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THERMAL NEUTRON BEAM CHARACTERIZATION AT THE HRPT INSTRUMENT AT THE SWISS SPALLATION NEUTRON SOURCE

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Abstract

The Swiss spallation neutron source (SINQ) at Paul Scherrer Institut (PSI) provides beams of thermal and cold neutrons to different neutron instruments. In a view of a potential SINQ upgrade, an experimental program characterizing the current performance of SINQ neutron beams was started in 2013. We present experimental results of the irradiation of imaging plates and gold foils at one of SINQ thermal neutron beam lines that hosts the high resolution powder diffractometer (HRPT) and compare the experimental results to the numerical MCNPX simulations of the neutron flux from the SINQ target-moderator system.

INTRODUCTION

The SINQ is a continuous neutron source driven by 575 MeV protons with 1 MW onto the “Cannelloni”– type spallation target [1]. The neutron beams from the two moderator inserts that use liquid D_2 at 20 K and ambient temperature H_2O are delivered to different neutron instruments. The proposed integral approach to an upcoming SINQ upgrade is based on complex performance optimization including all integral parts of SINQ, starting from the proton beam down to the neutron instruments [2]. The experimental characterization of the SINQ neutron beams shall provide reference values for the upgrade studies and at the same time allow for validating Monte Carlo neutronic calculations for the moderators.

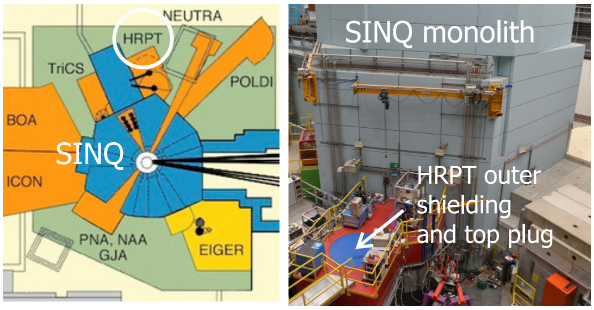

Figure 1: Left: layout of the neutron instruments around SINQ. Right: top view on the shielding bunker of the HRPT instrument and the monochromator top shielding plug.

The general layout of the neutron instruments around the SINQ monolith is illustrated in Fig. 1. The high resolution powder diffractometer for thermal neutrons HRPT is one of three instruments that are provided with thermal neutrons from the H_2O moderator [3]. The layout of the outer shielding around the HRPT beam line is illustrated also in Fig. 1. The neutrons from the H_2O moderator enter the 40×150 mm^2 opening of the beam port, pass through the Soller collimators and are finally filtered by a silicon crystal before they reach the monochromator of the instrument, as shown in Fig. 2. Access to the HRPT monochromator position is possible by removing the top shielding plug above the monochromator shaft. With the collimators in the beam line retracted it is possible to measure the neutron flux at the monochromator position directly from the H_2O moderator, to evaluate the moderator performance.

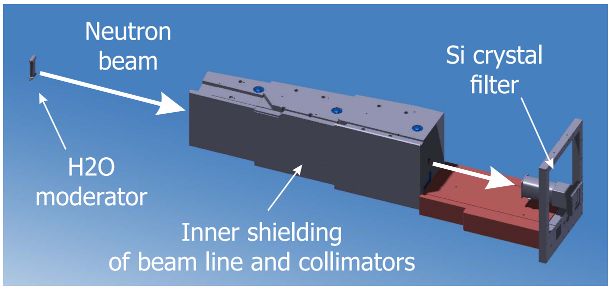

Figure 2: Extract from the 3D CATIA model showing the layout of the neutron beam line from the moderator towards the HRPT instrument (with the outer shielding removed).

NEUTRON FLUX IMAGING

The program of neutron flux measurements at the HRPT instrument was conducted in three steps. First, an imaging plate 406 (h) × 206 (w) mm^2 was exposed to the neutron beam as shown in Fig. 3.

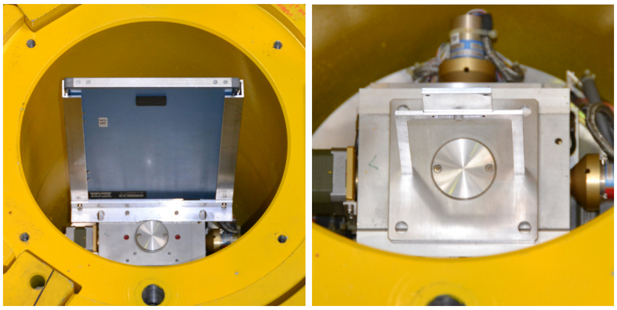

Figure 3: Imaging plate in a holder (left) and cassette with the gold foils (right) lowered into the monochromator shaft.

A horizontal Cd wire was attached to the holder of the imaging plate at a 145 mm distance from its bottom, which corresponds to the design center of the beam port. The measured vertical profile of the neutron beam averaged over a 20 mm wide band around the central vertical axis of the imaging plate is shown in Fig. 4. The image of the neutron

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beam port, of 150 mm in height, was clearly reproduced. The neutron flux at the monochromator position was found centered around the sharp dip at the position of the Cd wire. The observed difference in the neutron flux below and above the Cd wire can be attributed to the two crystal blocks of the silicon filter.

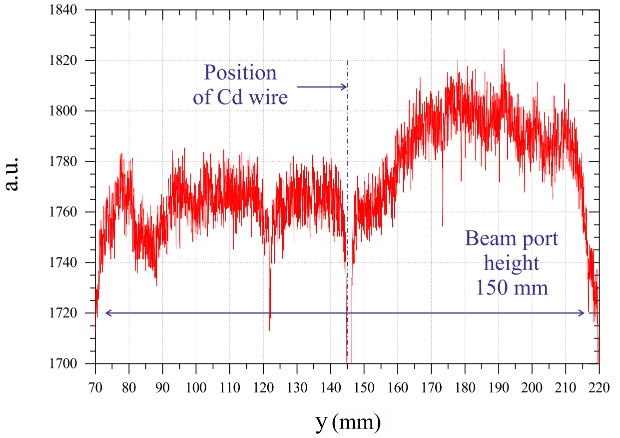

Figure 4: Vertical neutron flux profile at the monochromator position.

IRRADIATION OF GOLD FOILS

After the location of the neutron beam center was verified by the imaging plate measurement, two cassettes equipped with nine gold foils each were irradiated in two separate sessions at the same position (see Fig. 3). The nine gold foils of 10 mm diameter were placed in each cassette in a 3 × 3 row–column grid, covering a total area of 32 × 32 mm^2. The middle row of the foils was centered to the neutron beam. The front and back sides of the second cassette were covered by a 1 mm thick Cd sheet, to measure the activity by the epithermal neutrons only.

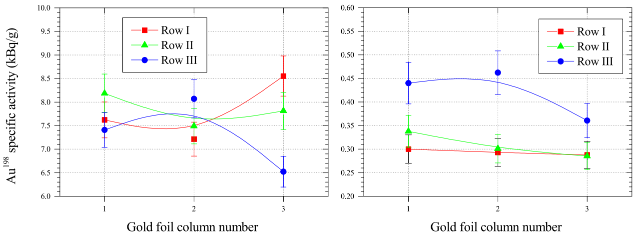

Figure 5: ^{198} Au specific activity for the two sets of nine gold foils, induced by the total (left) and epithermal (right) neutron flux.

After irradiation and cooling the gold foils were removed from the cassettes and their induced activity was analyzed. The obtained specific activities of the ^{198} Au nuclide (kBq/g) for the gold foils irradiated in the cassettes without and with the Cd sheet are shown in Fig. 5. The average values for the ^{198} Au activity are 7.65 ± 0.56 kBq/g for the irradiation by the total neutron flux, without the Cd sheet, and 0.341 ± 0.066 kBq/g for the irradiation by the epithermal neutron flux. Observed vertical (gold foil row dependent) and horizontal (column dependent) differences in the measured activities are subject to further detailed examination.

SIMULATION OF NEUTRON FLUX

Benchmarking the measurements of the neutron flux at the SINQ beam lines with the Monte Carlo simulations is one of the tasks of the project of conceptual studies for the SINQ upgrade. For the study presented here, the neutron flux at the HRPT instrument was simulated using MCNPX 2.7.0 [4]. The geometry model used in the simulations was based on the engineering 3D model (partly shown in Fig. 2) and included all the relevant details of the SINQ design. The neutron spectrum at the position of the HRPT monochromator simulated with MCNPX is shown in Fig. 6.

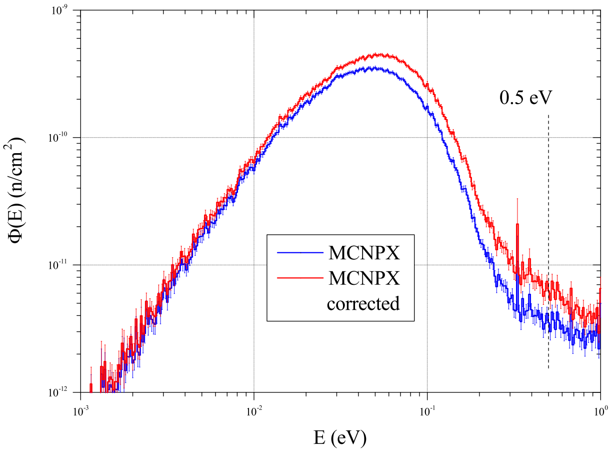

Figure 6: Neutron spectrum (blue) as simulated at the position of measurements and corrected with the temperature dependence of the total cross-section for crystal silicon (red).

The design of the HRPT instrument includes a silicon crystal filter that can be cooled by liquid nitrogen from room temperature down to 77 K [5]. The total cross-section of the crystal silicon is known to have strong dependence on the neutron energy below 1 eV. The classical experimental data on crystal silicon cross-section is shown in Fig. 7. As Fig. 7 demonstrates, the present cross-section library used in MCNPX to simulate neutron flux in the HRPT beam line allows for rather sufficient reproduction of the neutron transport through the silicon crystal at the room temperature. However, for the lower temperature the simulated neutron spectrum has to be corrected as, for example, the total cross-section at 0.1 eV for 300 K is 0.54 b higher than at 77 K. The corrected neutron spectrum is also shown in Fig. 6 (red curve). As the total cross-section of crystal silicon stops to depend on the temperature above ∼ 1 eV, the difference between the MCNPX-simulated and the corrected spectrum above 0.5 eV becomes negligible.

GOLD FOIL ACTIVITY CALCULATION

The MCNPX-simulated and the corrected neutron spectra were subsequently used to calculate the activity of the

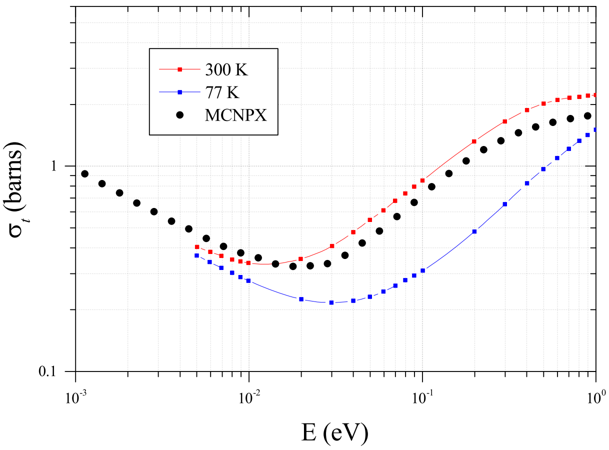

Figure 7: Total neutron cross-section of the single crystal silicon at 300 K (red curve) and 77 K (blue curve) after Brugger (1976) [6], compared to the total cross-section used in the MCNPX simulation (black circles).

^{198}Au nuclide in the gold foils. The procedure of the calculation was automated with the Activation Script [7, 8] and the FISPACT inventory code was used [9]. The results of the calculation using the MCNPX-simulated and the corrected neutron spectrum from Fig. 6 are compared to the measurements in Table 1.

Table 1: Specific activities of ^{198}Au nuclide, measured in gold foils after irradiation with the total and epithermal neutron flux, and their ratio, compared to the specific activities calculated using MCNPX, Activation Script and FISPACT

Average activity of gold foils	**Total (kBq/g)**	**Epithermal (kBq/g)**	**Ratio %**
Measured	7.65	0.34	4.4
MCNPX simulated	7.35	0.39	5.3
MCNPX, corrected	9.12	0.40	4.4

The gold foil measurements of the specific ^{198}Au activity agree within 5 % with the simulations, which is the uncertainty of the MCNPX simulation of the thermal neutron flux. Similar agreement is seen for the results of the irradiation of the gold foils with the epithermal neutrons. The total activity, calculated with the neutron spectrum corrected for the temperature dependence of the crystal silicon cross-section, is by ~ 24 % higher. In the case of the gold foil irradiation with the epithermal neutrons, the difference between the results calculated with the MCNPX simulated and corrected neutron spectrum is within the statistical error as well.

CONCLUSION

Two different measurement techniques were successfully used for the experimental characterization of the neutron beam delivered to the HRPT instrument at SINQ. Neutron flux imaging allowed for verifying the shape and the position of the incoming neutron beam. The irradiation of the gold foils provided the specific activities induced by the total and the epithermal neutron flux.

The measured values of the specific ^{198}Au activity were benchmarked against MCNPX simulations in a realistic model which included SINQ and the neutron beam line of the HRPT instrument. The preliminary results of the comparison show that the Monte Carlo simulation allows to reproduce the measured values. The measured non-uniformities of the neutron flux and the differences between the simulation and measurements are subject of further investigation.

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