ON THE WAY TO ULTRA COLD NEUTRONS AT PSI

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*At PSI, an intense source of **u**ltra **c**old **n**eutrons (UCN) is being constructed. UCN play an increasingly important role in fundamental physics and trigger interest world wide. Here, a short overview of the progress towards the realisation of this source is given.*

WHAT ARE ULTRA-COLD NEUTRONS? HOW ARE THEY MADE?

After Chadwick's discovery of the neutron in 1932 the sole way to study neutron properties was under conditions where the neutrons pass through the experimental set-up and therefore can only be observed for a short time. In 1946, Fermi discovered that neutrons were totally reflected on material surfaces under grazing angles of incidence. Later, it was discovered that ^{58}Ni and Be were especially suitable materials for neutron reflection. Neutrons with a velocity of less than about 8 m/s (300 neV) are totally reflected by these surfaces. Such slow neutrons are referred to as ultra cold, hence UCN. The accuracy of experiments exploiting UCN is currently typically limited by the available neutron densities.

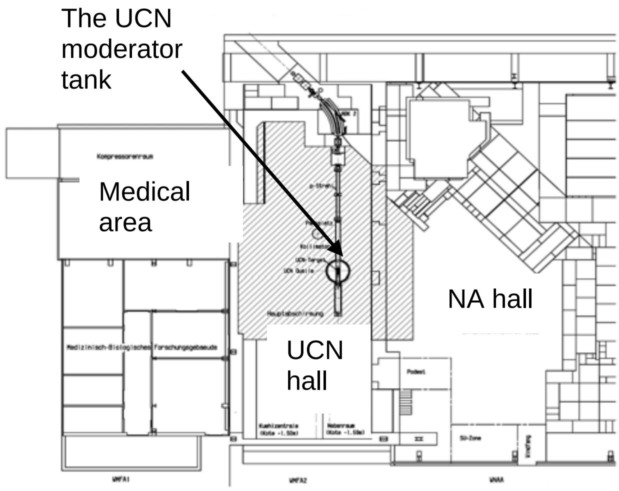

Fig. 1: Layout of the halls for the UCN installation.

At PSI, an intense source of UCN is being built. In this pulsed spallation source, a 590 MeV proton beam with a current of typically 2 mA hits a neutron production target, made out of a suitable heavy metal such as Pb, during a period of eight seconds. The proton beam is diverted from the beam line to the meson production targets M, E and the neutron production target SINQ (continuous neutron spallation source) towards the beam line to the UCN production target by means of a fast kicker magnet. The generated neutrons are cooled down to UCN energies in a moderator consisting of 4000 litres of heavy water at room temperature and 30 litres of solid Deuterium at 6 to 8 Kelvin. After production, the UCN are transferred into a storage volume from where they can be piped to the experiments. UCN behave very much like an ideal gas.

The repetition frequency for production of UCN and loading the experiments is about four pulses per hour. This means that every 15 minutes a proton beam pulse of a few seconds is required.

In 2003, the UCN project team was mainly working on development, design and construction. Primarily, the following tasks have been addressed:

ZIRCALLOY SPALLATION TARGET

The design of the zircalloy spallation target was carried out. Extensive calculations of the heavy water cooling became necessary in order to guarantee a continuous cooling especially for the target window. The experience gained during the construction of the SINQ target was incorporated. A final review and the detailed design work will be finalised in the first months of 2004.

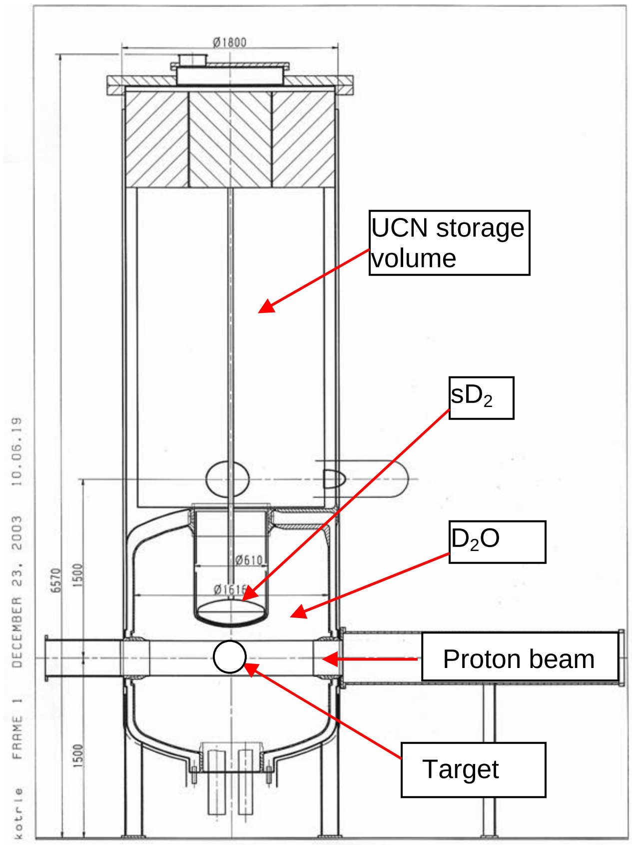

Fig. 2: The UCN moderator tank (draft design).

TARGET EXCHANGE FLASK

A preliminary design of the flask has been done. Its weight is limited by the capacity of the available 20 ton crane.

SOLID DEUTERIUM (SD_2) MODERATOR

In solid deuterium (sD_2), a small fraction of the neutrons are moderated into the UCN regime. The quality of the sD_2 crystal, e.g. its opacity and temperature, are important for the UCN yield. Development and design of the sD_2 moderator is being carried out in collaboration with PNPI Gatchina/Russia. Calculations on sD_2 heating and cooling have been done as well as investigations on the rigidity of the zirconium sD_2 vessel.

D_2 AND HE-SYSTEMS

The D_2 systems are needed to store about 30 m^3 of gaseous D_2, to liquefy the D_2, to convert the para D_2 into ortho D_2 and to transport the D_2 into the sD_2 moderator vessel.

The He-systems (cryogenic systems) are used to liquefy and consolidate the D_2 and to cool the UCN storage volume.

In 2003, R&D work and first detailed design were done. The protective gas containment, buffer volumes and pumping systems of the D_2 gas storage tank have been designed.

HEAVY WATER (D_2O) SYSTEMS

The D_2O systems are needed to thermalise the fast neutrons and to cool the spallation target. About 4000 litres, which are going to be stored in a special container in the “Tankraum” (tank compartment), are required. Before start-up of the facility, the D_2O is transferred into the moderator tank and spallation target loop. During operation, the D_2O is pumped through the cooling loop and moderator tank, where the short lived isotopes partly decay. Pumps, heat exchangers, filters and other necessary hardware will be integrated in the so-called “Kühlzentrale” (cooling centre). Design concepts have been finalised and specifications have been developed so that it is possible to purchase the pumps, valves, coolers and other necessary components. A pre-engineering draft of the storage tank and the connecting pipes has been laid out. The concept of the cooling centre and the tank compartment, including the shielding, is ready.

CONSTRUCTION OF THE UCN EXPERIMENTAL HALL

The experimental hall for the UCN source has to be modified in order to fulfil the specific requirements of the UCN facility: The existing open hall has to be tightly closed with a removable wall or door in the region of the crane tracks. The whole hall has to be thermally insulated. A pathway to the NA hall (Nucleon area) has to be realised.

Outside of the experimental hall, the water duct, lift ramp and door have to be modified. The foundation for the D_2 tanks has to be prepared.

In 2003, the concepts have been developed. These are now being used to invite tender requests.

UCN MODERATOR TANK

In the UCN moderator tank the most important components of the UCN production are united. The two moderators (D_2O and sD_2) decelerate the neutrons into the UCN energy range while the upper volume is used to store the UCN. Production of the UCN takes only about eight seconds. The storage tank serves as a buffer and provides a quasi static UCN flow to the experiments or delivers UCN synchronised with the typical storage cycle of UCN based experiments.

The design work is being carried out in collaboration with PNPI, Gatchina/Russia. A detailed concept has now been agreed upon (Fig. 2).

FIRST PREPARATORY EXPERIMENT: MEASUREMENT OF CRITICAL D_2 PROPERTIES FOR A UCN SOURCE [1]

The goal of the experiment is to measure the neutron scattering cross sections as a function of the sD_2 properties such as the quality or temperature of the crystal. A moderator chamber 10 mm thick and 30 mm wide has been built at PSI for this purpose. A neutron beam would pass through this chamber allowing the measurement of neutron transmission. An optical window perpendicular to the neutron beam is used for inspection of the sD_2 crystal by means of a digital camera and a Raman spectrometer. The whole chamber was successfully cooled down to 4 Kelvin. An UCN beam line consisting of a UCN chopper, collimators, the sD_2 target chamber and a neutron guide was designed and built at PSI. In order to measure the scattering angle of the neutrons, a novel special feature, a movable piece of neutron guide, was incorporated into the set up. Data were taken at SINQ and, at a later date, the experiment was installed at the ILL in Grenoble/France (Fig. 3).

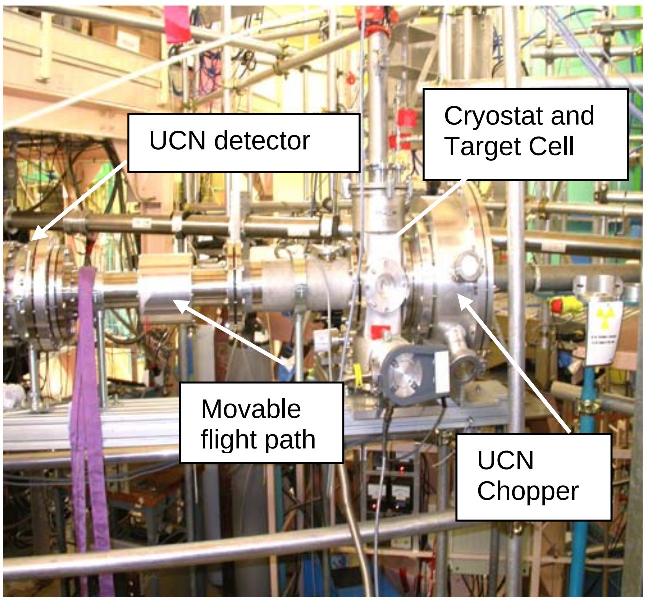

Fig. 3: The D_2 experiment installed at the UCN beam of the Institute Laue Langevin (ILL), Grenoble/France.

SECOND EXPERIMENT: MEASUREMENT OF LOSS AND DEPOLARISATION OF UCN DURING STORAGE [2]

The wall quality of a storage vessel mainly determines the UCN storage lifetime and thus also the final UCN density. Therefore, a detailed understanding of the vessel's wall properties is essential. An experiment to measure these properties has been designed and partially assembled in 2003. Data taking is foreseen at the ILL UCN source in early 2004.

Fig. 4 shows an overview of the set up: UCN enter horizontally into the switch below the sample volume. This UCN switch is designed and for the most part manufactured in the PSI workshops (Fig. 5). After equilibrium, UCN density is reached, the magnet is switched on therefore effectively closing the storage volume for one spin component while quickly draining the other one. After a certain holding time, only neutrons that have made a spin flip leave the storage volume. They are counted in a detector (at the bottom) thus allowing the measurement of the relevant storage properties.

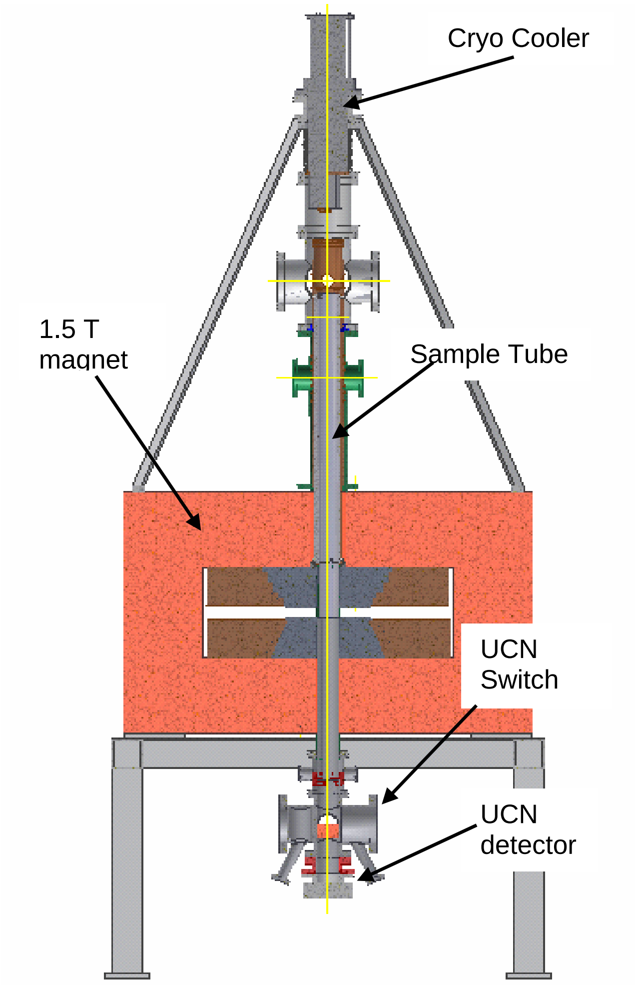

Fig. 4: Overview of the experiment to measure the wall properties of UCN storage vessels.

Fig. 5: UCN Switch: Vacuum housing (above) and movable piston (below).

OUTLOOK

The PSI UCN source is well under way and the present and future experiments will help us with the substantial design work waiting for us in 2004 together with the facility construction.

REFERENCES

[1] K. Bodek et al., *Experiments on critical D_2 properties for an UCN source*, PSI Scientific Report 2004, Volume II.

[2] T. Brys et al., *A new experiment to measure depolarisation and loss of stored UCN*, PSI Scientific Report 2004, Volume II.