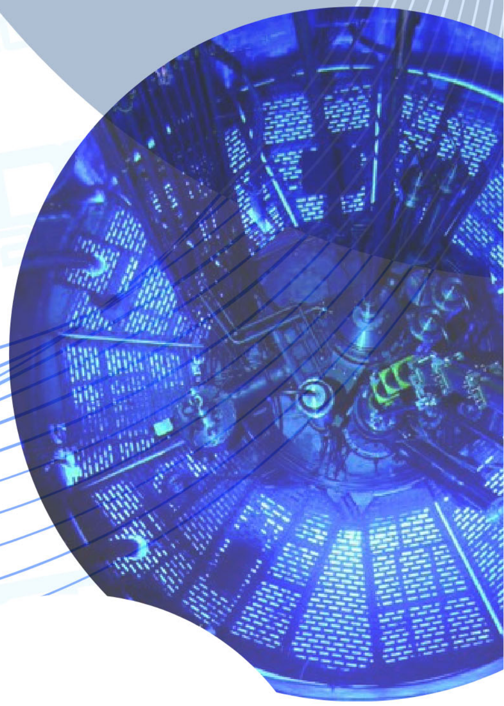
6TH INTERNATIONAL WORKSHOP ON NEUTRON DELIVERY SYSTEMS

Book of abstracts



NEUTRONS FOR SOCIETY

10 - 12 July 2023

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SESSION 1

NEW GUIDE SYSTEMS 1

Monday 10th July

1.10pm – 2.50pm

ILL2023 program and H1-H2 long shutdown achievements

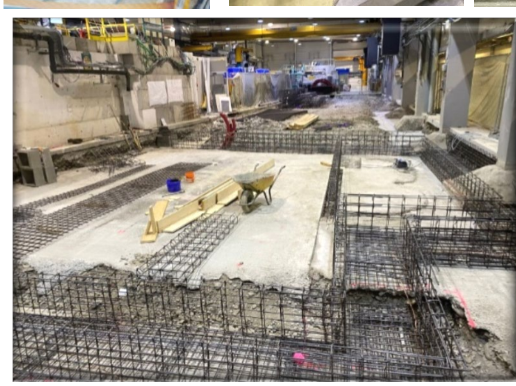
J Beaucour, S Pierrard, C Menthonex, N Wildes, F Marical, C Dewhurst, E Suard, M Plassard (Assystem).

In 2020, the ILL set and launched the multiannual ILL20-23 programme, which steered and coordinated with a new project driven organisation all the major upgrades of the instrument suite (Endurance), major reactor maintenances as well as advanced security and safety improvements for the reactor operations. ILL20-23 has been conducted based on a master resource-loaded programme schedule for coordinating instrumentation work and reactor activities during long shutdowns, whilst securing a maximum number of reactor cycles.

We will present the program organisation and way of operating as well as the work achieved during the most recent 2021-2022 long reactor shutdown period, a crucial part of the ILL20-23 programme. Dozens of ILL employees have indeed been involved in what has been a particularly intense period. The work has called for concerted efforts and goodwill of ILL staff within the Projects and Techniques (DPT), Reactor (DRe) and the Science Division (DS) and the Administration division.

As a result, the H1H2 long shutdown has been completed in line with its forecasted 16-month duration and on budget, leading to unpreceeding reliability and safety levels of its neutron reactor, the delivery of a fully modernised H24 guide, the primary part of the future H15 guides as well as a number of new world-class instruments now in operation.



H1H2 beam tube and guides renewal – Guide hall for future guides & instruments

Renewal of the H1-H2 Guide System at the ILL Research Reactor

M. Kreuz, J. Beaucour

The Institute Laue Langevin (ILL) is a world-renowned research center located in Grenoble, France, dedicated to the study of materials and fundamental science using the high neutron flux provided by its nuclear reactor. Founded in 1967, the ILL is one of the world's leading facilities for neutron science, providing researchers from around the globe with access to state-of-the-art instrumentation and expertise. Neutrons are extracted from the reactor core by special inserts called beam plugs made of aluminum or zirkaloy. Two of these plugs, called H1-H2 and H5, are used to provide neutrons to neutron guide systems feeding neutrons to instruments in the neutron guide halls far from the reactor. The plugs made of aluminum have to be replaced every 10-15 years as the material becomes brittle under the high neutron flux.

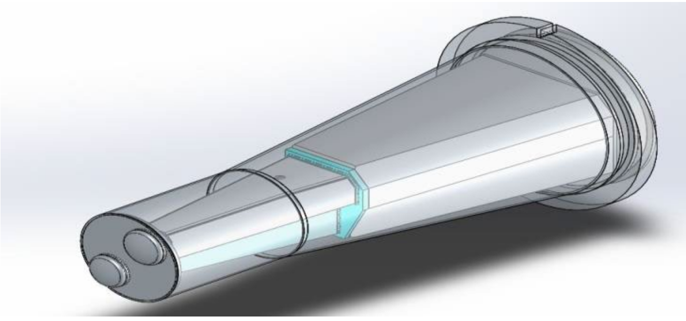


Figure 1: Drawing of the H1-H2 beam plug with a total length of 3.5m.

In the frame of the replacement of the biggest aluminum beam plug of the ILL, the H1-H2 plug (see Figure 1), a complete renewal of the first 10m of the corresponding H1-H2 guide system was realized during the 2020-2022 shutdown.

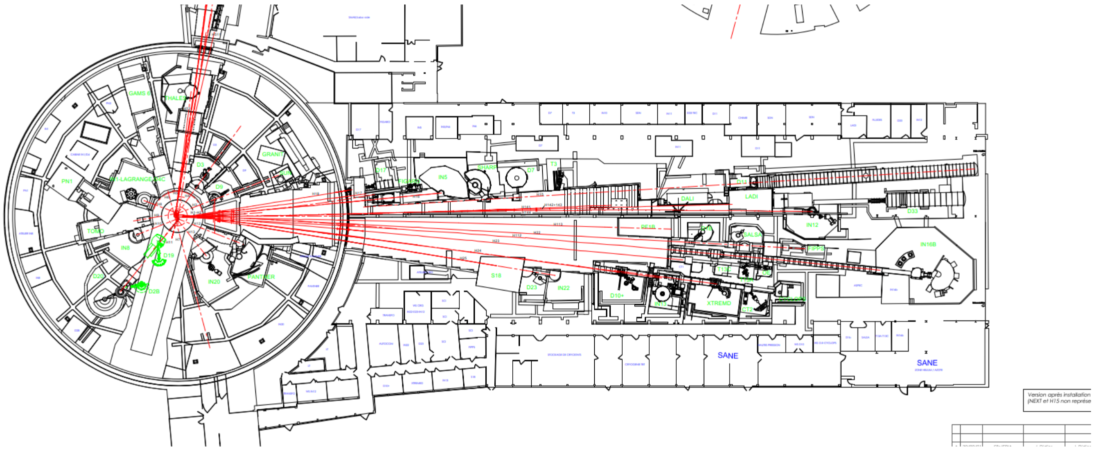


Figure 2: Schematic view of the H1-H2 guide system and the northern guide hall of the ILL.

The H1-H2 guide system consists of 7 cold and 4 thermal neutron guides. It provides neutrons to 22 scientific and 5 technical instruments in the northern guide hall. A schematic view of this guide system is shown in Figure 2. The replacement project was used to adapt the beginning of the neutron guide system to the new guides H24 and H15, which correspond to the last phase of the Endurance program. In addition, some small inconsistencies with the existing guide system were corrected to improve the exploitation of the existing infrastructure.
The first 3m of each neutron guide are actually installed inside the reactor core and inside the beam plug. The guides are mounted on support plates which are then fixed inside a very stable steel housing, the so called "Pink Housing". A drawing of this housing with the installed neutron guides can be seen in Figure 3 on the left side. The guides are then slid inside the beam plug to increase the filling of the neutron guides. The first guide will start at 2.7m from the cold source.
As the beam plug is part of the important installations of the nuclear reactor to avoid any contamination in case of an accident, no aggression of the plug is tolerated. Thus, the Pink Housing is fixed in such a way, that in case a major seismic activity no aggression of the beam plug occurs.

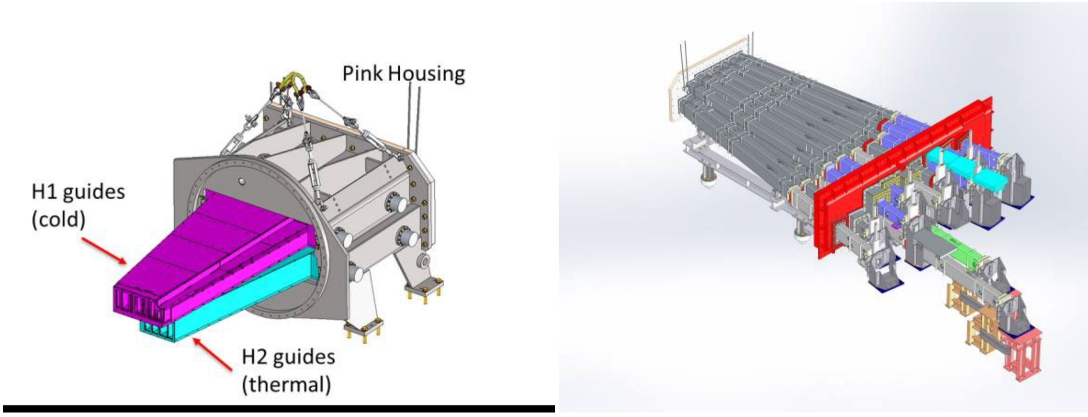


Figure 3: On the left, the Pink Housing assembly with the neutron guides installed. The upper guides are the 7 cold guides; the lower guides are the 4 thermal guides. On the right a view of the aluminum housings inside the Swimming Pool.

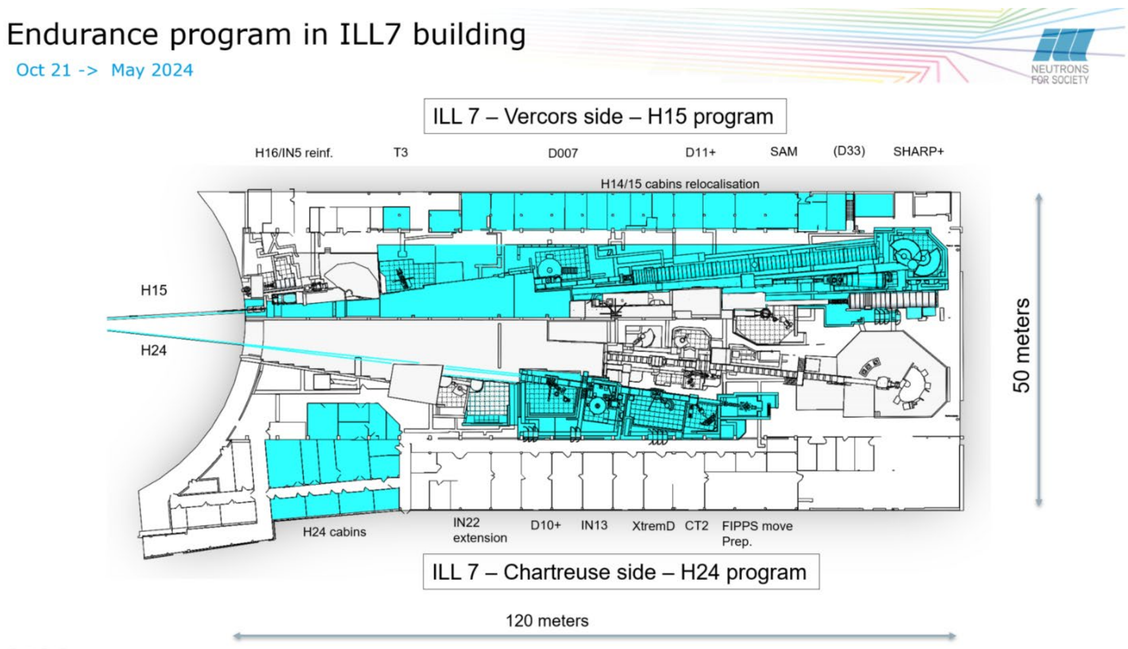
The Pink housing itself is installed under water in the H1-H2 swimming pool. The water guarantees the radiological shielding as the beam plug basically acts as a big hole in the reactor core for neutrons and high energy gammas. The swimming pool has a length of 8m and a total depth of 6m. The neutron guides inside the pool are installed in aluminum housings to avoid corrosion and activation. A view of the Swimming Pool part can be seen in Figure 3 on the right.
In addition to the first 10m of each neutron guide, the reactor feedthroughs for all guides were modified to comply with new seismic regulations. In fact, these feedthroughs had already been adapted in 2005, but due to the Fukushima incident, additional precautions were imposed by the nuclear safety authorities in France.
The new guide system is now operational and first flux measurements will be presented. The results show that the new guide system is performing well and that the neutron flux levels are as expected.

H24 and H15 guides – Design, works and installation

B. Giroud, C. Dewhurst, G. Manzin, J. Beaucour, Y. Gibert, M. Kreuz and all the ILL technical staff and scientists involved!

For 16 months, the ILL7 guide hall was the setting for many works, combining civil engineering and guide alignment or vacuum testing, activities that were not necessarily in line. Responsible for H24 and H15 guide installation, from dismantling to reconstruction, I will present the two projects, from design constrains to current reconstruction state, including total reconstruction for 10 instruments and neighbours (some big or long instruments e.g SHARP flight chamber or 80 meters for D11)

I will approach difficulties and technical solutions considered allowing to install H24 during our last long shut down, and prepare the installation for H15, and associate instrument for February 2024. One of the main challenges was to optimize the guide design to be able to have significant gain on instruments, and allow to obtain ten end-of-guide positions. Some interesting solutions were considered like evacuated "alubor" guide, deflector or neutron crossing concept.



Innovative neutron guide replacement at the Institut Laue Langevin: The H24 (thermal) and H15 & H16 (cold) neutron guides

High-performance instrumentation projects rely on high-performance neutron guide infrastructure. During the extended reactor outage (2021 – 2023) we have replaced the H1-H2 beam-tube, in-pile optics and three new guides with innovative geometries to provide intense neutron beams to new or upgraded instrumentation.
The upgraded IN5 (2019) time-of-flight spectrometer and its new elliptically focussing H16 cold-neutron guide demonstrates the best-use of phase-space and boasts huge gains in intensity, in particular at shorter wavelengths, while focussing onto much smaller samples.
The new H24 thermal-guide uses a rather elegant concept of a common-curved-trumpet exploiting two radii of curvature to naturally diverge and expand the guide to be split into two distinct branches with four dedicate end-of-guide positions for instrumentation.
The new H15 cold- guide has a rather complex opposing-curved expanding section, referred to as 'the trumpet' serving two important purposes: The first is to spatially expand the neutron guide allowing the guide to be split into multiple individual guide branches and dedicated end-of-guide beam positions. The second is that the opposing curve leaves a 'fingerprint' correlation between the divergence profile and spatial position at the end of the trumpet. Importantly, this allows guide branches to be more widely separated in angle therefore allowing space for substantially more instrumentation down-stream.

Primary author(s): DEWHURST, Charles (ILL)
Co-author(s): GIROUD, Benjamin; MANZIN, Giuliana; BEAUCOUR, Jerome
Presenter(s): DEWHURST, Charles (ILL)

The use of Copper substrates for Neutron guides at ESS

The proposed talk covers the concept and the intended use of Neutron guides with Copper substrates at the ESS facility in Lund.
The background behind the decision to use Copper-based substrates in certain locations of ESS Challenges and properties of Oxygen-free Copper in comparison to other guide substrate material Examples of Copper guide systems will be shown, from the concept stage to the completely integr

Primary author(s): Mr. SCHWEIGER, Hansdieter (European Spallation Source); Mr. SUTTON, Iain (European Spallation Source)

Presenter(s): Mr. SCHWEIGER, Hansdieter (European Spallation Source); Mr. SUTTON, Iain (European Spallation Source)

SESSION 2

NEUTRON OPTICS

Monday 10th July

3.00pm - 4.20pm

Recent achievements in advanced diffractive optics for neutron monochromators at ILL

P. Courtois*, F. Barneaud, B. Mestrallet, S. Michallat, F. Philit

Institut Laue-Langevin, 71 Avenue des Martyrs, BP 156, 38042 Grenoble Cedex 9, France

The Neutron Optics Service plays an active part in the modernisation programmes at the I.L.L. with the production of high-quality mosaic single crystals to be used in the construction of very efficient monochromators allowing significant improvement in the performance of neutron scattering instruments.

Under the framework the Endurance phase 1 projects, several neutron monochromators have been assembled. An overview is presented, from the production of mosaic crystals to the final assembly of optical devices. First results from ILL instruments will be also briefly discussed.

It includes double focusing HOPG monochromator and analyzer for the upgrade of the IN20 thermal triple axis spectrometer, a HOPG monochromator for the new D10+ and Xtreme-D single crystal diffractometers and a double face Ge monochromator for the test instrument CT2. We also successfully produced mosaic CaF_2 crystals which have been used in the construction of a temperature gradient monochromator for the IN13 thermal backscattering neutron spectrometer

Starting from high-quality large single crystals grown in the laboratory, the monochromator group produces copper crystals with a well-controlled mosaic distribution using plastic deformation at high temperature. These crystals exhibit excellent neutron properties, making it possible to construct extremely efficient neutron monochromators, such as the time-of-flight spectrometer PANTHER and the new single crystal diffractometer D10+ (Figure1).

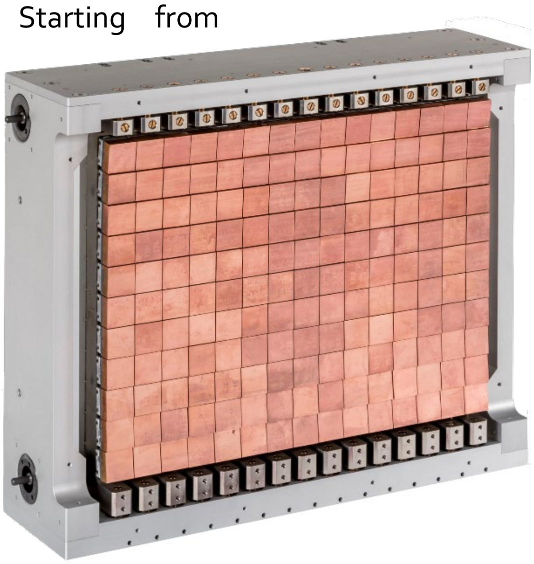


Figure 1: The new double focusing Cu(220) monochromator for the thermal time-of-flight PANTHER. The monochromator comprises 165 Copper pieces for a total active area of 660 cm^2.

We have developed new techniques to build advanced neutron optical components made from perfect Si single crystals. We validated an innovative multi-analyzer concept for the cold neutron triple axis spectrometer ThALES. The prototype consists in an array of 17 plastically bent Si(111) blades with a bending radius of 2 m (Figure 2). The prototype was successfully tested on the instrument showing the high performance of this device and the continuous energy analysis with good resolution that can be achieved. The technique of plastic deformation at high temperature was also used to produce high quality Si(111) crystals with a mosaic distribution close to 0.2° (Figure 3). Such crystals would represent an interesting alternative to replace Ge and potentially HOPG mosaic crystal monochromators in the future (Figure 4).

Figure 2: Photograph of the prototype multi-analyzer for the instrument ThALES at ILL. It consists in an assembly of 17 plastically bent Si(111) crystals with a radius of curvature of 2 m.

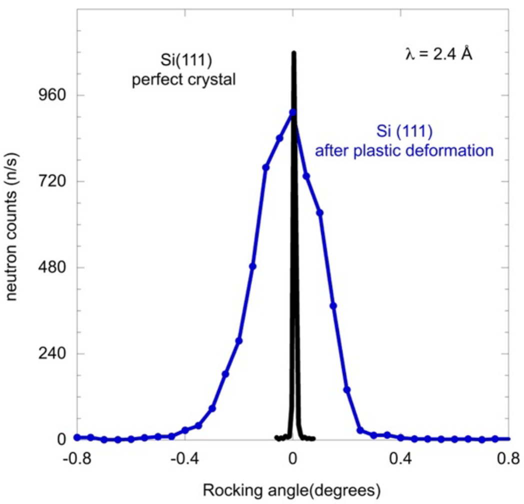


Figure 3: Typical neutron rocking curves from a Si(111) single crystal before and after plastic deformation.

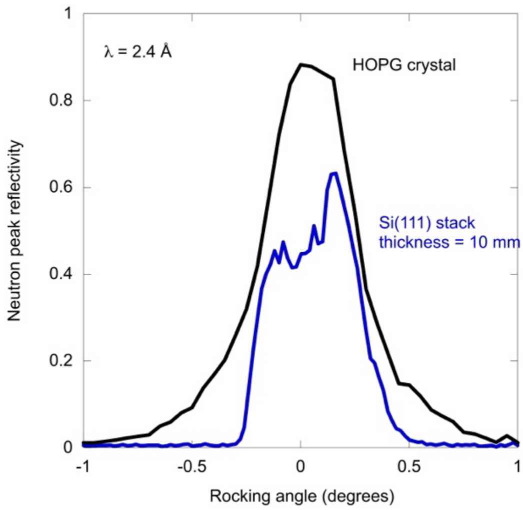


Figure 4: Experimental neutron peak reflectivity at λ = 2.4 Å for Si(111) and HOPG(002) crystals having both a mosaic spread of 0.5°

Vertical to horizontal beam double monochromator for reflectometry at BNC

Tamás VERES[1], **Ihor HAPON[1], Gyula TÖRÖK, Márton MARKÓ[1], László BOTTYÁN[1,2]**
[1]Budapest Neutron Centre, Center for Energy Research, Budapest, Hungary
[1,2]Wigner Research Centre for Physics, Budapest, Hungary

In course of the reinstallation of the V14 reflectometer relocated from the shut-down Berlin reactor to the Budapest Neutron Centre, the demand for redirecting a vertically extended (HxW: 100 x 25 mm^2) neutron beam into a HxW: 3 x 50+ mm^2 horizontally extended beam at an elevated height by 230 mm has arisen. Due to spatial restriction of the neutron guide hall at the available position of the guide (of m=2.5) in the BNC, double monochromator (mono 1 + mono 2) solutions were considered. The purpose of the present study to determine the structure and geometry of the two monos in order to maximize the horizontally collimated beam intensity at the sample position.
In the present concept the centre of the pyrolytic graphite (PG) elements of mono 1 are arranged on a tilted straight line within the vertical center plane of the guide and each element reflects the beam to a PG element of mono 2. Since the beam is Bragg-reflected, the element of a crystal pair must be parallel. The crystals of mono 2 are arranged on a horizontal line upstream of the entrance slit of the reflectometer. Each crystal pair is aligned to a slightly different wavelength in order to minimize Bragg back-reflection while transmitting through the downstream elements of mono 2. The average wavelength is fixed to 4.8 Å since the multilayer filter for higher harmonics suppression of V14 is optimized for that value. For technical reasons the number of crystals and the individual crystal sizes in mono 1 and mono 2 were assumed identical.
The only free parameters in the present scheme are the number of PG crystal pairs N and their angular spacing □□ On the one hand increasing the number of crystals increases the intensity on the sample, primarily due to the vertical compression of the beam. However, due to the divergence of the beam at the guide exit (± 0.1°/Å*m*4.8 Å = ±1.2°) and the mosaicity of the PG crystals (0.4°) the beam cannot be compressed infinitely, so this intensity gain saturates. Moreover, increasing the number of crystals steeply increases the transmission loss in mono 2 where the crystals are positioned behind each other. Consequently, there is an optimum in the number of crystal pairs. This optimum was searched for by VITESS simulations and we found that horizontally no gain can be achieved by more than one crystal, while in the vertical direction (of mono 1) the increase saturates at N=5.
The scattering angles of each parallel crystal pairs are misaligned equidistantly (by □θ), selecting slightly different wavelengths (by □λ). The overall band width of the mono is Δλ = N*□λ. Increasing Δλ decreases the resolution of the reflectometer, while decreasing □λ decreases the delivered intensity on the sample due to the Bragg back-scattering loss on the transmitted crystals of mono 2. VITESS simulations of the delivered neutron intensity by a parallel pair of PG crystals in optimum orientation were performed. The downstream crystal of the pair was a sufficiently large PG piece and the upstream piece was a crystal of horizontal size fully covering the guide width and of increasing vertical dimension. Simulations provide a linearly increasing intensity at the sample position up to almost 20 mm of PG crystal height, providing a full coverage of the 100mm

high guide by N=5 crystals. We find that the optimum scattering angle spacing between crystal pairs is 0.4°, resulting in a transmission of the neighbouring crystal of 80%. The optimum delivered intensity for N = 5 and = 0.4° is 3,8 times higher as compared with the case of two full size plane crystals with horizontal slits. Results of the experimental test of the monochromator will be reported elsewhere.

Hybrid neutron monochromator systems

Andreas K. Freund[1], Changyong Chen[2], Mike Crosby[2], Gergely Farkas[3], Brian Kozak[2], Dawn Krencisz[2] and Pavol Mikula[3]*

[1] *Consultant, 40 Rue Auguste Poirson, 33000 Bordeaux, France*

[2] *Momentive Technologies, 22557 Lunn Rd, Strongsville, Ohio, OH 44179, USA*

[3] *Nuclear Physics Institute, ASCR, 250 68 Řež, Czech Republic*

*Corresponding author, kafreund8@gmail.com

Introduction

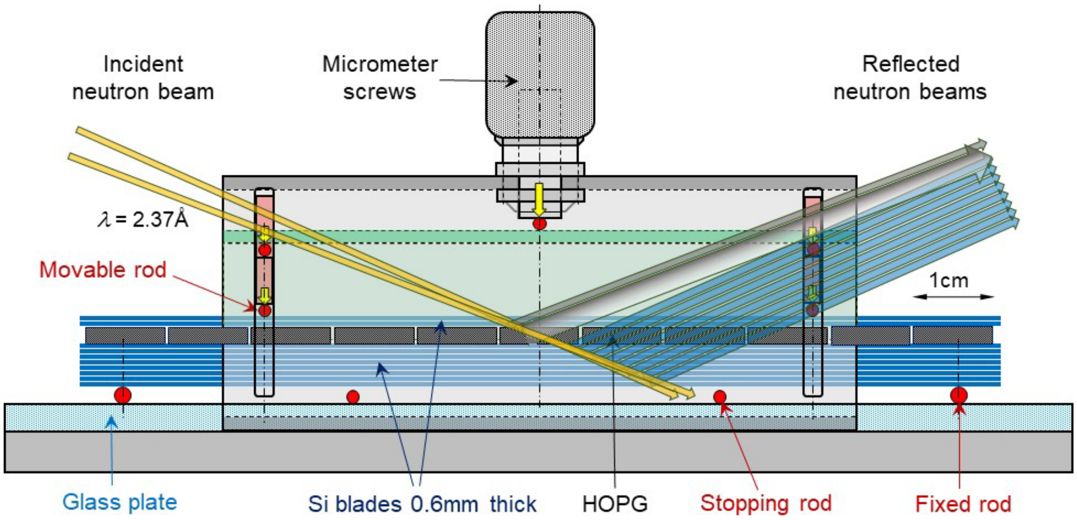
The mosaic crystal monochromators of many present-day neutron scattering instruments consist of separate single or double systems where flat mosaic crystals of Cu, Ge and HOPG (*highly oriented pyrolytic graphite)* about 2x2cm² in size compose a patchwork covering an area of typically 20x20cm². Each crystal is fixed on a neutron absorbing support and can be aligned individually from behind by a lever system to form a focusing monochromator. On the other hand, slabs of perfect Si crystals are used that are elastically bent to decrease the degree of crystal perfection and to achieve meridional focusing. HOPG delivers high flux whereas bent silicon gives high resolution at the expense of flux. Since these two types of beam defining devices are complementary, several monochromators are mounted on a turret inside the shielding and can be moved *alternatively* into the white neutron beam.

A novel design has been reported recently [1] where flat, about 2mm thick HOPG pieces that cannot be elastically curved were soldered with indium metal on rectangular steps of support blades consisting of perfect silicon crystals mounted on a bending device. By bending the silicon blades the HOPG crystals followed a polygonal shape. The advantage of this concept is the absence of any mechanical structure behind the bent crystals so that the transmitted beam can still be used further downstream. While this technique has been shown to work well, the shape of the support and the mounting procedure are complex and there is still soldering material in the neutron beam. Taking advantage of the parallelism between the lattice planes and the cleaved surfaces of HOPG, a different scheme has been imagined where the HOPG pieces are simply held between two flat, bendable plates without applying any bonding substance. Moreover, double and dual HOPG/Si monochromators have been proposed where the two materials are combined into bichromators, a system named POSI standing for **p**yrolytic graphite **o**n **si**licon [2, 3]. Two types of bichromators can be envisaged. If the surface of the Si crystals is parallel to the reflecting lattice planes, a dual-wavelength beam is selected out of the white incident beam and focused on the sample *simultaneously* under high resolution and high flux conditions. If the Si reflection is asymmetric, the sample can be exposed *successively* to the two beams reflected by the hybrid monochromator and the asymmetry [4] permits to decrease the meridional beam width.

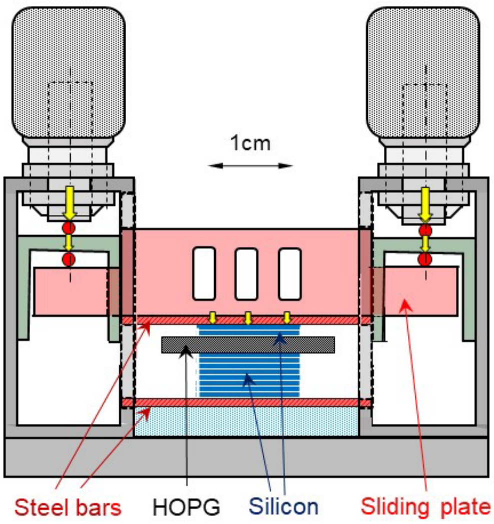
Experimental study

The second case was examined experimentally in the present work. Flat pieces of HOPG were held between blades of perfect silicon crystals without any bonding material. By the way, the cover blade could also be made of glassy carbon commercialized under the name *Sigradur* that is more transparent to neutrons and generates less background due to inelastic scattering than silicon. Moreover, because of its amorphous structure *Sigradur* does not produce Bragg peaks. The curvature of the silicon crystals was varied by a mechanical bending device based on the well-known four-point principle. Adapting to the curvature of the silicon blades the HOPG crystals formed a polygonal shape. The experimental setup is shown in figs. 1 and 2.

For the present study, 10 flat and polished, 0.6mm thick Si crystals measuring 118x12mm² with an asymmetric cut of 3.8° between the (111) lattice planes and the surface, were supplied by the company *Andrea Holm*, Gigerenz, Germany. The 11 HOPG pieces were kindly provided by Dr. Skoulatos, TUM Munich. Both materials reflected the incident monochromatic neutron beam successively when recording rocking curves by rotating the system about an axis perpendicular to the drawing plane running through the center of the HOPG/Si stack. The setup is shown schematically in figs. 1 and 2.



<u>Figure 1.</u> Side view of the four-point bending device in flat position. The pair of movable steel rods on top of two Si blades push on the HOPG pieces that bend eight Si blades lying on two fixed steel bars. When bending the blades the flat HOPG pieces form a polygon. For simplicity, symmetric reflection geometry is displayed and the beams reflected by the two top Si blades are not shown.



<u>Figure 2.</u> Front view of the bending device.

The surface height of the 11 HOPG crystals was recorded mechanically on the right and left parts of their top faces exceeding the silicon blades. The results obtained for a radius of curvature of 1.5m of the silicon blades are presented in fig. 3. They show that the polygonal figure approximates the shape of the silicon crystals to within the limits of the measurement accuracy. To evaluate the POSI performance in terms of rocking curve peak shifts and thus to determine an effective radius of curvature of the HOPG crystals, the POSI system was studied by neutron diffraction using a beam of 2.37 Å delivered by a bent perfect crystal monochromator as shown in fig. 1. The beam

was collimated to produce a footprint of 3.5mm on the HOPG crystals at a Bragg angle of 20.7°. Then the rocking curves of both the (002)-reflection of the HOPG crystals and the (111)-reflection of the silicon crystals, Bragg angle 22.1°, were recorded as a function of the beam position. The results of the neutron tests show a very good alignment between the HOPG lattice orientation and the silicon surface shape.

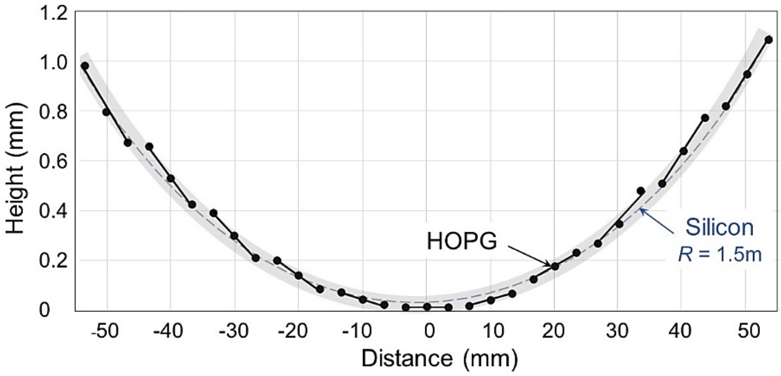


Figure 3. Results of mechanical tests of the POSI system.

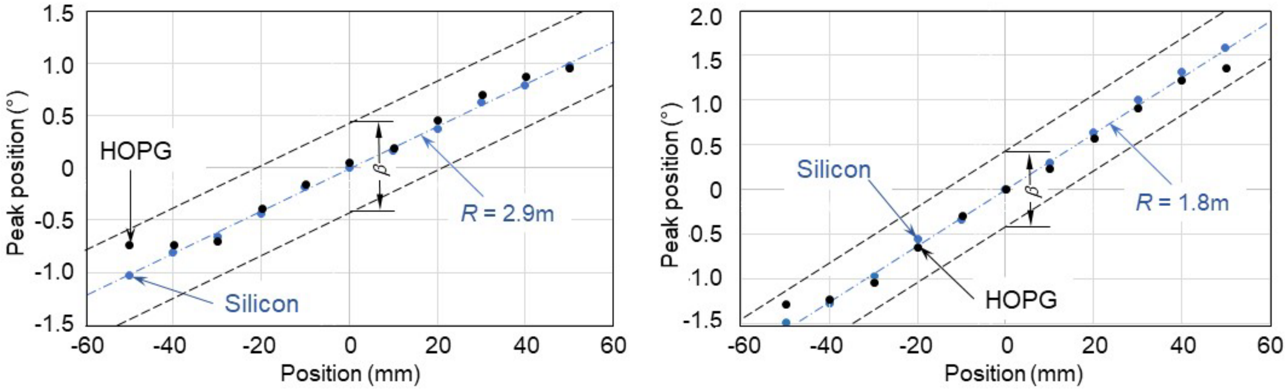


Figure 4. Peak positions of the HOPG (002)-reflection and the silicon (111)-reflection along the POSI system for two radii of curvature. β is the FWHM of the HOPG rocking curve.

Conclusion

First results of neutron test experiments showed that the hybrid concept called *POSI,* abbreviation of *pyrolytic graphite on silicon,* is capable to produce dual monochromators that augment the scope of experimental applications while decreasing the size and complexity and therefore also the cost of neutron monochromators. An added value of this design is the fact that the non-diffracted neutron beam is transmitted and can feed other instruments situated downstream.

The neutron diffraction experiments were carried out at the CANAM instrument of NPI CAS Řež installed at the CICRR infrastructure, which is financially supported by the Czech Ministry of Education and Culture, project LM2023041.

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11B/10B-modulated boron carbide neutron interference mirrors

Interface roughness, interlayer chemical reactions, and interdiffusion are the main limiting factors for reaching high reflectivity values from element-modulated neutron multilayer mirrors. We here demonstrate the feasibility of high reflectivity neutron interference mirrors based on 10B/11B isotope modulation as the sole scattering mechanism, consequently eliminating any chem- ical driving force for formation of interphase interlayers and nanocrystallites at the interfaces. The mirrors are synthesized by alternating magnetron sputter deposition of $^{11}B_4C$ and $^{10}B_4C$ layers producing 128 nm-thick B_4C coatings with internal 10B/11B modulation periods, Λ, ranging from 1.6 nm to 12.8 nm with 10B-to-Λ relative thickness ratios, Γ, from 1/8 to 7/8. Interdiffusion and kinetically limited roughness accumulation is minimized by employing a low-energy-modulated (0 eV/~20 eV) high-flux ion-assisted deposition at room temperature.

Neutron reflectivity (NR) exhibits very strong interference (Bragg) peaks corresponding to the in- tended 10B/11B modulation periods Λ. For example, 13% absolute reflectivity is measured from an isotope modulated sample with just 20 bilayers of Λ =60 Å. NR simulations indicate close to 0Å interface widths. No traces of elemental modulation or crystallinity are detected by X-ray reflec- tivity, X-ray diffraction or Transmission Electron Microscopy. ToF-ERDA indicate a B/C ratio of 5 with traces of O and N in the mirrors. The reflectors require few modulations to achieve high reflectivity which make them suited for high Q bandpass mirrors.

Primary author(s): Prof. BIRCH, Jens (Linköping University)

Co-author(s): Dr. STENDAHL, Sjoerd (Linköping University); Mrs. DORRI, Samira (Linköping University); Mr. ZUBAYER, Anton (Linköping University); Dr. GHAFOOR, Naureen (Linköping Uni- versity); Dr. ERIKSSON, Fredrik (Linköping University)

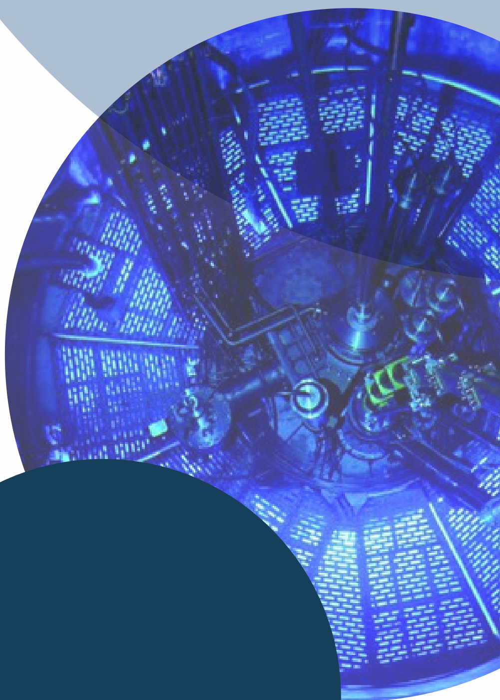
Presenter(s): Prof. BIRCH, Jens (Linköping University)

SESSION 3

POLARIZATION

Monday 10th July

4.40pm – 5.40pm



KOMPASS: The New Polarized Cold Neutron Triple-Axis-Spectrometer at FRM-II

D. Gorkov[1,2], M. Müller[2], G. Waldherr[2], A. Grünwald[1,2], J. Stein[1], S. Giemsa[3], P. Böni[3] and M. Braden[1]
[1]II. Physikalisches Institut, Universität zu Köln, 50937 Köln / Germany
[2]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, 85748 Garching, Germany
[3]Physik-Department E21, Technische Universität München, 85748 Garching / Germany

KOMPASS is a polarized cold neutron triple-axis-spectrometer (TAS) that has been recently installed at the FRM II. Complementary to the other triple-axis-spectrometers at the FRM II, the instrument is designed to operate exclusively with polarized neutrons and to provide options for longitudinal and zero-field 3D polarization analysis. The incoming polarization is imposed by a unique triple supermirror V-cavity, while different options will be available to guide the neutron polarization at the sample position and for polarization analysis of the scattered beam.

Instrument description

KOMPASS is located at the FRM II in the neutron guide hall West at a distance of 45 m away from the cold source, occupying the end position of the curved neutron guide NL1 (Fig. 1). In contrast to other TASs at the FRM II, KOMPASS is equipped with a unique permanently installed polarizing guide system. It is parabolically focussing in the scattering plane and consists of static and variable guide elements that allow for optimizing the beam to the specific scientific problem (see Fig. 2).

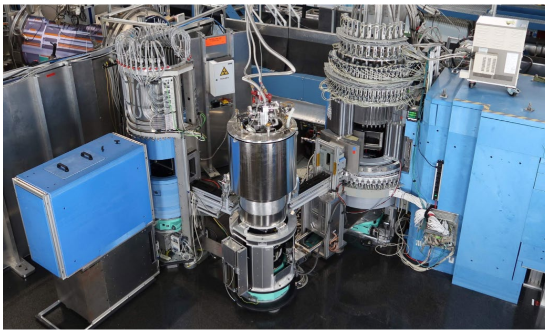


FIG. 1: Overview of the KOMPASS instrument with installed CryoPAD setup and a cryostat inside the CryoPAD.

The permanently installed static part of the guide system hosts a series of three polarizing multichannel V-cavities. Each of the three V-cavity systems consists of a stack of four parallel V-elements hosting a number of double-sided Fe/Si coated supermirrors sputtered on silicon substrates and separated by absorbing layers.

The polarization principle of a V-element is based on the spin-dependent reflection of the unpolarised neutron beam from the polarizing supermirror placed under a shallow angle ϑ_i to the incident beam (see Fig. 3a). The spin up component of the beam is reflected from the supermirror and gets absorbed in the underlying absorbing layer, whereas the spin down component is transmitted through the 0.3 mm thick silicon substrate. A careful choice of the supermirror structure allows reaching large acceptance angle for incident neutrons in combination with an almost perfect spin-dependent reflectivity resulting in superior quality factor $Q = T \times P^2$ (*T*- transmission, *P*- polarization) when compared with commonly used polarizing Heusler crystals [1].

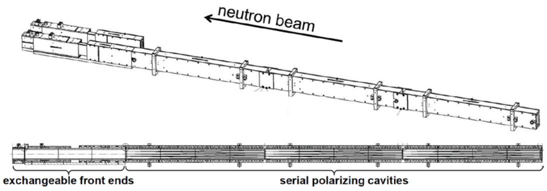


FIG. 2: Overview and side-view of the polarizing guide system of KOMPASS.

The cavities are surrounded by magnetic casings producing a constant saturating magnetic field at the supermirrors, thus ensuring a highly polarized and simultaneously highly intense neutron beam transmitted through the V-elements. The very first tests performed at KOMPASS confirmed the high quality of the incident beam with polarization of above 97.4% over the whole beam cross-section that will be further improved. Preservation of polarization is secured by guide fields installed along the entire neutron beam path on the way to the spin-analyser. The non-magnetic coating of the sides of the neutron guide changes progressively with decreasing width of the parabola towards higher critical angles of reflection, while the top and bottom sides provide a coating with a constant critical angle of reflection. Together with the optimized double-focusing monochromator design, the parabolic focusing guide system delivers a high neutron flux to a small sample volume that can be adapted to the experimental requirements.

The variable part of the guide system includes a few exchangeable front-end sections allowing adapting the energy- and momentum-resolution of the instrument to the needs of the experiment. Highest flux, high energy- and reduced momentum-resolution are obtained in the configuration with parabolically focused front-end sections. In contrast, for measurements requiring high transverse momentum-resolution, or for the investigation of steep dispersion relations, the parabolic front-end sections can be exchanged by straight guide tubes and optionally combined with a set of Soller-type collimators. Thus, the employed concept of the different guide ends allows for selecting an optimized energy- and *Q*-resolution according to the performance requirements of the scientific question. Moreover, it promises a superior energy resolution when compared with the conventional straight, or elliptic guide concepts at the expense of a reduced transverse *Q*-resolution [2,3].

The variation of the incident neutron energy within the range 2 meV ≤ E_{in} ≤ 25 meV is realized via tuning the take-off angle of the adjustable doubly-curved monochromator array consisting of 19 × 13 (W × H) highly oriented pyrolytic graphite (HOPG(002)) crystals. A similar large array of doubly focussing HOPG(002) crystals is used to analyse the energy of the scattered neutrons. Alternatively, a Heusler can be installed as analyser.

The spin state of the scattered neutrons can be analysed with a single, multi-channel polarization analyser shown in Fig. 3b. The polarization analyser is ca. 65 cm long and located between the (energy) analyser and the detector, where each of the total 13 channels has an embedded, double-sided Fe/Si coated V-cavity. The expected polarisation efficiency is $P > 96\,\%$ for neutron energies $E_n < 15$ meV. The quality of the secondary polarization can be improved by inserting vertical collimators that however, will severely cut the intensity in most inelastic studies.
A velocity selector installed in the focal point of the parabolic guide system in front of the monochromator serves for suppression of higher-order-wavelength neutrons, thus significantly

reducing the background of the instrument. Optionally the velocity selector can be removed from the beam and be replaced by a motorized slit realizing a "virtual source" concept and yielding an intensity gain at costs of spectral purity of the incident beam.

Special emphasis during the design of KOMPASS was put on its compact layout featuring short distances of less than 1.2 m between the essential components of the instrument (monochromator – sample – analyser – detector). For this purpose, a compact multiaxial sample table was engineered and built. Various degrees of freedom of the sample are provided by a motorized *xy*-stage, a set of orthogonal cradles and a *z*-table for the vertical adjustment of the sample.

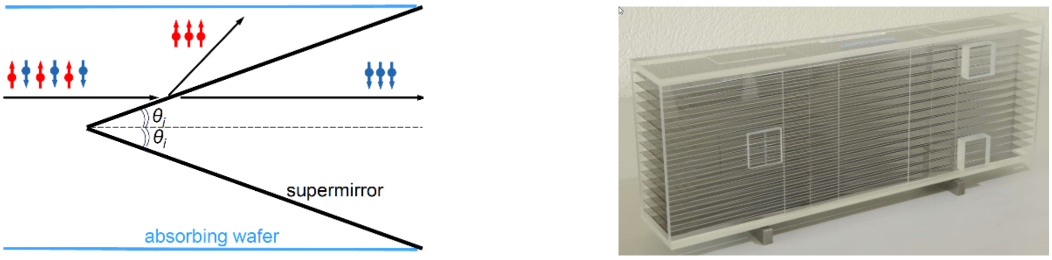
The detection of the scattered and analysed neutrons is foreseen either by a simple standard ^{3}He-tube or by a linear position sensitive ^{3}He-counter. The latter will allow for restricting the vertical Q-resolution and the degree of polarization quality in the data analysis.

Separately, we remind that the use of a large doubly focusing HOPG analyser for the definition of the final energies could result in the production of an intensive diffuse scattering close to the specularly reflected beam, thus hampering measurements of weak inelastic signals at small energy transfers. In order to overcome such a problem, one of two available dedicated radial collimators can be placed between the analyser and the detector. As a result, the acceptance angle of the detector tube is effectively reduced, which in turn minimizes the spectral weight of the undesirable diffuse scattering in the scattered beam.

In order to independently define the incoming and outgoing neutron polarization, the instrument will be equipped with a CryoPAD of the 3rd ILL-generation that so far can be combined with a standard closed cycle refrigerator. For studies with only longitudinal polarization analysis, alternatively an array of Helmholtz coils can be used. An optimized second set of Helmholtz coils is currently constructed to reach larger fields with further reduced dimensions.
A cooled Beryllium filter and a pyrolytic graphite (PG) filter can be located on optical benches before and/or after the sample table and will allow for the elimination of spurious signals.

First experiments at KOMPASS, present state and planned instrument development
The fast installation and commissioning of the primary spectrometer, sample table and detector portal allowed for first experiments in polarized diffraction mode with a set of Helmholtz coils for longitudinal polarization analysis. Besides documenting the quality of the neutron beam and polarization, these experiments yielded already scientific results [4-7].

At present, all components of KOMPASS are constructed and wait for commissioning and first polarized inelastic experiments with longitudinal polarization analysis. Current work is focused on optimizing the mechanical and software adaptation of the CryoPAD system, which allows for measurements with spherical polarisation analysis providing direct access to non-diagonal terms of the polarization matrix [8]. KOMPASS will also allow for time-resolved stroboscopic measurements to study the magnetic response to some external trigger, as it has been demonstrated for the switching of multiferroic domains by electric fields [9].



a) b)

FIG. 3: a) Polarizing principle of a V-element. b) Multi-channel polarization analyser used for the spin analysis of the reflected beam at KOMPASS. One can recognize 13 channels, each hosting a V-Cavity with embedded, double-sided Fe/Si coated supermirrors on Si substrates.

Typical scientific applications

During the last couple of decades, experiments using polarized neutrons and in particular zero-field neutron polarimetry underwent a significant technical improvement while becoming more and more important for the understanding of complex magnetic materials. The unique possibilities offered by spherical polarization analysis namely that the direction of the polarization vector of the scattered neutrons can be determined for any given incident polarization, and the inherent unambiguous separation of magnetic and non-magnetic signals, open up a wide field of applications.

Typical scientific applications, using the unique features provided by polarized neutrons and spherical neutron polarimetry are the investigation of complex magnetic structures and of the associated dynamics. Typical systems, for which KOMPASS may significantly advance the understanding, are all types of weak magnetic orders, complex (chiral) magnetic structures (e.g. rare-earths, skyrmions), quantum magnets, quantum effects associated with longitudinal magnetic excitations, quantum critical fluctuations, systems of reduced dimensions (e.g. thin films and multi-layer structures), as well as multiferroic and magneto-electric materials, high-T_c-superconductors, and itinerant magnetic systems.

The development and installation of KOMPASS is funded by the BMBF through the Verbund-forschungsprojekt 05K19PK1.

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Realization of an advanced broadband supermirror solid-state neutron polarizer for fundamental physics applications

For many experiments performed at the cold-neutrons fundamental physics instrument PF1B at the ILL, the polarizer is an essential component [1]. Placed after the cold H113 guide exit, it should produce a large-area, intense and well polarized "white" beam spanning a broad wavelength range (from 0.2 to 2.0nm), with no other inserted optical element than beam-defining apertures. Until recently, a "Schärpf-type" bender based on Co/Ti supermirrors was used [2], showing 98.5% polar- ization efficiency and about 50% transmission of "good" spin component. For higher polarization, the "crossed configuration" [3] could be used, yielding 99.7% polarization and 25% transmission. After more than 15 years of successful exploitation with a neutron integral flux of more than 2.1018 2.10^18 n/(s.cm^2), the polarizer showed significant Co activation and noticeable radiation damage. The present project aims at replacing the polarizer with a new one, having similar or better perfor- mance and less operational drawbacks. The concept [4] is a more compact solid-state "V-bender", based on Fe/Si supermirrors (m=3.2, Cobalt-free) deposited in-house on sapphire substrates and used in reflection. Special care was taken to limit depolarization effects [5] and to minimize an- gular misalignments when stacking the mirrors. Following the concept validation with the first prototypes and measurements [6], the realization of the record-breaking [7] final device [8] will be described, including fabrication and neutron characterization preceding final installation on PF1B. This example provides rather general guidelines for careful supermirror polarizer or ana- lyzer design, which we are applying already to another neutron instrumental configuration out of the fundamental physics domain.

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Primary author(s) : PETUKHOV †, Alexander Kuzmich (Institut Laue Langevin); BIGAULT, Thierry (Institut Laue Langevin); Prof. NESVIZHEVSKY, Valery (Institut Max von Laue - Paul Langevin)

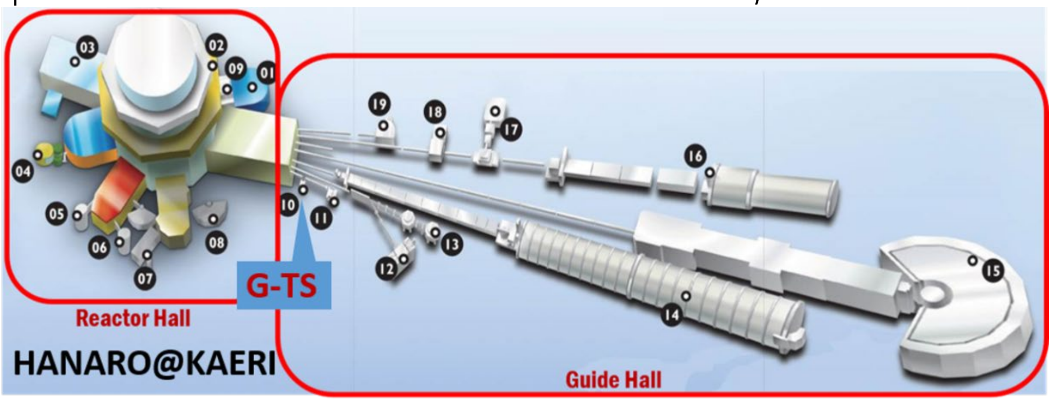
Co-author(s) : DELPHIN, Guillaume (Institut Laue Langevin); VITTOZ, Amandine (Institut Laue Langevin); JULLIEN, David (Institut Laue Langevin); SOLDNER, Torsten; DEVISHVILI, Anton (Insitut Laue Langevin, Uppsala University); COURTOIS, Pierre (Institut Laue Langevin)

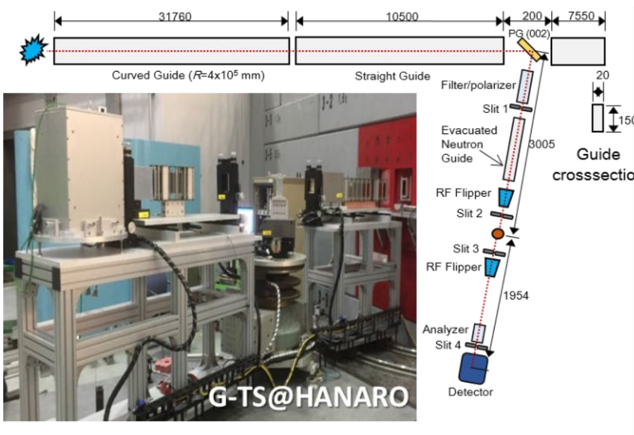
Presenter(s): BIGAULT, Thierry (Institut Laue Langevin); Prof. NESVIZHEVSKY, Valery (Institut Max von Laue - Paul Langevin)

Cold Neutron Guide Test Station with Polarization Analysis at HANARO

K.-Y. KIM[1], S.-M. LEE[2], S.-W. KIM[1], C.-S. KIM[1], J.-H. HAN[1], J.-Y.KIM, J. H. LEE[1], S.-J. CHO[1]
1 Neutron Science Division, Korea Atomic Energy Research Institute, Daejeon 34057, South Korea
2Laser Application Research Team, Korea Atomic Energy Research Institute, Daejeon 34057, South Korea

Guide-test station (G-TS, Fig.1) instrument at CG1 beamline in cold neutron guide hall at HANARO has been dedicated to test the unpolarized neutron supermirrors produced in-house. In order to make it feasible to measure polarizing supermirrors and magnetic thin films, we adopted polarizing neutron optics such as polarizer, neutron spin flippers, spin analyzer, guide field. HOPG (002) monochromator, made of seven pieces of slabs (40mm×20mm×2mm), deflects out neutrons with wavelength of 4.34 Å by a take-off angle of 80° from neutron guide with a cross-section of 20 mm wide×150 mm high. Monochromatic neutron wavelength is confirmed via time-of-flight technique and neutron flux was measured via gold foil activation analysis to be 1.12E6 n/sec/cm² at sample position at the condition of vertically focusing monochromator and wide open slit condition. Double reflection polarizer/wavelength filter device, switchable between polarized and unpolarized beam channels 2mm wide, was produced by Dr. Thomas Krist, Nano Optics Berlin GmbH, Germany.





Parameter	Characteristics	
Installation location	CNLB CG1	
Scattering plane	Horizontal	
Monochromator	Focused, HOPG(002)	
Wavelength	4.34 Å (Take-off angle= 80°)	
Detector	He3 Single	
Polarizer/ Wavelength filter unit	Unpolarized	Polarized
	Ni-Ti mono.	Fe-Si mono.
Analyzer	Fe/Si Supermirror (m=3)	
Spin Flipper	RF Gradient Field	
Electromagnet		
Flux (wide open)	Unpol. Beam	Pol. Beam
	~ 9.0E5	~ 4.5E5
Q resolution & range	0.6% 0.55Å^{-1}	
Min. reflectivity	<10^{-6}	
BKG	< 5cts/min	

Figure 1. (Top) HANARO neutron scattering facility, (b) G-TS instrument and specifications

Compared to He-3 polarizer or Heusler crystals, neutron beam with high polarization as well as high transmission can be available. Spin-up neutrons are produced from double reflection polarizer when neutron beam is incident on mirrors within angular bandpass of 0.2 degree around an incidence angle of 1 degree. In addition, this solid state device is maintenance-free in that it filters out second harmonic neutrons and makes widely used N_2-cooled Be filter unnecessary. Lastly, background noise is low because it is located right after monochromater inside heavy concrete shielding blocks and most of unwanted neutrons are unable to come out of the beam shutter. Spin analyzer is made of a single blade of m=3 Fe/Si supermirrors coated on both side of Si wafer. This analyzer was also fabricated by NOB GmbH. Spin down neutron is transmitted while, spin-up neutrons are totally reflected if incidence angle is in between their critical angles. To flip the neutron spin polarization by 180°, radio frequency gradient field spin flippers (SF) were in-house fabricated. Two SFs are located upstream and downstream with respect to sample position. Ac current via RCL series resonating circuit is applied to rf coil, producing horizontal ac field. Vertical dc magnetic field strength could be adjustable by a hybrid architecture combining iron plate and dc electromagnet. Neutron spin can be flipped by 180° when Larmor frequency associated with precession motion around dc vertical field is set to be equal to the ac resonating frequency near the center of rf-coil. It turns out that 1st SF has 115. 5kHz, Vpp=3.5 V, dc field =3.9mT, dc current= 3.5A and 2nd SF has 140.0kHz, Vpp=3.5 V, dc field =4.8mT, dc current= 3.0A, respectively. Finally, polarized neutron beam with overall spin flipping ratio (~ 90) and polarization (~97%) using a combination of polarizer and spin flipper and spin analyzer can be available at the G-TS instrument.

E-mail of the corresponding author: kykim3060@kaeri.re.kr

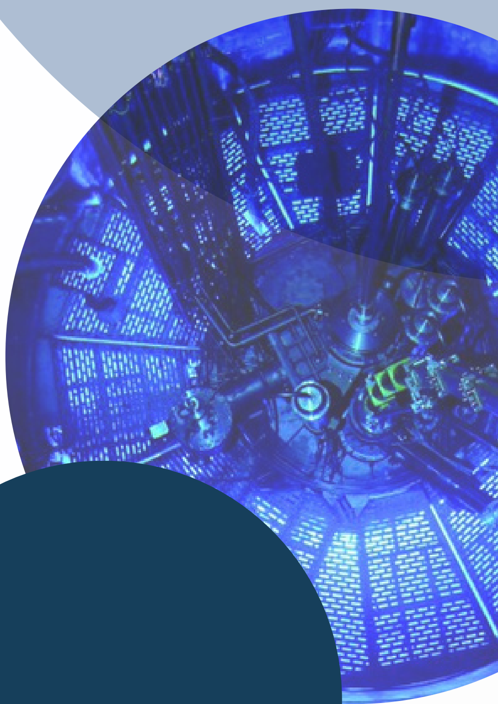
NDS 2023

SESSION 4

NEW GUIDE SYSTEMS 2

Tuesday 11th July

9.00am – 10.00am



ill NEUTRONS FOR SOCIETY

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Planed upgrade of the primary spectrometer of OSIRIS

Adrien Perrichon, Franz Demmel
ISIS Neutron and Muon Source, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, United Kingdom

After 25 years of operation and several improvements on the secondary spectrometer, it is timely for an upgrade of the whole primary spectrometer of the indirect time-of-flight near-backscattering spectrometer OSIRIS at the ISIS Facility.
This upgrade comprises a new supermirror guide with non-linear defocusing and focusing sections, a new wavelength bandwidth chopper system and a flexible slit system to adjust the divergence [1]. The new neutron guide, illustrated in Fig. 1, has an elliptical defocusing section, a curved section and an elliptical focusing section.

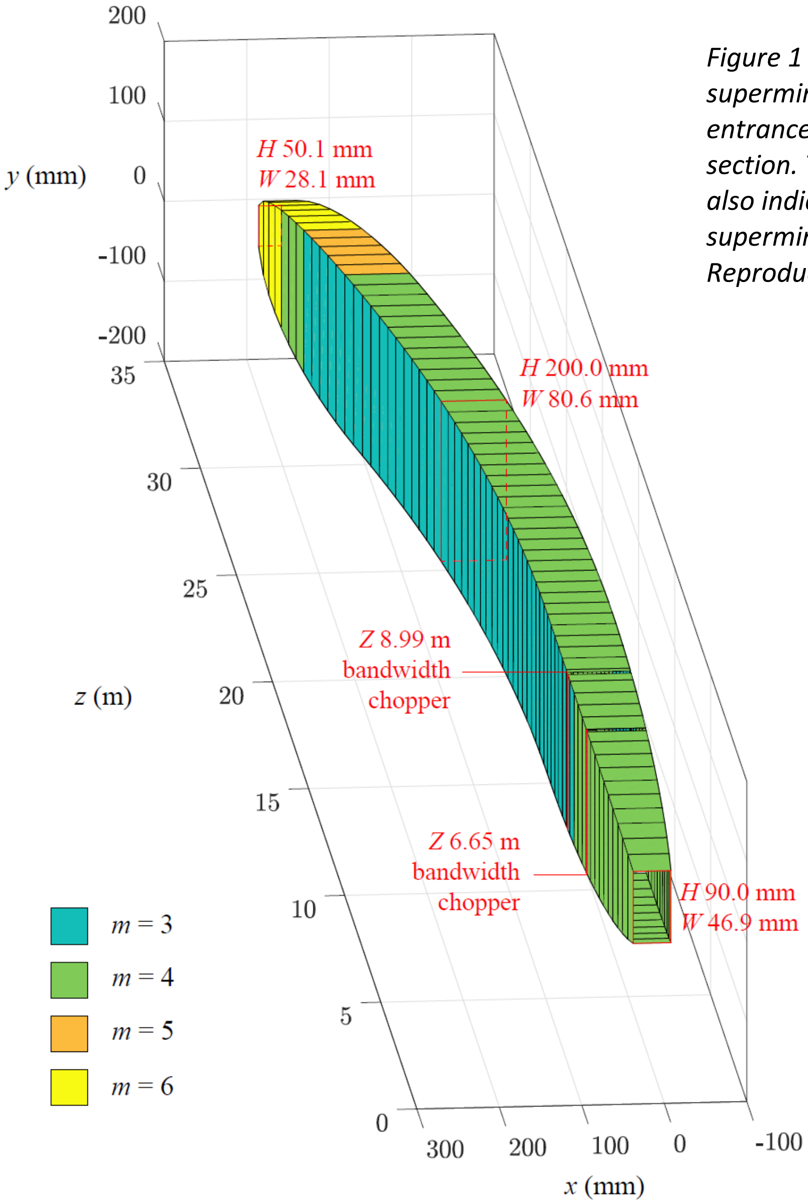

Figure 1 – Scheme of the proposed supermirror guide, with dimensions at entrance, exit, and in the curved section. The position of the choppers is also indicated. The m-values of the supermirror coating are colour-coded. Reproduced from ref. [1].

The estimated gain factor in intensity is wavelength dependent between 4 and 7 at the sample position, with a homogeneous divergence distribution on a smaller beam spot (cf. Fig. 2). The later will particularly benefit the new silicon analyser, currently being installed, which can achieve a resolution of 11 μeV for small, 1 cm³ samples [2]. The divergence will increase by up to a factor 3 compared to the present guide but can be reduced by up to a factor 5 through the slit system (cf. Fig. 3). The increased guide cross section requires a system of two counter-rotating disc choppers with larger disc diameters than the present ones for the selection of the wavelength bandwidth.

The substantial increase in flux will keep the OSIRIS spectrometer competitive in comparison with instruments at sources with higher power. The primary spectrometer upgrade will ensure a bright future for OSIRIS and the user community it serves beyond the year 2030.

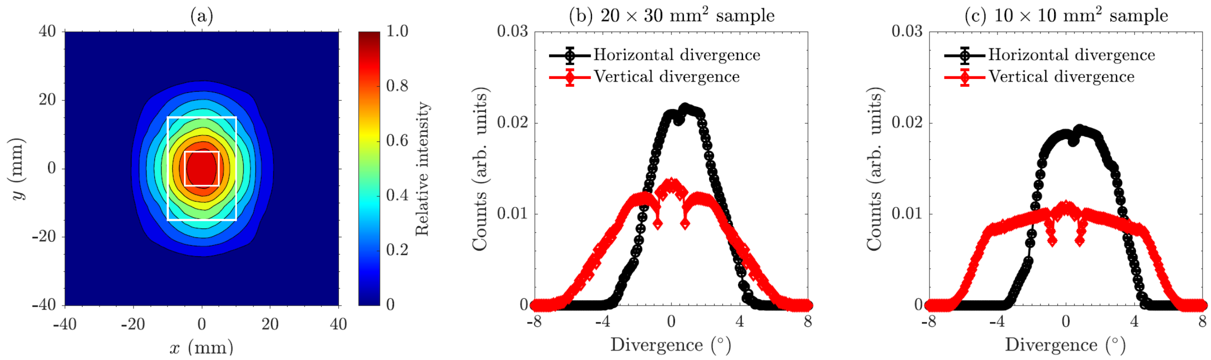

Figure 2 – (a) PSD-picture of the spatial distribution of the neutrons at the sample position. The rectangle indicates the sample dimensions for the optimization. (b,c) Horizontal and vertical divergence of the cold neutron beam at the sample position for the two sample dimensions. Reproduced from ref. [1].

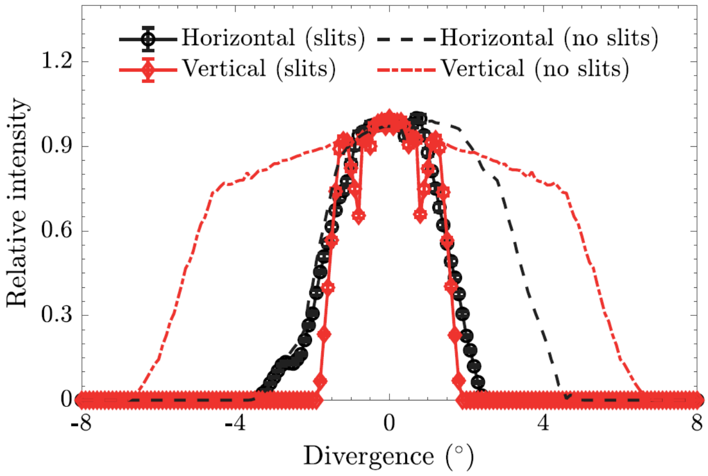

Figure 3 – The divergence at sample position with a three-slit system is plotted in comparison with the divergence of the unrestricted setup. Note that the off-centred distribution of the horizontal divergence due to the curved guide is compensated using asymmetric slit openings. Reproduced from ref. [1].

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Neutron shielding and transport calculations for the post-beryllium replacement HFIR cold guide hall

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) was constructed in the 1960s for the purpose of producing isotopes. Today, HFIR also supports a neutron scattering user program with neutron scattering instruments spread across 3 thermal beam tubes (HB-1, HB- 2, and HB-3) and 1 cold source (HB-4). Over time, radiation damage accumulates in the beryllium reflector, necessitating replacement as the beryllium approaches end-of-life. As such, the HFIR Beryllium Reflector Replacement (HBRR) is planned for 2028. The HBRR provides an opportunity to redesign and optimize the sources and instruments on each beam tube, and therefore significant changes to the shielding in the cold guide hall (CGH) will be made.
The present configuration of the CGH contains 4 neutron guides (CG-1 to CG-4). HBRR features a planned redesign of the cold guide network viewing HB-4. There is an expansion of the current CGH to provide more space for instruments and additional laboratory and sample environment space. The new CGH will feature 6 cold neutron beamlines:

- NB-1 IMAGINE - an existing instrument on CG-4D
- NB-2 Spin Echo - a new instrument
- NB-3 Bio-SANS - an existing instrument on CG-3
- NB-4 MARS - an existing instrument on CG-1D
- NB-5 GP-SANS - an existing instrument on CG-2
- NB-6 MANTA - replaces cold triple axis on CG-4C,
-

all of which will utilize newly optimized guides. The guide system has been optimized utilizing McStas and the shielding is evaluated using MCNP 6.2 with the goal of accurately representing the individual McStas guide models in the MCNP model with an eye to utilizing MCNP to study instrument backgrounds.
An accurate representation of a guide model in MCNP involves the use of two newly developed tools. The first tool, McStas2CAD, reads the output of a McStas trace and generates a CAD-compatible IGES file containing the neutron guides' boundary surfaces and the locations of other optical components (monochromators, velocity selectors, etc.). The instrument engineering team uses the IGES file as a basis for layout planning. The second tool, Geomwriter, reads the IGES file and utilizes additional information (such as supermirror parameters) to produce an MCNP- compatible input file. There is a suite of extensions to MCNP that have been developed for simu- lating neutron scattering instruments, including:

- neutron guides,
- single crystal scattering,
- velocity selectors,
- small angle neutron scattering.

The Geomwriter workflow provides the ability to make changes to the model without spending sig- nificant time correcting errors or recalculating thousands of surfaces. The resulting MCNP model of the HFIR CGH includes a detailed representation of the segmented guides in ≈1~m sections and includes the small gaps < 1~mm gaps between subsequent guide segments. The full model contains nearly 8000 cells and over 25000 surfaces.

The present system has a primary HB-4 shutter at approximately 5~m from the cold source. The guides first traverse the HB-4 tunnel, then pass through a thick concrete wall (bulkhead 1) into the Transition Building (TB), and then through another thick concrete wall (bulkhead 2) into the CGH and into a region referred to as the Common Shielding (CS). The guides have separated enough after the CS that individual guide/instrument shielding is required. The post-HBRR shielding needs are addressed using the detailed model that has been built using Geomwriter. Each beamline will have individual secondary instrument shutters, so that work on individual beamline velocity selectors can occur without closing the primary HB-4 shutter. These shutters will be downstream of the second bulkhead for NB1-5 and will be inside the TB shielding for NB-6, due to the position of the NB-6 velocity selector near the second bulkhead. The preliminary design of the secondary instrument shutters is a boron carbide layer as a neutron absorber with a steel backing layer and with the shutter surrounded by lead to attenuate the gamma rays produced by neutron capture when the shutters are closed.
The MARS instrument will have a velocity selector but it will not always be used for all configurations and thus there will be some cases where the full beam reaches the experimental area. The shielding needs of this configuration will be significantly different from one where the velocity selector intercepts much of the beam. Thus, preliminary calculations have been performed to investigate whether the MARS instrument will need an enclosed cave for personnel reasons and to minimize the backgrounds in the adjacent Bio-SANS and GP-SANS beamlines.
The model developed for the HFIR CGH has been completed by utilizing McStas2CAD and Geomwriter with great success. This process has led to feedback to the instrument optimization team when occasional overlaps between adjacent neutron beamlines have been found in the MCNP model, whereas such overlaps would not be found in the McStas model because each instrument is optimized individually. Work remains ongoing to further develop regions of the model incrementally.

Primary author(s): GRAMMER, Kyle (Oak Ridge National Laboratory)

Presenter(s): GRAMMER, Kyle (Oak Ridge National Laboratory)

Australian Centre for Neutron Scattering Recent Upgrades and Future Plans

The Australian Centre for Neutron Scattering (ACNS) currently operates 15 neutron beam instruments. Recent improvements across the facility, both in progress and completed, range from the neutron sources, in-pile guides to optics and shielding. One such major achievement is the replacement of the thermal in-pile guides and primary shutter at the Open Pool Australian Lightwater (OPAL) reactor face. The new installations introduced an additional thermal split beam guide, which paves the way for two new neutron beam instruments.
A significant project in the planning stage is the replacement of cold neutron source (CNS) within the OPAL reactor pool. Since the OPAL reactor also provides other services across health and industry, the shutdown is to be kept as short as reasonably achievable. The complex manoeuvre will therefore be devised with an emphasis on schedule optimisation.
Also highlighted are a series of performance upgrades to the neutron delivery systems at proximity to the instruments. These include projects for replacement neutron guides, monochromators, and shielding.

Primary author(s): LEE, Stan (ANSTO)

Co-author(s): ELTOBAJI, Andrew (ANSTO); PANGELIS, Steven (ANSTO); DARMANN, Frank (ANSTO); OLSEN, Scott (ANSTO)

Presenter(s): LEE, Stan (ANSTO)

SESSION 5

SOURCES & APPLICATIONS

Tuesday 11th July

10.20am - 11.40am

NEUTRONS FOR SOCIETY

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Modified Collimator for Narrow Fast Neutron Beams in Neutron Therapy

In clinical practice, when working with a target that emits neutrons in 4π space, it is always required to concentrate them into a mono directional beam. This is necessary both to increase the particle flux density and to give it the desired shape and optimal cross-sectional area. In principle, the beam shape can be changed using a collimator, which makes it possible to significantly narrow it and achieve minimal neutron absorption in structural elements. In this paper, simulation works using MCNP5 code have been carried out to find the possibility and reality of applying narrow beam of 2 cm and less of fast neutrons in radiotherapy. Simulations were performed on the origi- nal design of the treatment 8.5 x 8.5 cm2 collimator existed in the cyclotron laboratory of Tomsk Polytechnic University. The results showed that the neutron energy spectrum almost would not change in the fast region, but in opposite, there was about 11 % higher neutron flux when using the collimator with 2 cm aperture. The spatial distributions of fast neutrons were significantly narrower at 10 cm distance from the aperture compared to the original design 8.5 x 8.5 cm2. The narrower and intense neutron beam would save the healthy tissues beside the tumor and also de- crease the treatment time period which make the treatment procedures more comfortable. There is reason to hope that narrow beams will make neutron beam radiotherapy for the treatment of small and irregularly shaped tumors more accurate and safer for the patient.

Primary author(s): Dr. SHEHADA, Abdullah (Chechen State Pedagogical University)

Presenter(s): Dr. SHEHADA, Abdullah (Chechen State Pedagogical University)

Design and expected performance of the neutron guide systems at Breazeale Reactor at Penn State University

Penn State Breazeale Reactor Supermirror Neutron Guides Small Angle Neutron Scattering
Neutron Depth Profiling
Prompt Gamma Activation Analysis

At the Breazeale Reactor a new, mesitylene based cold source is being installed to build together with three neutron guides. The guide system is designed to deliver the optimal beam for three instruments: a SANS, a PGAA and an NDP instrument. The first beamline, TG1, serves the HZB V16 time of flight (TOF) Small Angle Neutron Scattering instrument that was donated to Penn State. The instrument is redesigned to fit in the space restrictions. To improve the flexibility of the instrument a velocity selector interchangeable with a guide section is designed that allows the instrument to work in high intensity constant wavelength mode. The maximal sample-detector distance is decreased comparing to the original V16 instrument due to the space restrictions, the chopper positions are determined to be able to work in different modes for close and large de- tector positions. The wavelength resolutions at different modes are 3, 5, and 8 %.In continuous wave mode the velocity selector provides a relative resolution from 10 to 40% depending on the tilting angle of the selector. TG1, having both the width and height of 40mm, consists of a straight section, a bender a second straight section and focusing sections interchangeable with beam defin- ing apertures to give the optimal size and divergence of the beam. The bender is needed to give enough space for the detector tank next to the TG2 guide. The coating was designed from the sample upstream till the source in the way that each section can give the divergence enough to fill the phase-space of the next section. The m-values are 1.5, 1.2, 3.5, 3 for the focusing section, the second straight sections, the bender and the first section respectively. The McStas calculation gives $1.71 \cdot 10^7 n/s/$cm2 for the integrated flux before the collimation section using the simulated intensity and wavelength distribution of the cold source. The second beamline (TG2) is being to build for an instrument will be decided later. The width and height of the guide is 25mm and 70mm respectively. The guide starts with a curved section to go out of line of sight followed by a straight guide. The coating of all sides are m = 3. The critical wavelength of the curved guide is 1.28 A. The integrated intensity at the end of the guide is $9.8 \cdot 10^7 n/s/$cm2. The third guide (TG3) delivers neutrons for a Prompt Gamma Activation Analysis instrument and a Neutron Depth Profiling instrument. The dimensions of the guide cross section are 25mm in both directions. The guide starts with a curved section followed by a straight section and a 1.5m flight tube that will contain the beam shaping elements to be designed later. The goal of the design of TG3 was to minimize the gamma background arriving from TG2 while the intensity is not decreasing significantly due to the large curvature of the guide. The calculated intensity is $8.29 \cdot 10^7 n/s/$cm2
A detailed description of the optimization method the final guide system and the redesigned SANS instrument will be presented.

Primary author(s): MARKO, Marton (Centre for Energy Research); Dr. ALEX, Szakál (Centre for Energy Research); Mr. KÁRPÁTI, Péter (Centre for Energy Research); UNLU, Kenan (Penn State University)

Presenter(s): MARKO, Marton (Centre for Energy Research)

Development of keV Scale Pulsed Neutron Source for Nuclear Recoil Calibration of Dark Matter and Neutrino Experiments

Pratyush Patel and Scott Hertel (for SPICE/HeRALD collaboration)

1 Introduction

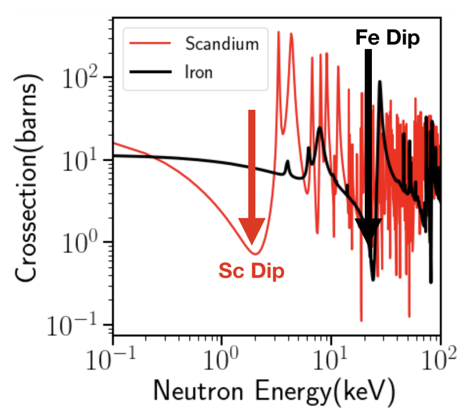
The detection of non-gravitational interactions between Dark Matter (DM) and Standard Model (SM) particles has been a persistent challenge in the field of particle physics. There is a large body of astrophysical evidence supporting the existence of dark matter. Over the past few decades, significant advancements have been made in Direct Detection experiments, wherein the signal is either an electron or a recoiling nucleus. The primary emphasis during this time frame has centered on Weakly Interacting Massive Particles (WIMPs) [3, 7], which refer to a range of DM masses spanning from (1 GeV to 100 TeV) and interaction cross-sections with Standard Model (SM) particles ranging from (10^{-40} to 10^{-50} cm^2). The scientific community has been able to expand their exploration beyond the WIMP paradigm due to advancements in detector technologies [6, 8, 16], theoretical comprehension of different inelastic processes [15] , and novel forms of DM interactions [14] [4, 9]. Numerous innovative and stimulating experiments have been proposed within the past ten years to investigate sub-GeV dark matter[11]. In experiments where the signal involves a recoiling nucleus, the energy imparted to the target nucleus by sub-GeV dark matter is typically on the order of $\mathcal{O}(<1\text{keV})$. Consequently, there exists a pressing requirement for low-energy Nuclear Recoil (NR) calibration techniques that are applicable to all sub-GeV Dark Matter (DM) experiments. The proposed plan involves the development of pulsed low energy neutron sources amd large area keV-scale neutron detector with the aim of enhancing understanding of detectors in the context of low NR energy deposits. The aforementioned neutron sources will also enable investigations into detector responses that are pertinent to coherent elastic neutrino-nucleus scattering CEνNS [5, 13]

2 Principle

The construction of the keV-scale neutron source that is pulsed and quasimonoenergetic is achieved through the utilization of the Neutron Filter concept, coupled with effective neutron moderation. Initially, it is imperative to establish a clear definition of a neutron filter.

The substance referred to as a neutron filter possesses a scattering cross-section between neutrons and nuclei that displays a distinct anti-resonance dip, which is both narrow and profound in nature. The observed reductions in the scattering cross-section facilitate the transmission of neutrons with minimal resistance. The aforementioned substances are commonly known as neutron filters, as depicted in the Figure 1. Iron and scandium are among the exemplars of such materials. The Breit Wigner formalism, as cited, has been utilized to comprehend the physics that underlie the manifestation of resonance and anti-resonance dips. These phenomena have been experimentally observed and comprehended. The utilization of neutron filters to produce quasi-monoenergetic neutrons is deemed ineffective. This process of using neutron filters to produce quasi-monoenergetic neutrons is not entirely novel. A quasi-monoenergetic neutron beam has previously been created using a similar technique at nuclear reactor sites [10], where neutrons are abundant. The challenge, or the novel aspect, is adapting the transmission filter technique to a portable pulsed neutron source. This is achieved by the usage of carefully tuned moderators to convert MeV scale neutron to keV scale neutron, followed by the neutron filtering.

Figure 1: Scattering crossection



- ***Neutron source***: The energy of neutrons resulting from the DD reaction is significantly lower in magnitude compared to the energy of neutrons produced by the DT reaction. This characteristic renders the DD reaction a more suitable option for a pulsed neutron source. In contrast, the DT reaction exhibits higher efficacy compared to the DD reaction, resulting in a greater neutron flux when utilizing DT. In order to achieve effective moderation, a substantial influx of neutrons is required. As such, the generator must possess a significant initial neutron flux, typically on the order of $\mathcal{O}(10^7)$ neutrons per pulse. Thus, the DT generator was selected for the particular design.

- ***Lead***: Subsequently, it is imperative to produce a group of neutrons with an average energy level below 1 MeV. The utilization of Lead's (n-2n) methodology enables the achievement of this objective. DT presents a compelling argument due to the activation of n-2n at a neutron energy of 10 MeV, a threshold that can only be achieved with DT. The residual moderation procedures possess the potential to generate quasi-monoenergetic neutrons with energy in the keV range through alternative techniques that can yield a substantial cohort of neutrons with energy levels below 1 MeV. This particular stage holds significant importance among the diverse range of moderation procedures. It is imperative to emphasize the importance of generating neutrons that possess energies below 1 MeV within a limited distance of a few tens of centimeters. This is essential in mitigating the loss of neutron flow, which is induced by the inverse square law ($1/r^2$). Currently, it is necessary to fully encapsulate the neutron generator utilizing lead shielding. Consequently, neutron generators possessing reduced radii are employed.

- ***Al/AlF$_3$ mixture*** Upon achieving a reduction in neutron energy to a level below 1MeV, it becomes feasible to employ an amalgam of Al/AlF3. The complementary resonances and anti-resonances of aluminum and fluorine facilitate the reduction of neutron energy to a range of 30-100 keV. In order to produce a viable solid material possessing a coarse density of 2.5g/cc, a combination of Al and ALF3 powders was employed. The Hot Isostatic Pressing (HIP) process was utilized to ensure consistent density maintenance throughout the procedure. Prior to the HIP process, a Cold Isostatic Pressing stage was implemented to enhance the compactness of the final product.

- ***Titanium***: The final phase of moderation in our assembly involves the attainment of a neutron population possessing an average energy level below 10 keV. The selection of titanium for the moderation process was based on its notable resonance characteristic at 30 keV. Neutrons that have undergone moderation have the potential to interact with titanium and decrease their energy level to below 10 keV, given their energy range of 30 keV to 100 keV. The aforementioned occurrence is commonly denoted as resonant scattering. The moderation step is necessary solely if Scandium is utilized as a neutron filter.

- ***Scandium***: The ultimate stage of this procedure involves filtration, wherein our system utilizes a Sc (Fe) neutron filter with a neutron energy of 2keV (24 keV). A quasi-monoenergetic neutron source was generated through the filtration of the white spectrum of neutrons that were generated and exhibited an energy range of 10 keV, specifically for Scandium. To obtain Iron, it is necessary to eliminate the moderation stage involving Titanium and solely filter the white spectrum produced by the Al/AlF3 mixture within the energy range of less than 30 keV.

A crucial concern pertaining to the utilization of pulsed DT generators is their restricted operational lifespan, which is characterized by a finite number of pulses. As a result of these limitations, the calibration of NR will suffer from a lack of statistical data. In a regime lacking sufficient statistical data, any increase in the proportion of nuclear recoils that exhibit a tagged and measured recoil angle holds significant value. The achievement of this objective necessitates the development of backing detectors with a large solid angle and high capture efficiency. The development of a sizeable backing detector has been finalized. The detection principle is briefly discussed below.

The process of thermalizing a neutron with a scattered energy level in the keV range is achieved through the utilization of HDPE and acrylic materials. Subsequent to thermalization, the neutron undergoes diffusion and subsequently becomes captured on a scintillator composed of Li-doped ZnS(Ag), which yields 1.6×10^5 upon each neutron capture, as reported in reference [1] which produces photons per neutron capture[18]. These photons

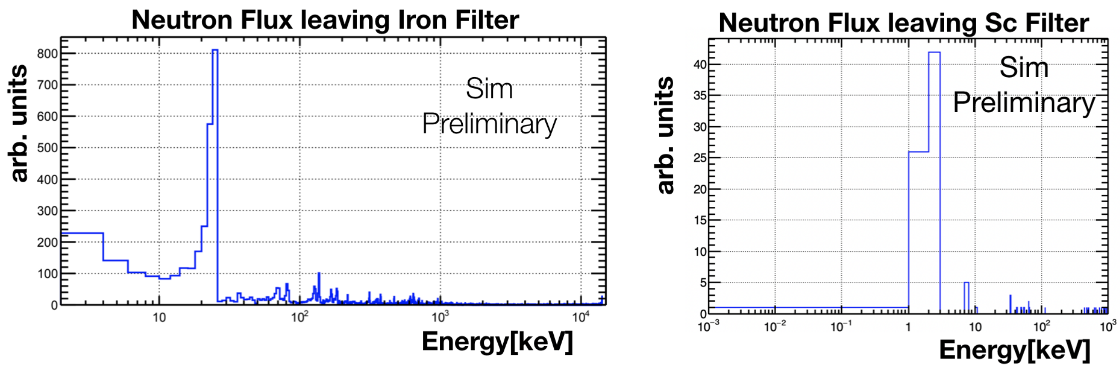


Figure 2: The figure concerns simulated neutron spectra that emanate from a filter. The left plot illustrates the utilization of Iron as the filter material, resulting in a quasimonoenergetic neutron beam at 24 keV. It is noteworthy that the second moderator Titanium is not employed in this process. The filter material utilized in the right plot is Scandium, resulting in a quasimonoenergetic neutron beam with an energy of 2 keV. Additionally, a secondary moderator is employed in this particular scenario.

are captured in wavelength-shifting(WLS) fibers (Kuraray Y-11)[2]. This backing detector has been buit and characterised recently. [12]

The aforementioned photons are trapped within wavelength-shifting (WLS) fibers, Kuraray Y-11. The selection criteria for Y-11 WLS fiber were established on the basis of the optical characteristics of Li-doped ZnS(Ag) scintillator [20]. The fibers have been incorporated within an acrylic matrix, which is subsequently enveloped by a Tyvek (diffusive reflection). Ultimately, the photons that have been captured or shifted are detected through the utilization of readily available Silicon PhotoMultiplers (SiPMs) manufactured by Hamamatsu. The SiPMs of the type S13360-6075CS exhibit a high level of quantum efficiency. The scintillator based on lithium provides discrimination between electronic recoils (ER) and nuclear recoils (NR) through the utilization of pulse shape discrimination (PSD) [19]. An Optical Simulation was conducted utilizing ANTS2[17] to optimize the quantity of WLS fibers present in the acrylic material. This optimization aimed to enable PSD, which would eliminate the occurrence of false triggers caused by gamma radiation. Due to the confinement of the active scintillating material within thin sheets, the rate and amplitude of gamma backgrounds are relatively low.

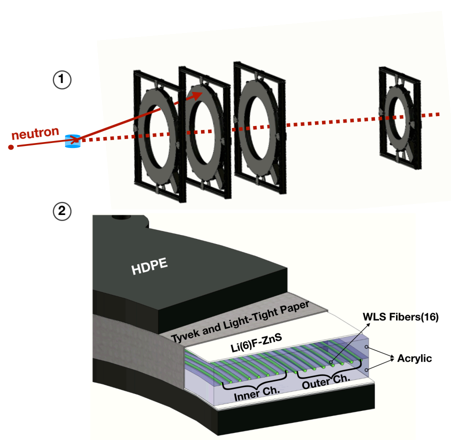


Figure 3: (Top) Shows the schematic representation of the calibration setup with the arrays of backing detectors. (Bottom) Shows the cross-sectional view of the backing detector. The central acrylic layer is divided into two parts, and the fibers were embedded on the grooves made on these parts.

3 Summary

The keV scale neutron source currently undergoing the installation phase. A large-area, keV scale neutron backing detector has also been built and characterized. Thus currently, we are in the process of establishing a low energy calibration facility. Further elaboration on the strategies employed for shielding, the gamma backgrounds, and the advancements made in the construction of the facility will be done in the talk.

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Detection of hydrate plugs inside submarine pipelines using neutron activation analysis

Sophie Bouat*[a], Ludovic Pinier[b], Xavier Sebastian[b], Adrian Losko[c], Rudolf Schütz[c], Michael Schulz[c], Zsolt Revay[c], Zeljko Ilic[c],[d,f], Eric Mauerhofer[e], Thomas Brückel[e], [f] and Ralph Gilles[c]
*Corresponding author: contact@science-saved.com

[a]Science-SAVED, 310 impasse Sansaret, 38 410 Grenoble, France; [b] TechnipFMC, 6/8 allée de l'Arche, 92 973 Paris La Défense, France; [c] Heinz Maier-Leibnitz Zentrum (MLZ), TU München, Lichtenbergstr. 1, 85748 Garching, Germany; [d] Jülich Centre for Neutron Science (JCNS-4) at MLZ, Forschungszentrum Jülich GmbH, Garching, Germany; [e] Jülich Centre for Neutron Science (JCNS-2), Peter Grünberg Institut (PGI-4) Forschungszentrum Jülich GmbH, Jülich, Germany; [f] RWTH Aachen University, Lehrstuhl für Experimentalphysik IVc, 52056 Aachen, Germany.

Abstract
Locating and detecting hydrate plugs inside submarine pipelines, in situ and contactless, is of first importance to get rid of them and restore pipeline flow. This detection can be done using neutron activation analysis that allows to study material composition. Cold and fast neutron-beam instruments at Heinz Maier-Leibnitz Zentrum (MLZ) were used to show that neutrons penetrate through the thick wall and the insulation of such pipes and even the induced gamma radiation can be detected outside to perform a non-destructive chemical analysis within the pipe. It was found that the change in the hydrogen concentration caused by a possible hydrate plug can be detected in seconds; while with a detailed analysis at a given spot lasting for a few hours, it is possible to unambiguously identify the hydrate phase inside the hydrocarbon phase. The path has been smoothed for a possible on-board equipment, in a submarine Remote Operated Vehicle, which could "fly" above subsea pipelines, locating hydrate plugs in situ and contactless.

Introduction

Submarine pipelines play a key role in offshore oil and gas transportation. A major problem that can endanger their operation is the formation of hydrates, a solid icy phase that blocks the flow of high-pressure hydrocarbons inside pipelines laid on the sea floor. Neutron-based techniques were proven to be successful to identify the hydrate plug in the hydrocarbon fluid, in situ and contactless [1].

Experimental details

60kg half pipes made of 21 mm of steel coated with 92 mm of polypropylene insulator were measured at MLZ to check if the neutron beam penetrates the thick wall and induces characteristic gamma rays strong enough for the analysis. The flammable hydrocarbon and hydrate were replaced with materials showing similar compositions. The H-to-C molar ratio changes from 4 to 16, when the liquid phase solidifies with hydrate formation. Using the FaNGaS (Fast-Neutron-induced Gamma Spectrometry) and the PGAA (Prompt Gamma Activation Analysis) instruments, it proved to be possible to differentiate between the two phases.

Results & discussion

With the FaNGaS instrument, the fast neutron-induced gamma-rays peaks of hydrogen and carbon were identified in the gamma spectrum. The H peak appeared in seconds, while it took longer for the C peak to become detectable (Figure 1). Thus, monitoring the rapid change in the hydrogen content was possible in seconds, while a longer analysis revealed the actual composition.

Using the PGAA instrument, we made similar experiments in the cold neutron beam using hydrocarbon-like (A: rubber) and hydrate-like (B: rubber + water) materials, and with an intermediate composition (C: rubber + oil). As shown in Figure 2, the analysis, based on the peak ratios, reproduced the expected H/C molar ratios for all three cases, proving the possible discrimination between hydrocarbon and hydrate. The change in the hydrogen concentration can be easily followed with the variation of the hydrogen peak intensity, even when the samples are covered with salty water to approach the submarine conditions (Figure 3).

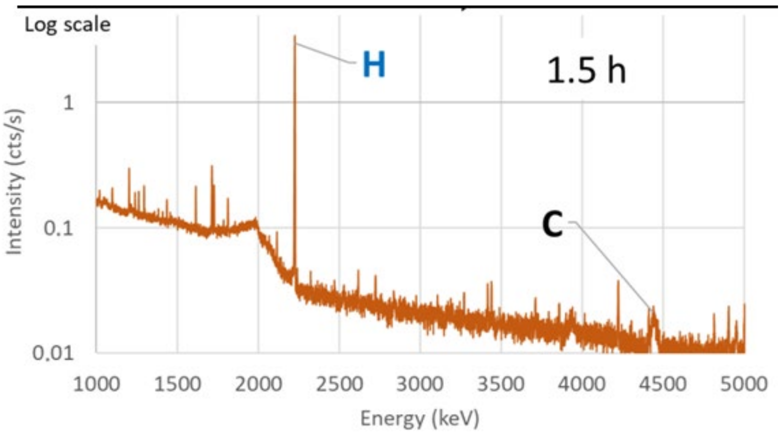

Figure 1: Gamma spectrum taken at the FaNGaS instrument during 1.5 h with narrow H peak and broad C peak

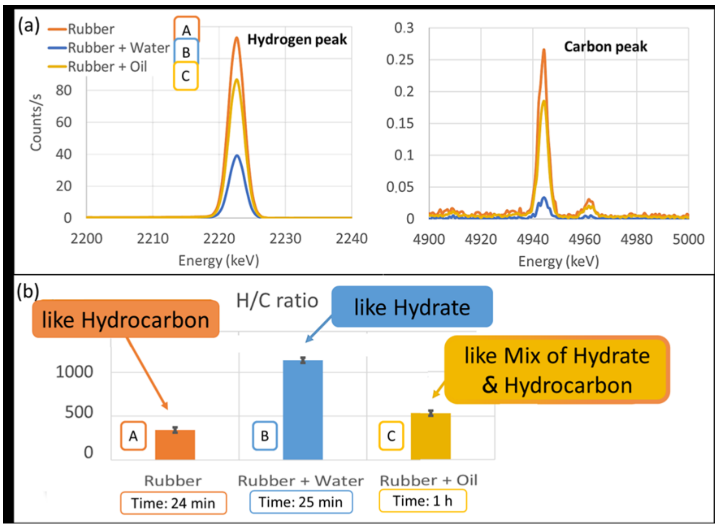

Figure 2: The flammable hydrocarbon and hydrate were replaced with materials showing similar compositions such as rubber (experiment A), rubber + water (experiment B) and rubber + oil (experiment C); (a) PGAA spectra with H and C peaks highlighted for experiments A, B & C; (b) H/C intensity ratios for comparison between experiments A (hydrocarbon-like), B (hydrate-like) & C (like a mix of hydrate and hydrocarbon).

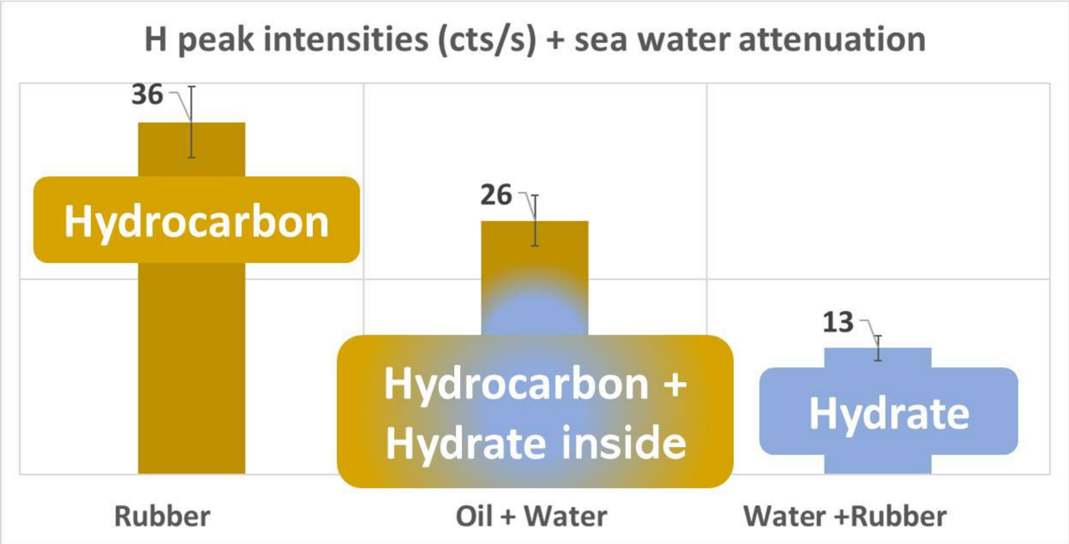

Figure 3: Hydrogen peak intensities from different sample configurations measured with salty water added in the neutron beam path to account for sea water attenuation.

The discrimination between the hydrocarbon and hydrate phases was possible with the PGAA technique. Using the more penetrating fast neutrons, this was possible even through the thick pipe walls, as the experiments at FaNGaS clearly showed. The feasibility of an *in situ* and contactless detection of hydrate plugs inside subsea pipelines using neutrons is thus demonstrated.

Conclusion

The change in the hydrogen concentration caused by a possible hydrate plug can be detected in seconds; while with a detailed analysis at a given spot lasting for a few hours, it is possible to unambiguously identify the hydrate phase inside the hydrocarbon phase. The path has been smoothed for a possible on-board equipment, in a submarine Remote Operated Vehicle, which could “fly” above subsea pipelines, locating hydrate plugs in situ and contactless.

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[1] Sophie Bouat, Ludovic Pinier, Xavier Sebastian, Adrian Losko, Rudolf Schütz, Michael Schulz, Zsolt Revay, Zeljko Ilic, Eric Mauerhofer, Thomas Brückel & Ralph Gilles (2021): "*Detection of hydrate plugs inside submarine pipelines using neutrons*", Nondestructive Testing and Evaluation, DOI: 10.1080/10589759.2021.1990284.

SESSION 6

ADVANCED CONCEPTS 1

Tuesday 11th July

2.00pm - 3.40pm

A Monte Carlo Simulation Framework for Nested Mirror Optics – Approach and Applications

The transport of neutrons from the region where they have been generated (e.g. a moderator) to a sample or detector are a crucial part of neutronic experiments and instruments.
In course of the currently running EU project HighNESS [1] a particular kind of these transport systems is being studied: nested mirror optics. These devices are assembled from several layers of neutron mirrors that are arranged in a particular geometry. In our case mirrors in elliptical and in Wolter optical shape have been studied. The nested composition makes highly efficient and compact components possible. To verify their performance as well as to find the best geometries of such devices in Monte Carlo simulations, a Python based library was developed. With its help these components can be customized to ones needs and generated easily from couple of input parameters. They are then used in McStas – a neutron ray tracing software – for the simulations. I will present the capabilities of the library, the simulation framework used and show two application examples: i.e. the NNBAR experiment and an in-beam ultracold neutron (UCN) source.

[1] Santoro, V., et al. "Development of a High Intensity Neutron Source at the European Spallation Source: The HighNESS project." arXiv preprint arXiv:2204.04051 (2022)

Primary author(s): WAGNER, Richard

Presenter(s): WAGNER, Richard

The new versions 3.5 and 4.0 of the VITESS simulation package

The new version 3.5 of the VITESS program for simulation of neutron scattering instruments and virtual neutron experiments is released in spring 2023. In version 3.5, most of the code is overworked and the visualization is realized for all modules. Additionally, several new features are added and technical data are updated, including a better description of supermirror coatings, a rotating monochromator, a new guide geometry, better filter and event handling options, improved monitor output and more realistic descriptions of a (thick) window, a velocity selector and a reflectometer sample. It has been thoroughly tested; download is available from a GitHub at Forschungszentrum Jülich (FZJ).
The new version 4 will use a Qt GUI, store instruments in a readable and editable YAML files and will use the advanced GR framework from FZ Jülich for monitor output. A version 4.0 containing the most important modules is currently tested. It will facilitate virtual experiments at facilities, which can be used to train new users, estimate beamtime, check parameter settings or replace real experiments during neutron schools. The first virtual experiments of this type will be at MARIA at MLZ.

Primary author(s): LIEUTENANT, Klaus (Forschungszentrum Jülich)

Presenter(s): LIEUTENANT, Klaus (Forschungszentrum Jülich)

Nested Mirror Optics – Towards a New Generation of Neutron Transport Systems?

Christoph Herb[a,c], Oliver Zimmer[b], Richard Wagner[b], Robert Georgii[a,c], Peter Böni[a]

[a] *Physics Department E21, Technical University of Munich, D-85748 Garching, Germany*
[b] *Institut Laue-Langevin, 71 avenue des Martyrs, F-38042 Grenoble, France*
[c] *Heinz Maier-Leibnitz Zentrum, Technical University of Munich, D-85748 Garching, Germany*

Introduction

Transporting neutrons between a source and the target position, e.g., a sample, has been achieved in the past using various neutron-optical geometries. The question of how to efficiently design the transport arises on different scales. In summary, one tries to maximize the ratio of neutrons interacting with the sample to those just missing it, which is crucial for the signal-to-background ratio. To this end, the extraction of neutrons from the source, their subsequent long-distance transport to the instrument, and the focusing of neutrons onto the target position are equally important.

For these challenges, elliptic neutron guides present a suitable solution, as they are designed to transport neutrons between infinitesimally small source and target positions by definition of their elliptically shaped reflective surfaces. However, when applied to realistic scenarios with extended sources and targets, various issues arise. These include geometric aberrations, which result in a non-uniform illumination of the target, thereby complicating data analysis. Furthermore, gravity-induced deviations from the calculated trajectories necessitate additional reflections of neutrons in the vertical dimension, possibly limiting the transport efficiency [1].

The complications associated with neutron transport by elliptic guides can be addressed by confining the guide to a small region around its semi-minor axis. To compensate for the reduced geometric acceptance of the short guide section, multiple of these short guide sections are laterally nested to comprise a Nested Mirror Optics (NMO) [2].

Email address: `christoph.herb@frm2.tum.de` (Christoph Herb)

Theory

Within the first part of this section we will briefly summarize the aforementioned problems associated with the use of long guides with a rectangular cross section and an elliptic profile along the trajectory of the neutrons, which are frequently installed at modern neutron sources [4]. In the second part, we will highlight how NMOs represent a possible solution to some of those drawbacks.

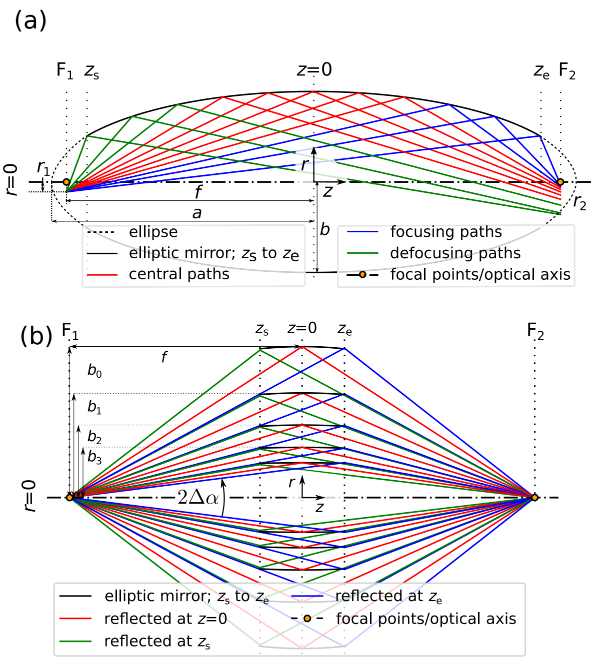

Figure 1: (a) Geometric aberrations in a long elliptic guide visualized by a selection of neutron trajectories emerging below the optical axis at distance r_1. (b) Schematics of the construction of an elliptic NMO ensuring the acceptance of all neutrons from the first focal point F_1 (except those at very small angles $|\alpha_i| \leq \Delta\alpha$). Figures adapted from [5].

When extracting neutrons from compact sources using guides with a cross section equal to or larger than the source in any dimension, "under-illumination" dilutes the phase space of the beam according to the mismatch between the size of the source and the geometric acceptance of the guide. The available, useful flux at the target position is then reduced compared to what could be provided by the source according to Liouville's theorem [6]. While elliptic guides are designed to transport neutrons between infinitesimally small sources and targets, the finite extent of both leads to geometric aberrations distorting the incident intensity distribution during the transport. As visualized in Fig. 1 (a), the distance of neutrons from the second focal point, r_2, depends on the distance from the first focal point, r_1, the focal length, f, and the individual point of reflection along the elliptic guide, z, and can be approximated by [7]

$$r_2 \approx r_1 \frac{f - z}{f + z}. \tag{1}$$

While neutrons reflected in the second half of the ellipse, $z > 0$, are focused towards the optical axis, neutrons reflected in the first half, $z < 0$, are defocused instead and will contribute to the background of the experiment.
However, by restricting the points of reflection to a region close to the semi-minor axis, $z \simeq 0$, a recovery of the original intensity distribution, i.e., a preservation of the phase space, is ensured. In practice, this is readily achieved by shortening the mirrors to a length $l \lesssim f/10$ centered around $z = 0$. In order to increase the geometric acceptance, which is significantly reduced by this shortening, several mirrors with common focal points and length are nested such that every neutron emerging from the first focal point interacts with one mirror. A visualization of the construction process and the resulting geometry can be found in Fig. 1 (b).

Experiments

We will summarize the experiments characterizing various NMO prototypes with emphasis on their efficiency of transport and the FWHM of the beam at the target position [5]. The prototypes, the measurement geometry employed at MIRA, and an overview of the results are shown in Fig. 2. First experiments performed on a prototypical, elliptic NMO (compare Fig. 2 (a), left) at MIRA,

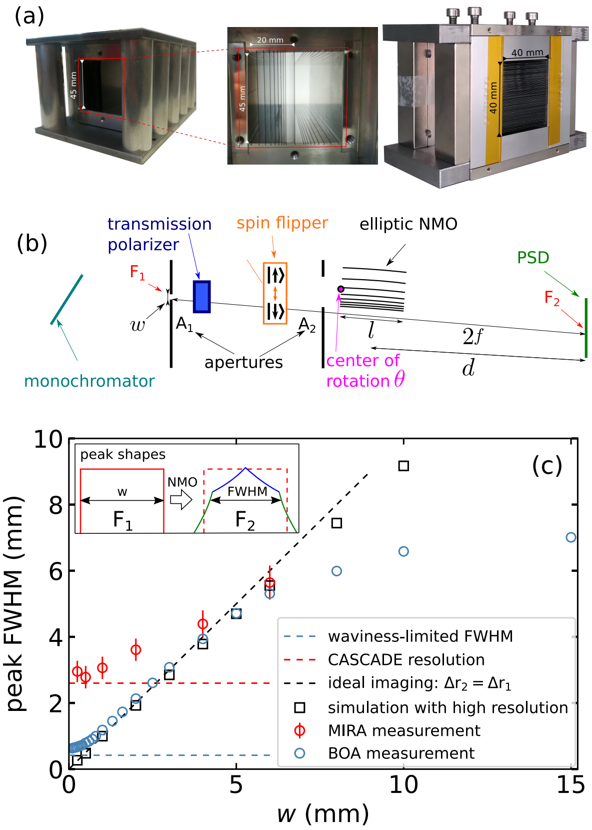

Figure 2: NMO prototypes (a), Measurement geometry at MIRA (b), and results showcasing the imaging qualities of elliptic NMOs in experiments and Monte Carlo simulation (c). Figures adapted from [5].

FRM II, already suggested a high efficiency of transport of about $Q = 72\,\%$ largely independent of the investigated widths of the virtual source, $0.25\,\text{mm} \leq w \leq 4\,\text{mm}$ [5]. However, the detection of more subtle features of the spatial intensity distribution was prevented by the coarse resolution of the employed detector. A repetition of a similar investigation this time utilizing the much higher resolution of the imaging beamline BOA, PSI, revealed that the preservation of the initial beam shape with width, w, holds in a range of widths from $w = 0.6$ mm to $w = 6$ mm (compare Fig. 2 (c)). This result is quite remarkable in light of the small focal length of the NMO, $f = 600\,\text{mm}$.
Besides these first results, very promising data has been collected from a further investigation of parabolic NMOs, which employ a similar array of parabolic mirrors with one common focal point to focus a quasi-parallel beam to a single focal point.

However, there are some minor complications associated with a warping of the individual mirror blades arising due to the applied supermirror coating, which require further investigation.

Applications

Finally, we propose some applications employing NMOs for the extraction, transport and focusing of neutron beams. As proven by Monte Carlo simulations and experiments, the elliptic NMO allows to preserve a volume of phase space when transporting neutrons from one focal point to another, thereby elegantly circumventing the problem of under-illumination. Furthermore, the insertion of apertures close to the source or the NMO, allows tailoring the size and the divergence of the beam at the target position. The compact geometry of the optical device ensures freedom in the use of biological shielding on the side of the neutron source and the employment of bulky sample environment close to the target, respectively.
One can envision further applications using two sets of parabolic NMOs for the extraction of neutrons from a compact source into a low-divergence beam, which can be transported over large distances with a simple neutron guide with a constant, rectangular cross section before being refocused by a second set of parabolic NMOs [5].
Further applications of NMOs for an in-beam source for ultra-cold neutrons are already being investigated [8].

Summary and Outlook

In summary, NMOs show promise in extracting neutrons from increasingly compact high-brilliance sources. NMOs are considered advantageous compared to contemporary solutions, because they ideally preserve the phase space density of the incident neutron beam. Additionally, they offer a number of practical advantages over long neutron guides. Among others, they can be readily replaced, can be placed distant from zones of increased radiation and are simple to align.
The use of different types of NMOs allows for the configuration of entire beamlines tailored to specific purposes. Moreover, they can be integrated into existing experiments, providing more flexibility such as high divergence options for triple axis spectroscopy.

This work has been funded by the BMBF, Germany grant (Project No. 05K19WO3, MIEZE-FOC) and by the Deutsche Forschungsgemeinschaft (DFG), Germany within the Transregional Collaborative Research Center TRR 80 “From electronic correlations to functionality” – Projekt ID 107745057 – which is gratefully acknowledged.

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Neutron beams with Intrinsic time structures - methods and possible applications

T.Keller,R.Gahler,R. Golub
MPI Festkörperforschung Stuttgart, ILL Grenoble, University North Carolina

We propose to develop neutron guides with intensity structured beams in time. The method is based on the Mach-Zehnder principle from optics. Using two RF-modulators in straight guides, continuous polarized beams can be shaped far downstream of the modulators into time-structured beams of frequencies up to 10 MHz with the signal occurring only in a fairly narrow region in space. Beam divergence and wavelength spread reduce the contrast only to second order. The region from the second modulator (or analyzer) to the signal area may be used for various instruments or techniques. Here we discuss:

- Increase of energy resolution in TOF
- Suppression of background and multiple scattering
- Tomography with isotope sensitivity
- Spin-dependent reactions;
- Analog to fine-structured beams in time, lateral structured neutron beams might be possible as well via the MZ-principle in space.

SESSION 7

SHIELDING & ENGINEERING

Tuesday 11th July

3.40pm - 5.00pm

Monte-Carlo simulations of the new radiation shielding at the thermal beamport SR8 @ FRM II with SERPENT 2

The thermal beamport SR8 at the research neutron source Heinz Maier-Leibnitz in Garching will be optimized to allow the simultaneous operation of three independent monochromatic powder diffractometers. SPODI will continue to be one of the world-leading high-resolution powder diffractometers. FIREPOD will be a dedicated high throughput instrument, well suited for a broad range of fast parametric studies. ERWIN will be a highly versatile multipurpose diffractometer for both powder as well as single crystals. Due to the unique characteristics of each instrument, the optimized beamport SR8 will be able to cater for a wide range of experimental demands and will substantially increase available beam time for neutron powder diffraction. To exploit the full capabilities of each instrument a complete rebuilt of the primary neutron optics at the beamport SR8 is necessary. This requires an entirely new radiation shielding around the neutron guides and monochromators.

In this contribution, the results from detailed Monte-Carlo simulations to optimize the biological SR8-shielding will be presented. Employing the *Serpent 2* code, the full radiation transport of neutrons, as well as gamma radiation through the different shielding materials is simulated. While taking boundary conditions such as available space, floor load and costs into consideration, the underlying detailed CAD-based model (which can be input directly into the Monte-Carlo simulations) is iteratively optimized to achieve a total dose rate lower than the desired limit of 3µSv/h outside the shielding. Additionally the ease of potential future modifications of the shielding as well as its eventual disposal were already fully taken into account during the shielding design.

Primary author(s) : HAUF, Christoph (MLZ); SENYSHYN, Anatoliy (TU Munich); Dr. HOELZEL, Markus; Dr. REITER, Christian; Mr. BONETE WIESE, Daniel

Presenter(s): HAUF, Christoph (MLZ)

Overview on Shielding Analyses for the VENUS Instrument at SNS

The Versatile Neutron Imaging Instrument (VENUS) [1] is a world-class neutron imaging instrument under construction at the Oak Ridge National Laboratory Spallation Neutron Source (SNS) facility. It is scheduled to be commissioned in 2023. The range of cold to epithermal neutrons will give users of VENUS access to novel imaging methods and significantly improved existing methods. The instrument is being built on SNS beam line 10 facing the decoupled poisoned hydrogen moderator.

The final optics design will provide the field of view (FOV) at the detector position to be as high as 0.20 m by 0.20 m. The large fraction of high-energy neutrons and the desire for a large footprint on the detector are challenges for the shielding design because the driving cost for the instrument is the beamline (front-end) and enclosure shielding. For cost reasons, the VENUS baseline design is optimized with respect to both the instrument cave footprint and its wall thickness, and front-end shielding is tailored along the beam direction.

The enclosure shielding supports operations with a 0.2x0.2 m2 beam with the To-chopper (synchro- nized to attenuate neutrons above 10 eV energy) running and a reduced beam size of 0.04x0.04 m2 for white beam operations when the To-chopper is parked open. However, the cave shielding is upgradable (doubling shielding side walls) later to allow white beam operations with a 0.20x0.20 m2 size. The front-end shielding and the cave ceiling are designed for future full-capability operation.

The shielding analyses were performed with the Monte Carlo particle transport code MCNPX [2]. Shielding solutions were developed for the beamline and the instrument cave to allow the defined beam conditions and meet the radiological requirement of 2.5 µSv/h at a 0.3-m distance from the outside surfaces in generally accessible areas [3]. This paper gives an overview of the instrument shielding design effort.

Assumptions and Methods

The shielding is modeled in layers of 5-cm thickness to easily apply geometry splitting for variance reduction. For scoring the neutron and gamma dose rates, mesh tallies are used. The 2D mesh tal- lies are defined in Cartesian coordinates in a vertical cross-section through the beam center line. The thickness of the slice is 20 cm, and the mesh size is 5 x 5 cm. Dose rates are obtained by folding neutron and gamma fluxes with flux-to-dose conversion coefficients [4].

Shielding analyses are performed using source terms [5] of a neutron beam as entering the beam-line at the core vessel insert, the most upstream beamline component, based on the Proton Power Upgrade (PPU) [6] beam conditions, assuming a 1.3 GeV proton beam at 2 MW power. The source is described in an angular binning in four bins for the nominal beam direction, 2°–4°, 1°–2°, 0.5°–1°, and 0°–0.5° and with an energy binning totaling an intensity of 2.51x1013 neutrons/s. For parts of the analysis, a special source term was developed that has the spinning To chopper accounted for, considering both the timing of chopper mass blocking the high-energy beam component and opening for the slower traveling thermal beam component and the attenuation of the high-energy beam component by the 30-cm-thick Inconel mass.

Historically shielding analyses for the instruments were performed as two separate sets – shielding for the front end and shielding for the instrument cave, which includes beamstop shielding.

Various operation conditions are analyzed in each set, including but not limited to various optics configurations, different samples and sample inclinations to the beam axis, and accident cases.

Instrument Layout

The instrument front-end and cave is modeled in MCNPX language and shown in Figure 1 in a vertical cross-section through the beam center line.

Figure 1. MCNPX model of VENUS, vertical cross section through the beam center line. From left to right: front-end, instrument cave. Dimensions in meters.

The MCNPX optics model includes collimators and fixed aperture in core vessel insert, a set of aluminum flight tubes, some of which are helium-filled, opening for variable aperture, To-chopper collimator 1, collimator 2, the set of 3 scrapers. Two beam options at the detector position are realized by a set of two collimators that, by translation, open up different aperture sizes. These optics components are surrounded by the air in the front-end cavity. At the downstream end of the front-end cavity close to the enclosure wall, a U-shaped steel shielding with density is placed around the downstream flight tube section to reduce streaming into the cave. The model contains high-density shielding with 3 surrounding the cavity from the sides and from the top and a poured- in-place shielding of regular concrete. Component shielding is added to the model to reduce the effects of To-chopper and radiation streaming through the cavity.

The VENUS instrument enclosure calculational model continues from the end of beamline shielding, about 17.55 m from the moderator, and includes the instrument floor, high-density concrete instrument cave, composite enclosure door (high-density concrete followed by borated polyethylene layer; both enclosed in steel), penetrations with supplemental shielding, flight tubes, sample, and beam stop with surrounding high-density concrete shielding, which is mounted on a regular- concrete base. Air is modeled inside and outside the instrument enclosure.

Results

The analyses are performed for normal operation with the two beam options defined by the collimator 1 and collimator 2 settings for both the front-end and instrument cave. Analyses for the front-end shielding show that the most radiation-producing case is with To-chopper stopped in an open position (white beam) and collimator configuration providing 0.2x0.2 m2 beam at the detec- tor position. The off-normal case for instrument cave for initial operation is 0.2x0.2 m2 beam and To-chopper open. This can cause elevated dose rates and will be mitigated by active monitoring. Total (neutron + gammas) dose rates map for the vertical and horizontal cross-section through the beam center line are shown in Figure 2. Red contour lines represent dose rates of 2.5 µSv/h. White lines sketch the VENUS enclosure and optics geometry contours.

Figure 2. Dose rates map (µSv/h) in the front-end vicinity in vertical cross-section (left) and horizontal cross-section (right) through beam center line.

Analyses for the instrument cave are performed for the initial VENUS operation with the restricted beam. The most radiation-producing case is for the white beam and collimator configuration pro- viding 0.04x0.04 m2 beam at the detector position. The dose rates map for the vertical and hori- zontal cross-section through the beam center line is shown in Figure 3.

Figure 3. Dose rates map (µSv/h) in the instrument cave vicinity in vertical cross-section (left) and horizontal cross-section (right) through beam center line.

Conclusions

Comprehensive shielding design analyses are performed for the VENUS instrument's final optics and shielding configuration for both the front end and instrument cave. The resulting dose rate out of the shielding shows that the materials, thicknesses, and configurations provide adequate shielding in generally occupied areas.

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Primary author(s): POPOVA, Irina (ORNL)

Co-author(s): Dr. GALLMEIER, Franz X. (ORNL)

Shielding Analysis of the CHESS Instrument at the Spallation Neutron Source Second Target Station

Thomas M. Miller and Kristel Ghoos
Second Target Station Project
Oak Ridge National Laboratory
millertm@ornl.gov, ghooskl@ornl.gov

One of the first instruments that will be designed, built, and commissioned at the US Department of Energy's (DOE) Spallation Neutron Source (SNS) Second Target Station (STS) is the Chopper Spectrometer Examining Small Samples or CHESS [1]. A shielding analysis of CHESS for preliminary design has been completed, and work on the analysis for final design will begin later in 2023. This analysis evaluated the entire length of the CHESS beamline, from the moderator to the neutron beam stop. Presented herein is a summary of the CHESS shielding analysis for preliminary design.

The preliminary shielding analysis of CHESS began inside the STS Bunker. To begin, a neutron beamline source was generated by simulating the protons that are accelerated to 1.3 GeV, with 700 kW of power and repetition rate of 15 Hz, onto the STS rotating solid tungsten target and tallying the neutron and photon leakage from the two liquid hydrogen moderators [2]. The neutron source entering STS beamline 11 (ST11) was selected as the generic shielding source for preliminary design because it is one of the forward directed beamlines, i.e., direction closest to the proton beam direction, so it has the hardest neutron spectrum. Inside the bunker, analyses were performed to ensure that the walls and ceiling were adequate to ensure the effective dose rate limit in generally accessible areas, which is 0.25 mrem/h (2.5 μSv/h), was not exceeded outside the bunker [3]. This analysis was performed with and without a t_0 chopper intercepting the beam inside the bunker. The final analysis inside the bunker was to optimize the CHESS operations shutter. The requirements for this shutter include the ability to reduce the prompt effective dose rate immediately outside the bunker wall, but inside the beamline shielding outside the bunker to 2 mrem/h (20 μSv/h). This will allow users to change the sample in CHESS while the proton beam is on. Several potential designs meet this requirement, but one of the leading candidates consists of 5 layers, which, in the direction of the neutron beam, are 3 cm B_4C, 28.2 cm copper, 40.2 cm carbon steel, 10.7 cm polyethylene, and 3 cm B_4C.

Outside the bunker, the preliminary design analysis began with the walls and ceiling of the beamline shielding between the bunker wall and the CHESS instrument enclosure. Like the analyses performed inside the bunker, the beamline shielding was analyzed with and without a t_0 chopper intercepting the neutron beam and the ST11 neutron source. The results of these analyses showed that the beamline shielding needs to be 88 cm of high-density concrete (3.84 g/cm^3) near the bunker wall and 28.5 cm of high-density concrete ~14.5 m from the bunker wall. Next, the CHESS beam stop was analyzed to determine the required dimensions of high-density concrete when it is exposed to the full white ST11 source. The beam stop begins at ~35.25 m from the moderator. With a 50 cm long tube (7 cm radius) centered on the neutron beam embedded in the beam stop to reduce backscatter to the sample location and neutron detectors, the beam stop must be 275 cm in the beam direction and 130 cm perpendicular to the neutron beam. The dimension of the beam stop in the beam direction was not affected by scattering in a sample, but the perpendicular dimensions of the beam stop were. Finally, the walls and ceiling of the CHESS instrument enclosure were analyzed using the ST11 neutron source with and without a sample present. The instrument enclosure extends from ~28.5 m to ~35.25 m from the moderator. The CHESS sample location is 31.5 m from the moderator. The walls and ceiling of the CHESS instrument enclosure are 5 layers, which, from the inside out, are 5 cm B_4C, 2.5 cm stainless steel 316L, 31.5 cm polyethylene, and 2.5 cm of stainless steel 316L. Without a sample to scatter the neutron beam, these nominal dimensions of the instrument enclosure ensure the effective dose rate limit in generally accessible areas outside the enclosure are respected. Introducing a 1 cm thick steel sample into the CHESS beam results in many capture gammas produced by iron, which are ~7.5 MeV. Since the nominal design of the walls and ceiling of the CHESS instrument enclosure are mostly polyethylene, this scenario requires additional gamma shielding on the outside of the enclosure. Increasing the thickness of the outer layer of stainless steel 2.5 cm to 6 cm adequately reduces the dose rate outside the enclosure for this scenario.

At this time shielding analysis of the CHESS preliminary design is complete, and analysis of the final design will begin soon. The shielding requirements determined for CHESS during preliminary design have been discussed here, and more details will be provided during the workshop.

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STS Standardized Neutron Delivery System Components

Peter Torres, Cameron Hart
Oak Ridge National Laboratory

The Second Target Stan (STS) of the Spallation Neutron Source (SNS) offers immense potential for neutron scattering research, as such, being a new facility design, STS offers the opportunity to develop and deploy standardized designs across the instrument suite to reduce design, operations, and maintenance costs over the life of the facility. This is an improvement over the variety of designs which were deployed at FTS. This talk presents an overview of a standardized ops support system concept for neutron instruments at the STS, covering key topics including the system overview, standardized optics supports design, standardized ops housing design, alignment schemes, and a possible method for monitoring the ops system for misalignment due to settlement

SESSION 8

NEW SOURCES

Wednesday 12th July

9.00am – 10.20am

An Update on the Development of a Cold Neutron Source and Cold Neutron Beam Facilities at the Penn State Breazeale Reactor

Kenan Ünlü and Daniel Beck

A third generation, mesitylene moderated cold neutron source (CNS) was designed, built and is being installed at the Penn State Breazeale Reactor (PSBR) at the Radiation Science and Engineering Center (RSEC). The main components of the PSU-CNS are a cold source cryocooler system and neutron guide system. Components of the cold source cryocooler system are a vacuum system, helium circulating and buffer system, compressor system, and mesitylene moderator. Mesitylene, a room temperature liquid, is frozen to solid form in a chamber to act as the cooling moderator. Circulating helium lines are attached to a cryocooler used to cool and maintain cold temperature of the mesitylene moderator using the method of forced flow helium gas circulated between the refrigeration unit (Cryocooler). A helium loop cools and maintains a cold neutron mesitylene moderating material at about 20 K in a 10 cm diameter aluminum chamber located inside the D_2O tank of the PSBR (Figure 1). The mesitylene moderator chamber, circulating helium lines, and moderator lines are isolated in a vacuum system for isolation from thermal transfer.

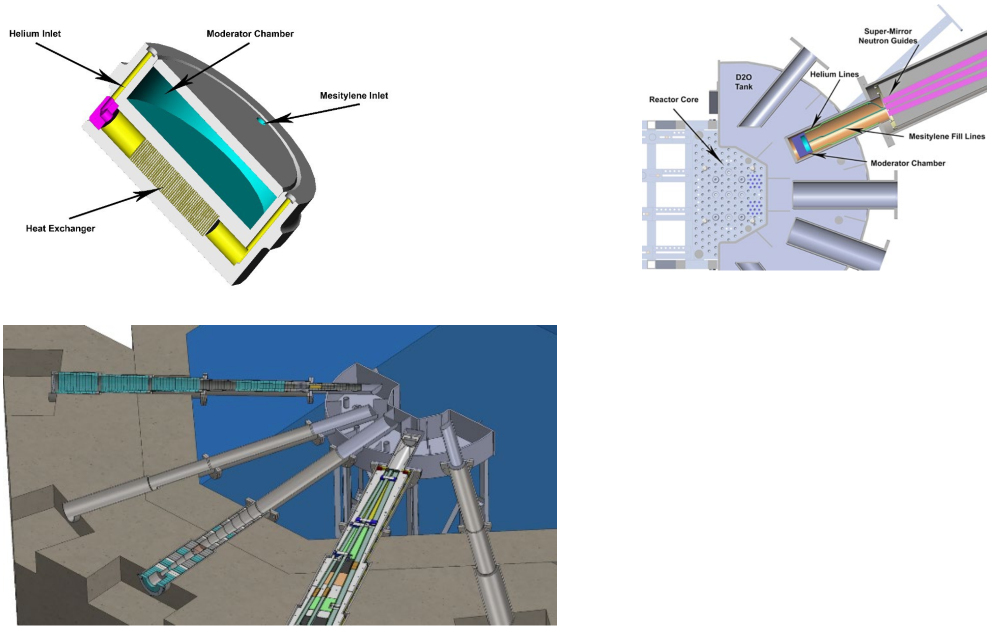


Figure 1: Schematic of PSBR moderator chamber and cold neutron beam port layout.

The cold neutrons coming from the mesitylene chamber are transported out of the biological shield of the reactor with three supermirror neutron guides. The in-pile neutron guide system of the PSU-CNS contains 3 independently adjustable in-pile segments. The supermirror neutron guide cross-sections are GT1- 40 x 40 mm, GT2- 25 mm x 70 mm, GT3- 25 mm x 25 mm constructed of borated float glass each ~5 mm thick with a surface coating of m=3 QC on all sides. Each is a 0 m radius straight guide of 2.8 m in length. Each in-pile guide is separated with material effective for shielding neutron and gamma radiation. The shielding and guide section with independent adjustment features has been designed to integrate into the in-pile vacuum housing, with optimal guide alignment with the moderator chamber. The three in-pile guides extend to out-of-pile guides with several different sections for Small Angle Neutron Scattering (Figure 2), Neutron Depth Profiling and Prompt Gamma Activation guide systems with straight guides, beam benders, and parabolic focusing guides with different surface coatings. The neutron guide elements were designed and are being built by Mirrotron Ltd. Budapest, Hungary.

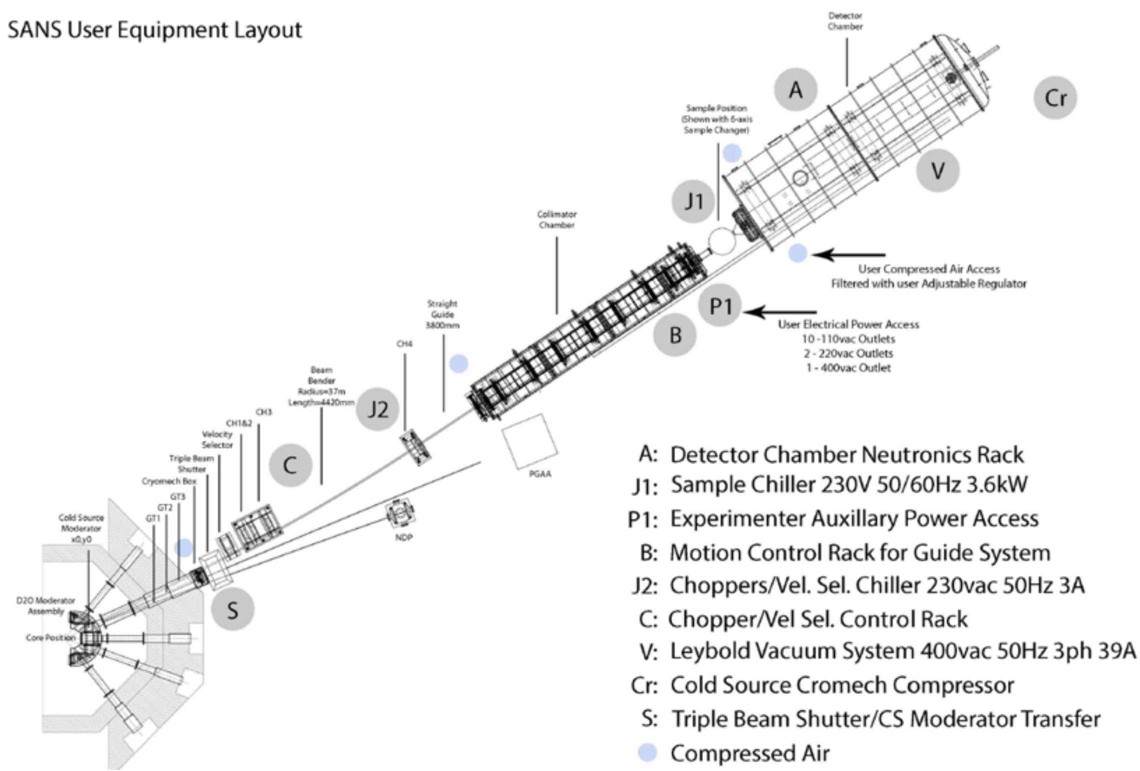


FIGURE 2: PSU - SANS LAYOUT AT THE PSBR

The PSBR is a 1 MW, TRIGA with moveable core in a large pool and with pulsing capabilities. In steady-state operation at 1 MW, the thermal neutron flux is $1x10^{13}$ n/cm^2sec at the edge of the core and $3x10^{13}$ n/cm^2sec at the central thimble. The PSBR can also pulse with the peak flux for maximum pulse ~ $6x10^{16}$ n/cm^2sec with pulse half width of ~10 msec. The RSEC facilities are heavily used for nuclear science and engineering research and education. A detailed description of the PSU-CNS will be presented.

Investigation of Pancake-like Moderator-Reflector Structure for the High Brilliance Neutron Source (HBS)

Junyang Chen[1,*], Jörg Voigt[1], Egor Vezhlev[2], Paul Zakalek[1], Ulrich Rücker[1], Jingjing Li[1], Thomas Gutberlet[1], and Thomas Brückel[1]

[1] *Jülich Centre for Neutron Science (JCNS-2/PGI-4), Forschungszentrum Jülich GmbH, 52428 Jülich, Germany*
[2] *Jülich Centre for Neutron Science (JCNS-4) at Heinz Maier-Leibnitz Zentrum (MLZ), Lichtenbergstr. 1, 85748 Garching, Germany*

The High Brilliance Neutron Source (HBS) project is developing a high-current accelerator-driven neutron source (HiCANS) to maintain a healthy neutron landscape in Europe. Despite the lower primary neutron yield of the nuclear reactions compared to reactor or spallation neutron sources, HiCANS achieve a competitive neutron brightness by a compact moderator and reflector design, which makes a large fraction of the primary neutron spectrum available for applications. The spectral and temporal, i.e. frequency and pulse length, characteristics of the neutron pulse are tailored to the instruments hosted at a target station.

Based on the 'pancake' and 'butterfly' moderator geometries developed for the European Spallation Source (ESS), we investigate a pancake-like structure by means of Monte Carlo simulations involving multi-parameter optimization routines. By increasing the interface area, we try to improve the coupling between thermal and cryogenic moderator. The extraction surfaces of the applied pancake-like geometry achieve a cold neutron flux of 85%-87% of a cylindrical para H_2 moderator (length= 10 cm, diameter = 2.4 cm) with ideal coupling. The flux through the thermal extraction surfaces reaches 70%-79% in comparison to an ideal case with just a single extraction channel looking at the thermal flux maximum in the center of the thermal moderator. The optimized structure with up to six extraction channels looks therefore very promising for target stations that serve a large number of thermal and cold instruments. At this workshop, we will present the results of our study of this moderator-reflector assembly.

The Jülich High-Brilliance Neutron Source Project

P. Zakalek[1], U. Rücker[1], E. Mauerhofer[1], J. Voigt[1], J. Baggemann[1], J. Li[1], K. Lieutenant[1], I. Pechenitzky[1], J. Chen[1], Q. Ding[1], A. Schwab[1], N. Schmidt[1], R. Hanslik[2], Y. Bessler[2], O. Felden[3], R. Gebel[3,4], O. Meusel[5], H. Podlech[5], T. Gutberlet[1], Th. Brückel[1],

[1]*Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany*
[2]*Central Institute for Engineering and Technology, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany*
[3]*Nuclear Phsyics Institute, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany*
[4]*GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany*
[5]*Institut für Angewandte Physik, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany*

The advent of high-current accelerator systems launched the development of high-current accelerator-driven neutron sources (HiCANS) utilizing low energy nuclear reactions. This development can counteract the increasing shutdown of existing fission-based neutron sources and a resulting decline in available neutron beam days as well as establishing HiCANS as a next generation national neutron source.
The release of neutrons via low energy nuclear reactions requires less shielding in comparison to reactor sources or spallation sources. This results in target station designs with very compact target-moderator-reflector assemblies. It allows the usage of low dimensional cryogenic moderators as well as to place optical elements like choppers and neutron guides close to the moderator surface. Such target stations are thus showing a very efficient coupling of the release, the moderation and the extraction of neutrons.
At NDS, we will present the current status of the High-Brilliance Neutron Source project developing such a HiCANS with up to three target stations. We will mainly focus on the unique characteristics of such sources for the neutron provision.

The ESS moderators

With pulsed proton accelerator of an average power of 2 MW, eventually reaching 5 MW, the European Spallation Source (ESS) will offer tremendous capabilities for research with neutrons. The user program will start in 2026. Fifteen neutron scattering instruments will be served by a high-brightness moderator based on the low-dimensional moderator concept, and placed above the spallation target. This upper moderator has a bi-spectral (thermal and cold) spectrum. The facility and its neutron beam extraction system are designed, so that a second moderator system can be placed below the spallation target. All the available neutron beamports can be pointed to both moderator systems. These upgrade possibilities are being explored by the HighNESS (Development of High Intensity Neutron Source at the European Spallation Source) project, which focuses on the design of high-intensity cold, very-cold, and ultra-cold neutron sources. The complementarity of the two sources will make ESS a very versatile neutron source offering unprecedented opportunities in neutron scattering and fundamental physics. An overview of these moderator systems will be given.

Primary author(s): ZANINI, Luca

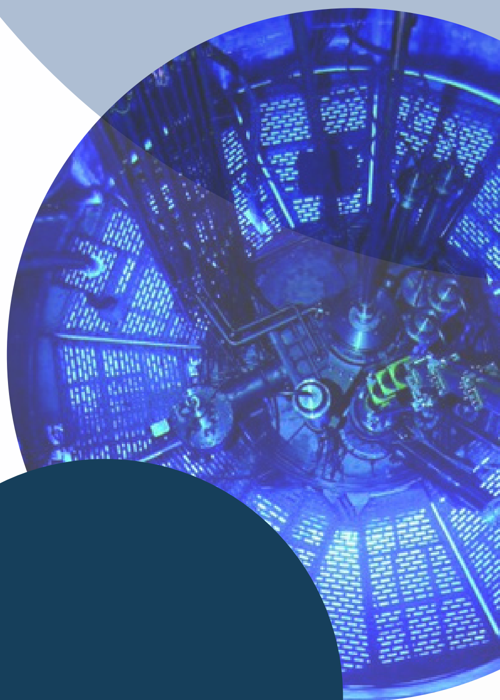
Presenter(s): ZANINI, Luca

SESSION 9

ADVANCED CONCEPTS 2

Wednesday 12th July

10.50am – 12.10pm



Beam monitoring strategy at the European Spallation Source

The European Spallation Source (ESS) is a facility at the forefront of science that will produce an unprecedented thermal neutron flux for scientific research. To ensure the reliable operation and performance of the neutron instruments, beam monitoring is critical. In this talk, the beam monitoring strategy to meet ESS requirements is described, which involves using a small set of well-established detector technologies, including MicroPattern Gas Detectors (MPGDs), ionisation chambers, and neutron cameras adapted for the purpose. These requirements include a large dy- namic range, good spatial and time resolution, in-vacuum environment operation with position sensitivity, low attenuation, radiation hardness, and high stability and reliability, all of which are necessary to ensure the reliable operation and performance of the neutron instruments and to mon- itor the neutron beam through a multitude of beamline components at ESS. The beam monitoring actions are driven through the common beam monitor project, which involves close collaboration with ESS instruments, detector R&D and production, performance and radiation hardness tests, and integration with other common projects and ESS activities. The present status of the beam monitoring project will be presented, as well as the challenges encountered in monitoring the neutron beam across a plethora of beam-line components at ESS.

Primary author(s): KATSIOULAS, Ioannis (European Spallation Source)

Presenter(s): KATSIOULAS, Ioannis (European Spallation Source)

Optimizing neutron production at ORNL's Second Target Station

Lukas Zavorka, Kristel Ghoos, Joseph Tipton, and Igor Remec
Oak Ridge National Laboratory, Oak Ridge, TN, USA

Oak Ridge National Laboratory's (ORNL) Second Target Station (STS) is designed to become the world's highest peak-brightness spallation source of cold neutrons. Extremely bright cold neutron beams will provide transformative capabilities to examine novel materials for advanced technologies in the decades to come. Bright beams will enable new neutron scattering experiments using innovative instruments under more extreme conditions, using smaller samples and shorter irradiation time. A comprehensive optimization study of neutron production is necessary to generate such beams. This work introduces an advanced optimization workflow that combines high-fidelity neutronics modeling with structural analyses and modern optimization algorithms. This multi-physics, multi-parameter optimization workflow is essential to completing the STS project successfully. The workflow can be applied in the design process at other neutron, experimental, and accelerator facilities.

The current conceptual design of the STS consists of a 700-kW water-cooled rotating tungsten target and two compact pure para-hydrogen neutron moderators at 20 K. The target will be driven by a short-pulsed (<1 us) 1.3 GeV proton beam at 15 Hz from the existing Spallation Neutron Source's (SNS) linear accelerator after the Proton Power Upgrade Project is completed. Neutrons with a broad energy spectrum will be generated in the target via spallation reactions. Some neutrons will escape the target and enter hydrogen moderators surrounded by a light water premoderator and a beryllium reflector. After their moderation, cold neutrons will exit through small 3x3 cm emission windows and travel towards one of the eventually 18 modern instruments.

A compact arrangement of the target and moderators is key to generating bright neutron beams. However, arrangements that improve neutronics output, such as narrowing the proton beam footprint on target, also typically reduce the structural integrity and thus increase the probability of failure. The goal of coupled neutronics and structural analysis is to maximize neutron production while maintaining high factor of safety, ensuring the safe and reliable operation of the facility. In the past, one iteration through neutronics and structural analysis took several weeks to months due to a large amount of manual modeling, data conversion, and results interpretation. With the new automated optimization workflow, the duration of one iteration has been reduced to hours, which allows us to explore many more design iterations, run coupled optimization studies with a larger number of independent parameters, and find the optimal solution faster.

The optimization workflow shown in Fig. 1 starts with the parametrized solid CAD engineering models of the key STS components, such as the target and moderators. The detailed models are automatically converted with Attila4MC [1] into Unstructured Mesh (UM) models for neutronics calculations with MCNP6.2 [2,3]. The automated CAD to MCNP conversion improves the fidelity of the neutronics models, reduces the potential to introduce errors during the originally manual conversion, and minimizes the time necessary to build the models. Importantly, the UM modeling provides neutronics results for the subsequent structural analysis directly on UM, which often has higher spatial resolution than the traditional rectangular mesh tallies. It also avoids the problem of having mixed materials in a single rectangular mesh cell. The high-fidelity energy deposition data from neutronics calculations are extracted together with neutron brightness. Energy deposition serves as input for the calculation of the factor of safety, which automatically evaluates both mean and peak amplitude stress with Sierra [4]. Neutron brightness and factor of safety are passed to the Dakota [5] optimization toolkit, which analyzes the results and proposes a new set of design parameters using one of the state-of-the-art optimization algorithms. This cycle repeats until the optimization workflow converges and the optimal design is found.

This talk will review the current STS design and introduce the fully automated optimization workflow. We will describe the individual steps of the workflow, share some practical information about its implementation, and discuss the results of the latest optimization runs.

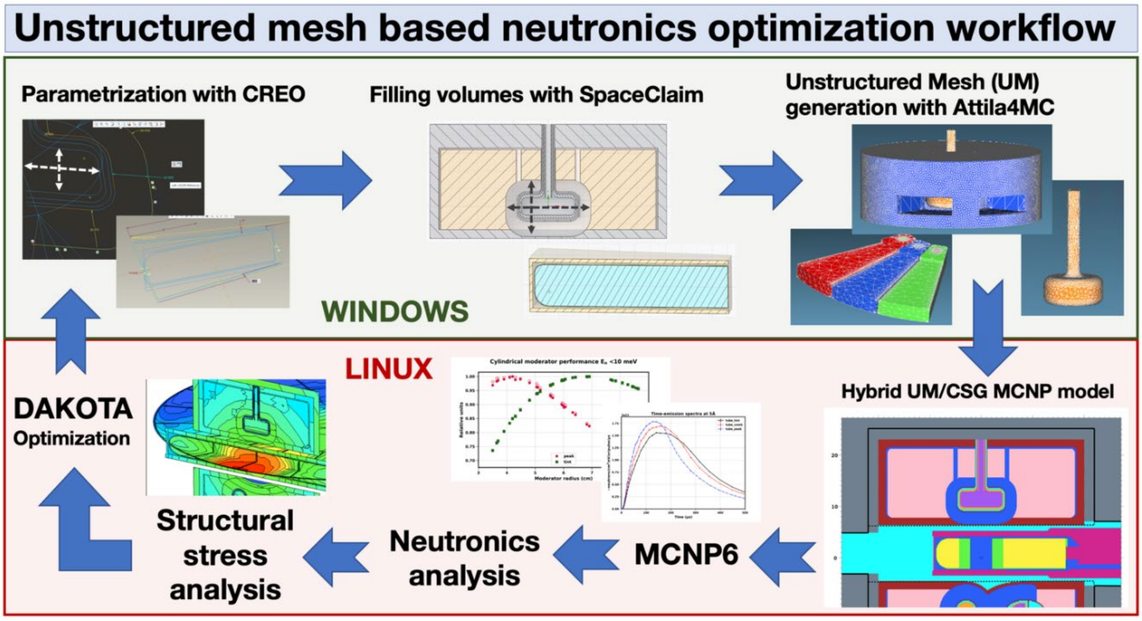


Fig. 1 Schematic of the automated optimization workflow.

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[2] C. Werner, et al., MCNP® User's Manual, Code Version 6.2, Los Alamos National Laboratory, 2017, LA-UR-17-29981.

[3] R. Martz, The MCNP6 Book on Unstructured Mesh Geometry: User's Guide for MCNP 6.2, Los Alamos National Laboratory, 2017, LA-UR-17-22442.

[4] Beckwith, F. N., et al., "Sierra/SolidMechanics 4.56 User's Guide", United States: N. p., 2020. Web. doi:10.2172/1608404.

[5] Adams, B.M., et al, "Dakota, A Multilevel Parallel Object-Oriented Framework for Design Optimization, Parameter Estimation, Uncertainty Quantification, and Sensitivity Analysis: Version 6.14 User's Manual," Sandia Technical Report SAND2021-5822, May 2021.

Neutron Mirror with Magnetic Repulsive Wall

A neutron mirror with a magnetic repulsive wall is under development. Since neutrons have a magnetic dipole moment, they are subject to forces in a magnetic field gradient. Using this phenomenon, a potential wall for neutrons can be formed by arranging permanent magnets in a planar configuration of a Halbach array. This potential wall acts as a mirror for a polarized neutron beam. A prototype mirror 20 mm high and 30 mm wide was fabricated, and preliminary neutron reflection experiments were conducted at the MINE2 port of JRR-3. As the next step, we plan to fabricate a mirror with a larger size and conduct experiments at the J-PARC MLF. In this presentation, the principle of the mirror, the results of preliminary experiments at JRR-3, and the status of the mirror fabrication for the experiment at J-PARC will be reported.

Primary author(s): FUWA, Yasuhiro (Japan Atomic Energy Agency)
Co-author(s) : Dr. HIROTA, Katsuya (High Energy Accelerator Research Organization); Dr. IWASHITA, Yoshihisa (Kyoto University); Dr. KITAGUCHI, Masaaki (Nagoya University); Dr. KURIYAMA, Yasu- toshi (Kyoto University); Dr. SHIMIZU, Hirohiko (Nagoya University); Dr. YAMADA, Masako (High Energy Accelerator Research Organization)

Presenter(s): FUWA, Yasuhiro (Japan Atomic Energy Agency)

Efficient Neutron Transport and Imaging with Magnetic Lenses

Magnetic lenses have been developed for neutron beam transport. When the spin is parallel to the magnetic field, the neutron beam is focused by a sextupole magnet due to the magnetic dipole moment of the neutrons. On the other hand, the rest of the neutron beam is defocused. We are de- veloping a powerful permanent magnet type sextupole lens which enables focal length modulation in synchronization with TOF. The status of the development research will be presented.

Primary author(s) : Dr. IWASHITA, Yoshihisa (Kyoto University); FUWA, Yasuhiro (Japan Atomic Energy Agency); Dr. KURIYAMA, Yasutoshi (Kyoto University); Dr. SHIMIZU, Hirohiko (Nagoya University); Dr. KITAGUCHI, Masaaki (Nagoya University); Dr. HIROTA, Katsuya (High Energy Accelerator Research Organization); Dr. YAMADA, Masako (High Energy Accelerator Research Orga- nization)

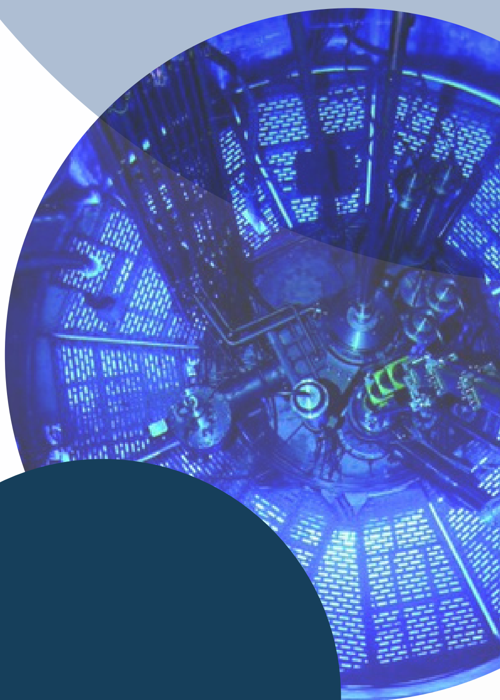
Presenter(s): Dr. IWASHITA, Yoshihisa (Kyoto University)

SESSION 10

UCN

Wednesday 12th July

11.10pm – 3.10pm



Commissioning of the ultracold neutron guide system for the n2EDM experiment at PSI

The nEDM collaboration is setting up the n2EDM experiment (Eur. Phys. J. C 81, 512 (2021)) at the ultracold neutron (UCN) source the Paul Scherrer Institute, to search for the neutron electric dipole moment (nEDM) with a sensitivity ten times higher than the current best limit of $1.8 \cdot 10^{-26}$ e·cm (90 % C.L.) (Phys. Rev. Lett. 124, 081803 (2020))
We developed a new efficient UCN guide system to transport neutrons from the UCN source to the experiment. The positions of the experiment and the UCN guides were optimised using Monte Carlo UCN transport simulations. The tubular segments of the guide system are made of borosil- icate glass, some of the more complex shaped parts are made out of highly polished aluminium. The experiment requires a highly homogeneous magnetic field, which imposes an ultralow upper limit of tens of picotesla at 5 cm distance on the remaining local impurities of the guides. Therefore, all inner surfaces are coated with a nickel-molybdenium alloy (NiMo 85:15), for high neutron opti- cal potential and its non-magneticity at room temperature, using an in-house established sputter deposition technique.
I will present the status of the commissioning of the UCN guide system. This includes quality control, such as the measurement of the UCN transmission and checking for remanent magnetic dipoles, and UCN transport simulations to understand and interpret our measurements.
Support by SNF Grant #188700 is gratefully acknowledged.

Primary author(s): DOORENBOS, Cornelis (Paul Scherrer Institute)

Presenter(s): DOORENBOS, Cornelis (Paul Scherrer Institute)

Comments: On behalf of the nEDM collaboration.

Ultra-cold neutron source using He-II at TRIUMF

Kenji Mishima[1,2] on behalf of TUCAN collaboration
KEK[1], J-PARC[2]

Densities of UCNs are limited by Liouville's theorem. To overcome this limit, super-thermal UCN production was suggested, which converts cold neutrons to UCNs using down-scattering by phonons in superfluid helium (He-II) [1]. A cold neutron with kinetic energy of 1 meV can be converted to a UCN by just passing its energy to a He-II phonon. The produced UCNs accumulate and increase the density until they are lost; they can be lost due to up-scanning by phonons in He-II. To control this loss, He-II should be cooled down to about 1 K. The TUCAN (TRIUMF Ultra Cold Advanced Neutron) collaboration, between Japan and Canada, aims to achieve UCN densities more than 100 times higher with coupling a spallation neutron source and 1-K He-II. This will enable to explore the neutron electric dipole moment (nEDM) with a sensitivity of 1×10^{-27} e·cm, which is one order of magnitude higher than the current limit, with data acquisition over a period of 400 days (Fig.1 left).

The He-II UCN source at TRIUMF is coupled with a spallation neutron and liquid deuterium (LD_2) which cools down the produced neutrons to cold neutrons. A proton beam of 500 MeV from TRIUMF's main cyclotron is irradiated on a tungsten target. The current is planned to be 40 μA, and the beam power will be 20 kW. The produced neutrons from the spallation reactions are cooled down to ~1 meV by 125 L of LD_2. The UCN production volume of He-II is 27 L and the UCN production rate is expected to be 1.4 to 1.6×10^7 UCN/s [2], which is about 500 times as large as in the prototype UCN source [3].

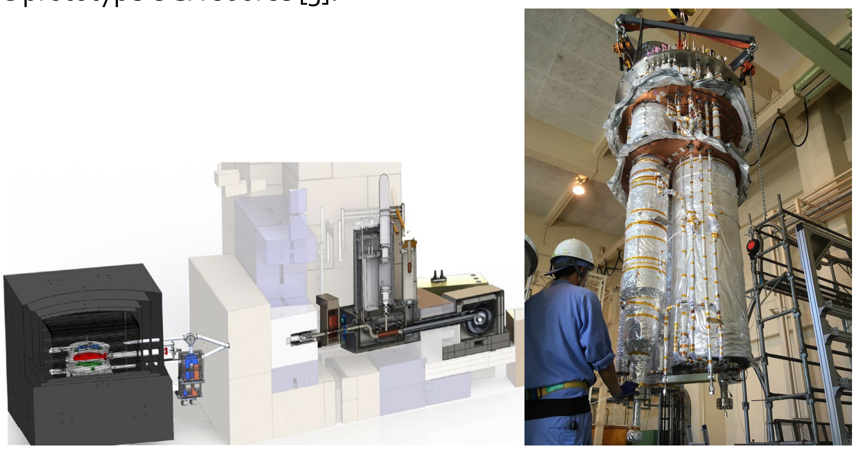


Figure 1: (Left) Overview of the TUCAN source and the nEDM spectrometer. (Right) Photograph of the He cryostat [4].

We plan to operate the TUCAN source with a 20-kW proton beam. Because the heat load is expected to be approximately 10 W during beam irradiation, enhancing the cooling power of the UCN source is essential. The helium (He) cryostat (Fig.1 right), a crucial subsystem of the TUCAN source, was designed to achieve this cooling power. It cools liquid ^{3}He down to 0.8 K using 8,800m^3/h vacuum pumps. He-II is condensed in the UCN production volume and cooled down to approximately 1 K via a heat exchanger attached between the ^{3}He pot and the UCN volume. The construction of the He cryostat began at KEK in 2019, and a cooling test of the He cryostat was conducted with 4He, confirming that liquid 4He was successfully condensed in the 3He pot in 2020 [4]. The He cryostat was shipped to TRIUMF in 2021, and re-assembly and initial testing have begun.

In parallel to the UCN source, we have been developing the other nEDM components. One of these items is detailed studies of NiP plating of UCN guides. Nickel-phosphorus (NiP) plating, which is inexpensive and easy to process, is used for UCN transport guides to connect the UCN generation point and the nEDM measurement cell over approximately 12 m. A UCN is totally reflected on the surface, by absorbed with very little probability, on the order of 10-4-10-5. It is known that the absorption has a large variation depending on the fabrication process and surface condition. We are studying the characteristics of NiP coatings using either the prototype UCN source, the UCN source at J-PARC, or Los Alamos National Laboratory (LANL) [5]. UCN storage experiments of the UCN production volume were also performed at LANL in 2021. The LD2 cryostat, gas handling for 3He and 4He, and the liquid helium transfer line are being designed and constructed at TRIUMF. With these systems, we aim to produce UCN in 2024.

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[5] H. Akatsuka et al., *Nuclear Inst. and Methods in Physics Research A* 1049 (2023) 168106.

Brightify: A tool for calculating brightness in neutron sources

Mina Akhyania, Henrik M. Rønnow[a]
[a] *Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland*

Brightness is an important metric for optimizing the design of the neutron sources and the beamlines. According to Liouville's theorem [1], the particle phase-space distribution, i.e. brightness, is constant along the trajectories of the system. Therefore, brightness can be a key factor for estimation of the moderator (or in general source) performance and it depends on the design of the source.

In this talk, we will introduce Brightify, a Python-based tool for calculating brightness that overcomes limitations found in existing methods [2-3]. By utilizing the mcpl file format [4], which contains comprehensive neutron data, i.e., the position, direction, energy, weight, etc, Brightify enables brightness calculations on any surface or geometry, at any distance or energy range. Unlike previous approaches, Brightify can easily identify locations with the highest brightness and corresponding directions, generating brightness maps for insights into optimal neutron source design.

We will discuss the methodology of Brightify. The algorithm will use a spiral scanning scheme to avoid any missing point on the recording surface. Brightify can calculate the brightness by knowing three parameters: number of scan points which determines the extent of coverage across the entire surface, as well as the degree of overlap between neighbouring windows, position window which is the area of the mesh in the phase-space, and the direction window, which is the desirable divergence of the neutrons inside the phase-space mesh.

We demonstrate the consistency of Brightify with existing methods through a case study. Additionally, we will highlight the limitations of existing techniques by contrasting them with Brightify's identical results. We will showcase various applications and capabilities of Brightify for directional moderators, high-energy, thermal and cold brightness, emphasizing its computational efficiency and its ability to give the right direction to align neutron guides for maximum brightness.

Keywords: *Brightness, Monte-Carlo particle list, Neutron source*
Topic: simulation of neutron sources and neutron transport

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Characterization of intense cold neutron beams for superthermal ultracold neutron sources

Skyler Degenkolb (1,2) and Husain Manasawala (1)

(1) Physikalisches Intitut, Universität Heidelberg; (2) Institut Laue-Langevin

We present measurements and simulations characterizing the H523 cold neutron beamline that supplies the new SuperSUN source of ultracold neutrons (UCN) at the ILL. Detailed measurements of the beam profile, divergence, and spectrum are compared with McStas simulations starting from the Horizontal Cold Source (HCS) and referenced to gold foil activation measurements. This comparison highlights that integrated captured flux measurements, such as gold foil activation, are not in general sufficient as inputs for a detailed simulation. We discuss strategies for using our measurements to improve models of the HCS, and prospects for high-density UCN production at SuperSUN. General features of superthermal UCN sources based on superfluid helium are also mentioned, in the context of broader European efforts to advance this technology for a wide range of science cases.

Development of a UCN guide and other handling devices at J-PARC with pulsed UCNs

Sohei Imajo[1] on behalf of TUCAN collaboration
RCNP, Osaka Univ.1

Metal tubes with nickel-phosphorus plating are used in many fundamental physics experiments using ultra-cold neutrons because of their easy fabrication, but their surfaces have a large average roughness of 25-150 nm. Our aluminum UCN guide tubes for the TUCAN experiment [1] also have a root mean square roughness of 6.4-17 nm. There has been no model to describe the diffuse scattering of UCN on such surfaces by using microscopic surface roughness information. We have developed a scattering model in which the scattering from random surface waviness with a size larger than the UCN wavelength is described by the microfacet Bidirectional Reflectance Distribution Function (mf-BRDF) model [3]. In our model, the scattering direction of UCNs is mainly determined by the classical specular reflection, and the calculation of scatterings from smaller structures in which the direction is determined by quantum mechanical calculations is replaced by the Lambert's cosine law. The parameter characterizing the magnitude of the surface waviness is only the standard deviation of the slopes of the local micro-surfaces and was estimated from the images obtained from atomic force microscopy measurements of a guide tube sample fragment. The probability of Lambertian diffusion per reflection is the only free parameter in this model and is determined by UCN transport experiments.

We have measured the UCN transport efficiency of this guide tube using pulsed UCNs produced by a Doppler-shifter type UCN source at BL05 in the J-PARC/MLF [3], as shown in Figure 1. In this experiment, pulsed UCNs collimated to a divergence angle smaller than ±6° were injected into the tilted guide tube, and the attenuation and deformation of the time-of-flight spectra of transmitted UCNs caused by diffuse reflections were measured. The guide tube was mounted by an angled flange at an inclination angle of either 0°, 10°, 15°, or 30°, by which the total number of reflections of the transmitted UCN beam was controlled. Comparison of these results with particle transport simulations using our reflection model showed that the mf-BRDF model explains the experimental results better than Lambertian diffusion alone for both attenuated UCN transmittance (shown in Figure 2) and deformed TOF pulse shape as the inclination angle increases.

In this presentation we will primarily present this development of the UCN guide tube. We have also developed several other UCN handling devices at BL05, which will also be presented.

[1] H. Akatsuka et al., Nucl. Instr. Meth. Phys. Res. A 1049, 168106 (2023).
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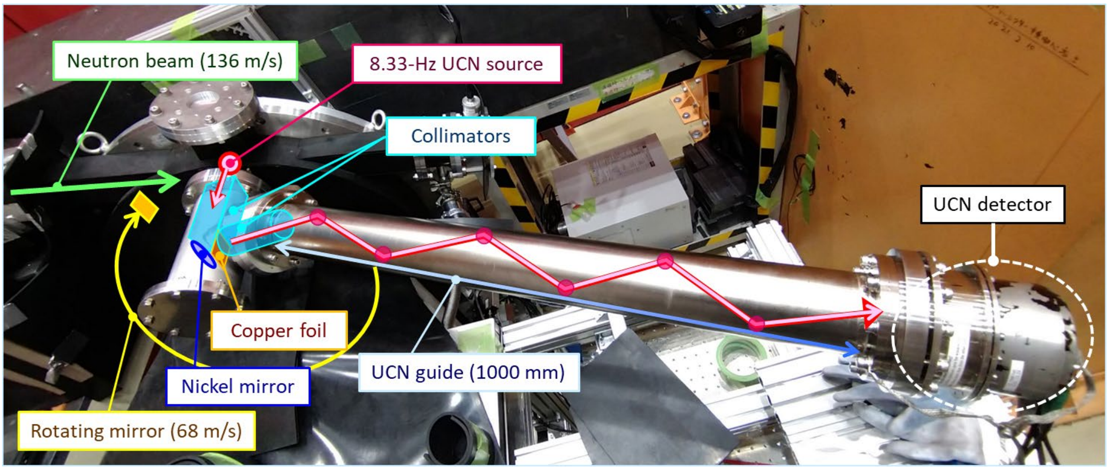

Figure 1: Photograph of the experimental setup of the UCN transmittance measurement at J-PARC. In the photo, an UCN guide is installed with the 30-degree configuration. Key components are schematically drawn. The mean flight path of UCNs is estimated to be 1.6 m.

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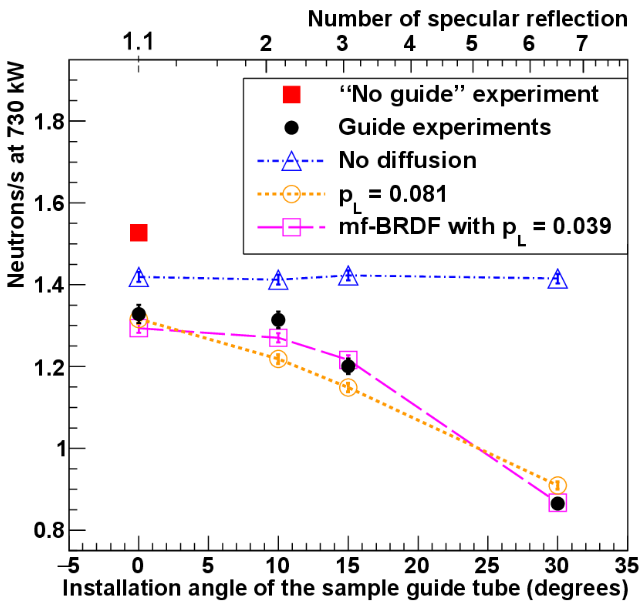

Figure 2: Measured rate of transmitted neutrons with no guide (a red square) and with a sample guide installed at different angles (black dots), compared to simulations with no diffuse reflection (blue triangles), pure Lambert scattering with probability $p_L = 0.081$ (orange circles), and mf-BRDF scattering combined with Lambert scattering with probability $p_L = 0.039$ (pink squares).

The Compact Accelerator based Neutron Source (CANS) project "LvB" at Martonvásár, Hungary[1,2]

Zs. Ludanyi[1], G. Anda2, E. Dian1, Á. Horváth2, R. Mezei1, H. Shuai1, P. Sipos1, G. Szász1 and F. Mezei1

[1]*Mirrotron Ltd., Hungary*

[2]*Centre for Energy Research, Hungary*

The Compact Accelerator based Neutron Source (CANS) project "LvB" is in the early commissioning phase at the Martonvásár facility of Mirrotron Ltd. in Hungary.

The LvB CANS now consists of a 2.5 MeV RFQ proton accelerator, 20 mA peak current in 1.25 ms pulses, 40 Hz, 5 % duty factor and custom designed target, reflector and moderator system. An optimized bi-spectral thermal and cold neutron moderator system will be able to accommodate at least 6 neutron scattering instruments. In addition, an epithermal/fast neutron beam is envisaged in the forward direction from the out-set. Some innovative design solutions are protected by patents applications: one is already awarded, and another is pending.

The business plan calls for neutron scattering instruments for material research in the cold/thermal neutron energy range, epithermal and fast neutron irradiation possibility, and development of CANS sources, including design, construction, delivery of turn-key CANS facilities. Current, mainly funded developments and on longer term considered up-grade potentials will also be discussed.

NDS 2023

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Tuesday 11th July

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*BRI worked in close collaborations with leading organizations of Govt. of India Viz., **BARC, IPR, TAPP, RAPS, IUAC, VECC, NPCIL, ECIL, ISRO, UGC-DAE** & exclusively with International Users Viz., **ANSTO, DESY, NIST, RAPISCAN, ADM Nuclear Technologies, JINR, TU DELFT UNIVERSITY, ALHBERG ELECTRONICS, STAR SCIENTIFIC, ISP SYSTEMS** & many more.*

Direction to: Boron Rubbers India, E-36, BOL Industrial Estate, Sanand-II, Ahmedabad - 382170 (INDIA)
Contact Information: www.boronrubbersindia.com I sales@boronrubbersindia.com I +91-990-451-4703

Advantages :
- Better Neutron Absorbance
- Flexible
- Light Weight
- Less Space Requirement
- Water, Ozone & Heat Resistant

Easy to :
- Cut & Shape (with ordinary blade and scissors)
- Bend & Fold (with out breaking Bent in to small radii)
- Stable in Vacuum
- Roll & Install (By non-specialized personnel)
- Mount on Wall (Using standard mounting technique)

BR 287
Flex Boron Sheet

Flex Boron Sheet

BR-287 Flex Boron Sheet is a flexible, heat & ozone resistant, lightweight synthetic based polymer containing variable percentage of Boron **(5% to 52%)**. Therefore the material has an extremely good attenuation factor for thermal neutrons providing an excellent shield against it. This product is also stable in vacuum. Flex Boron Sheet can easily be handled & installed by non-specialized personnel. This flexible material can be cut & shaped using an ordinary knife & scissor.

Pure Polyethylene

BPE-14 Pure Polyethylene is often used as a moderator to slow fast neutrons to thermal energies. To be most effective in these applications it is important to maximize the hydrogen content and minimize impurities that absorb neutrons. It is in high purity, density & Ultra highmolecular weight polyethylene.

Boron Polyethylene

BPE-155 Boron Polyethylene is the combination of polyethylene with its high hydrogen content and boron, makes a very useful shielding material in areas of Low & Intermediate Neutron Flux. The Boron content **(5% to 30%)** attenuates thermal neutrons and reduces the level of capture gamma rays, while the high hydrogen content thermalizes fast neutron. It is a lightweight material that can be machined & shaped with standard tools.
BPE-510 is a 30% Boron Polyethylene material containing very high boron concentrations are used, very effective in the capture of thermal neutrons.
BPEX-124 is a Self-Extinguishing Boron Polyethylene.

Lead Boron Polyethylene

BPEL 180 combines lead & boron in polyethylene providing an effective shield against mixed neutron/gamma fields. The hydrogen in polyethylene will thermalize fast neutrons. The boron captures thermal neutrons & suppresses capture gamma rays. The lead provides shielding against primary gamma rays.

We Understand
We Offer
We Design
We Deliver

Reach us

www.boronrubbersindia.com
sales@boronrubbersindia.com

SAFETY

Direction To: Boron Rubbers India
E-36, BOL Industrial Estate
Sanand - II, Ahmedabad - 382170
INDIA T: +91-990-451-4703

Added Value Solutions (AVS) is an international company which aims at providing technology-based services to innovative and challenging projects. Founded in 2006, with Headquarters in the North of Spain, we are a global SME strongly focused on the development of outstanding devices, mechanisms, instruments and structures for research infrastructures worldwide.

AVS's expertise covers design, manufacturing, assembly, tests and supply under ISO 9001 EN 9100, providing our customers all the way up from the conceptual design to the turnkey.

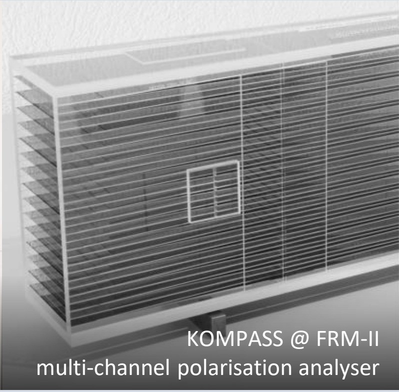
AVS skills on engineering design, mechatronics and positioning in UHV, extreme magnetic fields / radiation / temperature, neutron instrumentation, opto-mechanics and detection make AVS the perfect partner for instrument construction at neutron sources. Our company is also very active in other fields like Fusion, Space, Particle Accelerators, Astrophysics and Lasers.

AVS develops neutron instrumentation for reactors and spallation sources worldwide, including ESS, ILL, ISIS, FRM II, HZB, LAHN, CHESS, ANSTO, NIST and more. Our portfolio includes all kind of turnkey instruments including TAS spectrometers, SANS instruments, TOF spectrometers and diffractometers.

AVS designs and develops all-size non-magnetic vacuum chambers, neutron guide selectors, sample positioning systems, guide fields and magnetic circuits, neutron collimation systems, double focusing monochromators and analysers, neutron detectors and complex shielding solutions.

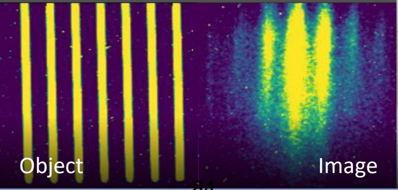
www.a-v-s.es/areas/neutron
Pol. Ind. SIGMA, C/Xixilion, 2 bajo Pab. 10 - 20870 Elgoibar - SPAIN
Phone: + 34 943 821 841 E-mail: avs@a-v-s.es

H14 @ ILL
neutron guide splitter

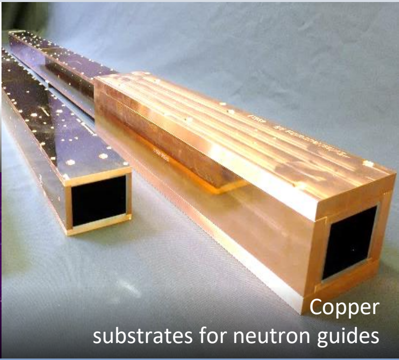


KOMPASS @ FRM-II
multi-channel polarisation analyser

Scheme of Nested Mirror Optic



Object Image



Copper
substrates for neutron guides

Nortemecánica
Work, dedication and experience
Area Industrial de Tabaza I, Parcela E-5. E-33469 Carreño, Asturias
+34 985 57 98 57 www.nortemecanica.es

Our experience in Big Science

Manufacturing and assembly of:

- Shieldings for Neutron Facilities
- Complex Girders and Undulator Support Systems
- Neutron research detector support assemblies
- Vacuum Vessels, Pressure Vessels
- Storage flasks assemblies (radioactive waste)

Quality:
- laser trakers for measurements
- controlled temperature during machining and verifications

FARO Edge Scan Arm

Faro Vantage E

Leica AT403

■ ESRF
■ ILL
■ IBS
■ EMBL

ESRF

- (A) Central Building & Reception
- (B) Visitor Centre
- (C) Safety training
- (D) Experimental Hall
- (E) Control Room

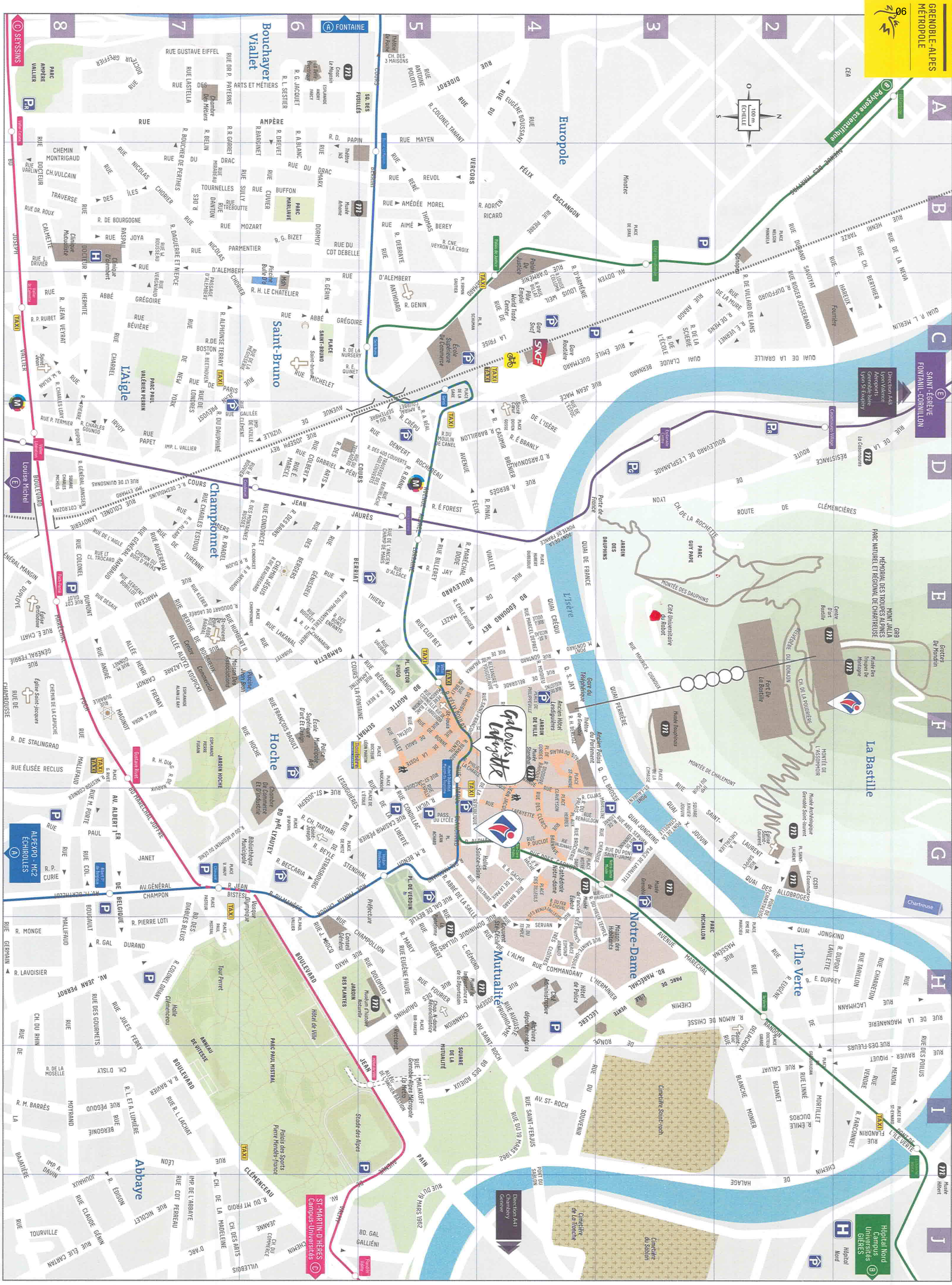
ILL

- (0) ILL50 ILL Entry point (ZAC access badge) Remote instrument control rooms
- (1) ILL1
- (2) ILL2 Self-service & mechanical workshops
- (3) ILL3 ILL stores
- (4) ILL4 Chadwick amphitheatre Seminar room Offices
- (5) ILL5 Reactor building Experimental hall
- (6) ILL22 Experimental hall
- (7) ILL7 Experimental hall
- (8) ILL17
- (9) ILL9 Works council building
- (10) ILL26
- (11) ILL19 IT building

- Site entrance
- Science building
- CIBB building

- Medical Service
- Guest House
- Restaurant & Cafeteria
- Scientific Library
- Deliveries

Office de Tourisme
GRENOBLE-ALPES MÉTROPOLE



Office de Tourisme de Grenoble-Alpes Métropole | 14 rue de la République - Grenoble | TÉL. +33(0)4 76 42 41 41

Bureaux d'information touristique | Vizille TÉL. +33(0)4 76 68 15 16 | Le Sappey-en-Chartreuse TÉL. +33(0)4 76 88 84 05 | La Bastille TÉL. +33(0)4 76 89 46 45

www.grenoble-tourisme.com | welcome@grenoble-tourisme.com

GALA DINNER
TUESDAY 11TH JULY@7PM

Le Ciel Rooftop Restaurant, Grenoble

2 rue du Général Marchand
38000 Grenoble

09 51 12 70 76

=> Getting to Le Ciel <=

Corner of Condillac and General Marchand streets

Le Ciel is a 5-minute walk from Verdun

Public transport: Tram A/ Tram B

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