BROOKHAVEN NATIONAL LABORATORY

managed by Brookhaven Science Associates
for the U.S. Department of Energy
www.bnl.gov

Building 510B
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-3761
Fax 631 344-2739
zaliznyak@bnl.gov

SNS Spallation Neutron Source

HYSPEC Top Level Specifications

This document defines "top-level" requirements for all components of the hybrid spectrometer, HYSPEC, planned for installation on beamline 15 (BL15) of the Spallation Neutron Source (SNS) that is now under construction at Oak Ridge National Laboratory. All HYSPEC components, whether designed by the Instrument Development Team (IDT), members of the SNS staff, or by third party manufacturers, are expected to comply with these requirements. It becomes effective only if signed by all of the parties whose names appear below. Changes and additions (or deletions) can be initiated by any of the signatories (or their replacements) at which time a revised document must be prepared with all modified sections identified as such. They become effective only after all parties sign the revised document. Whenever revisions are made, the earlier document is to be retained as part of the IDT record.

Principal Investigator:	S. Shapiro	…………….…………..,	Date ………...
Principal Investigator:	I. Zaliznyak	…………….…………..,	Date ………...
Project Scientist:	TBA	…………….…………..,	Date ………...
SNS Instrument Systems:	K. Crawford	…………….…………..,	Date ………...
SNS EFD Head:	I. Anderson	…………….…………..,	Date ………...
SNS Director:	T. Mason	…………….…………..,	Date ………...

Requirements for HYSPEC.[1]

1. Instrument footprint and placement on the floor.

HYSPEC shall be placed at the end position of the SNS beam-line illuminated by a coupled, supercritical H_2 moderator. Sufficient floor space must be available at this position to accommodate the instrument's secondary spectrometer for all incident energies and sample scattering angles specified in sections 3 and 5 below. The greater part of the instrument footprint will be a 6.3 m radius semi-circle, on one side of the beam-line or the other. It will be centered at the monochromator position, at a distance L_{SM} of about 20 to 25 m from the moderator face; nominal moderator-to-monochromator distance L_{SM} = 20000 mm is used in this document. It is assumed that this semi-circular footprint shall be entirely inside the SNS experimental hall. A combined "get-lost" pipe and beam-stop – if they prove to be necessary – may extend outside the building.

It is currently envisioned that HYSPEC will be located on BL15, behind a shorter instrument served by an ambient water moderator on BL16A. Should SNS Instrument Team judge that spectrometer footprint cannot be accommodated on BL15 in accordance with the above requirements a mutually acceptable alternative shall be negotiated between the HYSPEC IDT and the SNS. The possible alternatives, in the IDT order of preference, are: (i) HYSPEC reassignment to another beam-line served by a coupled, super-critical H_2 moderator, such as BL14B; (ii) slight modification of the instrument design by reducing the secondary flight-path: the energy resolution is relaxed proportionally, but the footprint is reduced also; this, however, may also impact the polarization sensitivity; (iii) complete re-design of the instrument secondary spectrometer so that the longest secondary flight-path available for each scattering angle is used, as a result the footprint becomes elongated and "pear-shaped"; (iv) extending the spectrometer primary flight-path to a building outside the SNS experimental hall; at a given analyzer resolution this reduces the incident neutron flux in proportion to the length of the primary spectrometer, and, while being more expensive, is somewhat equivalent to reducing the secondary flight-path.

2. Primary flight-path system

2.1 Neutron guide system

The incident neutron guide system is to be composed of three super-mirror guide sections, **G1-G3,** all with top and bottom coatings with critical angles of $3\theta^{Ni}_c$ and with side coatings with the largest practical critical angle larger than $3\theta^{Ni}_c$. **G1** is to be integrated into the primary shutter. So located, its upstream end with an internal aperture of w_0 x h_0 = 40 mm x 128 mm will be at a distance L_0 = 2000 mm from the front face of the coupled, supercritical H_2 moderator. Gaps of the smallest possible size are to be provided in the guide system to accommodate shutter, choppers and (if necessary) a beam filter assembly. **G2** and **G3**, the sections external to the biological shield, are to be steel-jacketed. All guide sections shall be 40 mm wide; their internal vertical profiles will be chosen to optimize the neutron current illuminating the 240 mm tall, vertically-focusing monochromator crystal that will be located downstream of **G3** at a distance of L_{SM} = 20000 mm from the front face of the moderator. Optimization is to be achieved at a reference incident neutron energy E_i = 15 meV. Existing Monte-Carlo simulations indicate that the optimum guide dimensions are:

Guide section	Length	Entrance size, *w* x *h*	Exit size, *w* x *h*
G1	5000 mm	40 mm x 128 mm	40 mm x 150 mm
G2	11000 mm	40 mm x 150 mm	40 mm x 150 mm
G3	2000 mm	40 mm x 150 mm	40 mm x 180 mm

These dimensions will be further refined as design work proceeds, however, and might, at a later stage, differ slightly from the above values.

The guide support system should be designed to allow easy alignment of the individual guide segments (both vertically and laterally) with positional precision better than 0.5 mm and angular precision better than 1 minute of arc.

To the extent feasible, the primary flight path sections should be either evacuated or filled with ^{4}He gas to minimize air scattering losses.

2.2 Beam line shielding

Beam line shielding shall consist of a stationary bottom piece carrying the guide support and alignment systems and removable modular pieces on the sides and top. The removable shielding is to be designed so as to: (i) minimize the space immediately surrounding the guide system (as specified in section 2.1) that is not filled with shielding material; (ii) minimize the total thickness and weight of the modular shielding and (iii) provide rapid and convenient access to the choppers and (if installed) filters for maintenance and, if necessary, for their removal. Shielding shall be composite and contain materials needed both to slow down and absorb neutrons and to absorb the prompt gamma radiation. Radiation dose rates and background outside the beam line shielding shall be as low as reasonably achievable (ALARA); less than 5 mR/hr and in compliance with the limits established by the SNS.

2.3 Shutter

The primary beam shutter for the instrument shall be the SNS shutter inside the biological shield. When closed it must reduce the radiation incident on the choppers and monochromator crystal sufficiently to allow them to be removed for repairs while the SNS is operating at full power and also reduce the radiation level at the sample position to less than 5 mR/hr. The **G1** section of guide is to be built into the "open" channel of the shutter, as specified in section 2.1. Shutter position shall be controlled by a single switch interlocked to form a radiation exclusion zone details of which are to be specified by SNS. A clearly visible sign will show the shutter position; this information shall also be available to the instrument control computer. Shutter opening and closing times are to be less than 30 sec.

2.4 Filters

If MCNP-X based neutronics calculations indicate that single crystal beam filters can significantly reduce fast neutron beam contamination, a three-position filter exchanger is to be positioned immediately downstream of the in-shield shutter. The filters are to be large enough in their lateral dimensions to intercept the full beam as specified in section 2.1. Each filter shall have the same supermirror coatings and shielding as the **G1** guide so that neutrons must either pass through the filter or be absorbed in the surrounding shielding. A refrigerator system should be provided to cool the filters to 77 K (or colder) and maintain them at that temperature even when fully illuminated by the neutron beam. Filter transmission better that 60% for neutrons throughout the energy range $5<E_i<90$ meV is defined as being acceptable. Filter changes are to be effectuated from the instrument control computer. The filter choices shall be:

2.4.1 **None:** An open channel with lateral dimensions that accommodate the full beam as specified in 2.1.

2.4.2 **Sapphire:** Single crystal sapphire grade B4 or better with a beam path length of 100 mm (available from Crystal Systems Inc.). The orientation of the single crystal material is to be uniform throughout the filter to within 10 degrees. However, the average crystal orientation with respect to the beam direction is unimportant and should be chosen to minimize cost.

2.4.3 **PG:** Pyrolytic graphite grade ZYH with a total beam path length of 100 mm (available from Advanced Ceramics). The c-axes of the individual crystal plates must be aligned to within 2 degrees of the local beam axis.

3. Monochromating system

3.1 General principle

Incident neutron energy selection in HYSPEC shall be defined by the combined effects of time-of-flight (TOF) along the primary flight-path and Bragg reflection from the monochromator crystal. TOF energy selection relies on restricting the burst time τ_0; i.e. the time interval during which the sample is illuminated by the incident neutron beam. A counter-rotating disc chopper pair, $\mathbf{T_2}$, positioned as close as possible to the upstream face of the monochromator crystal is to be used to define burst times $\tau_0 > 50$ μs. An additional "rotating collimator"-type Fermi-chopper, $\mathbf{T_3}$, operating at high rotation speeds shall be used in those cases where shorter burst times are needed. It is to be placed at the downstream end of the converging supermirror guide **G4** between the monochromator crystal and the sample, as described in section 3.5.

Crystal monochromator with variable vertical curvature shall serve to vertically focus the 240 mm tall neutron beam delivered by the guide system onto a sample placed in the beam center at a distance L_{MS} from the monochromator rotation axis. The crystals will also serve as pulse-shapers, cutting off much of the unwanted higher-energy tail from the spectral distribution of neutrons produced by the moderator. Pyrolytic graphite crystals will be used for most unpolarized beam applications although in certain cases where very low incident neutron energies are needed fluorinated synthetic mica crystals may be employed. For polarized beam studies, a vertically-focusing Heusler alloy crystal monochromator will be used to provide polarized monochromatic neutrons incident on the sample. The monochromator crystals shall be mounted in fixtures such that they can be remotely aligned and also remotely rotated around a vertical axis to define the "take-off" angles needed to Bragg reflect neutrons with energies in the nominal range $2.5<E_i<100$ meV.

A sample position arm rotating around the monochromating crystal shall connect the monochromator axis and the sample stage with its alignment and rotation axes. The arm shall hold a converging super-mirror guide, a Fermi chopper, a collimator, an incident beam monitor, beam defining slits, beam attenuators (including a beam shutter), and a polarized beam equipment such as a guide field and flipper for polarized applications. It shall be rigidly attached to the rotating exit aperture in the monochromator crystal shielding in such a way that the sample is always at the center of the monochromatic neutron beam reflected by the crystal. The converging super-mirror guide, Fermi-chopper and collimator are all to be contained within the monochromator shielding. Distances from the monochromator to the sample, L_{MS}, and to the upstream counter-rotating chopper pair, L_{T1M}, should be minimized while maintaining all other specifications. In normal operation the nominal value for L_{MS} is assumed to be 1800 mm.

3.2 Disk choppers

Three disk choppers designated $\mathbf{T_0}$, $\mathbf{T_1}$ and $\mathbf{T_2}$ rotating about their horizontal axes at a multiple or sub-multiple of the source frequency and kept very precisely in phase with the source shall be installed in the primary flight-path. All should fit as tightly within the gaps between guide sections as possible, housed in SNS approved, blast-proof housings, and should have neutron-transparent windows which, as the chopper rotate, provide time-dependent and uniform vertical illumination of the full downstream guide apertures as specified in section 2.1. Beam transmission should be at least 98% in the chopper "open" positions for neutrons with energies in the range $2.5<E_i<100$ meV; a minimum beam attenuation of 10^{-5} in the chopper "closed" position is defined as being acceptable. To the extent feasible, chopper modules shall be based on the standard designs developed by the SNS Instrument Systems Group. Because choppers are significant sources of scattering, additional modular shielding is to be placed around the beam-line at each chopper position to reduce radiation leakage to acceptable levels as specified in section 2.2.

3.2.1 **T_0 chopper:** A chopper with a highest rotation rate of 120 Hz and a lowest rotation rate 30 Hz made of a material that efficiently blocks fast neutrons and gamma-rays from the moderator is to be placed as close as possible to the moderator shielding face or possibly inside it. This chopper must block prompt fast neutrons and gamma rays but be open to neutrons in the energy range $2.5<E_i<100$ meV. Also its "open" channel should be supermirror-coated and of the same lateral dimensions specified in section 2.1 for the surrounding guide so that the downstream guide is fully illuminated when the chopper is open.

3.2.2 **T_1, the order-suppressing and frame-overlap chopper:** This chopper is to be a 300 mm radius, single rotor disc chopper with a highest rotation rate of 240 Hz and a lowest rate of 30 Hz. It shall be located either between guide sections **G1** and **G2**, or in a gap in **G2**. The chopper should be designed to remove all unwanted higher-order neutrons that could otherwise pass through the **T_2** chopper (when operating at high rotation speeds) and be reflected by the monochromator crystal. In cases where frame overlap contamination becomes a problem either this chopper or the **T_0** chopper (or both) should be capable of being operated at half the source frequency (30 Hz) to block alternate pulses from the moderator.

3.2.3 **T_2, the energy-defining chopper:** This is a double-rotor chopper composed of a pair of the counter-rotating 300 mm radius disk choppers with a highest operational rotation rate of 360 Hz. It should be placed as close as practical to the front face of the monochromator crystal, either between guide sections **G2** and **G3** or in a gap in guide **G3**.

3.3 Monochromator crystal assemblies

HYSPEC shall have two or more vertically focusing, segmented crystal monochromators mounted on a remotely-controlled exchanger; one shall be of pyrolytic graphite (PG) and one of Heusler alloy. Optional additional monochromator crystals based on intercalated PG, synthetic mica, silicon or germanium will be specified at a later stage. Their design is to be based on standard GMI-type segmented frames with a single-motor-driven mechanism to vary vertical curvature. Individual crystal segments shall be attached to aluminum alloy plates of the minimum practical thickness using aluminum screws or pins. All monochromator crystal assemblies should be of dimensions w_m x h_m = 240 mm x 240 mm so as to accommodate the full size of the neutron beam exiting guide **G3** for all scattering angles 20º < $2\theta_m$ < 120º. All parts of the monochromator frame and its support and crystal exchange mechanisms and such other components as a magnetic yoke to provide the field needed to saturate the Heusler crystals are to be covered with a neutron-absorbing material such as B_4C and/or LiF. It should be possible to remove either or both monochromating crystal assemblies from the instrument for service while the SNS is in full power operation. A web camera with appropriate lighting shall be provided to enable remote viewing of the monochromators for diagnostic purposes when they are moved.

3.3.1 **PG monochromator:** shall be assembled of 3x60 = 180 individual rectangular plates of ZYA grade pyrolytic graphite (from Advanced Ceramics or another vendor) with an isotropic intrinsic (x-ray) mosaic spread with a full width at half maximum (FWHM) of 25(5) minutes of arc. The plates shall be 1 mm thick and have lateral dimensions *w* x *h* = 80 mm x 12 mm. The plates shall be attached to the holder in sets of three and stacked with aluminum spacers to slightly offset the angles between them, so that the effective horizontal mosaic FWHM of the array is 60(6) minutes. Voids between the adjacent plates shall not exceed 0.5 mm.

3.3.2 **Heusler alloy monochromator:** An array of precisely aligned Cu_2MnAl crystals (well annealed so that the (111) Bragg reflectivity approaches that expected for ideally imperfect crystals) is to be mounted on a standard frame as described in section 3.1. The Mn moments in the crystals are to be fully aligned by an external magnetic field produced by permanent magnets co-mounted with the frame. A polarization efficiency better than 95% and reflectivity better than 50% for polarized neutrons at a reference energy E_i = 15 meV are defined as being acceptable. This monochromator assembly is to be procured from a vendor such as ILL or ORNL with a demonstrated ability to produce Heusler crystals of good performance.

3.3.3 **Optional additional monochromators:** A set of potassium-intercalated PG or synthetic mica crystals, whichever is more practical, is to be mounted on a standard GMI frame for very low-neutron-energy applications. Also to be considered as a possible future option is a high-wave-vector-resolution and/or perfect crystal focusing arrangement based on silicon or germanium crystals.

3.4 Monochromator exchanger

This device shall enable computer-controlled remote selection of one or the other of two crystal monochromator assemblies. Monochromator exchange is to take less than 1 minute. During typical operation exchange might occur as often as once a week. The exchanger should be designed so that either of the monochromators can be removed from the incident beam for service while the SNS is operating at full power.

3.5 Monochromator-to-sample supermirror guide

A vertically-tapered, vertically-converging supermirror guide, **G4,** with a supermirror coating of the largest practical critical angle larger than $3\theta^{Ni}_{c}$ shall be located on the sample arm between the monochromator and sample. It should extend from as close to the monochromator as possible to within 400 mm of the sample. It shall be 40 mm wide; the inside height as a function of the distance, *x*, from the sample shall be given by

$$h(x) = h_S + (h_m - h_s)\frac{x}{L_{MS}},$$

where h_s=40 mm is the nominal sample height, h_m= 240 mm is the monochromator height and L_{MS} = 1800 mm is the nominal monochromator to sample distance. **G4** shall be split into three sections, **G4a**, **G4b**, and **G4c**, all mounted on the sample arm as described in section 3.1. A computer-controlled exchanger should permit remote replacement of the 150 mm long middle section **G4b** by a Fermi-chopper module as specified in section 3.6. Additionally there should be a computer-controlled exchanger permitting remote replacement of the 150 mm long **G4c** section (the closest to the sample) by one of a set of Soller collimators as specified in section 3.7. The guide sections shall be either evacuated or filled with ^{4}He gas, wherever this will significantly reduce beam air scattering.

Each guide segment shall be centered and aligned with respect to a horizontal reference line connecting the sample rotation axis to the monochromator rotation axis. Centering should be accurate to within 0.5 mm and alignment accurate to better than 1 minute of arc. All guide segments inside the monochromator drum are to be tightly embedded in the shielding. Materials that are illuminated by the monochromator and visible from the sample position should have the smallest possible incoherent scattering cross section.

3.6 Fermi-chopper

For high resolution applications, a computer-controlled exchanger shall replace guide section **G4b** with a module of matching size containing a Fermi-chopper, $\mathbf{T_3}$, designed to reduce the sample illumination times to 10 μs < τ_0 < 50 μs. Because this chopper is not intended to be energy-selective it should have short, straight slots and rotate about a vertical axis in phase with the source at up to 480 Hz (8 times the source frequency). The outer diameter of the rotor shall be 120 mm or less, and the height of the slotted channel should match the exit height of the **G4a** section of guide.

3.7 Collimators

When necessary, a computer-controlled exchanger should make it possible to replace the guide section **G4c** nearest the sample with one of a set of four Soller collimators of identical external dimensions. The four collimators should define effective horizontal beam divergences of 20’, 40’, 60’, and 120’ respectively. Collimator blade thicknesses should be 0.1 mm or less. If feasible, the top and bottom surfaces of the collimators should have the same super-mirror coatings as guide **G4c**.

3.8 Monochromator shielding

The monochromator shall be surrounded by a neutron and gamma-ray absorbing composite shielding with a movable beam-port opening that is mechanically connected to the sample arm and rotates with it. To the extent practical it should be constructed of non-magnetic materials that have minimal long term neutron activation cross sections. The range of take-off angles accessible through the beam-port should be -5° to 120°. It should take less than 2 min. to change the take-off angle from one extreme to the other. The combined monochromator crystal and beam-port rotation should define the monochromator crystal take-off angle to $\pm 0.02^{o}$ or less. Whether the shielding mechanical design is to be based on a drum, pie-wedge section or other concept is yet to be determined.

The beam-port opening in the shield should be of internal dimensions that accommodate the converging guide **G4a-c**, the Fermi-chopper and the collimators. The shield design should also provide for incorporation of the remote exchange mechanisms. Shielding must be fitted tightly around all neutron optics elements attached to the sample arm as specified in sections 3.5-3.7 (with radiation steps where necessary) so that neutrons from the monochromator either pass through these elements or are absorbed in the shielding. The inner dimension of the shield should be such as to accommodate the monochromator crystal exchange mechanism with two monochromator crystal assemblies. Radiation protection requirements will determine the outer radius of the shield. It must contain neutron and gamma ray absorbing material sufficient to reduce the radiation rate and the background to acceptable levels: i.e. the radiation dose rate, and background outside the shielding and outside of monochromatic beam should be no more than 5 mrem/hr at a distance 300 mm from the neutron beam and in compliance with all SNS radiation protection requirements and ALARA. Shield thickness should not exceed 1400 mm, so that a clearance of at least 400 mm between the shield and the sample axis is provided. Internal shield design should be such that the amount of the material inside the shield exposed to the incident neutron beam is minimized; all shielding around the monochromator that can be viewed from the sample position must be recessed in such a way that it is not directly illuminated by the incident neutron beam. A convenient access to the monochromators and other beam-line neutron optic elements for servicing and replacement must be provided.

The location and characteristics of the beam dump or “get lost” pipe (whichever is applicable) must be chosen to minimize its contribution to the detector count rate. In addition, an interlocked radiation exclusion zone around the instrument is to be defined in collaboration with the SNS operations staff.

3.9 Beam optics between collimator and sample

A neutron optical bench shall be permanently attached to the sample arm and/or to the beam-port outside the shielding and aligned to better than 1 minute of arc with respect to a horizontal reference line connecting the sample rotation axis to the monochromator rotation axis as described in section 3.5. All components listed below are to be mounted on this bench downstream of the **G4** super-mirror guide. Components 3.9.1-3.9.3 shall be semi-permanently mounted; their combined thickness must not exceed 80 mm.

3.9.1 A beam monitor with a sensitive area larger than the exit aperture of the guide **G4c** and with a wavelength-proportional sensitivity that is no greater than 10^{-5} at 15 meV.

3.9.2 A four position beam attenuator controlled from the main instrument control computer and capable of introducing three different planar objects into the beam. Two of the positions should provide 10 times and 100 times attenuation of the beam respectively at 15 meV. These two attenuators shall be permanently installed in the exchanger. The third position is to be slot that can hold a plate of width 40 mm, height 100 mm and between 1 mm and 10 mm thick. When selected by the attenuator exchanger this plate shall be positioned in the center of the beam to within 1 mm. The fourth position shall be a local beam shutter.

3.9.3 A computer-controlled, variable-opening, thermal neutron aperture covered with layer of LiF on the side facing the monochromator crystal. The aperture must be centered in the beam to within 0.5 mm and should have four independent degrees of freedom controlling the right, left, top and bottom opening with a positioning accuracy of better than 0.5 mm. The design should permit the width and height of the aperture to be varied from fully closed to the full width and height of the beam as defined by the exit aperture of the guide **G4c** as specified in section 3.5.

3.9.4 A computer-controlled aluminum flipper coil, not more than 20 mm thick, designed to rotate the neutron polarization in the incident beam by 0°-180°.

3.9.5 Auxiliary neutron optics components (of a total length not exceeding 150 mm) required for applications to be specified in the future.

4. Sample stage

The sample stage shall be rigidly attached to the sample arm and supported on the floor in such a way that it can move with the arm without tilting as it rotates to beam position defined by the monochromator crystal take-off angle. The positional accuracy of the sample stage should correspond to the same 0.02° precision as for the combined monochromator crystal and sample arm setting angle, as specified in section 3.8. Sample area shall be surrounded with interlocked shielding that reduces radiation levels to 5 mrem/hr or less and meets all SNS radiation protection requirements.

4.1 Space and location

The space available for sample stage positioning must allow monochromator crystal take-off angles covering the range $-5° < 2\theta < 120°$. Space for the power supplies, pumps and other auxiliary equipment required for both polarized beam operation and special sample environments must also be provided on the sample floor. The distance from the sample rotation axis to the monochromator crystal rotation axis shall be variable within restricted limits which are to be defined. It should be no greater than necessary to accommodate a Fermi-chopper, a Soller collimator, a neutron beam monitor, and polarized-beam equipment (such as a flipper) as specified in sections 3.5-3.9. A monochromator-to-sample distance L_{MS} = 1800 mm is defined as nominal.

4.2 Degrees of freedom provided.

4.2.1 Sample rotation 0-360^o with an accuracy of 0.005 degrees.

4.2.2 Tilt of sample table ±12^o about two mutually perpendicular horizontal axes. Tilt accuracy must be better than 0.1^o for loads in the range specified in section 4.3; the effective rotation axes must lie within 20 mm of beam center height.

4.2.3 Vertical translation of ±40 mm above and below the beam center with positional accuracy better than 1 mm.

4.2.4 Horizontal translation of ±20 mm along two mutually perpendicular horizontal directions parallel to the sample tilt axes, both with positional accuracy better than 0.5 mm.

4.3 Dimensions and load capacity.

The sample stage mounting surface shall be at least 152 mm below the beam center. Its on-axis load capacity shall be >500 kg. A (maximum) horizontal torque of $5 \cdot 10^2$ N·m should result in less than a 0.1^o tilt of the sample rotation axis from the vertical.

4.4 Materials requirement

Sample table shall be made of non-magnetic materials. The force on any of its elements in a magnetic field gradient of 10 Gauss/mm should not exceed 1 N.

4.5 Guide field

A computer-controlled coils capable of generating either a vertical or a horizontal magnetic field larger than 10 Gauss throughout the neutron beam path around sample are to be provided. Coils should be mountable on the sample table and be large enough to accommodate a standard sample environment (ie provide a horizontal clearance of at least 400 mm in diameter around the sample axis).

5. Analyzer-Detector system

5.1 General principle

Analysis of the scattered neutron energy will be by time-of-flight in a secondary flight-path of length L_{SD} = 4500 ± 4 mm as measured from the sample axis to the individual detector axis. The secondary flight-path shall include a variable vertical aperture after the sample, shielding, a gas-tight or vacuum-tight flight vessel containing either a radial collimator or a transmission polarizer assembly and a detector array as specified below. The secondary flight-path (analyzer) vessel shall be mobile, and designed to move on the floor in such a way that: (i) for all monochromator crystal take-off angles the axis of the cylindrical detector array remains vertical and coincides with the sample axis to an accuracy of better than 2 mm (ii) the detector bank can be sequentially moved (as specified by the experimenter) to those positions where the range of sample scattering angles accepted by detectors is best matched to the measurement.

5.2 Detector bank

The detector bank shall consist of a cylindrical array of identical, vertically mounted, one-dimensional, position-sensitive, tube-type ^{3}He detectors centered on the sample axis and symmetric about the horizontal scattering plane. The angular size of the individual detector pixels (as seen from the sample position) shall not exceed 20 minutes of arc in either the vertical or horizontal direction. Each detector shall cover a scattering angle of at least ± 7.5° in the vertical direction; the horizontal angular coverage of the entire detector array will be at least 60°.

Detectors shall have partial pressure of ^3He gas and thickness to achieve 90% detection efficiency for 15 meV neutrons.

An array of 190 or more 64-pixel, position-sensitive detectors 20 mm to 25 mm in diameter and 1200 mm to 1300 mm long satisfying the above specifications are to be purchased from an established detector manufacturer. They shall be mounted with their axes vertical to within 5 minutes of arc and positioned with an accuracy of 2 mm on a 4500 mm radius circle in the horizontal plane. This is also the accuracy to which the detectors are to be co-centered at the nominal beam-sample height. Voids between adjacent detector tubes are not to exceed 1 mm.

The detector array shall be fixed inside the mobile analyzer vessel. The vessel design will allow the detector array rotation around an axis concentric with the sample axis to within 2 mm with the accuracy of angular positioning better than 0.02°. Detector voltage supplies, preamplifiers and primary acquisition electronics shall be mounted on the analyzer vessel and move with it to reduce the number of cables connecting the mobile detector array to the stationary part of the data acquisition system to 1 or 2 high-speed, optical or other, communication lines.

5.3 Analyzer vessel

Except for the initial 400 mm downstream of the sample axis, the path of the neutrons scattered by the sample shall be contained within a mobile secondary flight-path (analyzer) vessel which is to be either evacuated or ^4He/Ar gas-filled, to minimize beam loss and background from air scattering. The auxiliary equipment needed to either maintain vacuum or gas pressure shall be permanently mounted on the vessel and shall move with it. Either a radial collimator or a transmission polarization analysis assembly shall be positioned in the scattered beam inside the flight vessel, with its upstream face at a nominal distance of 400 mm from the sample axis, as specified in sections 5.6-5.7. The vessel shall be equipped with a computer-controlled automated exchanger that selects either one of the four radial collimators or one of the two polarization analysis assemblies.

5.3.1 **Materials:** The analyzer vessel shall be made of high-strength aluminum alloy or similar non-magnetic material with a low neutron activation cross section. Its inner walls and all parts of the collimator or polarization analysis assembly that are visible to the detector array should be covered with a neutron-absorbing material such as B_4C or LiF. The scattered beam entrance window on its upstream face should be made of high neutron transparency, high strength aluminum alloy and be of the minimal thickness necessary to support either vacuum or a small over-pressure of gas within the vessel.

5.3.2 **Dimensions:** The size and the shape of the inner and outer cylindrical walls of the flight vessel shall be designed to (i) allow either a one of the radial collimators or one of the polarization analysis assemblies be positioned with its upstream face 400 mm from the sample; (ii) provide space for the automatic exchanger and the collimators and polarization analysis assemblies that are not in use, and (iii) accommodate the detector array which is to be rigidly attached the vessel to the vessel outer wall inside. A removable port(s) are to be provided for convenient access to the automatic exchanger and the detector array. The flat walls on the sides, top and bottom of the vessel are to have inner dimensions which restrict the area of sample illumination to the size of the detector array. For example, the inner height, *h(x)*, of the vessel should vary with distance, *x*, from the sample axis in accord with the expression

$$h(x) = h_S + \left(h_d - h_s\right)\frac{x}{L_{SD}},$$

where h_s=40 mm is the nominal sample height, h_d= 1280 mm the nominal detector height and L_{SD} = 4500 mm the sample to detector distance.

5.3.3 **Position:** The analyzer vessel shall move on the floor following the sample arm so that the axis of the cylindrical detector array coincides with the sample axis with a positioning accuracy of better than 2 mm, as described in section 5.1. The accuracy of the detector bank angular positioning with respect to the axis of the beam incident on the sample should be better than 0.02° and should be reproducible after 1000 analyzer vessel movements. If not restricted by the incident guide and associated shielding, sample scattering angle extreme positions of -5° and +120° should be accessible to at least one detector for all monochromator take-off angles. It should take less than 2 minutes to move the analyzer vessel with detector bank between the extreme angular positions. Vessel support and moving systems shall be chosen to minimize the cost of construction, operation and maintenance while at the same time meeting all of the above-listed specifications.

5.4 Variable vertical aperture after sample

Upstream of the secondary flight-path shielding (but as close to the sample as practical) there shall be a computer-controlled slit capable of restricting the height of the beam scattered by the sample from h_{min}= 0 mm to h_{max}= 100 mm. This slit should be centered to within 1 mm of the beam-center height and have top and bottom apertures that are independently motorized and controlled. It can either be an independently mounted device made of 40 mm thick B_4C-rich material and covered with LiF on the side facing the sample or a mobile extension of the analyzer shielding that can be positioned as close to the sample as needed.

5.5 Shielding

Shielding made of high neutron cross-section materials shall be placed around the analyzer vessel. This shielding shall either be a stationary structure enclosing all possible analyzer positions or be attached to the mobile analyzer vessel itself; the choice is to be made on the basis of practicality and cost-efficiency. In either case, the shielding inner surface shall be covered with a thermal-neutron-absorbing material such as cadmium or LiF. A background count rate of 1 count/min/detector when the SNS is operating but both the beamline shutter and the shielding entrance window are closed is defined as being acceptable. The interior height of the stationary shielding must be sufficient to contain the analyzer vessel and all auxiliary equipment mounted on it, as specified in section 5.3. Also, its top must be modular and allow for easy access to the analyzer vessel for maintenance and, if necessary, replacement of the vessel and/or its components. If MCNP-X neutronics calculations establish the necessity of a “get-lost” pipe, it should be incorporated into the shield design.

5.5.1 **Dimensions and position:** The shielding should start as close as possible to the variable vertical aperture after the sample specified in 5.4. The distance from the sample axis to the upstream face of the shielding shall be such that the analyzer vessel can be positioned with the upstream face of the radial collimator or polarization analysis assembly (whichever is in place) 400 mm from the sample axis. This shielding should have a 100 mm tall scattered beam entrance window and a computer-controlled horizontal aperture of width and position that can be varied so that a selected number of detectors (from a minimum of 1 to a maximum of all detectors in the array) are visible from the sample position. It should be so designed that - if not restricted by the incident guide and its associated shielding - extreme sample scattering angles of -5° and +120° are accessible to at least one detector at all monochromator take-off angles as specified in section 5.3.3. A sufficient clearance downstream the flight vessel should be provided to permit easy assembly and maintenance of the detectors and detector electronics.

5.5.2 **Beam stop:** In some positions of the analyzer vessel the axis of the primary beam could intersect the detector array. It will therefore be necessary to have either a primary beam stop or a “get-lost” pipe to prevent the primary beam from either directly impinging on the detector array or creating an unacceptable background of primary beam neutrons scattered into the detector array. A beam stop should be designed to produce as little neutron and hard gamma radiation as possible; its exterior width should be minimized and its position chosen so that it cannot scatter neutrons into any of the active detection channels.

5.6 Radial collimators after sample

Immediately behind the upstream face of the analyzer vessel there shall be a four-position collimator exchanger capable of accurately positioning any one of four radial collimators or, alternatively, one of two polarization analyzer assemblies in the scattered beam. In all positions the collimator axes should be concentric with the sample axis to better than 2 mm. Changes from one collimator or polarization analyzer to another are to be effectuated from a control computer and should take less than 30 seconds. All collimators are to be embedded in high boron content neutron shielding material in such a way that neutrons either pass through the window of the collimator or are absorbed. In addition, the lateral dimensions of their entrance windows should match the lateral dimensions of the entrance window of the flight vessel and their internal dimensions should match the dimensions of the scattered beam illuminating the detectors in the same way as the inside surfaces of the analyzer vessel match the scattered beam dimensions, as specified in section 5.3.2. The spacing between blades is to be determined by the expression

$$d = \alpha \ell ,$$

where $\ell = 200$ mm is the length of the collimator blades and α is the effective beam divergence. Horizontal divergence angles α for the four collimators shall be 20’, 40’, 60’ and 120’ respectively. Blade thicknesses should be 0.1 mm or less.

All the radial collimators are to be positioned with the sample rotation axis as their focal point to within 2 mm and should be parallel to one another to within 0.01 degree. A line passing through the central blades of the collimators should also pass through the sample rotation axis to within 2 mm.

5.7 Broadband transmission polarizers.

It shall be possible to place either of two broadband, multi-channel supermirror transmission polarization analysis assemblies in the same position as the radial collimators (i.e. immediately behind the upstream wall of the analyzer vessel, at 400 mm from the sample axis) using the same computer-controlled collimator exchange mechanism. One of the two polarization analysis assemblies is to be configured for optimum performance at 15 meV; the other at 7.5 meV. It should also be possible to substitute the polarization analysis assemblies for radial collimators in the exchanger. Changing from one combination of polarization analyzers and collimators to another will be done manually and should not take more than 30 minutes to complete. Like the collimators, the polarization analyzers are to be embedded in a boron-rich neutron shielding material so that neutrons either pass through the polarizing windows or are absorbed.

5.7.1 **Polarization analysis assembly:** Each polarization analysis assembly is to consist of 19 identical channels mounted in a common magnetic frame supplying a permanent magnetic field of at least 300 Gauss; i.e. a field sufficient to magnetically saturate the polarization-sensitive supermirror coatings in all channels. Each channel is to be 20 mm in over-all width and have a height profile that matches the scattered beam height as specified in section 5.3.2. The height should not, however, exceed 200 ± 10 mm at its downstream end. The channels should be equally spaced on the circumference of a circle centered at the sample position with an accuracy of 2 mm, and co-leveled with the sample height with the same accuracy. Tight fitting, wedge-shaped neutron absorbing spacers are to be placed between channels to assure that all neutrons incident on the detectors pass through and not between the channels. Sample scattered neutrons passing through the channels will be split into two separate beams of opposite polarization. The channels should be designed so that the oppositely polarized beams from each channel are fully separated at the detector position but are not overlapped by beams from adjacent channels for scattered neutron energies $3< E_f<30$ meV.

5.7.2 **Individual polarization analysis channel:** Each channel shall consist of a 20 mm wide and 150 mm long collimator immediately followed by a stack of 20 mm wide, polarization-sensitive, supermirror-coated, thin silicon wafers 50 mm long and tall enough to accept the full scattered beam height as specified in section 5.7. Aluminum spacers are to be used to bend the silicon wafer stacks to a horizontal cylindrical curvature that optimizes the polarization analysis efficiency of the channel at the nominal neutron energy for which it is designed. The collimator and polarization analyzer are to be placed in a rigid frame and co-aligned so as to achieve optimum beam transmission and polarization analysis efficiency at the nominal neutron energy. A choice of 10', 20' or 40' collimation should be provided for each channel. The critical angle of the supermirror coating for one neutron polarization direction should be at least $3\theta^{Ni}_c$ (or larger if possible) and for the other it should be no larger than θ^{Ni}_c (or smaller if possible). Over-all, the transmission of the polarized collimated beam through the channel is to be better than 90% for energies $3<E_f< 30$ meV. The center-line of every polarization analyzer collimator should pass through the sample rotation axis to within 2 mm.

6. Instrument Control and Data Acquisition

Three independent computer systems are to be supplied with the instrument. To the extent possible, standard software developed by the SNS staff is to be utilized.

6.1 Instrument Control System. An Instrument Control Program (ICP) running on a dedicated computer shall control the status and operation of all instrument systems as specified in this document, including any automated sample environments needed for particular measurements. The ICP shall communicate with the data acquisition program (section 6.2) to provide information about the instrument configuration and to synchronize and up-date their mutual status during the course of the experiment. The ICP shall also communicate with the experiment planning and data analysis program (section 6.3) to make it possible for the experimenter to pre-select optimum instrument configurations and input parameters for the planned measurement.

6.2 Data Acquisition System (DAS). There shall be a separate, dedicated computer with an advanced high-capacity storage system that is able to communicate with the detector electronics and collect, pre-process and store the data from the individual detectors. Data is to be stored in files using the HDF-type (hierarchical data) format common to all SNS instruments. Along with the data, the files should contain headers with a complete description of the instrument configuration and instrument parameters provided by the ICP.

6.3 Experiment Planning and Data Analysis Program (EPDAP). HYSPEC shall have a dedicated and integrated software package, EPDAP, to plan measurements so as to take optimal advantage of the wide-angle, multi-channel TOF analyzing system and also to analyze the data. The EPDAP should run on a separate, dedicated computer equipped with an extensive set of the peripheral devices for data transfer and visualization. It should be able to communicate with the ICP to export/import the instrument parameters and with the DAS to read the data for analysis and visualization.

7. System Wide Requirements

7.1 Hard and soft limits. All instrument degrees of freedom must be equipped with soft and/or hardware limits that prevent collisions but allow a full range of physically achievable positions. Sample rotation is a special case where hardware limits must be variable to allow for the different constraints imposed by different sample environments.

7.2 Automated calibration and alignment. There should be an automated detector calibration procedure and an automated alignment protocol for all degrees of freedom of the instrument.

7.3 Permanent electrical wiring. The number of cables should be minimized; wherever possible optical communication lines are to be used. All wiring is to be permanently installed and is to comply with all applicable industry and SNS standards.

7.4 Crane. There must be an overhead crane capable of lifting weights of more than 1 metric ton such as, for example, major secondary flight-path instrument components. It should also be capable of lifting heavy (and more than 1500 mm tall) sample environment devices - such as, for example, cryomagnets - and mounting them on the sample table. Crane coverage should extend over the monochromator shielding, the sample table and the secondary flight-path systems.

7.5 Radiation Safety Exclusion zone. In accordance with the “as low as reasonably achievable” radiation safety requirements, the instrument is to be surrounded by an interlocked exclusion zone within which personnel will not be permitted when the primary shutter is open and the beam is on. Details are to be specified by SNS Health Physics.

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(1) Metric units have been used throughout this document. Where standard stock sizes of materials differ from those specifiied, the closest four-digit decimal inch value is to apply.