COMMISSIONING OF THE 1 MW SPALLATION NEUTRON SOURCE SINQ

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Abstract

First beam tests were carried out successfully on the spallation neutron source SINQ at Switzerland's Paul Scherrer Institut (PSI) in December 1996. SINQ is driven by the PSI 590 MeV isochronous cyclotron which is now operating routinely at a current level around 1.5 mA. After running at 20 μA for several hours to enable radiation surveys and neutron beam measurements on December 3, the current was raised in steps to its maximum value within 3.5 hours on December 4, making the power on SINQ the highest one ever reached on a spallation target so far.

The tests allowed measurements of neutron and gamma radiation levels around and in the extracted neutron beams and guides and included beam transport studies in the new section of the proton beam line. At the same time the whole target system including its associated cold neutron moderator was tested successfully.

1 THE ACCELERATOR FACILITY AT PSI

PSI has been operating a cyclotron facility for the production of intense proton beams since 1974. The accelerator complex and its evolution during two decades having been described previously (cf. e. g. [1]), only its main features will be summarized here. Protons are accelerated to their final energy of 590 MeV in an isochronous cyclotron with an injection energy of 72 MeV. Its main components are 8 sector magnets, 4 acceleration cavities (50 MHz) and 1 flat top cavity (150 MHz). The injector is also an isochronous ring cyclotron, with 4 sector magnets, 2 coaxial resonators for the acceleration and 2 flat top cavities. It is fed from a Cockcroft Walton type preaccelerator of 0.87 MeV. The 590 MeV protons from the main ring, after passing through two pion production targets in sequence used to be stopped in a beam dump.

The facility was originally designed for a current of 100 μA, but very soon was routinely operated at a level up to 250 μA with a limitation of 350 μA arising from the available RF-power. Beam dynamics considerations, however, yielded an estimated intensity limit between 1 and 2 mA. This promising outlook into a high current future at PSI stimulated the planning of a spallation neutron source, called SINQ, which would make use of the remaining beam after the targets. With a view on this new facility an upgrading program for a current up to 1.5 mA, corresponding to a beam power of almost 1 MW, was started in the late 70's. The main steps in the upgrade were:

- Replacement of the original Philips injector cyclotron by a new Injector 2, which was commissioned in 1985 and reached 1.5 mA in 1990.
- Adaptation of the two target stations (in 1986 and 1990) to the future megawatt beam and improvement of the secondary beam lines.
- Stepwise upgrade of the 590 MeV ring between 1990 and 1995 during the annual shut down periods, increasing the cavity voltages by about 50 % and the available RF-power per cavity from 200 kW to about 600 kW.
- Replacement of all injection and extraction elements, installation of improved local shielding, new beam diagnostics and upgrade of the control system.

Fig. 1 summarizes the performance of the accelerators for the period 1974 to 1996. Although the beam current and the charge accelerated per year increased by a factor of 6, the average extraction losses stayed almost constant at a level of about 0.3 μA since 1989. To date, the highest beam current measured on target was 1.7 mA.

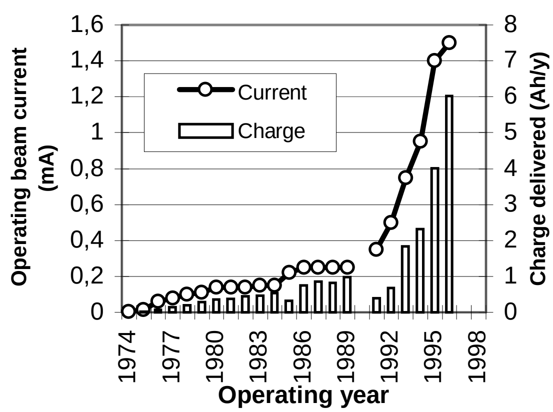

Fig1. *Evolution of the beam current of the PSI accelerators from 1974 to 1995. The bars show the total beam charge delivered per year. In 1990 one of the two target stations was completely rebuilt and the ring upgrade program was started.*

For the users of the facility, the stability of the beam and its availability are of similar importance as the beam current. The availability, as measured over periods of one week, is between 80% and 92% (in 1996). Figure 2 shows the operating current, the weekly average beam current and the number of beam trips of more than 1 min

† The authors stand for the whole project team and would like to acknowledge the continuing support by the PSI management to accomplish this goal and the enormous effort of all persons involved to get the facility ready in time for these tests.

duration, which are mainly caused by voltage breakdowns in cavities and electrostatic devices

After several years of high power operation the activation of the accelerator components is still within levels for normal hands on maintenance. Only exposed components and their suroundings, such as extraction devices, beam splitters and targets are equipped with local shields and need remote handling.

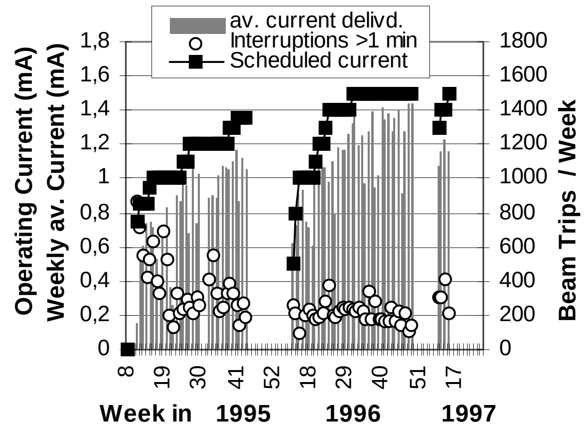

Fig. 2: *590 MeV operation of the PSI accelerators since 1995.*

2. THE NEW SECTION OF PROTON BEAM LINE

The new section between the second, thick target (TE) and the SINQ target, installed from 1990 onwards, is 55 m long. It features 4 bending magnets, 12 quadrupole lenses, 9 pairs of profile monitors, 5 horizontal steering magnets, 7 collimators and 3 pairs of slits. The apertures of all beam line elements are between 20 and 26 cm. This makes the magnets relatively heavy (up to 60 tons for the final 64 degree bend). Optically this beam line consists of a long stretched "Z" and a flat "U". Because the protons enter the SINQ target region vertically from below, the beam line is rotated into a vertical plane. Just below the target, 3 collimators prevent beam line components from being activated by back scattered neutrons and avoid deposition of protons on the rim of the entrance window to the target. The position and width of the beam entering the target region can be monitored by electrically insulated electrode segments mounted in front of each of the 3 collimators.

The main components of this beam line are grouped in two regions: the first one behind TE is in the old experimental hall, and the second one in a new 11 m deep channel below the SINQ target hall. They are connected via a 12 m long drift tube passing below the foundation of the 2 adjacent halls and pointing downwards at an angle of 28 degrees.

Reshaping the beam with collimators and slits after passage through TE is important for low loss transport of the remaining part of the proton beam (60 %) to the SINQ target and in order to achieve a beam diameter of 10 cm at the target. The projected emittances in both directions are defined by the cut-off at an elliptically conical collimation system after the blow up in the 6 cm of pyrolithic graphite of the rotating wheel target. This trimming can well be seen when looking at the measured beam profiles which are all but gaussian in shape.While the beam losses at the target E, the nearby collimators and other aperture constraints add up to 40%, the losses after the 2 moveable slits (which act as beam halo scrapers) and the 12 m long drift tube were computed to be as little as 10 ppm along the last 25 m of beam line, using an enhanced version of the computer code TURTLE. First measurements of the dose deposited along the beam line and the readings of the installed ionisation chambers during beam-up time confirmed these results. This is very important for future maintenance and repair work, which

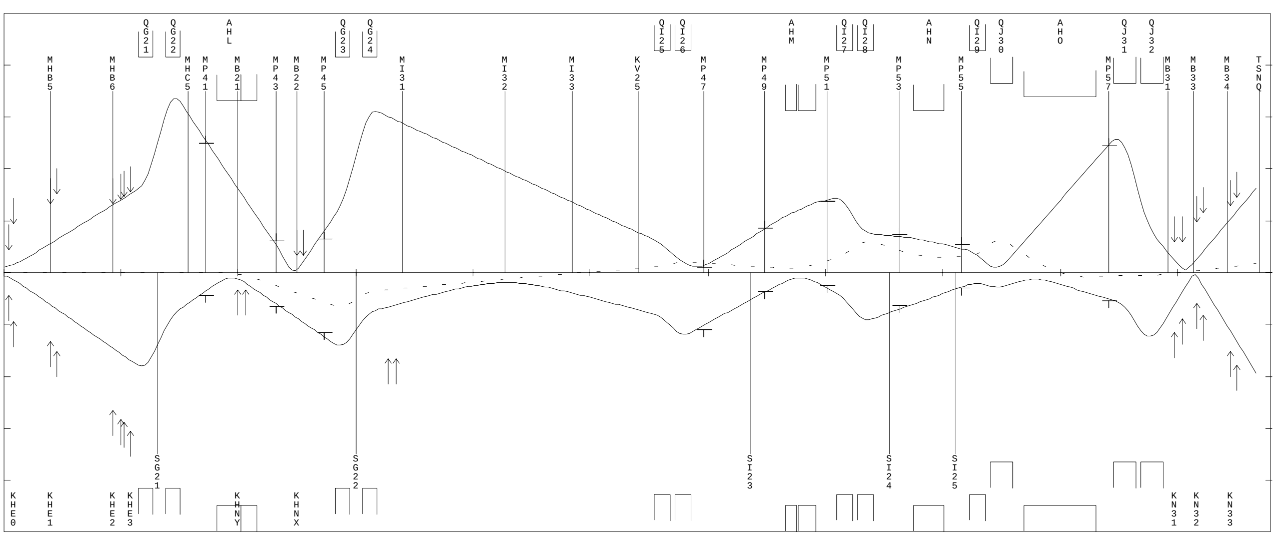

Fig 3: *Envelope fit for the 900 µA beam during the commissioning of the new proton beam line.* ⊤ *and* ⊥ *represent measured beam widths. The lower and upper half-frames show data for the vertical (bending) plane and the horizontal plane respectively. Computations were done with the code TRANSPORT. Full scale in both direction is 15 cm. The dotted line shows the assumed 1% dispersion trajectory.*↑, ↓ *symbolize slits and collimators.*

would be impossible under high activation levels in this complex environment.

3. THE SINQ NEUTRON TARGET STATION

At the end of its passage the remaining 60% of the proton beam hits the SINQ target from underneath with an elliptical beam spot whose half axes are about 4.5 and 6 cm (right hand side of Fig. 3). The target used for the commissioning phase is an array of 10 mm diameter Zircaloy rods, arranged perpendicular to the proton beam, in which the beam is completely stopped and which is cooled by heavy water in cross flow. Little under 60% of the beam power is deposited in the target material. The rest goes into binding and kinetic energy of the neutrons and other radiation generated and is deposited in the structures surrounding the target. About 5 neutrons per protons are generated with energies below 15 MeV, and are slowed down in a surrounding heavy water moderator to thermal energies (around 25 meV), which is what is required for neutron scattering experiments on extracted beams. Thermal neutrons are extracted through beam tubes penetrating the shielding of 4.5 m of steel and 30 cm of borated concrete and ending in the moderator in a configuration tangential to the target. A vessel containing 25 litres of liquid deuterium and placed next to the target serves as a cold moderator and feeds even lower energy neutrons into an array of 7 supermirror coated neutron guides. These guides are curved and heavily shielded over their first 30 m of length to clean the beams from unwanted fast neutron and γ-radiation and then transport neutrons in straight sections to the various neutron scattering instruments.

SINQ is unique in two ways: with its design beam power of 1 MW it has the highest power rating of any spallation neutron source world wide and, being driven by a cyclotron, it is the only continuous spallation neutron source. This makes it of interest not only for its neutrons but also in terms of its prototypic character for the technology of future high power spallation neutron sources. It was, therefore, with great interest that the results from the first beam tests were anticipated, with respect to the neutron flux level, as well as to backgrounds from fast neutrons in the beams and in the instrument halls.

A low current run at 20 μA was scheduled for the first day, Dec. 3, 1996 of the commissioning phase, enabling measurements of intensities in the neutron beams and surveys of radiation levels in the whole area. Although the need for additional shielding was identified at various locations, no serious deficiencies were detected and it was decided to run a full power test on the following day, with a limit on the total charge of 2 mAh (cf. Fig. 4)

This also enabled monitoring of the radiation levels in the cooling plant room (Fig. 5) and analysis of the cooling water activation. In general, these measurements confirmed calculated production rates.

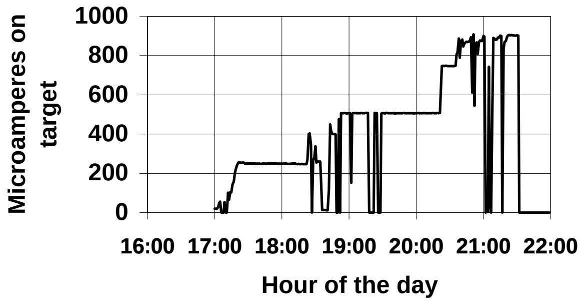

Fig. 4 *High current beam test of the SINQ target on Dec.4,1996. The beam trips were mainly caused by low levels set in loss monitors. At 21:35h the charge limit of 2 mAh was reached*

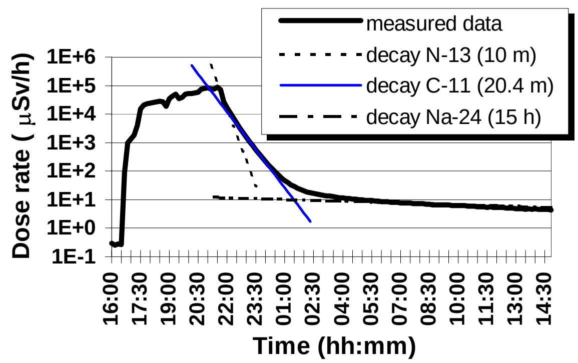

Fig. 5 *Dose rate in the SINQ cooling plant room from short lived isotopes in the cooling water during and after the high current test of Dec. 4, 1996.*

Also neutron intensities measured at the beam tubes and cold neutron guides [2] conform well with expectations based on calculations. Cold neutron currents at the guides are around 2.5 to 3.5x10^8 $cm^{-2}s^{-1}$ at the positions of the instruments and around 6.3x10^8 $cm^{-2}s^{-1}$at the edge of the target shield. Thermal neutron currents at the beam tube exits are about 1-2 10^{12} $cm^{-2}s^{-1}.sr^{-1}$. All values refer to 1 mA on target and are expected to double when the next generation target containing lead filled tubes instead of Zircaloy rods will be installed. Fast neutron contamination (>20 MeV) was checked with a ^{11}C detector and was found to be below 10^{-4} of the thermal netron flux in the beam tubes and absent in the guides.

REFERENCES

[1] U. Schryber et al., Proc 14^{th} Int. Conf. on Cyclotrons and their Applications, Cape Town (SA) 1995, p.

[2] W. Wagner, G.S. Bauer, J. Duppich, S. Janssen, E. Lehmann and M. Lüthy, "Flux Measurements at the New Swiss Spallation Neutron Source SINQ", to be published