD_2$) concept. The neutrons are produced via spallation and subsequent separated neutron storage. The source is driven by the full 590 MeV proton beam from the PSI ring cyclotron (Ip > 2.2 mA) using several seconds long pulses at a 1% duty cycle. The operation in pulsed mode with a low repetition rate facilitates the cooling of the $sD_2$ after the high energy deposition during the proton pulse.

## 2. Basic Concept

A scheme of the UCN source at PSI is depicted in Figure 1. A lead/zircaloy cannelloni spallation target (i.e. lead filled Zircaloy tubes) is used for neutron production. The spallation neutrons produced by protons hitting the target are thermalized in the ambient temperature heavy water moderator. Thermal neutrons will be scattered into the $sD_2$ moderator, a volume of 30 liters of solid Deuterium at a temperature around 5 K, and will be further cooled and partly downscattered.

Downscattered neutrons leaving the moderator vertically upwards will be further slowed down by gravity, and a fraction will reach the UCN storage volume with energies below 300 neV. These neutrons can be trapped in the UCN storage tank. After a proton pulse duration of 4 - 8 s the storage volume will be closed by a shutter; the UCN are now trapped and can be guided to the experiments through neutron guides.

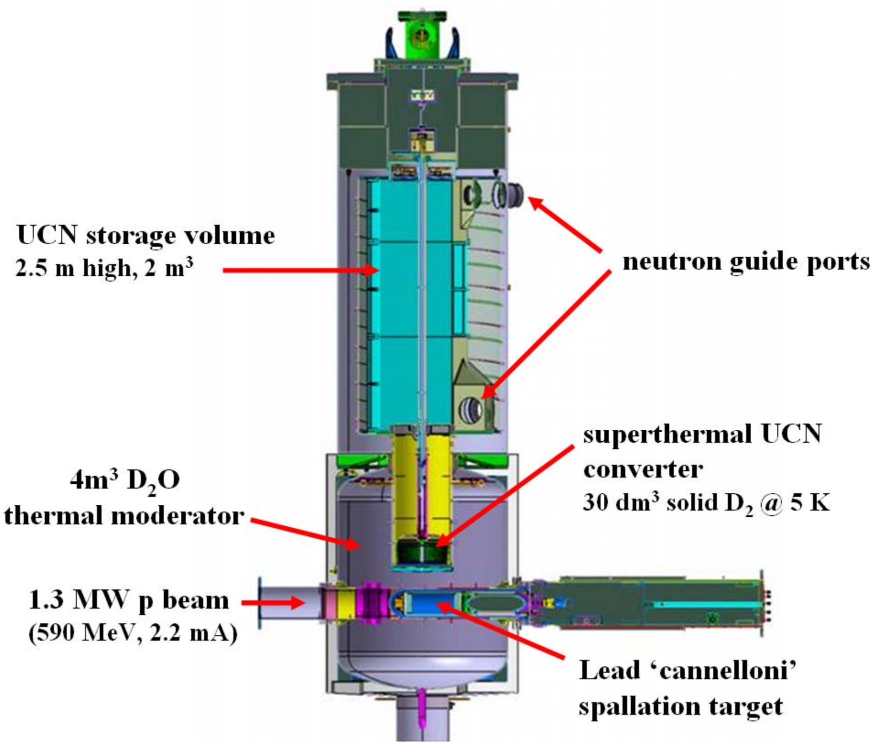


Figure 1: Layout of the UCN source at PSI. The proton beam hits the spallation target from the left. Spallation neutrons will be thermalized in the ambient temperature $D_2O$ moderator, further cooled and downscattered into the UCN regime in the cold $sD_2$ moderator. Through a vertical neutron guide the UCN reach the storage volume were they can be trapped and distributed to the experiments.

## 3. Technical Realization

The following sections aim to give some details on the technical realization of the core components, and to provide an overview of the current status of the different components of the source. Figure 2 shows the so-called UCN vacuum tank housing the $D_2O$ moderator vessel and (in the final configuration) the $sD_2$ moderator and UCN storage volume. The photos were taken after delivery to PSI in 2008, and after installation in its final position, partly surrounded by shielding, as of July 2009.

The UCN storage volume is shown in Figure 3, as such, and surrounded by the thermal shield, suspended from the top-shielding of the UCN tank. At the lower end, the cylindrical vertical neutron guide is visible which guides the neutrons up to the storage volume when they escape the $sD_2$ moderator vessel through the top lid. The ~$2m^3$ large volume should store as many UCN for periods as long as possible. The special UCN preserving coating on the inside of the volume is made from diamond-like carbon. The technical challenge was to produce and coat the large wall and bottom pieces and assemble the volume with minimal slits in order to avoid losing stored ultracold neutrons. The vertical guide has a NiMo coating at the inside.

Figure 2: The UCN tank housing the $D_2O$ moderator vessel and (later) the UCN storage volume. Left: shortly after delivery to PSI, with the target insertion tube still visible. Right: At its final position, partly surrounded by shielding, with the lower neutron guide channels mounted.

Figure 3: Square-box shaped UCN storage volume as such (left) and with the surrounding thermal shield mounted, suspended from the top-shielding of the UCN tank (right).

The $sD_2$ moderator itself will be inserted from top through the storage volume down to the bottom of the vertical guide. The $sD_2$ vessel is one of the technically most challenging components. The vessel will contain 30 liters of solid $D_2$ at 5 K, cooled by supercritical Helium circulating in a multi-channel labyrinth through the side wall and bottom plate. Figure 4 illustrates this vessel in some details. The top lid, a donat-shaped calotte, is machined from a forged block of ultra-pure aluminium, only 0.5 ± 0.05 mm in thickness, to minimize UCN absorption when leaving the sD2 upwards into the vertical guide, a great challenge to manufacturing. At the same time the lid has to withstand an outer pressure of 1 bar-a (i.e. atmospheric pressure outside and vacuum inside) and/or an overpressure of 3 bara from the inside.

Figure 4: Design drawing (half-cut) of the $sD_2$ moderator vessel (left), the donat-shaped top lid (centre) and vessel body with the liquid $D_2$ and He feeding pipes in the centre (right).

Besides the inner components, the ancillary systems outside the actual source are partly very complicated and demanding. One example given here is the so-called cryobox (see Figure 5), an external system confining the D2 gas-to-liquid condensation vessel, para-ortho conversion vessel and He phase separator, along with cryovalves and complicated piping for save operation in different modes. All systems will be installed in a man-high insulating vacuum vessel.

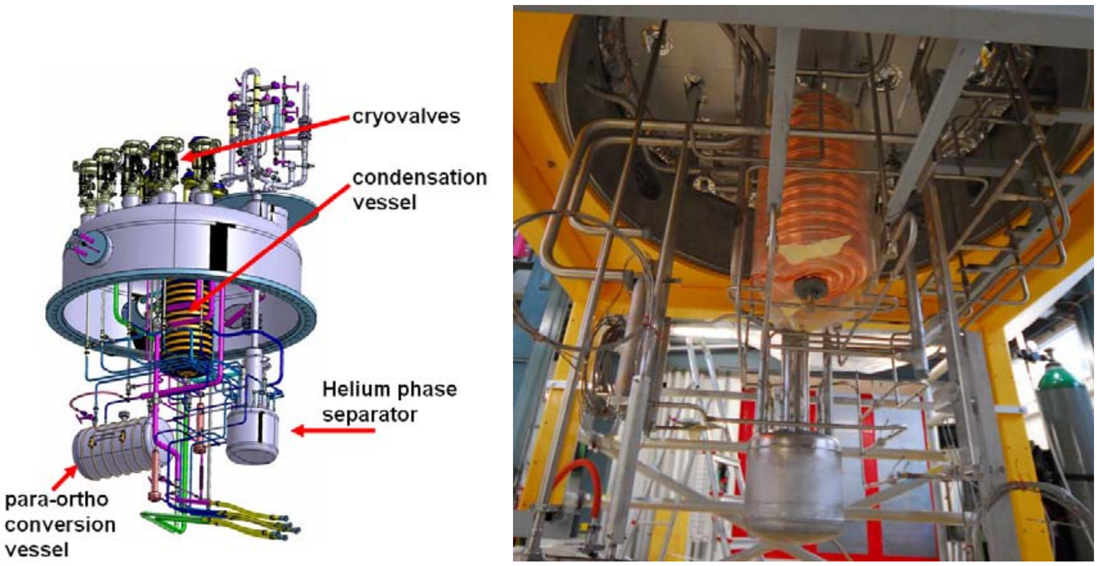


Figure 5: Left: Design drawing of the interior systems or the cryobox. Right: Photo of the systems during manufacturing, showing the condensation vessel in the centre and the He phase separator at the bottom.

## 4. First Beam Tests on Target

In December 2009, the PSI Ultra-Cold Neutron Source received the first proton beam on the spallation target. Although not all installations were ready for UCN production – the $sD_2$ moderator in combination with the storage tank was not yet installed – the system as such was ready to receive the beam. The beam was delivered in a well-elaborated sequence of 5 ms pulses, from 100 μA up to the full beam current of 2 mA. First neutrons were produced and observed in the experimental area (Figure 6). This test run successfully confirmed the beam-line and system integrity for beam-on operation and neutron production.

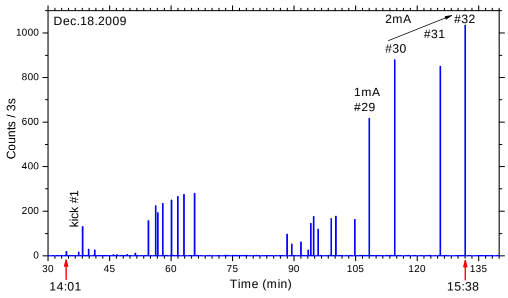


Figure 6: Observed neutron counts in the experimental area west during beam test. Neutron counts peaked at times matching unambiguously the proton beam kicks. The detected neutron intensities were found to depend on proton beam current and tuning.

Installation and commissioning of the cryogenic system, including the $sD_2$ vessel, and the commissioning of the full source including storage volume and all neutron guides are the main activities up to the envisaged completion date in July 2010.

The UCN source will serve two experimental areas. In area south, the experiment to search for the electric dipole moment of the neutron (nEDM) has been installed. The nEDM collaboration is already pursuing an extensive offline measurement program and will be ready to detect the first delivered ultracold neutrons.