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STATUS AND DEVELOPMENT OF THE SWISS SPALLATION NEUTRON SOURCES SINQ&UCN

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ABSTRACT

The present paper outlines the most recent endeavours towards an improved SINQ spallation source, describing the newly developed concept of the solid 'cannelloni' target. This target was ready for operation in spring 2009, yielding a considerable increase in neutron flux compared to its predecessor. The paper further gives a brief summary of the status of MEGAPIE. On the side of new instrumentation and methods, the status of EIGER, a new thermal TAS instrument, and the most recent developments in neutron imaging are addressed. Last not least, the status of the upcoming new Ultracold Neutron Source at PSI is briefly reviewed.

1. Introduction

The primary dedication of SINQ is the User Facility, operating at present 15 instruments for neutron diffraction, spectroscopy and imaging. Being a continuous neutron source, driven by PSI´s 590 MeV /51 MHz proton cyclotron accelerator, SINQ has to compete in terms of total performance with medium and high flux research reactors. This goal undoubtedly has been accomplished, not at least by the continuous efforts to improve the spallation targets with regard neutron production efficiency, reliability and sustainability for higher power. Motivated by the high neutron yield of the MEGAPIE liquid metal target, the recent development activities at SINQ concentrated on the improvement of the solid 'lead-cannelloni' target. The result is highlighted in the following section.

Besides improving the source itself, the development of existing and new instruments and methods as well as ancillary systems like sample environment are endeavors of high priority. The paper addresses the status of EIGER, a new thermal TAS instrument, and the most recent developments in neutron imaging.

Taking advantage of PSI's extensive experience with SINQ development and operation, a second spallation source at the proton accelerator facility is in the final phase of installation, dedicated for the production of ultracold neutrons. This new UCN source will share the proton beam with the meson targets and SINQ in a 1% duty cycle. The expected UCN density of this source is expected to exceed the presently most powerful one at the ILL by a factor of 100. The present paper briefly addresses the status of this source, referring to more extensive papers in this volume.

2. Recent developments of the SINQ solid target

For many years, starting in 2000, the spallation targets operated at SINQ were made of lead rods contained in austenitic stainless steel 316L tubes (Mark 3). This design was nicknamed ‘cannelloni’ target. As a special feature, all SINQ targets carried rods filled with miniaturized samples of different materials, metals, steels and ceramics, for studying radiation damage effects induced by high energy protons and spallation neutrons. This so-called SINQ Target Irradiation Program STIP [1,2] was initiated in 1998 as an international collaboration, and is as strong as ever.

Having experienced the high neutron yield of the MEGAPIE liquid metal target, exceeding the standard lead-cannelloni target by about 80%, PSI started a renewed initiative for improving the solid target towards higher neutron yield, not neglecting reliability and sustainability for higher power.

One option for improving the SINQ solid lead/steel cannelloni target, the replacement of the steel cladding by Zircaloy (Zr) tubes, was tested with Target 5 of SINQ (operated in 2004/2005): where three rows of Zr-clad rods had been implemented at both peripheral sides of the reaction zone, and four individual test tubes in the centre. After two years of service and more than 10 Ah of proton charge received, all the Zr-clad tubes were found in excellent shape. Visual inspection (Figure 1) and neutron radiography did not show any indication for damage or degradation. Metallographic investigation of three test tubes confirmed an undamaged, homogeneous bulk structure, at the outside covered by a thin, about 30 µm layer of most likely oxide or hydride, see Figure 2.

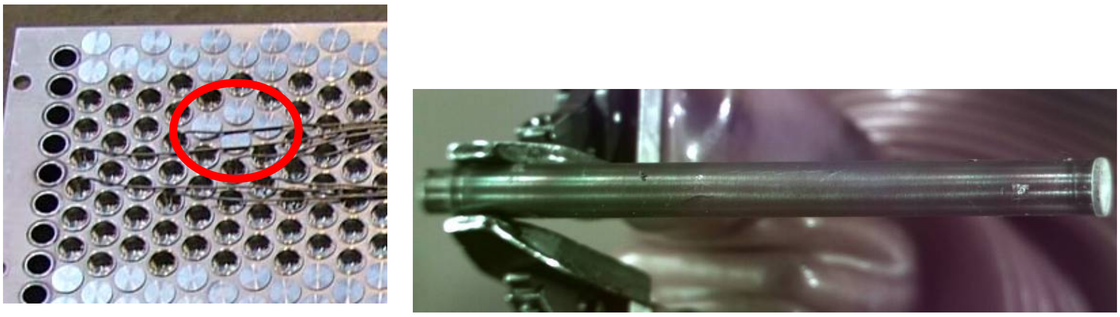

Figure 1: Left: Rod array of SINQ Target 5: The Zr-clad rods are clearly distinguished (flat covers) from the steel-clad ones: three peripheral rows and an assembly of 4 rods in the centre (encircled). Right: Visual inspection of one of the 4 central Zr-clad rods after 2 years of irradiation in the SINQ target.

Besides the normal beam exposure the tubes sustained two severe beam excursions (unintentionally focused beam) with peak current densities around 70 µA/cm2 for 8 hours. Although these beam excursions caused severe damage in two of the central steel-clad rods, the Zircaloy rods did not suffer any damage or degradation. The undamaged bulk structure gives promising perspectives that such a high current densities may be possible also for extended periods of time.

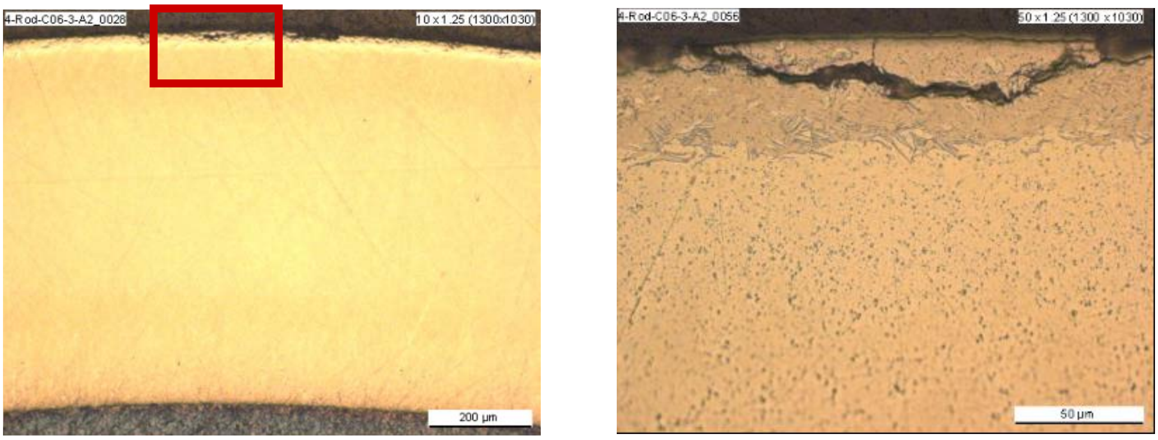

Figure 2: Left: Typical metallographic observation from a polished cross section of the Zr-cladding tube wall (thickness 750 µm) after 2 years irradiation in SINQ, showing an undamaged, homogeneous bulk structure. Right: higher magnification of the square marked on the left, distinguishing the about 30 micron thick layer of most likely oxide or hydride at the outer tube surface [3].

With the proven robustness of the Zr-cladding the steel cladding was completely replaced by Zr-tubes in a new target (Target 6), granting a neutron yield increase between 10 and 13% compared to the steel-cladded predecessor. Motivated by this first step, the following improvements were realised in the follow-up Target 7: Closer packing of the rods, a circular cannelloni support structure replacing the square-shaped frame, lead reflectors (blankets) in the cooling water gap around the cannelloni structure, inversion of the hemi-spherical beam entrance window of the safety hull to minimize the energy loss of the protons before entering the cannelloni part of the target, and omitting (ad interim) the STIP sample rods. Figure 3 shows the design drawings of this target, highlighting the main new features.

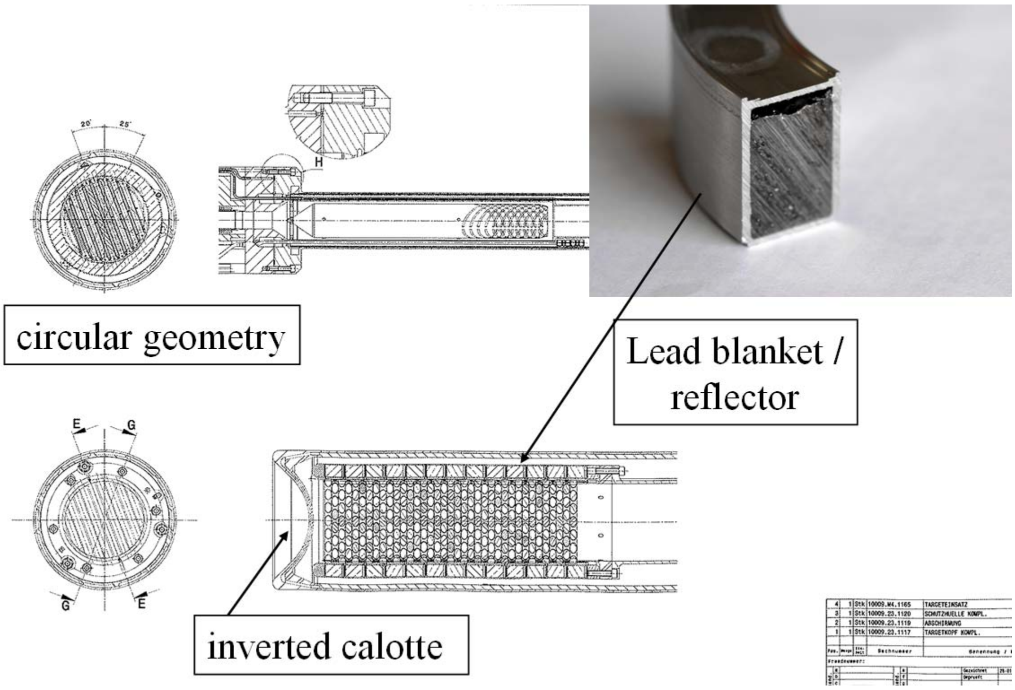

Figure 3: Design drawing of SINQ Target 7, highlighting the main new features: circular geometry, the lead blanket/reflector and the inverted calotte.

The so modified Target 7 started operation in early 2009. Figure 4 shows photos of the target reaction zone, without and with the lead reflector, ready for the safety shroud to be mounted. For this target simulations predicted improvements in useful neutron flux by 35 to 40%, the already realized increase from Zr-cladding not counted. Flux measurements at two beam ports, one for thermal and the other one for cold neutrons, nicely confirmed the calculated flux increase by 40% on average.

Figure 4: SINQ Target 7, without (left) and with the lead-containing reflector rings (right), ready for getting the safety shroud mounted.

Figure 5 illustrates the complete history of SINQ targets operation since the start-up in 1997. The bar chart shows the relative neutron production in comparison to the yearly accumulated proton charge. The corresponding numbers give the relative neutron yield compared to the day-one solid Zircaloy target (labeled 1.00). For Target 7 in 2009 this value is 2.19, which means a relative gain in primary neutron yield of about 120 % normalized to the same proton beam power. Only MEGAPIE, the Lead Bismuth Eutectic liquid metal experimental target operated at SINQ in 2006 surpassed this value by about 15%.

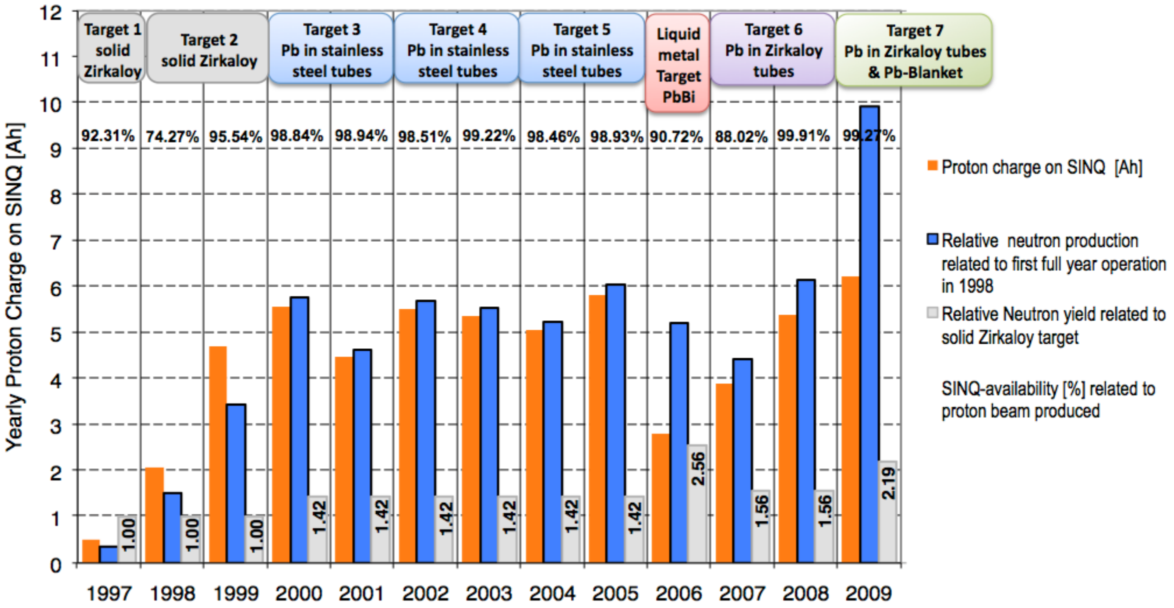

Figure 5: History of yearly accumulated proton charge and related neutron yield. The numbers in the top row indicate the availability of SINQ (for most years >98%).

Prompted by the gain in neutron production at SINQ a systematic investigation of the impact of variations in beam geometry has been started. Unexpectedly, experimental results demonstrate significant flux increases at instruments when reducing the extension of the proton beam footprint compared to the standard settings. Figure 6 shows the results obtained for systematic variation of the beam footprint. Starting from reference conditions the beam was first widened (e.g. 10 % in x-dimension) and then narrowed, for x and y directions separately and finally, in both extensions simultaneously. Almost 10 % variation in neutron fluxes was observed between the widest and most narrow beam foot prints investigated. The beam current was very constant at 1000 µA during the whole campaign. Initial numerical simulations reproduce the general tendency; more detailed calculations are ongoing.

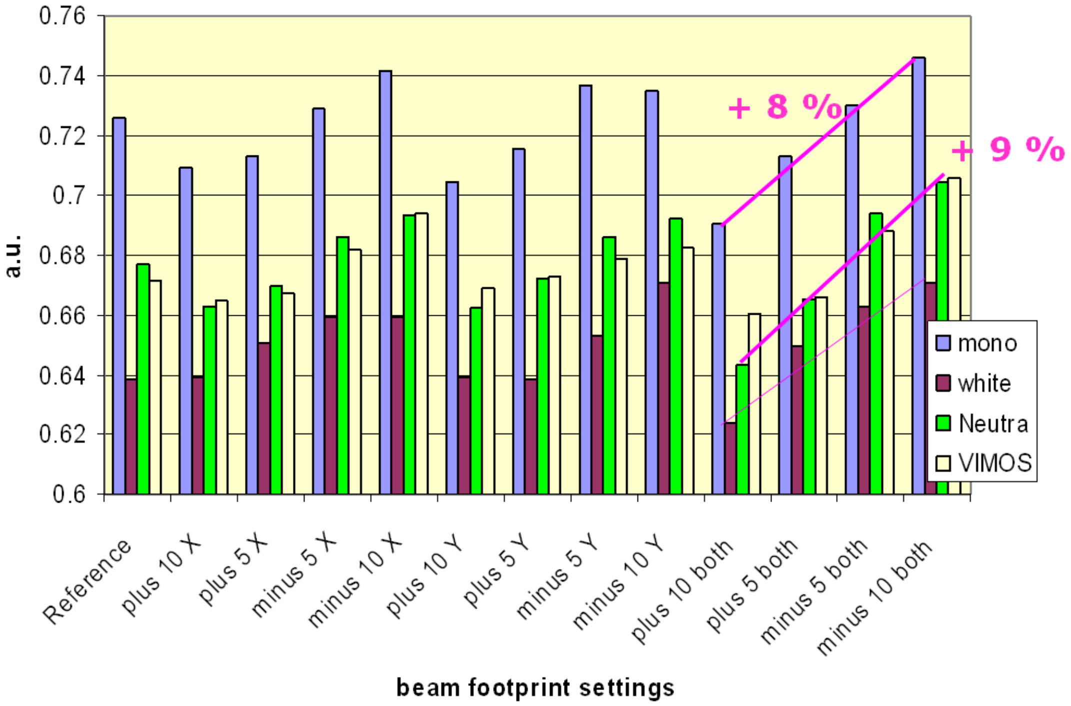

Figure 6: Results obtained for systematic variation of the beam footprint, showing almost 10 % variation in neutron fluxes between the widest and most narrow beam foot prints investigated. The beam current was very constant during the whole campaign at 1000 µA.

3. Status of MEGAPIE

At the time of the previous ICANS XVIII meeting the MEGAPIE target had just finished the 4 month irradiation period in SINQ, and had been stored in the SINQ storage pit. In the meantime, substantial activities were initiated towards dismantling, cutting and sample extraction for the upcoming Post Irradiation Examination (PIE). Cutting was accomplished in the hotcell of ZWILAG, the Swiss intermedate storage facility for radioactive waste. The transport from PSI to ZWILAG, a jouney of about 1 km, took place in July 2009. It looked a bit spectacular but happened without any problem. The year befor, the cutting action had been exercised by extensive 'cold-tests' of any detail of the full chain of actions. Meanwhile the pieces of the MEGAPIE target are packed in two containers, one conditioned for disposal, the second one to be transferred to the PSI hotlab for specimen cutting and preparation of the PIE. More details on these activities you can find in [4].

Figure 7: xxx

4. New instrumentation and methods at SINQ

4.1 EIGER – a new thermal neutron spectrometer at PSI

To complement the cold neutron spectrometer suite at SINQ (TASP, RITA-2, FOCUS and MARS), a thermal neutron spectrometer for Enhanced Intensity and Greater Energy Range (EIGER) is currently under construction. The use of thermal neutrons will extend the achievable energy transfers from currently 10-15 meV to 70 meV, and for applications where resolution can be relaxed provide 1-2 orders of magnitude gain in intensity down to 2 meV energy transfers. Figure xx shows the components of the secondary spectrometer which are already in place on a high-precision granite flor for air cushen movement, and the base monochromator shielding with turning unit which has just been setup. The instrument is expected to be ready for operation in fall 2010.

Figure 8: The secondary spectrometer of EIGER in place on the high-precision granite (left) and the lower part of the base monochromator shielding with turning unit.

4.2 Neutron Imaging @ SINQ: advanced method developments

Among the 15 neutron instruments at SINQ are two dedicated for neutron imaging: NEUTRA for thermal neutrons, and ICON viewing the cold D_2 moderator. With about 100 projects at both beam lines per year which are performed together with external scientific users, commercial partners and for own projects and further developments, the two operating imaging beamlines are very lively used. A third beam line is under preparation (BOA, the former FUNSPIN installation) to be used partly for neutron imaging. It has much higher contributions in the spectral range above 4 Å and provides polarized neutrons.

The neutron imaging facilities are equipped with stat-of-the-art digital imaging systems, mainly based on CCD sensors, which deliver the transmission images from a neutron sensitive scintillator screen. By this way, sequences of images can be obtained within a few seconds or even faster. This enables the high performance tomography, and also the study of time dependent phenomena.

To raise the detection limit in respect to spatial resolution, a micro-tomography system was built recently with pixel size in the order of 10 µm and a field-of-view of 27 mm [5]. Figure xx shows an example. There is ongoing research to improve the performance of the scintillator screens in respect to efficiency and inherent resolution. With the help of a tilted detector alignment [6] the observation area is stretched in one direction and the resolution is improved further by at least a factor of 4.

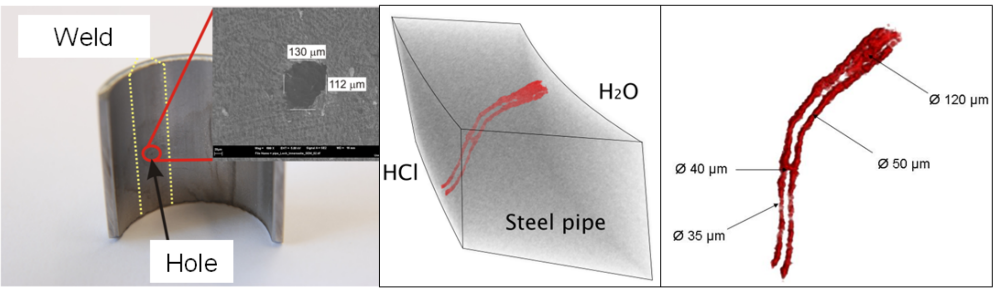

Figure 9: Micro tomography steel pipe, discovering a double channel interpenetrating the tube wall at a weld position. The spatial resolution is clearly below 35 µm.

Energy selective imaging has been proven to be a very useful tool for material research which promises the study of texture and possibly strains in metallic structures non-invasively with the high inherent spatial resolution and in very short time [7]. This topic will be further enhanced by the installation of a single crystal based selection system (ESI project) which will enable to improve the energy resolution to about 5% compared to the existing velocity selector resolution of only 15%.

The utilization of phase information from the image data will be enhanced further after very successful trials at ICON [8] by a dedicated setup based on grating interferometry. In addition, the phase propagation method for spatially coherent neutrons will be further improved using the 1 mm aperture at ICON together with the detector with the highest possible spatial resolution.

5 UCN – the new Ultracold Neutron Source at PSI

The PSI UCN source is a new type of ultracold neutron source based on neutron production via spallation and subsequent separated neutron storage. It is driven by the full 590 MeV proton beam from the PSI ring cyclotron ($I_p > 2mA$) using several seconds long pulses at a 1% duty cycle. A lead/zircaloy cannelloni spallation target is used for neutron production. The proton beam-line up to the target was successfully tested in December 2009 and the first neutrons were produced and observed. A large D_2O moderator, a solid deuterium (sD_2) converter, a storage volume and the UCN delivering neutron guides are the main system components. The UCN density delivered to experiments is expected to be about 1000 UCN/cm^3, an increase of almost two orders of magnitude over the present best source (at ILL). Figure xx shows the finished setup of the UCN storage volume surrounded by the heat radiation shield during a test installation in Feb. 2010. With the completion of the installations, mainly the cryogenic system including the solid D2 moderator vessel, and the commissioning of the full source we expect to start UCN production in summer or early fall 2010. For more details we refer to [9]

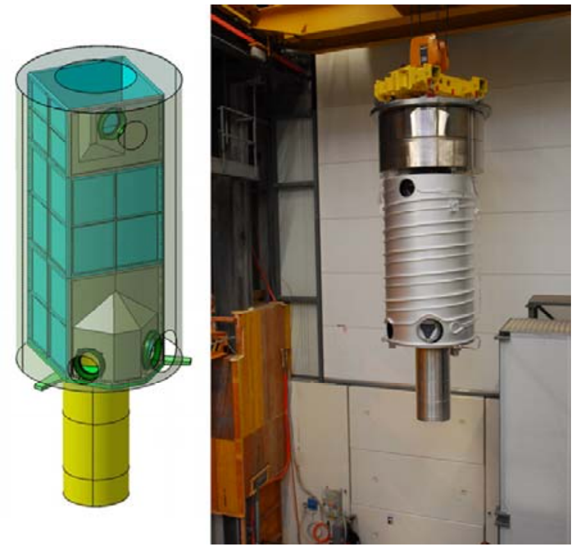

Figure 10: Finished setup of the UCN storage volume surrounded by the heat radiation shield, vertical UCN guide on the bottom and ~10 tons steel shielding on top (about 5m tall): a) design drawing, b) during transport to the final position in the UCN tank.

6 Summary

The improvements of the SINQ solid target from the first, solid Zircaloy rod target to Target 7 accumulate to a total increase in useful primary neutron flux by a factor of 2.19. Only MEGAPIE, the Lead Bismuth Eutectic liquid metal experimental target operated at SINQ in 2006 surpassed this value by about 16%. In total, together with a proton beam current upgrade by a factor of 1.75 since the start-up of SINQ, the users at present benefit from a factor ≈4 of higher neutron flux at the instruments.

The MEGAPIE project is at the onset of the last, but not least important phase: the sample preparation and the PIE. When these activities will be accomplished, hopefully until the end of 2012, then the MEGAPIE project has really proven that a liquid metal target for MW beam operation can be conducted from A to Z, from the concept through operation to final investigations and disposal.

Besides ever ongoing improvements at the instruments and methods at SINQ, a very important and promising project at PSI is approaching completion: A second spallation source driven by the full-power proton beam, dedicated for the production of Ultra Cold Neutrons. The facility promises to surpass the at present strongest ILL-UCN source by almost 2 orders of magnitute in UCN density at the instruments. The future will show whether this ambitious goal will be accomplished.

7 References

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