The H5 guide system—the latest innovative guide system at the ILL

J. Beaucour, M. Kreuz, M. Boehm, R. Boffy, V. Cristiglio, B. Demé, L. Didier, P. Falus,
P. Fouquet, R. Gandelli, Y. Gibert, B. Giroud, B. Jarry, P. Lachaume, S. Roux,
F. Thomas, and A. Vorobiev
Institut Laue Langevin, 71 Avenue des Martyrs, 38000 Grenoble, France

Introduction

As the world's leading center for neutron science, the ILL provides scientists with a very high flux of neutrons feeding some 40 state-of-the-art instruments which are constantly being developed and upgraded. In addition, the transport of neutrons to the different instruments is continually being adapted to the newest available technologies to maximize the available useful neutron flux.

Since the development of modern high reflectivity mirrors for neutrons, the philosophy of neutron transport has changed. In former times the same guide was usually shared between different instruments. This lead to rather important losses for the downstream instruments, at the gaps necessary for the installation of monochromators, because of transmission losses across monochromators and for other reasons, like e.g. misalignments or aluminum windows. Nowadays it is possible to collect a highly diverging neutron beam in primary guides, and, thanks to the proper choice of supermirror coating and guide geometry, to split them into several individual guides having the necessary radii of curvature to separate adequately the different branches without significant lost for a targeted neutron spectrum. Thus, dedicated neutron guides are created that have an optimized geometry and wavelength spectrum for the individual instruments.

The H5 guide system at the ILL that was completely replaced in the last four years implemented successfully this new principle. Most of the work was performed during the 10 months long shutdown in 2013/14 [1]. The guide system feeds neutrons emitted from the horizontal cold source filled with liquid deuterium to the smaller western guide hall of the ILL. In total, eight new or renovated instruments are situated on the H5 guides: one in the reactor building and seven in the guide hall. The present article will describe the main principles of the H5 guide system as well as the first results that have been obtained. A comparison with the expectations from guide simulations will be shown at the end.

Technical overview of the new guide system

Primary guides

In the old H5 guide system, three guides were available to feed seven instruments. For the new guide system, six individual guides are created, providing neutrons to eight instruments. Multiplying by a factor of two the number of guides optimizes the neutron delivery system for every instrument.

Three primary neutron guides could be installed in the pile. This was possible due to the use of a special element at the very beginning of the guide system, the so called "separator," built in one piece from aluminum, polished and coated with a high reflectivity m = 3 neutron mirror. As shown in the Figure 1, the separator consists of a 1 m long common part that allows the transport of a maximum number of neutrons from the source to the part of the beam tube where there is enough space to separate into three individual neutron guides. The primary guides are called H51, H52 and H53. They will be described in more detail in the following paragraphs. At the separation of these guides, initial angles are applied to be able

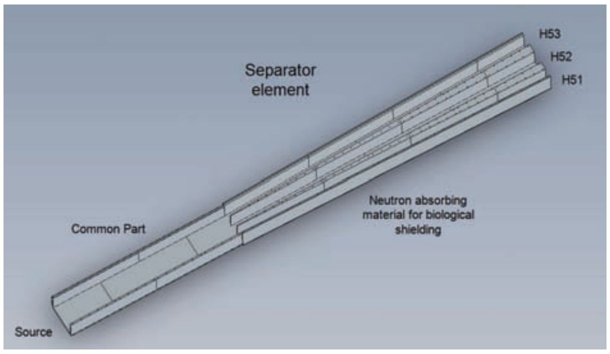

Figure 1. The H5 separator element in the reactor pile. After a common section, the element is split into the three guides H51, H52 and H53. The common part of the separator has a length of 1 m and a section of 120 mm (h) × 170 mm (w). The total length of the element is 2.75 m. © ILL. Reproduced by permission of ILL. Permission to reuse must be obtained from the rightsholder.

to separate the guides quickly. While H52 is parallel to the H5 axis, H51 and H53 have an angle of 1.33° and 1.5° respectively. The geometry was chosen in such a way that all three guides are completely filled with a neutron beam of angular divergence larger or equivalent to the maximum beam divergence acceptable for the downstream instruments. In the old guide system, the in pile element had been made of polished Ni, which has two major drawbacks: (i) the acceptance angle was reduced compared to the critical angles of state-of-the-art supermirror coatings and (ii) Ni was heated to several hundred degrees due to the radiation in the proximity of the reactor core (the in-pile part is in about two meter distance from the core). This temperature would not have been compatible with modern neutron mirrors. The use of an Al guide element, much more transparent to neutron and gamma radiation permitted to reduce the maximum temperature to around 100°C in a worst case scenario with no conductive thermal coupling. This temperature is compatible with modern supermirror reliability.

Secondary guides

The H51 neutron guide has been installed without any significant changes with respect to the old configuration. This guide was indeed already split in a "modern" way into two separate guides with a m = 1.2 supermirror coating and the divergence profile was already optimized for the two instruments D22 (small angle scattering) and IN15 (spin echo spectrometer). All guide elements were realigned to restart the instruments with the optimal configuration and the maximum useful flux. At the same time, both instruments were upgraded: IN15 got a new set of precession coils which increased the field integral by a factor of 4 (see p. 15 in this issue). This improves the resolution and the sensitivity of the instrument and opens the possibility for new experiments. D22 obtained a new collimation system to improve the reliability of the instrument as well as a high-speed chopper adding a time of flight option (Time involved SANS - TISANE). In addition, a biological shielding was added to allow measurements with a white beam as an option.

The H52 neutron guide is the biggest neutron guide of the system. To be able to split it into three individual guides, it expands over the first 17 m from an initial guide section of 60 × 120 mm^2 to 120 × 240 mm^2 (m = 2). This increase of the section reduces the huge beam divergence from the beginning of the guide. Thus it is still fully filled at the split point with the required divergence to be transmitted to the instruments. The three individual guides then transport the neutrons into the guide hall. The separation is done by using three different radii to the left: 4000 m (H522), 1500 m (H521) and 800 m (H523), respectively. The smallest radius of curvature cuts off all neutrons with wavelength less than 4.5 Å. This neutron guide was optimized to feed neutrons to a cryostat with liquid He-4 inside to create very slow neutrons that can be stored in bottles, so called ultra cold neutrons (UCN). The second guide with a radius of 1500 m is shared in the classical way between three instruments. It transmits neutrons with wavelength greater than 3 Å and is used by the diffractometer D16, the reflectometer Super ADAM and D50, an instrument for industrial applications using several different techniques. Both instruments, D16 and Super ADAM, have been improved during the shutdown. D16 now has a new monochromator and the instrument has been optimized for the guide geometry (p. 22 in this issue). This leads to an impressive boost in performance by one order of magnitude with respect to the performance before the modifications. Super ADAM has been fully rebuilt from scratch and the first results are very promising (see p. 25 in this issue). The last neutron guide from H52 finally transports neutrons with wavelength $\lambda > 2$ Å and is used for the new spin echo spectrometer WASP. Its installation will be finished in 2016.

The H53 guide is a 15 m long m = 3 guide that is optimized for a three axis spectrometer (ThALES) placed in the reactor building (see p. 18 in this issue). It transports the required high divergence to the instrument with a beam size of 60 mm × 120 mm leading to a considerable increase in neutron flux after the double focusing monochromator, as compared to the old IN14. Thus very fast measurements have become possible which is particularly interesting for three axis spectrometers to be able to scan different regions within a relatively short time frame for an experiment.

In Figure 2, there is a representation of the H5 layout from the reactor to end of the guide hall with ThALES inside the reactor building and the seven instruments outside.

All new neutron guides make use of modern neutron mirror technologies. This leads on the one hand to the transport of more neutrons but on the other hand also to the creation of additional hard gamma radiation along the neutron guides. For the old guide system, concrete walls with a thickness of 40 cm were sufficient to protect people and scientific instruments from the radiation of the neutron beams outside the core direct view. Now, we need to add typically 10 cm of lead to the concrete wall (or any equivalent material) to reach the same effect. This increases, of course, the cost and the complexity of the project significantly. In addition, the floor load became an issue, as shielding weight is now close to the acceptable limit, especially inside the reactor building.

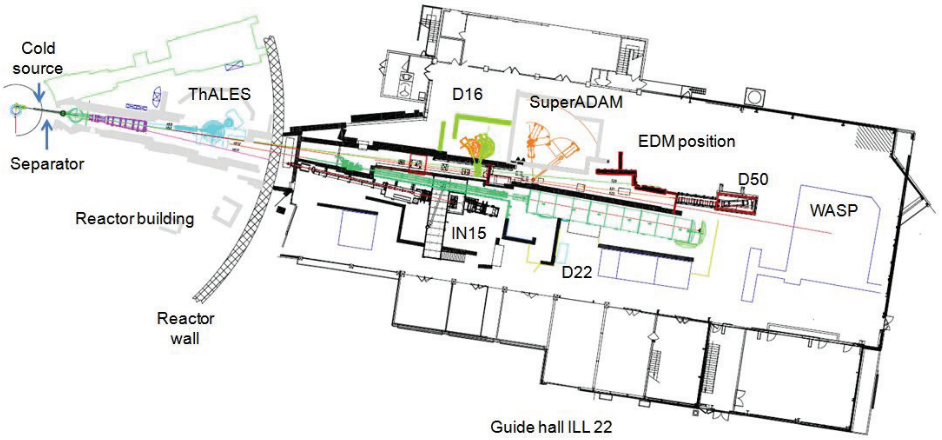

Figure 2. The H5 layout from the reactor to the end of the western guide hall ILL 22. © ILL. Reproduced by permission of ILL. Permission to reuse must be obtained from the rightsholder.

Neutron transport simulations

The H5 guide system was the first guide system at the ILL that could be built completely from the source up to the different instruments using modern techniques. This made it possible to simulate the whole system in advance and to optimize it globally, taking into account, of course, the geometrical constraints of existing equipment and minimum distances. The simulations were carried out in different steps by several persons prior to the launch of the detailed studies and let to the prediction of the expected neutron fluxes for the different instruments.

The neutron transport simulation started on the first meters of guide that is to say in the H5 beam tube, where both the Cold Source and the guide first element, the *separator,* are located. By the concurrent use of MCNP, McStas [2,3] and SimRes [4,5], it has been possible to optimize the shape and distance to the neutron source of the guide nose. MCNP was used to calculate the divergence and energy spectrum of the neutrons moderated by the *H5* Cold Source while McStas and SimRes were optimizing the neutron flight path down the guide. As usually done at ILL, the beam intensity in a guide is scaled on *gold foil activation* measurements. In the case of H5 flux predictions, the best flux values of the old H512 were used as reference points, as this guide was not planned to be significantly modified. A great part of the neutron beam simulation and optimization concerned H52. As explained above, this large guide feeds three regular beam lines: H521, H522, and H523. Strong efforts were pushed toward the optimization of the guide splitting in order to have the most adapted flux for each instrument. This means not only the guide cross sections, but also their position with respect to the H52 curvature. One feature, for instance, is the vertical splitting of the beam between H522 and H523. The entrance of the latter is located in the inner side of the curvature which is adapted to the fact that it is dedicated to produce UCNs using 9 angstroem neutrons, while H522 is located in the outer side where the beam energy spectrum is more balanced.

Beam flux simulation results are shown in Figure 3. It represents the neutron beam capture flux intensity (neutrons·s^{-1}·cm^{-2}) in the different renovated H5 guides as a function of the distance to the H5 cold source. For a given colour, lines correspond to simulations (inflection points are the computed values) while symbols correspond to gold foil measurements. The simulation of *capture flux*[1] by McStas allows a direct comparison of the results with gold foils measurements. From the different values of Figure 3, one can see that simulation and experimental measurements are in reasonably good agreement, specifically at a distance above 15 meters from the H5 cold source. In the case of H511 for instance, the difference between calculations and simulations is in the % range. Moreover, for a more complex beam line such as H521, the simulation predicted the real values with an accuracy between 4% and 12%, which is remarkable considering the drastic evolution the guide and especially the in-pile parts were submitted to.

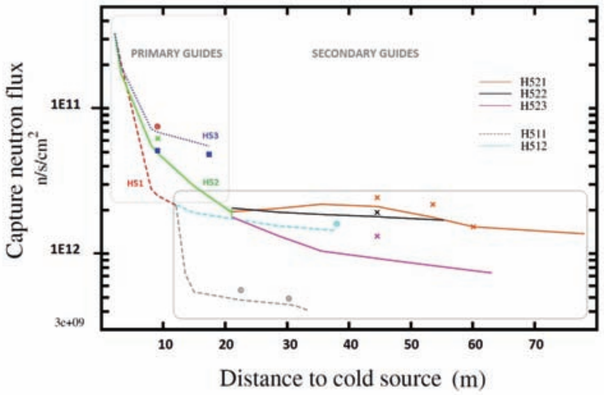

Figure 3. H5 beam flux simulation (lines) and gold foil measurements from November 2014 (points). © ILL. Reproduced by permission of ILL. Permission to reuse must be obtained from the rightsholder.

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[1] The technique provides an equivalent flux of neutrons at 1.8 Å (thermal neutrons).

Table 1. Capture flux gain of the refurbished H5 instruments, as measured at the secondary guide exit, just upstream monochromator, velocity selector or any specific instrument equipment (gold foil measurements). Please note that the flux for EDM has not yet been measured at the extremity of the H523 guide and that D50 and WASP are new instruments, so the flux cannot be compared to the old reference.

Measured at the end of the guide preceding each instrument	***Recent best (10 years) before renovation***	***H5 - 1988 commissioning***	***H5 - 2015 commissioning***	***GAIN***	
				ref. 1988	*ref. best 10y*
	(n/s/cm²)				
IN15	3,12E + 09	1.64E + 09	4.95E + 09	3.0	1.6
	2006 – 33.6 m	*33.6 m*	*33.6 m*		
D22	1.34E + 10	1.60E + 10	1.61E + 10	1.0	1.2
	2006 – 38 m	*38 m*	*38 m*		
Super ADAM	4.90E + 09	9.10E + 09	1.53E + 10	1.7	3.1
	2004 – 71 m	*71 m*	*60 m*		
D16	6.20E + 09	1.14E + 10	2.18E + 10	1.9	3.5
	2007 – 66.3 m	*66.3 m (EVA)*	*53.5 m*		
Thales	2.00E + 10	2.77E + 10	4.82E + 10	1.7	2.4
	2010 extrapol. at 19 m	*19 m*	*17.4 m*		

Flux gain on the H5 instruments

If we consider now the in-guide flux evolution at entrance of the eight instruments served by the H5 guide system, we observe an increase of neutron flux for all of them (see Table 1). Flux increases vary between a factor of 1.2 and 3.5 compared to the best values ever measured over the last 10 years, and 1.0 to 3.0 compared to the 1988 commissioning measurements. In the case of IN15, fed by H511, and D22, fed by H512, the guide geometry and the coating efficiency (m-value) of the guide did not change. The reasons of their respective recent improvement (×1.6 and ×1.2) must be found in the change of few elements and in the remarkable efforts of the technical teams that worked on the realignment of the guide sections before the instrument. The beam intensity gain for Super ADAM, H521 line, comes from the combination of the suppression of guide cuts before the instrument, the use of mirrors with higher reflectivity and, as in the case of H511, the fresh alignment of the elements. The D16 diffractometer has recovered an optimized beam geometry, a large experimental area and benefits from a renovated monochromator with new graphite crystals. The gain flux upstream its monochromator (×3.5) comes from the coating improvement in addition to the gain coming from the in pile section and guide realignment. In total, the flux at the sample position has increased by a factor of 10 with respect to its provisory position on H5 (2007–2013) after the move from H17 in 2007. Finally, the flux at the future EDM position is not yet measured at the extremity of the H523 guide. According to the simulations validated by an upstream measurement inside the guide, a total gain of a factor of 5 is predicted with respect to the old position. For the useful flux at 8.9 Å that is used for the production of ultra cold neutrons a value of 1.0×10^8 n/Å/s/cm^2 (capture flux) has been calculated.

Conclusions

The H5 program with the complete rebuild of the guide system and the upgrade or renovation of all instruments leads to a tremendous increase of the instrument performances. The improvement was obtained both in terms of more useful flux and upgrade of the different instruments (e.g. higher field density for IN15). In addition, the industrial application instrument D50 offers an addition to the ILL instrument suite (see p. 27 in this issue). With the commissioning of the new spin echo spectrometer WASP in 2016, the H5 program will be completed and a considerable improvement for the ILL instrument park will be finalized.

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