A Selene Guide for AMOR

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Abstract. We present the new guide design for the reflectometer AMOR at SINQ optimized for high intensity on the sample (gain factor 10) and reduced background. The design uses wavelengths longer than 3.5 Å and homogeneously illuminates horizontal samples with a 30 mm x 10 mm cross section. It allows for short counting times due to simultaneous measurement of $\Delta \theta = 1.5^\circ$ in the specular regime. The beam transport relies on Selene guides using point-to-point focusing. We describe the application of this geometry to the conditions at SINQ including a focusing antitrumpet for transport to the virtual source. McStas simulations show a high performance of the new design. Shielding design has been checked with MCNP simulations.

1. Introduction
The demand for high performing neutron reflectometers is persevering. AMOR [1] is a TOF reflectometer at SINQ [2] with a polarized option. After the upgrade of the SINQ guide system, it is going to be the sole reflectometer available at SINQ. It is therefore designed as a vertical reflectometer accommodating all samples; including liquid interfaces. The new design relies on the Selene guide.
Neutron transport via Selene-type guides is a truly focusing technique. The footprint of the beam at the sample position, the final focal point, is defined at the (virtual) source, the initial focal point. The neutrons are transported by planar-elliptical guides in both dimensions normal to the beam. Coma aberration is corrected to first order by having two subsequent centrosymmetric guides sharing one common focal point. This type of guides has been proposed for neutron optics in 1963 [3], and a demonstrator for Selene-type guides has been successfully tested and is being used as an add-on at the current AMOR reflectometer [4].
With this type of transport system, measurements can be sped up significantly: The defined transported phase space makes it possible to measure simultaneously the specular reflectivity of all incident angles. Defining the footprint far away from the sample has the advantage that only neutrons that are going to touch the sample are being transported. This reduces background that would be created by beam-shaping elements close to the sample and detector environment. Furthermore, by focusing onto the sample, neutron contact with the sample environment is minimized, reducing neutronic background [5, 6, 4]. Neutrons that are being successfully transported by the geometry are being reflected exactly four times. This is advantageous over long distances where the number of reflection can be higher as a function of divergence.

2. The Selene Geometry at SINQ
AMOR is located at the RNR17 beamline supplied with neutrons by the cold D$_2$ source. The current AMOR guide shares the beamport and the first few meters of guide with the SANS-1
Table 1. Basic Selene parameters for implementation at AMOR

| Parameter                                | Value                     |
|------------------------------------------|---------------------------|
| moderator to detector distance           | 40 m                      |
| distance virtual source to sample        | 30 m                      |
| minor half axis                          | 130.8 mm                  |
| maximum size virtual source              | 30 mm x 10 mm             |
| divergence                               | 1.5° x 1.5°               |
| coating                                  | m=4                       |
| minimum wavelength                       | 3.5Å                      |

beamline. After that, the guides are separated into two individual (opposing) bent guides that share a vacuum vessel over a couple of meters. AMOR is bent over 24 m by a radius of 1234 m. A subsequent straight guide section transports the neutrons towards the chopper and polarizer.

The new transport system based on the Selene guide is shown in Fig. 1. The elliptic part has a total length of 30 m where the individual guide elements Selene I and II are 9 m long. Tab. 1 summarizes the most important elliptic parameters. Opting for the transport of 1.5°
of divergence, geometrical restrictions at SINQ make it necessary for the initial focal point to be at 6 m from the cold source surface. The maximum cross section of this rectangular virtual source is 30 mm x 10 mm and can be tailored to the sample size via diaphragms. The virtual source is fed by a rectangular linear anti-trumpet that assures the delivery of 1.5° divergence, pictured in Fig. 1: After sharing 1.5 m with SANS-1, the guides are split early on. The AMOR feeder at the lower beamport position decreases its cross section from 50 mm x 50 mm to 30 mm x 10 mm. The central axis is tilted downward and to the side by some tenth of a degree. This avoids collision with the SANS-1 guide further downstream and helps for irradiation of liquid samples. The major axis of the ellipse is tilted then upward such that the sample position is at a height of 1.93 m.

The performance of this set-up is compared to the current set-up via McStas simulation.

| sample size [mm] x [mm] | gain |
|-----------------------|------|
| 5 x 5                 | 12.2 |
| 10 x 10               | 10.8 |
| 40 x 40               | 2.9  |

Results are presented in Tab. 2 comparing the current guide with the Selene guide, using the full divergence delivered. The Selene guide is clearly advantageous for small samples.

3. Optics

The main optical features of the current AMOR instrument are being maintained: The instrument offers wavelength resolution and polarization. The double disc chopper [7] is moved into the neutron guide bunker. It is placed symmetrically with respect to the shared focal point between the two guide segments. Polarization is achieved via logarithmic spiral polarizers [4], placed after the chopper. By placing major optical devices inside the neutron bunker, background can be further suppressed. A slit system close to the sample allows to tailor the incident divergence to the specific experimental needs, including off-specular measurements.

4. Shielding

MCNP simulations of the beamline have been conducted to study possible background sources in the energy range from thermal to 590 MeV neutrons except for background by the sample environment. The small opening of the feeder anti-trumpet limits the amount of background neutrons that enter the bunker region. In addition, it is inherent to the Selene guide to move out of direct line of sight efficiently. Optical beam manipulation can be done in the 6 m gap between the two guide segments inside the neutron bunker. This also reduces background at the sample position. Despite the good inherent shielding of the design, absorbing elements are added for further background suppression and to avoid contamination of neighbouring instruments: L-shaped absorbers are placed at the centre of each guide segment. A copper disc is placed at the shared focal point of the two guide segments to shield fast neutrons. A particular challenge for shielding is that cut-outs in bunker walls are relatively large compared to the beam size. This is due to the fact that the Selene guide needs an external vacuum vessel. At the last wall to the experimental hall a special shielding plug has been optimized: The guide and thus the vessel end inside the 3 m thick neutron guide bunker wall. A distance of 30 cm is available to insert a plug that is equivalent to 3 m of concrete. We opted for a combination of a first layer of steel (fast neutrons), followed by borated polyethylene (thermal neutrons). The thicknesses of the
two layers have been optimized for total neutron flux absorption and consist of 7 cm steel and 23 cm polyethylene, see Figs. 2 and 3. This configuration maximized the steel thickness while keeping the total number of neutrons exiting the shielding near the minimum. The plug will end by a gamma shield to suppress the 2.2 MeV photons emitted by (n,\(\gamma\)) reactions in hydrogen (although this can be minimized by using a high concentration of boron in the polyethylene to ensure most of the absorption happens in \(^{10}\)B).

5. Summary
We have shown the new design of AMOR implementing a 30 m Selene guide at the RNR17 beamport. Simulation show gain factors of 10 in flux for the standard 10 mm x 10 mm sample. Shielding elements were simulated and optimized to cater to the challenges risen by the guide geometry.

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Figure 2. Neutron flux transmitted by the steel-polyethylene plug as a function of the steel thickness.

Figure 3. Neutron flux transmitted steel-polyethylene plug as a function of steel thickness for different energy regimes.