SINQ and UCN – two high-power spallation sources operating at PSI

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Abstract. This paper presents an overview on most recent developments at and around SINQ, addressing accelerator and target performance, and the control system refurbishment. New instrument developments focus on EIGER, the new thermal triple axes spectrometer now at the start-up of operation, the strain scanner POLDI in a phase of major refurbishment and upgrades, and BOA, a new universal beamline. The status of MEGAPIE is briefly reported, after successful dismantling now having entered the PIE phase. One of the highlights at PSI in 2011 was the successful commissioning of UCN, the new spallation source for ultracold neutrons, which started operation in August 2011. First operation experience is briefly addressed. Details on this endeavour are reported in separate paper of this volume [1].

1. SINQ operation and developments

At the end of 2011, the Swiss spallation neutron source SINQ celebrated its 15th year of successful operation. The year 2011 was outstanding for SINQ with respect to both target and user operation. The target received a total charge of 6370 mAh, which exceeds clearly even the previous record of 6220 mAh from 2009. This is especially remarkable, since the operation period was shorter than usual (no accelerator operation in December). The gain was caused by three reasons: (i) an outstanding performance of the proton accelerator with an availability of 91% (ii) the further increase of the proton current with many highly stable periods of 2.2 mA (of which SINQ receives ~1.6 mA) and (iii) the again outstanding availability of SINQ itself (97%) with respect to the proton accelerator.
The facility meanwhile hosts 17 instruments for neutron diffraction, spectroscopy and imaging, 12 of them in the user program. The excellent technical boundary conditions allowed almost 440 scheduled experiments on the 12 SINQ instruments.
The presently operated spallation target (target 8) is a second edition of the compact Zr-canned lead ‘cannelloni’ target, in detail described in [2]. The first version (target 7, see Figure 1), having been in service in 2009/2010, is now awaiting inspection, dismantling and disposal. Target 7 had shown a problem, probably caused by some very fast abnormal deflection of the beam out-of-centre, hitting the

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edge of the collimator and most likely also the Al-canned lead blanket. The failure was detected by lead-spallation products, in the first place 127Xe, in the water of the target cooling circuit. The inspection planned for early summer 2012 is expected to give information about the cause and location of the failure in order to allow future improvements.

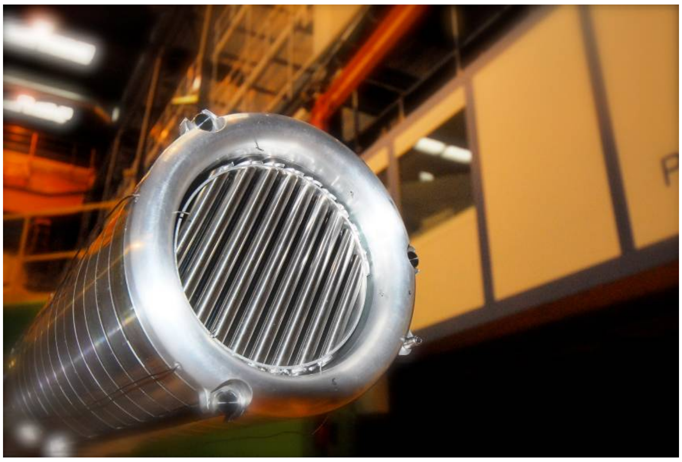

Figure 1: The compact Zr-canned lead-‘cannelloni’ target, of circular shape surrounded by a lead blanket/reflector canned in Aluminium

In the presently operated target 8 such improvements could not yet be implemented, but so far it operates well. This target again (after a break with target 7) carries several tubes with STIP (SINQ Target Irradiation Program) samples, continuing this very important materials research program [3,4]. In spite of these STIP tubes, which were expected to reduce the neutron yield by up to 5%, our routine flux measurements by gold foil activation, within the scatter band of such measurements, did not reveal a flux decrease compared to target 7. Figure 2 shows the updated version of proton charge and related neutron production history. The year 2011 set the record in terms of highest proton charge accumulated and neutrons produced since the start-up of SINQ

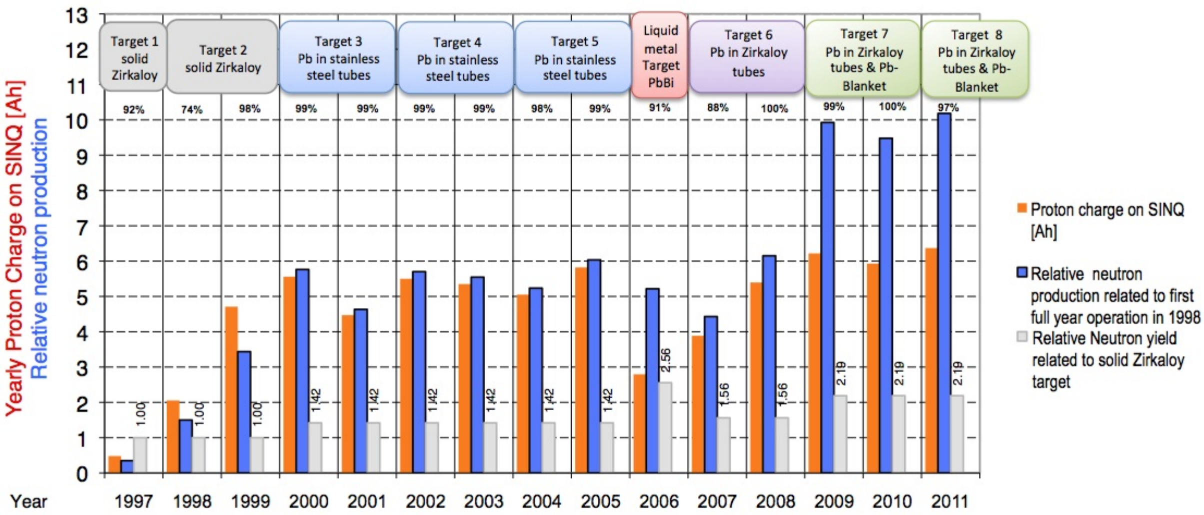

Figure 2: History of yearly accumulated proton charge on the SINQ target and related neutron production

The major upgrade project of SINQ, ongoing ‘in the shadow’, is the replacement and refurbishment of the entire control system, including the surveillance and safety systems (fast and slow beam-shutoff systems) and all operation- and control devices of the ancillary systems. This refurbishment is a major endeavour, partitioned in 3 slots timely distributed over 4 yearly shutdowns. During this period, both systems, the old and the new one, must be reliably operational in parallel, not to disturb the user operation of the facility.

2. New instruments and user installations

2.1. EIGER – a new thermal neutron spectrometer at PSI

EIGER is a new thermal triple axes spectrometer, complementing the cold neutron spectrometer suite at SINQ (TASP, RITA-2, FOCUS and MARS). The use of thermal neutrons will extend the achievable energy transfers from currently 10-15 meV to 60 meV.
The primary spectrometer includes a variable virtual source and a monochromator shielding that has ample space for up to four large monochromators. At present the instrument is equipped with a double focusing PG monochromator. The secondary spectrometer is of conventional type with horizontal focusing analyzer and a single 3He-tube detector. Non-magnetic monochromator shielding and supports allow for magnetic fields up to 15 T in the sample area. For the future, a flat cone type secondary spectrometer and a polarized neutron option are planned.
The construction of EIGER has been finished. Figure 3 shows a top view of the instrument and a photo of the EIGER double focusing monochromator. The instrument should be ready for first users in summer 2012.

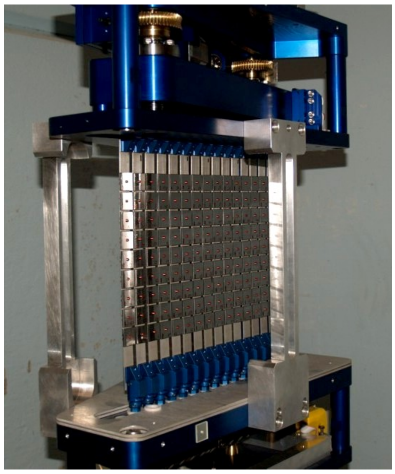

Figure 3: left: The new EIGER thermal TAS spectrometer at SINQ. The strikingly massive primary instrument provides ample space for up to four large monochromators. At present it is equipped with one, double focusing PG monochromator (shown at the right)

2.2. The engineering diffractometer POLDI

POLDI (Pulse OverLap Diffractometer) is a multiple pulse overlap TOF diffractometer, designed for applications in materials science and optimized for strain scanning experiments. The primary part of the instrument houses a disc chopper with 32 slits arranged in pseudo-random distribution and a 10 m guide section with an elliptical neutron mirror integrated. The secondary instrument has a heavy load sample table and a one dimensional position sensitive 3He detector with a set of radial collimators in front. For more details see [5,6].
POLDI operates successfully since 2003. In the meantime, besides static strain measurements the applications extended to in-situ measurements of the response of materials to externally applied stresses. One example of high technological interest is the stress sharing of the different components in composite materials. Figure 4 shows a photo of two young scientists at PSI, which align a tensile sample inside of a mechanical load frame installed at POLDI. These in-situ experiments provide an insight into the deformation behavior of metals and alloys by means of neutron diffraction [7].

To facilitate and optimize performance in particular for these new applications, a major upgrade program is under way. Three main projects have been launched: i.) A new chopper with magnetic bearings, will allow higher rotation speed for better resolution. ii.) A biaxial test rig for ±100 kN load for the main axis and ±50 kN for the second axis. In addition, the main axis will be equipped with a ±200 Nm torque actuator and a furnace for temperatures up to 1200oC. iii.) The most challenging upgrade is the development of new scintillation-based detectors for POLDI. A twin-set of detectors is planned viewing under 90° from opposite directions to the sample for simultaneous measurements in two principal strain axes. The new detectors will be based on scintillation in combination with APDs, avalanche photo diodes. Furthermore, in the past user-friendliness at POLDI was already improved by providing special equipment for fast and precise sample positioning and by installing enhanced software for instrument operation and data handling.

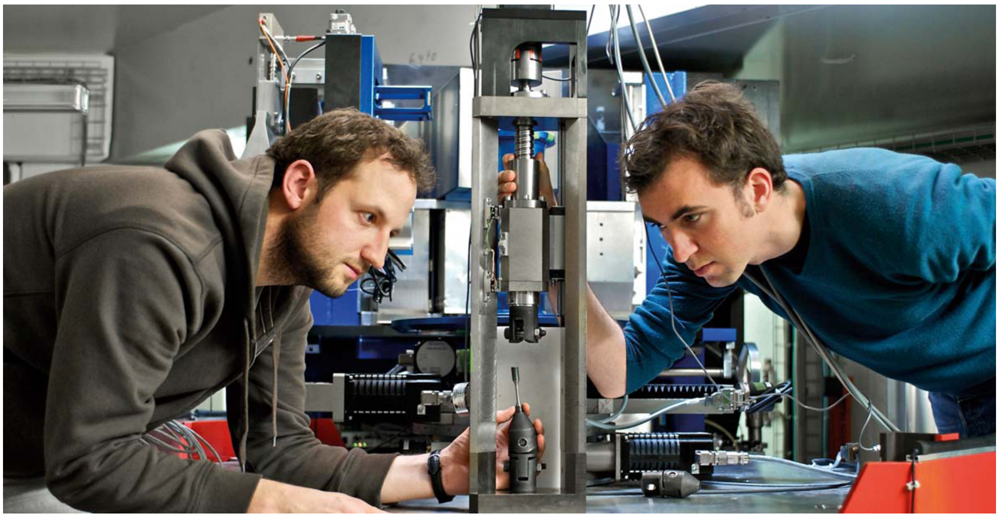

Figure 4: Two young scientists at PSI adjust a tensile sample inside a mechanical load frame installed at the POLDI instrument. These in-situ experiments provide an insight into the deformation behavior of metals and alloys by means of neutron diffraction.

2.3. BOA, a new Beamline for neutron Optics and other Approaches

BOA is replacing the FUNSPIN experiment which was dedicated to neutron decay and time reversal experiments in particle physics. BOA inherited a polarized beam originating from the cold D2 moderator of SINQ, and a large experimental bunker.

At the exit from the polarizing bender and a successive guide section, the beamline now has two flexible positions for beam adjustment devices, spin flippers or a chopper. Three fully motorized positions further downstream allow a flexible setup of various kinds of equipment, sample environment, detectors etc. The intention is to provide a flexible beamline for multi purpose setup, for tests of new equipment, neutron optics devices, or for load relief from other beamlines. For example, neutron imaging with polarized neutrons is one of the most interested candidates for occasional use of BOA. Figure 5 gives a glance on the preparation of the first experiment at BOA in summer 2011.

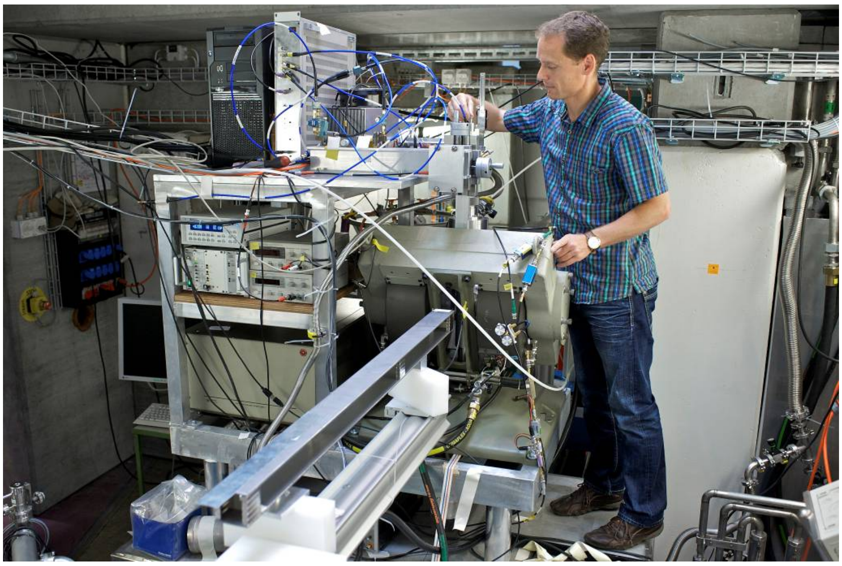

Figure 5: Our colleague Uwe Filges preparing the first experiment at BOA in summer 2011

3. MEGAPIE in the PIE phase

The MEGAPIE liquid metal (Lead Bismuth Eutectic, LBE) target had been operated in SINQ for 4 month at full beam power, and, after an appropriate cooling period, was successfully dismantled and cut in slices in the hot cell of ZWILAG, the Swiss intermediate storage facility for radioactive waste. Selected slices were packed in a special transport container and transferred to the PSI Hotlab for specimen cutting and preparation for the post irradiation examination PIE.
First steps of the PIE and the sample extraction process have started. The related activities in the Hotlab can be grouped in 8 major steps:

1. Visual inspection of all sample pieces delivered from ZWILAG
2. Gamma mapping of the tip of the AlMg3 safety shroud
3. Thickness measurements of the beam entrance window by ultrasonic probing
4. LBE sample taking
5. Melting out the LBE from structural materials
6. Raw-Cutting of the PIE structural material samples
7. Cleaning of the samples from LBE (where needed)
8. Fine-Cutting of the PIE structural material samples

Meanwhile, steps 1 – 4 have been accomplished. Gamma mapping determined the realistic time-average proton beam footprint, necessary as input to refine calculations of the dose and temperature distribution in the target during operation. About 70 LBE samples were taken from different positions across the target volume, axial and radial, with particular emphasis for samples close to or at the interfaces to the walls. These samples are necessary to determine the nuclide inventory and its distribution across the target volume. The □ measurements are already finished. While 207Bi is distributed homogeneously as expected – since Bi is a macro-component of the target material - strong inhomogeneity occurred for some of the other elements. Bulk LBE contains only noble metals that have a significant solubility in LBE (e.g. 194Au). Radionuclides of elements that have low solubility in LBE or are sensitive to oxidation –for instance Hf/Lu – are only detected in samples taken at the LBE/steel and LBE/cover-gas interfaces. These findings confirm earlier results [8].

Step 5, melting out of the LBE, has started in Dec. 2011, and should be finished in April 2012. After that, steps 6 – 8 are planned, with the aim to have the final samples ready for testing or shipping to the partners latest in September 2012.

4. UCN – the new spallation source for ultracold neutrons

The UCN facility operating a second spallation target station at PSI has started routine operation in August 2011. The full 2.2.mA proton beam @590MeV is kicked towards the UCN spallation target with maximum pulse duration of 8s at a maximum of 1% duty cycle. Typical fully-automated operation over many days was delivering full beam in 4s pulses every 480s.

As for SINQ, a lead/zircaloy cannelloni spallation target is used for neutron production, at SINQ inserted vertically from top, at the UCN source inserted horizontally [9]. A large D2O moderator, a solid deuterium (sD2) converter together with its complex cryo-system, a storage volume and the UCN delivering neutron guides are the main system components.

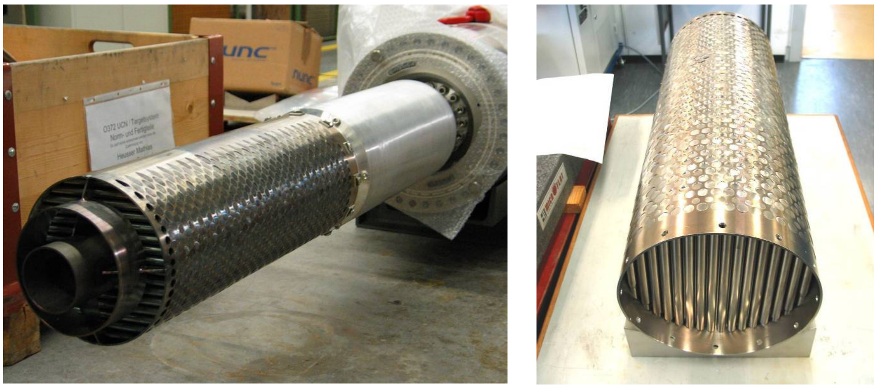

Figure 6: The UCN spallation target [9] consists of 760 Zr-II tubes filled with lead. A heavy water flow between the tubes is used for cooling.

The first 4 months of operation were dedicated to source characterization and optimization. The rather demanding fast deflection (kicking) of the accelerator beam to the UCN target and back was readily accomplished. All systems worked reliably and according to specification. Successful conversion of para- to ortho-deuterium could be confirmed. The most crucial and most difficult optimization procedure is that of the controlled freezing of the deuterium in the large (30 liter) sD2 converter to obtain a sufficiently high-quality solid D2 crystal, a tedious and long-lasting procedure which requires distinct patience. Details on the first operation experiences are given in a separate paper [1].

5. Summary

After 15 years of successful operation of SINQ, in August 2011 PSI has started the operation of a second spallation source, UCN, dedicated for the production of ultracold neutrons. The UCN source shares the proton beam, 2.2 mA @ 590 MeV, in a pulsed fashion with SINQ and the meson production targets at a duty cycle of 1%.

SINQ continued operating with the usual reliability and availability as the years before. At present, a second version of the new compact spallation target, lead-‘cannelloni’ with Zr-canning, is in service, this one again carrying various STIP samples. The qualification of the Zr-canning and our operation experience may be of particular interest for upcoming new spallation sources.

The MEGAPIE target, after having been cut in slices, has now entered the PIE phase. First results are available, samples from LBE have been taken and samples from the structural material are in preparation.

Recent accomplishments on the side of instruments and user installations focus on i) EIGER, a new thermal neutron spectrometer recently commissioned, ii) the engineering diffractometer POLDI, which at present is in a phase of major upgrades, and iii) BOA, a new Beamline for neutron Optics and other Approaches.

6. References

[1] B. Blau, B. Lauss, et al., Proceedings of ICANS XX, Bariloche, this volume (2012)

[2] W. Wagner et al., Status and Development of the Swiss Spallation Neutron Source SINQ, Proceedings of ICANS XIX, Grindelwald, CH (2010)

[3] Y. Dai, G. S. Bauer, Status of the First SINQ Irradiation Experiment, STIP-I, J. Nucl. Mater. 296 (2001) 43

[4] Y. Dai, X. Jia, R. Thermer, D. Hamaguchi, K. Geissmann, H.P. Lindner, M. James, F. Gröschel, W. Wagner, G.S. Bauer, The Second SINQ Target Irradiation Program, STIP-II, J. Nucl. Mater. 343 (2005) 33

[5] U. Stuhr, Nucl. Instruments and Methods A, 545 (2005) 319 – 329,

[6] U. Stuhr et al., Nucl. Instruments and Methods A, 545 (2005) 330 – 338

[7] M.A. Weisser, A.D. Evans, S. Van Petegem, S.R. Holdsworth, H. Van Swygenhoven, In situ room temperature tensile deformation of a 1% CrMoV bainitic steel using synchrotron and neutron diffraction, Acta Materialia, 59, Issue 11, June 2011, Pages 4448–4457

[8] D. Schumann, J. Neuhausen, Non-homogeneous distribution of radionuclides in proton-irradiated liquid-metal targets, PSI Scientific Report 2010 p.52; http://www.psi.ch/info/MediaBoard/PSI_ScientificReport_2010.pdf

[9] M. Wohlmuther and G. Heidenreich, The spallation target of the ultra-cold neutron source UCN at PSI, NIMA 564, (2006) 51-56