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ARTICLE

High-Resolution Powder Diffractometer Facility (HRPDF) for Low and Medium Power Research Reactor

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Abstract: The present paper suggests a design of a high-resolution powder diffractometer facility that fits the low and medium power research reactors. The design choice guarantees the acceptable cost of a high-standard facility. Some components can be created in-house, while the design also includes detailed information about the commercially available components. It is highly recommended to carry out Monte Carlo simulations of realistic expected luminosity and resolution parameters of the finally designed and approved instrument in advance. Monte Carlo simulations can eventually show which components should be modified in order to achieve the expected resolution and luminosity parameters of the facility.

Keywords: High-resolution powder diffractometer, Design, Construction, Low and medium research reactors.

I. Introduction

This study presents a detailed recommendation on the design of a high-resolution powder diffractometer facility (HRPDF) as one of the research facilities that can be constructed at any low or medium research reactor. The objective of this work is to serve as a comprehensive resource for interested scientists, engineers, and decision-makers, enabling them to locate all the essential elements and components of the HRPDF in one place.

The principles of operation of HRPDF are similar to X-ray diffraction [1, 2]. Contrary to X-rays, most scattering of neutrons occurs at the atom nuclei, thus providing information not accessible with X-rays. The neutron, furthermore, carries a magnetic moment, which makes it an excellent probe for the determination of the magnetic properties of matter. In the majority of cases, diffraction is the main mechanism of the interaction of neutrons with matter. This is why powder diffraction experiments are, perhaps, the most straightforward of all neutron scattering techniques.

The most common information typically extracted from HRPD experiments includes the symmetry of crystal lattices, the dimensions of the unit cells of the crystal structure, and, hence, the elemental composition. Additionally, the fractional coordinate and occupation factor of the atom within the unit cell are typically extracted with very high precision, providing reliable information on the interatomic bond distances, angles, and thermal displacements of atoms. Finally, microstructure parameters characterizing the grain size distribution and microstress in the crystal lattice can also be determined. The reader can consult with the available literature on the subject, for example, reference [3] on the uranium oxide study.

In addition, the ability of a neutron to penetrate a material makes it ideal for *in situ* experiments using sophisticated sample environments. This allows for measurements at both low and high temperatures, within electric

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and magnetic fields, and under varying levels of values. Examples of applications include investigating phase transitions with temperature, studying geological samples under pressure, analyzing magnetoresistive materials, and exploring magnetic transitions at ultra-low temperatures, among other research endeavors. Many important compounds contain light isotopes, such as hydrogen, helium, deuterium, lithium, carbon, nitrogen, and oxygen. The neutrons' sensitivity to these elements and the difference in scattering between isotopes make neutron powder diffraction an important technique in determining the structural features of compounds with these elements. Examples include ceramics (oxides), Li batteries, magnetoresistive materials, hydrogen storage materials, superconductors, zeolites, and so on. Magnetic structures can be studied using neutron powder diffraction due to the magnetic interaction between the neutron and local magnetic moments in the compound. Examples include rare-earth hard magnets, molecular magnets, correlated electron systems, magneto-elastic coupling, and so on [4].

In this paper, a design of the neutron powder diffractometer is introduced. The approximate cost of individual components that contribute to the total cost of the facility can also be provided in the references. The total cost of constructing an HRPDF varies from country to country and is impacted by different factors, including manpower and labor, local input of shielding and building materials such as concrete and steel, licensing costs, etc. However, the majority of the expenses are attributed to the purchase price of the main components, which is in the range of one million US dollars. Since the benefits of having an HRPDF facility can rationalize the cost of construction, this paper concentrates on the fundamental performance using a very effective and simple solution, as demonstrated in [5]. This foundational solution can be extended and/or supplemented with other components based on various alternatives and market choices. As can be seen from the schematic layout in Fig. 1, the diffractometer consists of the following main units: monochromator unit, collimators, sample table, and detector system. The monochromator accepts the white neutron beam from a polychromatic neutron source. The monochromatic beam shutter enhances personnel safety and reduces radiation exposure. The shutter must be custom-designed to be appropriate for the radiation burden in the beam and for the mechanical constraints of the instrument installation. Sets of collimators determine the divergence of the beam, which then has an influence on the diffractometer resolution. The detector records the scattered neutrons through a specific scattering angle. In a modern instrument, the neutrons are recorded in Position Sensitive Detectors (PSD). The readers can consult with the available literature on PSD, reference [6] as an example. Shielding plays a crucial role in removing undesirable neutrons as well as γ-radiation. The choice of shielding requires special attention in order to achieve an acceptable level of neutron and gamma background.

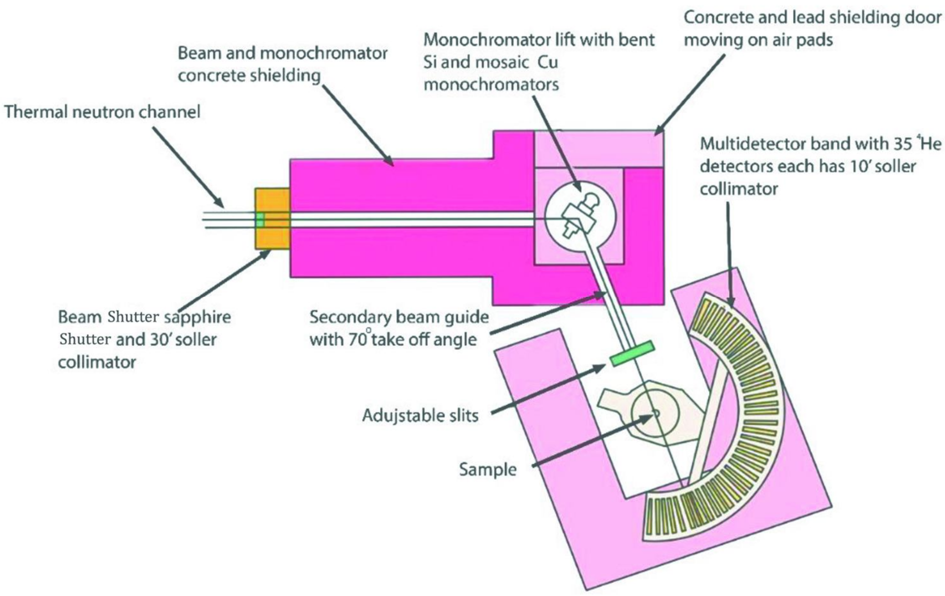


FIG. 1. Schematic layout of neutron diffractometer installed at steady state source.

II. Main Components of the HRPD

The facility should be designed and constructed in such a way that it can meet its objectives and goals. Therefore, it is crucial to select and identify the instruments and tools meticulously, ensuring that their specifications are well-matched and compatible with each other. This synergy among the components is essential to achieve the best performance. The HRPD instrument should consist of three main components listed below. These components should be compatible with each other and include all necessary components.

II.A. Neutron Beam-Related Components

The beam transferring components should safeguard delivering sufficient, clean, and focused neutron beams from the source. In addition, these components should make sure that the working environment is radiologically safe. The main components are listed below.

1. Beam shutter. The beam shutter should guarantee an acceptable dose rate level at the reactor hall when the neutron beams are not in use. This is a very important criterion at the stage of designing the HRPDF in an open pool research reactor where the neutron beam is carried out from the reactor pool to the experimental hall.

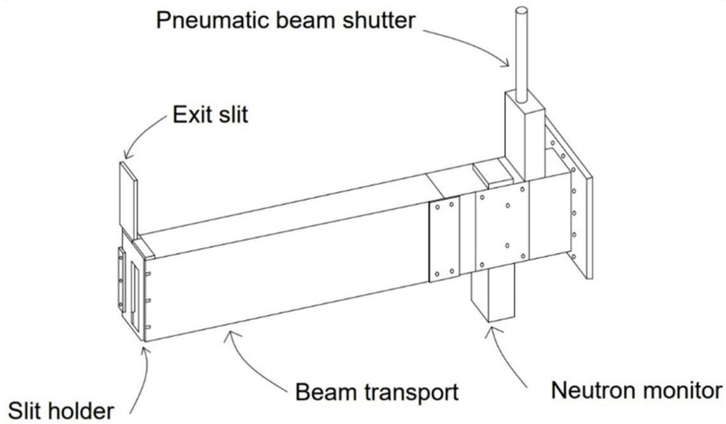


FIG. 2. Sketch representing beam transport, monitor, and pneumatic shutter [12].

2. Neutron filter. The neutron beam filter should reduce as much as possible the contribution of fast neutrons and gamma background spectra at the beam port of the HRPD. Therefore, the material used in the manufacturing process should be carefully selected in order to deliver a clean thermal neutron beam.

3. Neutron collimators. Collimation has a strong impact on the resolution and intensity of the measurement. The collimators set the divergence in the horizontal and vertical directions to produce a clean, coherent, and sufficiently intense beam. In order to obtain a high instrumental resolution, it is necessary to use a radial collimator, as it helps in focusing the diffraction pattern. See, for example, the simulation of collimation in [28] presented in Fig. 3.

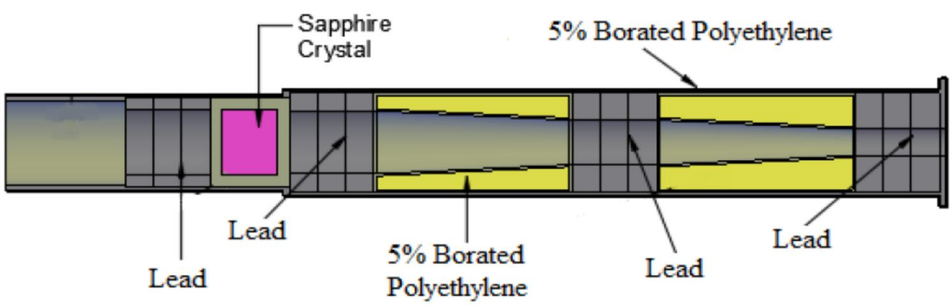


FIG. 3. Layout of neutron beam collimator as presented in [28].

4. **Beam line shielding.** Shielding in diffraction experiments plays a critical role in the safety of the environment and the quality of the experiment. Multiple sources of background radiation and noise exist, including the scattering of the thermal beam, the broad divergence of fast neutrons and γ-rays at the beam port, and the incoherent scattering of thermal neutrons at the experimental station. More than one option in shape and material can be used to construct the shielding walls and blocks, for example, the C and H shape bricks as shown in Fig. 4.

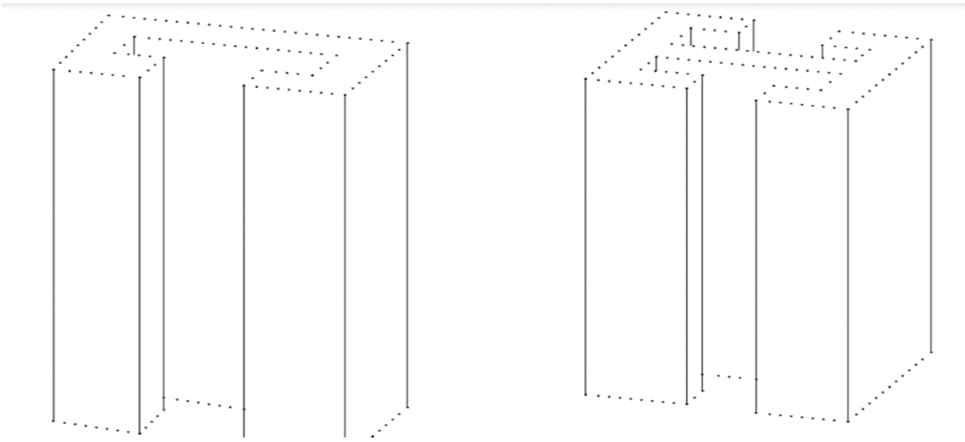


FIG. 4. Sketch of C and H shape shielding bricks.

5. **Neutron monochromator unit, including the slit systems.** The basic function of the monochromator is to diffract the neutron beam at a particular wavelength into a particular angle through the successive beam apertures from the core to the beam port. As the angle-dispersive methods at constant wavelength are used to measure the powder diffraction pattern, a single wavelength is selected from the white beam using a single-crystal monochromator such as Cu, Be, Ge, or Si. The latter two crystals are the best, since they have a high resolution for the perfect crystals.

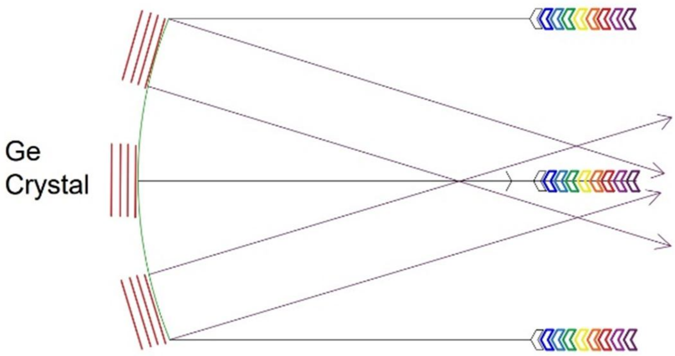


FIG. 5. Self-explanatory monochromator made of Ge crystal.

The monochromator should be placed in a house of a proper material in order to protect it from damage in case of a structural failure in the main beam line. The material type and thickness of the housing should be able to withstand the ambient vacuum pressures and transmit the neutron beam with the desired wavelengths. Generally speaking, the materials and components of the HRPDF should be of grades and types according to the specifications in Ref. [12]. Collimation slits serve to determine the angular resolution. They must cover the desired range of dimensions with proper accuracy.

6. **Sample positioning.** This term refers to the accurate alignment of the sample with the collimated beam and with the detector system. The alignment can be achieved using various methods, such as optical, mechanical, or by employing a neutron curve scan. The alignment requires a table that can be moved along the x, y, and z axes.

7. Detector system. For neutron detection, a low background and high thermal neutron sensitivity, combined with a good localization of the detection event, is essential. ^{3}He-based detectors with a proper sensitive area can cover the diffracted beam under almost all measurement conditions.

8. Shielding. The main function of the shield is to protect against unwanted radiation, damage, and fields, such as thermal and electromagnetic radiation. Therefore, there is a need for thick shielding walls and the establishment of an exclusion zone around the facility building and the instruments such as the neutron source and detectors.

Generally speaking, shielding has to be designed to satisfy the aforementioned functions. Because the fission process produces high energy neutrons, the primary shielding surrounding the source needs to be relatively thick. Furthermore, to attenuate and absorb unwanted radiation, it's important to incorporate robust shielding for components such as the monochromator. In this context, using shielding with easy-to-manage blocks is advisable. The shielding can be made using a combination of materials like polyurethane and boron carbide. Nevertheless, it's worth noting that while shielding is essential for safety, it can reduce the active solid angle for data collection. Therefore, its design and manufacturing should be approached with careful consideration to ensure it does not compromise the instrument's performance and should be handled with care.

9. Electronics and software. In experimental sciences, high-quality data are fundamental for achieving successful experimental outcomes. The neutron powder diffraction technique can be used for various experimental objectives. For example, experiments on crystallography can provide information on crystal and magnetic structures of materials, thermal and electromagnetic properties, mechanical properties, etc. These requirements justify spending some extra money and effort to select the appropriate electronics and software in order to achieve the objectives of the experiment. This includes the use of compatible, user-friendly software and the incorporation of suitable electronics to handle tasks such as data acquisition and analysis.

II.B. Sample Environment Depending on the Planned Experiments:

The term "sample environment" refers to the equipment employed for regulating experimental parameters, including temperature, pressure, and magnetic fields. This equipment, which can include items such as cryostats and furnaces, is vital and routinely used in scattering experiments to position the sample securely and maintain its conditions. The following sample environment equipment is imperative for the current design:

1. Goniometer heads
2. Eulerian cradle
3. Powder sample containers
4. Cryogenic device
5. Furnace apparatus
6. Tension/compression rig

II.C. Accessories Including Monte Carlo Simulations:

Powder-measured diffraction patterns contain instrumental as well as sample contributions. Monte Carlo simulation of the interaction of neutrons with atoms is a powerful tool that allows following the history of the individual neutron from its creation until detection, and hence, taking the instrumental as well as the sample contributions into account. The simulation should take into account the effect of the main components, such as the moderator, on the flux, neutron guide, neutron detectors, collimators, etc. It is not the purpose of this report to carry out simulations. However, the necessary simulations using one of the neutron tracing software such as McStas [25] should be carried out at the proper time of implementing the design.

III. Recommended Systems, Equipment, and Materials for the Main Components of the HRPD

The recommended diffractometer consists of a monochromator unit and two large goniometer circles. The smaller one provides sufficient space for placing the various sample environments. The detector bank is mounted in a molded neutron shielding made from boron carbide (B_4C) powder in epoxy resin [8]. The detection bank contains 35 ^{3}He point counters with corresponding 10' Soller collimators [9]. They are all individually adjustable and set at angular intervals of 4.00° in 2θ. To ensure smooth and precise positioning of this heavily loaded bank, it is mounted on air pads and is driven by a stepping motor. Diffraction patterns can be collected in the angular range from 2° to 148° in 2θ with step down to 0.02° and step delay controlled by strict time or neutron flow read by monitor. As an option, a two-dimensional PSD or an array of several one-dimensional PSDs can be used. Depending on the construction of the monochromator unit, several individual wavelengths of the secondary beam can be selected for measurement. Concerning the monochromator unit, as an example, a simple vertically changeable monochromator system can be used. Another choice of doubly focusing monochromator system can be used. This option can be useful for several individual neutron wavelengths [8]. In the following, a description of the material and equipment is presented.

1. Shielding Walls

Shielding walls can be constructed from C- and H-shaped polyethylene bricks containing 3%-5% of B^{10}. One wall requires several bricks of C of standard dimensions 25×8×12 cm put together in four layers and then inserted into a frame.

2. Radiation Shielding Solid Lead Bricks

For radiation, solid lead bricks of $PbSb_3$ can be used to make shielding walls. It is highly recommended to use two layers of bricks around the neutron collimator inside the concrete shielding before the monochromator. B_4C sheets can be used as an alternative shielding material [10]. Cadmium (Cd), plates can be customized for apertures, diaphragms, slit blades, and shutters [11]. It is recommended to cover the concrete beam housing with one-centimeter-thick Boron-carbide sheets. Table 1 presents the nuclear density, capture cross-section, scattering cross section, attenuation cross, and fraction absorption after 10 cm of various shielding materials for fast 2 MeV neutrons.

TABLE 1. Nuclear density, capture cross-section, scattering cross-section, attenuation cross, and fraction absorption after 10 cm of various shielding materials for fast 2 MeV neutrons.

Material	Nuclear Density (Nuclei/Cm^3) 10^{22}	(2 MeV) σ_c (cm^{-1}) 10^{-7}	(2 MeV) σ_s (cm^{-1})	(2 MeV) σa (cm^{-1}) 10^{-3}	Fraction attenuated after 10 cm
H_2O	3.346	8.36	0.1673	111.1	~ 52%
Li^6	5.33	5.33	0.1066	2.052	~ 54%
Li^7	4.59	1.97	0.0597	3.216	~ 41%
B^{10}	1.391	1.11	0.01391	6.955	~ 84%
Cd^{114}	4.565	5.21	0.002	2.803	~ 49%

3. Neutron Detection System

Neutrons cannot be detected directly. Indirect detection involves the interaction of the released neutrons with the material releasing charged particles and inducing ionization current. Therefore, a material with a high absorption neutron cross can be used for neutron detection. BF_3 and ^3He are the main gas detectors because of their high absorption cross-section. For HRPDF, more than one alternative can be used:

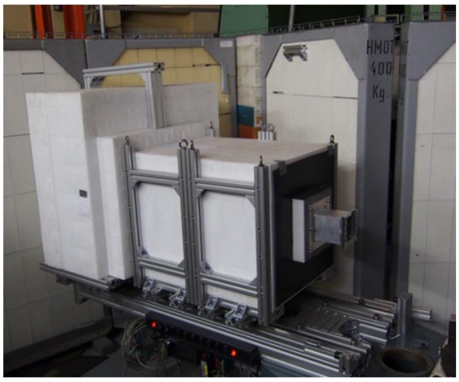
1. The use of a multidetector system [12] or
2. The use of one or two pieces of two-dimensional PSD covering a reasonable range of scattering angles. In both cases, it is recommended to purchase the whole system.

A rather easier and cheaper way to build the detector system is to use two pieces of 2d-PSD, each situated to a massive shielding as shown in Ref. [13]. Fig. 6 presents one detector shield and one 2D detector, 2d-PSD (20x20 cm active area) made in Frank Laboratory of Neutron Physics, JINR, Dubna, and the other made in NPI Řež.

4. Aluminum Construction Profiles

A complete range of modular system products - made by the German-based item Industrietechnik und Maschinenbau GmbH, are available in the market [14]. This system is based on precise anodized aluminum profiles with longitudinal grooves and holes for mounting the connecting elements and extensive accessories; the surface is corrosion- and abrasion-resistant.

The system's concept offers significant flexibility, high precision, robustness, rapid adaptability, and the potential for reusing various system components. The profiles with the air pad systems can be effectively used for the detector system support as well as for easy movement of the detection unit in the scattering plane around the sample.


(a)

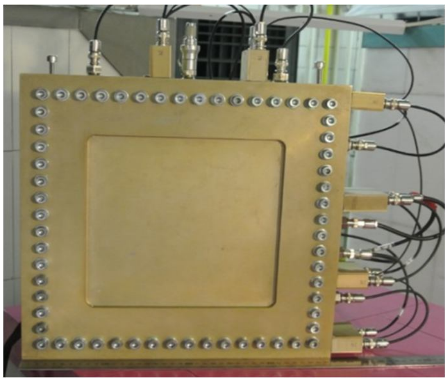

(b)

FIG. 6. One detector shield and one 2D detector, 2d-PSD (20 cm x 20 cm active area) made in Frank Laboratory of Neutron Physics, JINR, Dubna [13] (a), and the one made in NPI Řež, Czech Republic (b)

5. Cryostats for Neutron Scattering [16, 17, 18, 19]

For short-duration experiments (one day or less), the simplest cryostat system is a small continuous flow. This type of cryostat is connected to storage Dewar for the length of the experiment. This type of system is designed for operation down to ~5 K, with short excursions to lower temperatures down to 2 K. The sample is placed in the vacuum space of the cryostat. The system can be easily built with an aluminum vacuum shroud suitable for use with neutrons.

This short-duration system can also be of a liquid helium-cooled type with a built-in reservoir for the cryogens. It is typically built with a sample tube with static exchange so the user can stay away from systems with flowing liquid helium in the beam path. Another cooling option is to build a closed-cycle refrigerator system, which is suitable for operation down to ~4 K. In this unit, the sample is located in the vacuum space of the cryostat and must be warmed up in order to change the sample. Note, that the system uses a large cryocooler rated to have 1 W of cooling power at 4.2 K. It is worth noting that other models of cryocooler are available in the market, which are lighter-weight and lower-priced but these come with less cooling power.

For long periods of experimental time, a closed-cycle refrigerator system for operation down to ~4 K can be used. This type is a top-loading system, so the sample can be changed while the cryostat remains cold.

The PTSHI-950T cooling system is similar to the SHI-950T [16] such that it is a top-loading closed-cycle refrigerator system, but it is configured for continuous operation below 2 K. The sample is in static exchange gas and has a separate helium gas circuit, which provides the sub-2 K^o cooling.

6. Neutron Monochromator Assembly [12]

The monochromator system has an area of approximately 13.03 x 19.05 cm^2 and consists of nine silicon blades, which are mechanically bent in the horizontal plane. In the vertical plane, the blades are mounted in a polygonal approximation to the surface of a sphere. Both the horizontal and vertical curvatures can be adjusted and optimized for the beam geometry at the instrument site.

The monochromator is mounted with the [110] plane vertical axis so that all the reflections of the [110] zone are accessible. Several of these reflections are useful for neutron diffraction. The [115] 1.478A^o, [113] 2.316 A^o and [335] 1.171 A^o reflections can all be accessed by simple rotations of the monochromator, assuming a fixed 90° take-off angle. The [331] 1.762 A^o and [551] 1.075 A^o reflections can be accessed by "flipping" the monochromator and mounting it with the top and bottom swap. The monochromator goniometer should consist of a translation, rotation, and tilt stepper motor.

The Popovici monochromator is a doubly bent, perfect single-focusing silicon crystal [20] composed of nine slabs of perfect single-crystal silicon cut from a single wafer with nominal dimensions of 1.45, 0.053, and 19.05 cm.

For a 90^o take-off angle, the reflections and wavelengths accessible for the monochromator are [113] 2.316 A^o, [115] 1.478 A^o, [335] 1.171 A^o, [117] 1.075 A^o, [331] 1.762 A^o, [551] 1.075 A^o. The most intense reflection is from the [115] plane, although some other reflections are also useable for diffraction experiments.

7. Sample Goniometer

A two-theta rotation, tilt, and translation motions are needed for aligning the monochromator in the white beam should be provided.

In order to perform neutron powder diffraction experiments in special environment chambers (cryorefrigerators, cryostats, furnaces, etc.) as well as to reduce environmental background, it is necessary to suppress the scattering from vacuum and heat shield walls that are external to the sample itself. A radial oscillating collimator (ROC), which must be well shielded, is used to accomplish this task [12,21]. The ROC has thirty-six 145,86,0.13 mm stainless steel blades separated by an angle of 1.25° and coated with neutron-absorbing paint. They are radially oriented and can effectively prevent scattered neutrons at a distance larger than two centimeters from the sample position from reaching the detector. The front and back faces of the ROC are covered with 0.6 mm thick Cadmium metal shielding bonded to thin aluminum plates.

8. Linear Position Sensitive Neutron Detector Assembly

It is recommended to use 11 position-sensitive neutron proportional counters containing helium and argon gases. The detector tubes are clamped onto a plane array that is mounted in the detector shield. Appropriate decoding electronics, software, interconnecting cables, and high voltage bias should be supplied. Furthermore, the installation of a position encoding module (PEM) is essential to determine the event position in linear position-sensitive proportional counters [12, 22]. To facilitate the operation of the neutron diffractometer, it is crucial to integrate an appropriate neutron diffractometer control system (NDCS), such as the one available from Instrumentation Associates, as referenced in [12], into the system.

9. Power Module: PWR

A wide NIM bin that supplies preamplifier power to the detector array should be obtained from [12], as a possible provider. The PWR module supplies clean +/- 6 V from 2 DB-9 connectors mounted at the back of the module. One PWR module can supply power for up to 15 detector elements (30 preamplifiers). The PWR module also contains a detector preamplifier that can be used to exercise PEMs. Two BNC connectors at the back of the module and two BNC connectors on the front of the module are connected to the internal preamplifier. A single input BNC connector at the front panel is a pulser to test input signals.

10. Position Encoding Module (PEM)

The Position Encoding Module (PEM) described in [12] was developed specifically to determine an event position within fully equipped linear position-sensitive proportional counters. It is a wide NIM device that accepts signals from the detector preamplifier, digitizes them, and calculates the event position from the ratio of the signal amplitudes. It maintains pulse height and event position histogram in its internal memory and delivers the information to the instrument host computer via the USB bus on command. One PEM is used to service the signal from a single detector element. Appropriate software with the source codes can be provided. The PEMs yield event positions in the form of "position spectra." To make these data useful, they need to be correlated with the instrument's geometry and detector calibration. This correlation is essential for converting the position spectra into angular histograms and for amalgamating the data obtained from all PEMs and detector elements.

11. Detector Shield

The large size and high efficiency of the linear PSD array require an effective shield. The shield can be constructed using a combination of materials, including high-density polyethylene and borated polyethylene, and it should also be lined with cadmium metal. Figure 7 presents a sketch diagram of a 15-element detector shield. It is composed of high-density polyethylene and borated polyethylene and is lined with cadmium metal [12].

The detector array can be moved within the shield assembly to two different distances from the sample position: typically 1.6 m is used as the sample-detector separation for the highest resolution with 24 in. (61 cm) long detector elements. At this distance, the detector spans 20° two-theta. The detector can also be placed at 1.05 m from the sample, spanning 30° two-theta at a somewhat lower resolution. Data acquisition at the 1.05 m detector distance is nominally 2.6 times faster than that at the 1.6 m detector distance using the three mm sample holder. The detector array is mounted on rails inside the shield assembly and has two preset locations set by mechanical stops. At the top of the shield, there is a slot for the insertion of a precision comb mask for detector calibration. The detector can be serviced without the need to remove the array from the shield.

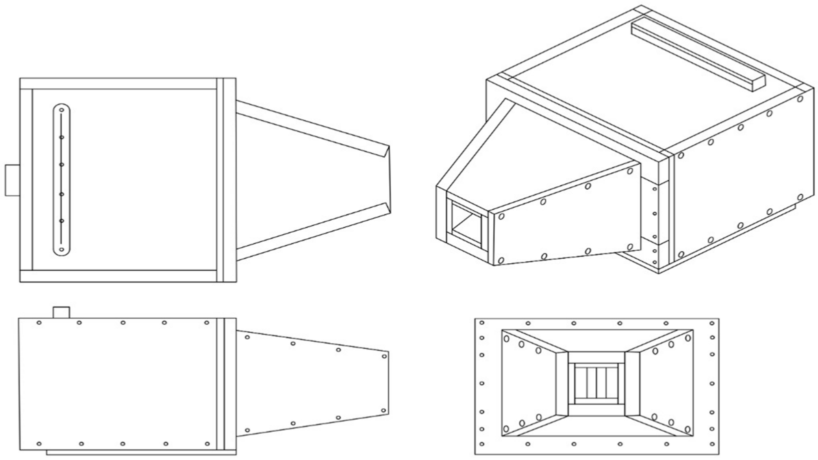


FIG. 7. A sketch diagram of the detector shield. It is composed of high-density polyethylene and borated polyethylene and is lined with cadmium metal (not to scale).

A scintillator-CCD neutron camera should be provided to facilitate the alignment of the sample with the neutron beam. Generally, neutron camera/beam visualization, used to visualize the monochromatic beam, exit slit, and sample position, greatly increases the efficiency of adjusting the diffractometer for different experimental conditions. The neutron camera can be used with a small LCD TV-type display or with a frame-grabber module that can provide images to the host instrument computer for enhancement or record keeping.

12. High Temperature Furnace

The central portion of the furnace should consist of a tube (stainless steel: melting point 1510 °C, boiling point 2750 °C for lower temperature operation, alumina: melting point 2072 °C, boiling point 2977 °C for higher temperatures [18]) into which the sample is lowered (with appropriate heat shields on the sample down-rod). The diffractometer design requires that the central tube be filled with a static gas (typically Argon) but a minor modification to the design will allow for continuous controllable gas flow, with the gas introduced below the sample and vented at the top [12]. A high vacuum pumping station is required for both the furnace and the low-temperature sample environment. Two heaters surround the central tube, one above and one below the sample location. These are potted Kanthal Super (or similar) elements that can be operated above 1000 °C [23]. A type K thermocouple, consisting of Chromel and Alumel conductors to meet the specified output requirements mentioned in Ref. [7], is affixed to the surface of each heater nearest to the sample. Additionally, two more thermocouples are attached to the upper and lower sections of the sample container. A heat shield encompasses the heaters, and depending on operational requirements, one or more supplementary heat shields, varying in diameter, may be positioned within the vacuum space. The shell of the furnace is made of aluminum. In general, samples are changed without breaking the vacuum, so the lifetime of the elements in the vacuum space should be quite long. The furnace controller is fully integrated into the control system, but can also be operated in stand-alone mode to produce the calibration data.

13. Cryorefrigerator System

A low-temperature sample environment cooling system based on Advanced Research Systems (ARS) with integrated software should be provided [12]. The system should control the temperature between room temperature and 10 K^{o}. It should be designed to mount on the sample table X-Y translation at the proper height for neutron diffraction data acquisition. Samples are placed in an aluminum can, sealed with indium O-rings, and mounted to the end of the cold-head cold-finger. Two exchange-gas sample cans should be available. The cans are normally filled with compressed helium gas before the indium O-rings.

14. Furnace System

A top-loading furnace designed to operate between room temperature and (conservatively) 800 °C, is recommended. This furnace has a center zone that opens from the top to allow sample insertion and removal without breaking the vacuum around the heater elements. The center tube should be made of stainless steel for low-temperature operation and can be interchanged with an Al_2O_3 tube for high-temperature operation. The center space contains two tubes (fill and vent) to allow for gas circulation around the sample. The vacuum space encloses two heaters surrounding the central tube separated at the sample height, as well as heat shields, power leads, etc. Thermocouples are mounted on both heater elements and at the top and bottom of the sample (or sample holder). The furnace controller allows a pair of thermocouples for the temperature control and for all thermocouples to be displayed simultaneously. Because of heat transfer issues, the heater thermocouples will be used for the control at low temperatures, while the sample thermocouples can be used for control at higher temperatures. The control system is integrated into the NDCS and provides computer access/control for four separate PID (proportional integral derivative) temperature controllers and a visual display for the current set points, temperature, and alarm conditions.

15. Stepper Motor Controllers (per axis)

A microprocessor-controlled stepper motor driver appropriate for the monochromator goniometer and ROC motions is recommended. These stepper motor controllers should communicate with the user instrument control computer via software.

16. Vacuum System

A microprocessor-controlled diaphragm backing pump, turbomolecular pump integrated vacuum station with vacuum gauges, vacuum valves, connecting tubes, and fittings should be supplied for the pump out of the cryorefrigerator and furnace peripherals.

IV. Conclusion

The present paper suggests a suitable design of a high-resolution powder diffractometer facility that can be built in low or medium multipurpose research settings [26]. The design is simple, low cost, and can use the instruments and tools available in the market. Nevertheless, the facility can only be operated efficiently when ancillary equipment is provided. In this context, it is worth mentioning that the complete neutron diffractometer is supplemented by a variety of additional components that should be included to obtain the functionality of the instrument. These components are not “optional”; they are integral to the proper functioning of the instrument. Some examples of ancillary equipment are listed below.

Neutron beam monitors and support electronics. A low-efficiency neutron detector, placed directly in the beamline upstream of the specimen position, is used to control the duration of neutron scattering experiments.

Interchangeable monochromatic beam slits and slit holder. A set of interchangeable monochromatic beam slits is used to limit the beam so that only the sample is exposed.

Recirculating chillers with good cooling capacities. Chillers covering a range from 0.3 to 20 kW can be used in the suggested design. An example is the FL11006 Recirculating Cooler [24].

Finally, Monte Carlo simulation is inevitable for the design and construction of an HRPDF to be complete. However, for each neutron source, there are particularities that should be taken into account, see, for example, the Jordan Research and Training Reactor [27]. Therefore, the simulation has been left to a later stage of the decision. A possible layout of the HRPDF can follow the facility arrangement of the North Carolina State University presented in Fig. 8. Also, the reader can note that the components and equipment introduced are fundamental for every HRPDF, which is the main theme of this report. This design is versatile and capable of meeting the requirements of researchers in various applied sciences. Furthermore, it can be readily adapted and expanded to fulfill the evolving needs of researchers across different fields of study in the future.

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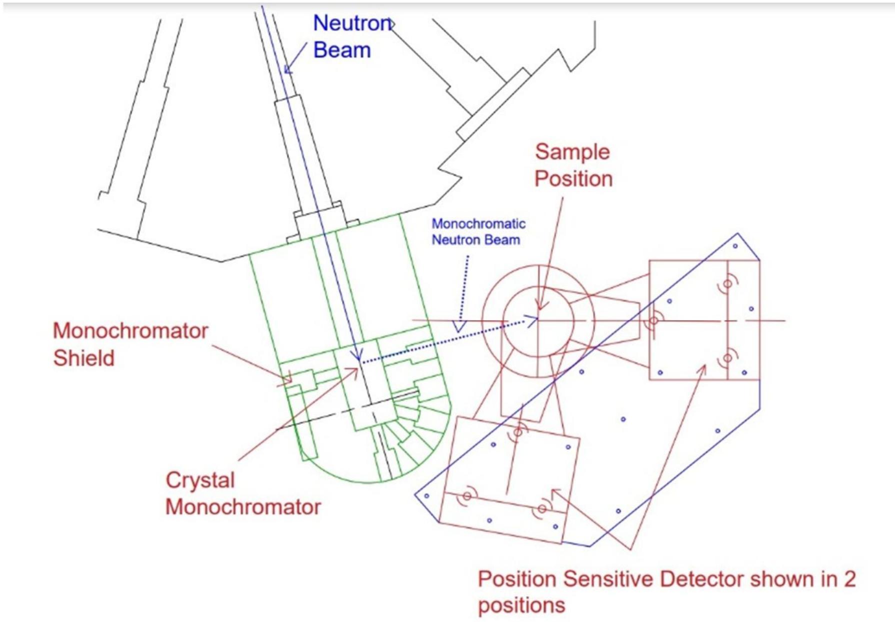

FIG. 8. Layout of North Carolina State University HRPD

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