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RESEARCH ARTICLE

# High Current Accelerator-driven Neutron Sources - The HBS project for a next generation neutron facility

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## Abstract

### Background

Research with neutrons is usually related to the use of fission-based research reactors or neutron spallation sources to offer neutron beams for science and industry. In recent years a novel way for the production of brilliant cold, thermal, and epithermal neutron beams has emerged with the availability of high current proton accelerator systems. These "High-Current Accelerator-driven Neutron Sources" (HiCANS) offer pulsed neutron beams with high peak brilliance close to present day neutron sources.

### Methods

A project was launched at the Jülich Centre for Neutron Science for the development, design and demonstration of such an innovative high-current accelerator driven neutron source termed "High-Brilliance neutron Source" (HBS). The aim of the project is to construct a scalable neutron source as a user facility.

The basic technical components consist of i) a high current proton accelerator with a proton energy below 100 MeV, ii) a compact

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neutron target, moderator and reflector unit and iii) a neutron extracting, and transport system optimized for neutron beams with high brilliance to serve a suite of high performing instruments with epithermal, thermal and cold neutrons for various applications.

**Results and Conclusions**

The HBS project will offer open access and services to the various and changing demands the scientific and also the industrial community asks for. The project offers flexible solutions to a broadest scale of applications in science and industry. The conceptual design of HBS as well as the technical design was published recently in a series of reports as blueprint of a HiCANS facility. HBS will complement and develop further the landscape of high-end neutron facilities in Europe. In addition, HBS will allow intense training and preparation for experiments at the highest level at flagship European neutron sources such as the ILL or, in the future, at the ESS.

**Keywords**
neutron source, proton accelerator, neutron instrumentation, neutron moderators, cold moderators, CANS, HiCANS

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## Introduction

High current accelerator driven neutron sources Research with neutrons is usually related to fission in research reactors or to spallation in accelerator-based neutron sources as the basic nuclear reactions to create free neutrons from the nucleus of the atom. These large-scale infrastructures usually offer highest neutron flux and a large variety of experimental capabilities to perform neutron scattering experiments, neutron imaging, neutron analytics, and experiments with neutrons in nuclear and particle physics in many areas of research.

Besides that, the bombardment of elements with electron beams or rather low energy ion beams (preferred protons H+, or deuterons D+ with energies up to 13 MeV) to initiate nuclear reactions are employed as neutron sources on smaller scales. These smaller neutron sources are often referred to as "Compact Accelerator-driven Neutron Sources" (CANS) operated at universities and research institutes.[1,2] The neutron beams from such sources provide neutron fluxes which are some orders of magnitude below neutron fluxes of the large neutron facilities.[3] Still these CANS facilities play an important role in dedicated applications, training of users local and the development of experimental methods.

In recent years a novel way for the production of brilliant cold, thermal, and epithermal neutron beams has emerged with highly competitive instrument performances.[4] Using the elementary known processes of nuclear reactions at low energies with protons this approach exploits technological developments achieved recently in accelerator physics, neutron target- and neutron moderator technology, neuron beam delivery systems, neutron optical devices and state-of-the-art instrument developments. These kinds of facilities have been labelled as "High Current Accelerator-driven Neutron Sources" (HiCANS). Yet no HiCANS is existing worldwide, a number of projects are being in development in Europe in order to realize such a facility.[5]

HiCANS will offer pulsed neutron beams with high peak brilliance, which are close to present day neutron sources. Hence, they can have strong potential to step into and replace the network research reactors had in Europe, as outlined recently in a position paper of the "League of advanced European Neutron Sources" (LENS).[6] HiCANS produce neutrons very cost efficient, as the low energy accelerator can be installed and operated at comparably low price and as the radiation shielding can be reduced significantly thanks to the lower source strength and the softer primary neutron spectrum.

At Forschungszentrum Jülich a highly ambitious project to develop and establish a HiCANS is pursued in collaboration with the Helmholtz-Zentrum Hereon and various partners from local universities and national and international research organizations. In this contribution we describe the layout of the facility planned, labelled "High Brilliance neutron Source" (HBS - https://hbs.fz-juelich.de/),[7] introduce key features and provide an outlook towards the next generation of neutron facilities.

## The concept of the HBS facility

The High Brilliance neutron Source (HBS) represents a concept for a novel high-current accelerator driven neutron source which will open the door for a scalable and cost-efficient neutron user facility between accelerator-based sources of low power (<1 kW) (e.g. CANS) and flagship facilities.

The basic specification for the HBS is a linear proton accelerator to produce pulsed proton beams distributed via a multiplexer to the three neutron target stations with thermal power of 100 kW each and a variable set of beamlines located around each target station (Figure 1).[8]

## Accelerator

The HBS accelerator must provide a proton beam of 100 mA current, an energy of 70 MeV and a duty cycle variable of ~6%.[8] A hydrogen plasma is ignited in a plasma generator to extract a high current proton beam as proton source. As ion source an Electron Cyclotron Resonance (ECR) system is considered as the most favorable technology driven with an RF (Radio Frequency) gas discharge.[9]

The charged proton beam then enters a Low Energy Beam Transfer (LEBT) section, followed by a double 2.5 MeV RF quadrupole and a long section of Drift Tube Linacs (DTL). 45 room temperature H-type DTL cavities accelerate the protons to the final beam energy of 70 MeV. Designed for high duty cycle operation the RF structures operate at a frequency of 176.1 MHz.[9]

The accelerator delivers a sequence of pulsed proton beams distributed to the three target stations each with a beam power of 100 kW. In total the full proton beam power reaches 420 kW with a duty cycle of ~4.8% total.[9] A normal conducting accelerator has been identified to achieve these parameters. A normal conducting linear accelerator run at room temperature offers the advantage of easy access, simple and available technology, low price and high reliability. Comparable accelerators exist, such as the Linac-4/SPL,[10] the FAIR-p-Linac,[11] the ESS[12] or the SNS[13] accelerator.

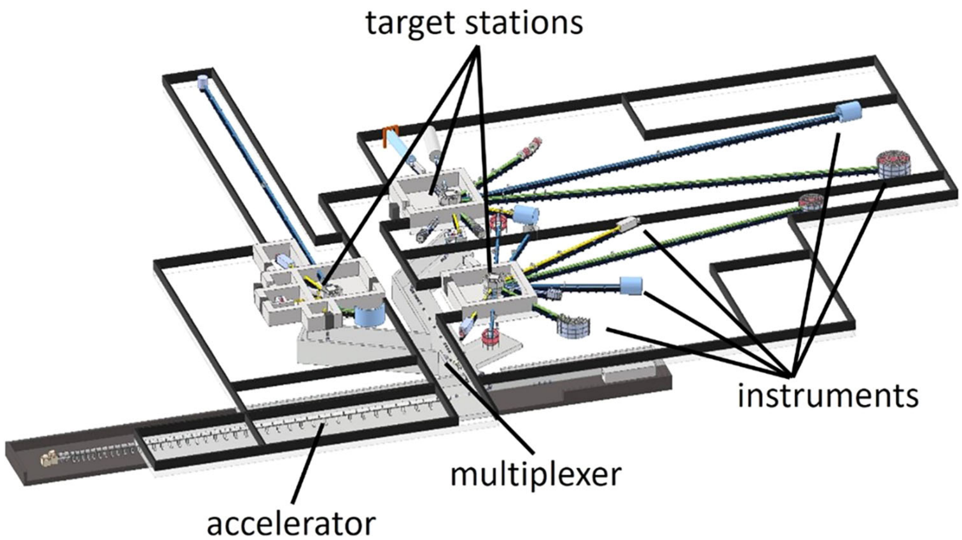


**Figure 1. Schematic layout of HBS with the proton accelerator, a multiplexer to distribute neutron pulses to three target stations with attached instruments.**[20] Adapted with kind permission by Forschungszentrum Jülich GmbH.

At a HiCANS source, the proton energy in the MeV range allows splitting the beam and thus feeding more than one target station with proton pulses. Using a sophisticated multiplexer in the High Energy Beam Transfer (HEBT) the beam is distributed to three different targets at HBS (Figure 2).[14] The location and arrangement of the HBS target stations determine the outline of the HEBT based on the requirements for the space of the individual neutron targets, the size and orientation of the instruments and corresponding auxiliary buildings and support structures.

Different sections interact in combination in the HEBT. The beam is horizontally bent in the first section by 90° from the Linac towards the experimental regions. In the second section the beam is deflected vertically by 90° from the ground floor into the basement. Both sections consist of double-bent achromats with corresponding two 45° sector bending magnets. In the basement the beam is transferred towards the third section of the HEBT structure. A quadrupole triplet focus the beam towards the multiplexer.[15]

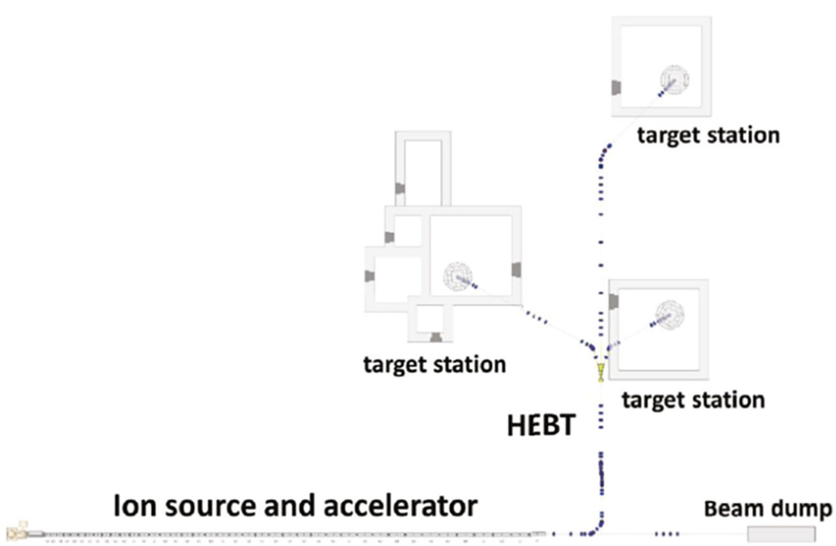


**Figure 2. Sketch from top view of HBS accelerator structures, showing the ion source, accelerator, beam dump, HEBT beamlines and the three target stations.**[9] Adapted with kind permission by Forschungszentrum Jülich GmbH.

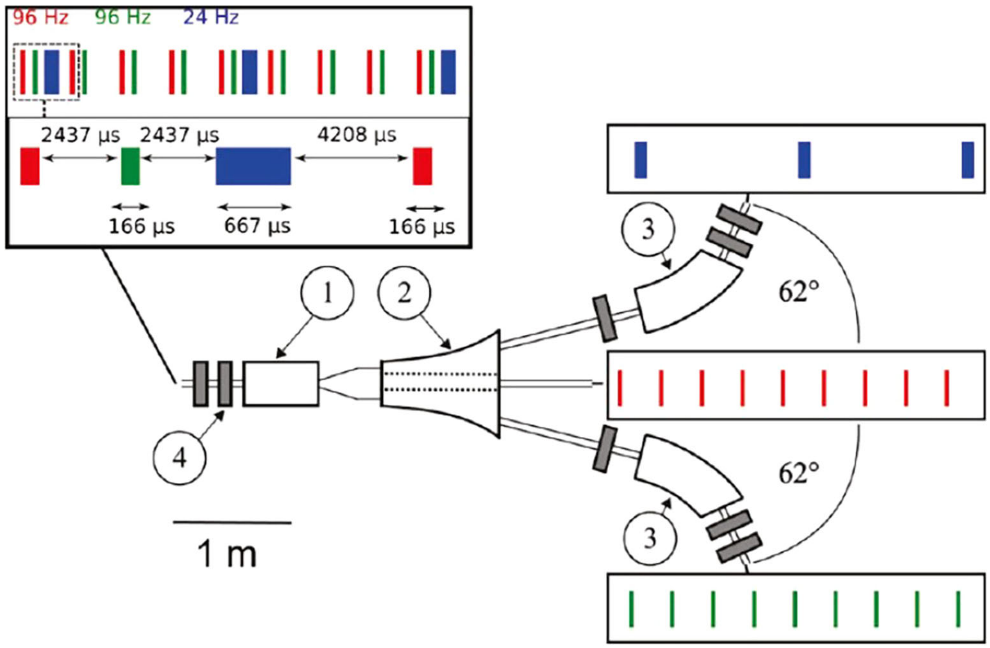


**Figure 3. Schematic outline for the design of the HBS multiplexer system.**[14] 1: Bipolar kicker magnet, 2: Septum magnet with three different field regions, 3: 45° sector bending magnets, 4: Quadrupole magnets (all in grey). After the multiplexer The proton pulses are split into three beam trails with a tilt of ±62°. The timing scheme of the pulse sequence is shown: red and green with two 96 Hz pulses of 167 µs length, blue with one 24 Hz pulse of 667 µs length.[9] Adapted with kind permission by Forschungszentrum Jülich GmbH.

The dynamics of the ion beam in the setup defines the deflection angle from the particle orbit. Using a combination of a kicker magnet and septum magnets a 20 mrad kicking angle is introduced with a fast kicker magnet onto the beam's trajectory. Afterwards a 125 mT DC magnet takes over at a well-defined separation distance of the beam from the straight directory to deflect further the beam towards the target.

Behind the multiplexer each individual proton beam has a specific time structure to offer an optimum resolution of the various instruments assembled around the specific target station (Figure 3). The experimental requirements define the lengths of the macro pulses which have been fixed at 167 µs (96 Hz) and 667 µs (24 Hz). The proton beam is guided towards the target stations from the bottom which allows maximum space for the arrangement of beamlines horizontally.

## Neutron target and moderators

A HiCANS neutron target station must deliver neutron beams tailored to the required spectrum in energy and time for the neutron instruments. The HBS target consists of a fixed single structure made of tantalum.[16] The target has a thickness of 21 mm, width of 112 mm and length of 120 mm and the area irradiated is $100 \times 100$ mm$^2$ (Figure 4). To cool efficiently the thermal power of 100 kW power provided by the proton beam into the small target volume, a micro channel cooling[17]

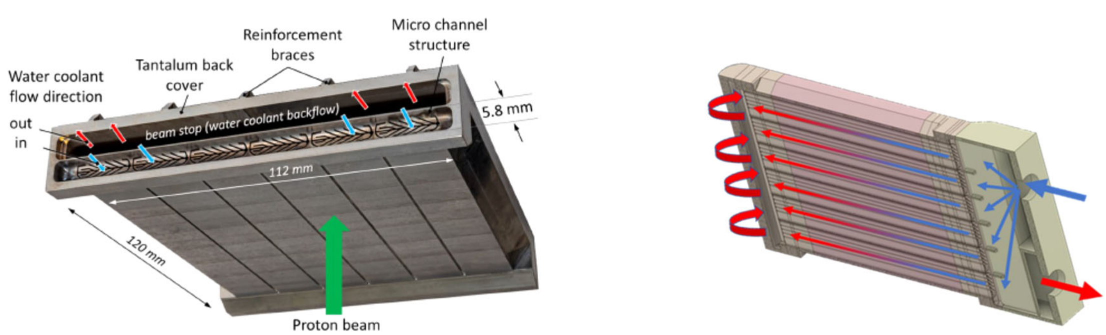


**Figure 4. HBS target made of tantalum with micro-channel cooling structure embedded and water beam stop (left).** Direction of cooling water flow (right).[20] Adapted with kind permission by Forschungszentrum Jülich GmbH.

structure has been designed with water as coolant. The width of the channels is 0.35 mm only in the layer where the neutrons are produced which allows to remove sufficient heat of more as 1 kW/cm$^2$. The total thickness of the neutron producing layer including the cooling structure is 5.8 mm. This results in the production of neutrons in a volume less than 100 ml which minimizes the amount of material activated and maximizes the neutron brightness. A water coolant backflow behind the target serves as proton beam stop.

To exchange the target is possible by standard operation during regular maintenance periods. The neutron source strength at an individual target station reaches $\backsim 10^{15}$ n/s time averaged. The irradiation with protons and the high neutron and gamma radiation level within the target station will lead to irradiation-induced damages of the solid target. The life-time of the tantalum target has been estimated to be 2.6 years[18] with the calculated high proton induced displacement per atom (DPA). Hence, the exchange of the target at HBS will happen on an annual basis, to secure a high margin of safety.

The overall design of the target station of the HBS project shows an octagonal structure. The total width is 4 m and height is 4.5 m.[16] The biological shielding consists of 4 double layers of lead and borated polyethylene. It covers a total thickness of 1.5 m and an octagonal space is left free inside with 1 m width to host the assembly of the moderator and the reflector unit as shown in Figure 5.

Different moderator-reflector assemblies can be arranged in inner space of the neutron target station. They can be tailored the varying proton pulse structure, and the space requirements of instruments placed around the target station. In Figure 5 a cut along the plane of the extraction channels of the moderator-reflector assembly[16] is shown. To thermalize the primary neutrons released in the target a light water moderator is embedded which feeds additional cold moderators along the extraction ducts.[19] Around the thermal moderator a lead reflector is placed to scatter back unmoderated neutrons into the thermal moderator. The lead reflector acts also as a first layer of shielding against gammas and fast neutrons. Inside the extraction ducts various moderators can be installed for the extraction of thermal or cold neutrons, e.g. using liquid hydrogen or methane as cryogenic moderators.

By choosing the moderator type, it is possible to shift the neutron energy spectrum from thermal temperatures at 1.3 Å for water to cold temperatures at 3 Å for liquid hydrogen or for methane.[20] Calculations with MCNP6 have estimated the peak brightness of the various moderator systems to be in the range of $10^{13}$ s$^{-1}$sr$^{-1}$Å$^{-1}$cm$^{-2}$. This is comparable to modern research reactors and sub-MW power spallation sources.[20]

The spectrum of the neutron energy is reduced below the thermal spectrum by cold moderators which moderate the neutrons at cryogenic temperatures. Reactor based- or spallation neutron sources use mostly only one single cold moderator. This cold moderator is designed accordingly to deliver a specific cold neutron spectrum, which is used by several instruments independent of their specific spectral requirements. The HBS is changing that paradigm of "one-size-

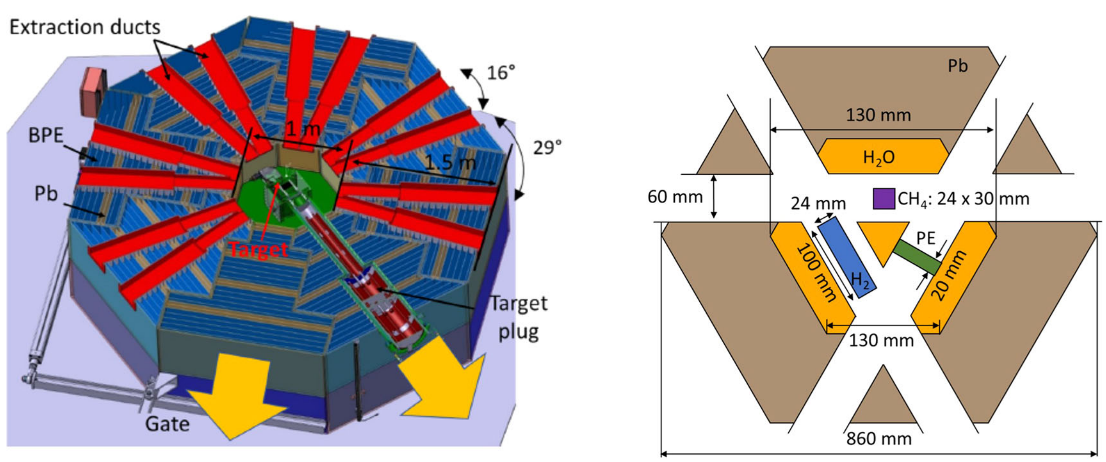


**Figure 5. Cut along the plan of extraction channels of the HBS target-moderator-reflector assembly showing the extraction ducts, shielding arrangement and target exchange plug[16] (left).** Moderator-reflector assembly inside the target station showing the thermal water moderator and the surrounding reflector of lead.[16] In the extraction channels a polyethylene (PE) moderator and two cryogenic moderators, with liquid hydrogen ($H_2$) and methane ($CH_4$) are placed (right). The target feeds the moderators with neutrons from below.[20] Reproduced from Ref. 16 under the terms of the Creative Commons Attribution License 4.0.

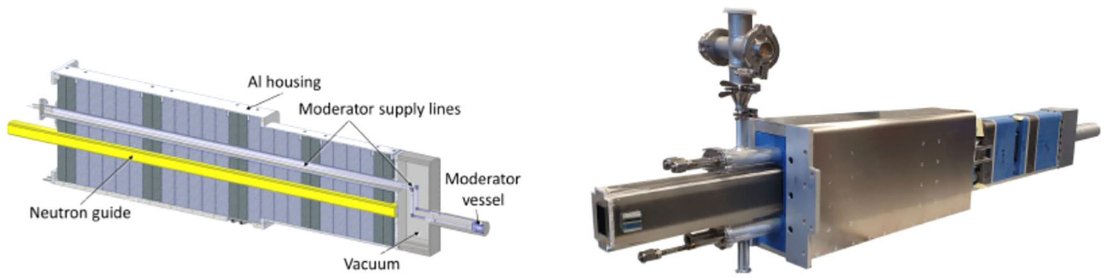


**Figure 6. Moderator plugs for a methane cryogenic moderator with included neutron guide and supply lines.** The length of the plug is 1.5 m.[20] Adapted with kind permission by Forschungszentrum Jülich GmbH.

fits-all". At HBS every instrument has its own moderator, and cold or thermal neutrons are provided from this specific neutron source. Hence, the thermal or cold moderator is a dedicated part of the neutron instrument which can be optimized within the process of the instrument design and development.

For providing a high density of cold neutrons, thermal neutrons have to interact with the moderator material at a small volume. Liquid hydrogen ($H_2$), solid methane ($CH_4$) or solid mesitylene ($C_9H_{12}$) are the materials most suitable and in particular liquid para-hydrogen is most appropriate to be used for one-dimensional cold moderator systems.

A one-dimensional cold "finger" moderator has been developed[21] and tested. The design shows a small cryogenic moderator vessel (10 cm long cylinder with 2 cm in diameter, looking like a "finger") at the end a long vacuum tube (Figure 6).[16] The cold moderator can be installed inside the thermal moderator within an extraction duct without dismantling the shielding or reflector of the target station. The cryogenic material will be placed within the maximum of the thermal flux where it can be fed optimally with thermal neutrons from the neutron source. Through the extraction channel the cold neutrons are emitted free in the direction of the instrument and views the full volume of the cylinder, where the mean free path of cold neutrons matches the length of the cylinder. By this approach future developments in cold moderator devices and materials can be adopted flexible.

## Instrumentation

The instruments to be built at HBS are designed in a time-of-flight (TOF) setup.[22] They are grouped following their technical requirements and placed at the most suitable target station (Figure 7).[23] The instrumentation foreseen at the HBS

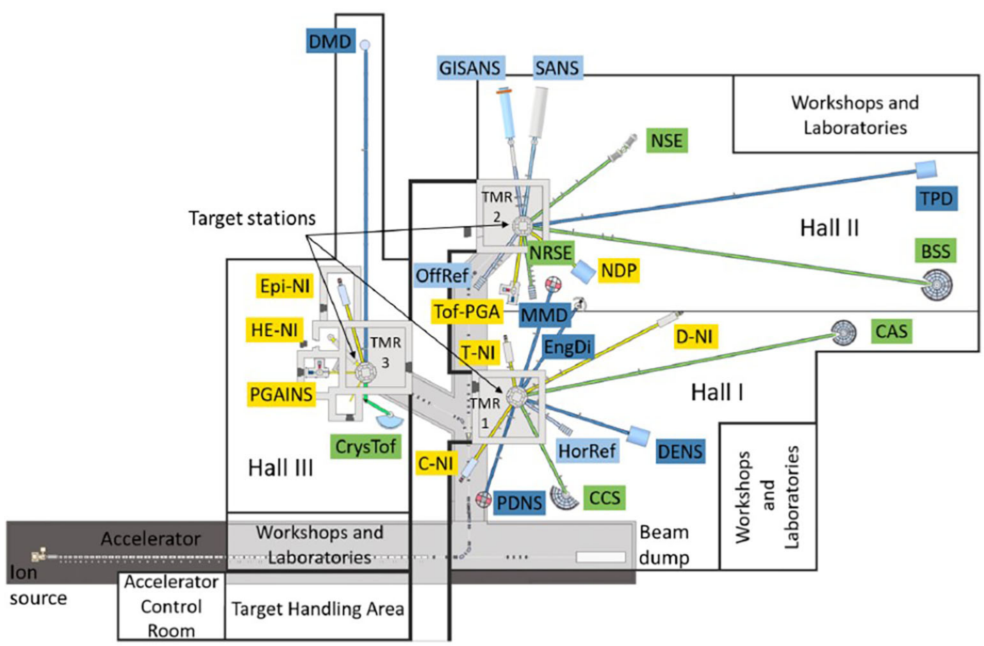


**Figure 7. HBS facility as proposed with three target stations and 24 instruments.** The acronyms of the instruments correspond to those in Table 1.[24] Adapted with kind permission by Forschungszentrum Jülich GmbH.

**Table 1. Key parameters of the instruments for HBS.**[23] Values for flux and resolution are given for typical instrument configurations. The acronyms of the instruments correspond to those in Figure 7.[24]

| | Instrument | $\tau_{pulse}$ [µs] | $L_{tot}$ [m] | Det. cov. [sr] | $\lambda_{min}$ [Å] | $\lambda_{max}$ [Å] | $\delta\lambda_{pulse}/\lambda_{min}$ [%] | $\delta\lambda_{pulse}/\lambda_{max}$ [%] | $\varphi_{aver}$ $10^6$ [n/cm$^2$s] | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| SANS | High-Throughput SANS | 667 | 23.7 | 0.01 | 3.0 | 9.8 | 3.7 | 1.1 | 0.41 | low angle |
| | | | 14.7 | 0.81 | 3.0 | 9.8 | 8.8 | 2.0 | 41 | wide angle |
| GISANS | SANS with GISANS option | 667 | 23.7 | 0.01 | 3.0 | 9.8 | 3.7 | 1.1 | 0.41 | low angle |
| | | | 14.7 | 0.08 | 3.0 | 9.8 | 5.9 | 1.8 | 41 | wide angle |
| OffRef | Offspecular Reflectom. | 667 | 13.0 | 0.08 | 2.0 | 12.0 | 10.1 | 1.7 | 48 | |
| TPD | Thermal Powder Diffractometer | 30 | 80.0 | 5.71 | 0.6 | 2.7 | 0.2 | 0.1 | 0.55 | high res., 2 frames |
| | | 667 | 80.0 | 5.71 | 0.6 | 2.7 | 5.5 | 1.2 | 160 | high int. 2 frames |
| NSE | NSE Spectrometer | 667 | 25.0 | 0.04 | 6.0 | 16.0 | 1.8 | 0.7 | 2.8 | very cold neutrons |
| NRSE | NRSE Spectrometer | 667 | 25.0 | 0.04 | 6.0 | 16.0 | 1.9 | 0.7 | 2.8 | very cold neutrons |
| BSS | Backscattering Spec. | 60 | 85.0 | 3.66 | 5.6 | 7.6 | 0.06 | 0.04 | 7 | |
| Tof-PGA | Tof-PGNAA | 667 | 12.4 | | 0.03 | 9.0 | | | 130 | |
| NDP | Neutron Depth Profiling | 667 | 8.2 | | 0.0 | 20.0 | | | 210 | white beam |
| HorRef | Horizontal Reflectom. | 252 | 11.0 | 0.01 | 5.0 | 8.6 | 1.8 | 1.1 | 7 | small sample |
| | | 252 | 11.0 | 0.01 | 1.6 | 8.8 | 5.7 | 1.0 | 10 | multi beam |
| EngDi | Engineering Diffractom. | 35 | 21.8 | 2.52 | 0.8 | 2.7 | 0.8 | 0.2 | 0.23 | 4 frames |
| DENS | Diffuse Elast. Neutr. Scatt. | 252 | 21.2 | 5.24 | 2.0 | 3.9 | 2.4 | 1.2 | 50 | |
| PDNS | Pol. Diffuse Neutr. Scatt. | 252 | 21.0 | 2.09 | 2.0 | 4.0 | 2.4 | 1.2 | 52 | |
| MMD | Single Crystal Diffractom. | 252 | 21.5 | 9.39 | 2.0 | 3.9 | 2.3 | 1.2 | 18 | 0.8° FWHM div. |
| CCS | Cold Chopper Spec. | 252 | 24.0 | 2.07 | 1.6 | 10.0 | 2.6 | 0.4 | 0.34 | |
| CAS | Crystal Analyzer Spec. | 252 | 60.0 | 0.85 | 1.8 | 6.0 | 0.9 | 0.3 | 200 | |
| C-NI | Cold Neutr. Imaging | 252 | 15.0 | | 1.0 | 15.0 | 6.6 | 0.4 | 0.3 | high res. |
| | | | 5.0 | | 1.0 | 15.0 | 20 | 1.3 | 3 | high int. |
| T-NI | Thermal Neutr. Imaging | 252 | 10.0 | | 0.5 | 4.5 | 20 | 2.2 | 0.35 | high res. |
| | | | 4.0 | | 0.5 | 4.5 | 50 | 5.5 | 10 | high int. |
| D-NI | Diffractive Neutr. Imaging | 252 | 30.0 | | 1.0 | 15.0 | 3.3 | 0.2 | 2 | |

**Table 1.** *Continued*

| | Instrument | $\tau_{pulse}$ [μs] | $L_{tot}$ [m] | Det. cov. [sr] | $\lambda_{min}$ [Å] | $\lambda_{max}$ [Å] | $\delta\lambda_{pulse}/\lambda_{min}$ [%] | $\delta\lambda_{pulse}/\lambda_{max}$ [%] | $\varphi_{aver}$ $10^6$ [n/cm$^2$s] | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| DMD | Disorder. Materials Diffr. | 167 | 85.0 | 6.42 | 0.1 | 0.58 | 7.8 | 1.3 | | |
| PGAINS | PGAINS | 167 | 8.6 | | 0.0 | 0.37 | | | 16 | |
| Epi-NI | Epitherm. Neutr. Imaging | 2 | 35.0 | | 0.01 | 0.29 | 2.5 | 0.1 | 0.2 | |
| HE-NI | Hi-Energy Neutr. Imaging | 167 | 10.0 | | 0.0 | 0.01 | | | 80 | |
| CrysTof | CRYSTOF | 252 | 9.5 | 2.34 | 0.83 | 2.86 | 12.6 | 3.7 | 0.2 | |

represents the full spectrum of neutron beam applications with an emphasis on applications relevant for industrial research (indicated in yellow in Table 1[24]) such as imaging instruments enabling device inspection thanks to the unique penetration power of neutrons or Prompt Gamma Activation instruments, providing ultimate isotope sensitivity also in large and complex specimen. Instruments studying large scale structure (shown in light blue in Table 1) profit from the high cold neutron brightness and the well adapted time structure of the HiCANS requesting only a simple chopper system to collect data.[23] The suite of diffractometers (presented in dark blue) provides atomic spatial resolution typically with a chopper system to achieve the required wavelength resolution. The access to the full dynamical range relevant to study the dynamics of atoms and spins in condensed matter from the sub Å to several 100 nm length scale and from ps to µs time scale is a unique feature of neutron scattering, that will be addressed by the spectrometers (presented in the green rows). These instruments require the dedicated time structure and spectral distributions that are provided at the individual target stations. Table 1 provides the information about the expected performance of the instrument confirming the competitiveness of the instrumentation to existing neutron facilities.[24]

## Conclusions

The High Brilliance neutron Source (HBS) project represents a novel and innovative concept for a high current accelerator driven neutron source. Such projects can fill the gap currently existing between low power (<1 kW) accelerator-based neutron sources, and the large national and international flagship neutron facilities. Within the last few years, the project has evolved from conceptual studies based on nuclear simulations to a detailed technical design, addressing and providing solutions for the key challenges of such a facility. Furthermore, experiments have been performed at the JULIC neutron platform providing the proof-of-principle for the central installations, such as the Ta target, the low dimensional cryogenic moderators or the beam multiplexer including the interplay of all those components.[25]

The HBS project is working to develop, demonstrate and finally to realize a cost-efficient and innovative high current accelerator driven neutron source. A Conceptual Design Report was written and has been published where a description was given and an overview of the project with all relevant components. As the HBS project involves many different technological challenges - accelerator system, neutron targets, moderators, instruments - each individual component has to be investigated and optimized in a holistic concept. The result of this is described in the recently published Technical Design Report of HBS.[9,20,24] It is planned to develop and construct a prototype facility based on the design presented in order to prove the feasibility and to show the realization of a full-fledged facility. This will secure a sustainable access in Germany to neutrons and beyond within the upcoming decades.

The research with neutrons will be placed on a new broad basis by HBS.[4] Neutron science will open up and will include better industry in all areas. It will enhance competitiveness with easy access to neutron facilities in basic as well as in applied research. HBS will complement and develop further the landscape of high-end neutron facilities in Europe.[6] In addition, HBS will allow intense training and preparation for experiments at the highest level at flagship European neutron sources such as the ILL or, in the future, at the ESS.

## Ethics and consent statement

Ethical approval and consent were not required.

## Data availability statement

No data are associated with this article.

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**Publisher Full Text**

5. ELENA: European Low Energy accelerator-based Neutron facilities Association.
**Reference Source**

6. LENS: League of advanced European Neutron Sources, Neutron Science in Europe.
**Reference Source**

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# Open Peer Review

## Current Peer Review Status: ✔ ✔ ? ✔

Version 1

Reviewer Report 28 March 2025

https://doi.org/10.21956/nuclscitechnolopenres.18888.r28010



✔ **Arun Persaud**
Lawrence Berkeley National Laboratory, Berkeley, USA

The paper describes details of a concept for a high current accelerator-driven neutron source. The authors describe the beam requirements and outline the beam parameters needed for the experiments, e.g., max current, energy, pulse structure. They describe the envisioned accelerator setup to be able to achieve the required energy and how multiplexing will be used to feed three target stations. The authors then describe the neutron production target and how multiple neutron end stations will be fed by each neutron production target and how different moderators can be applied to different end stations enabling custom energy profiles for each final instrument.

I approve of the indexing and would like to thank the authors for their excellent work, which made the review process straightforward and enjoyable.

**However, I would suggest some small, optional edits in the text:**

a)"The HBS accelerator must provide a proton beam of 100 mA current" -> the authors could specify if they mean average or peak current here

b)"To exchange the target is possible by standard operation during regular maintenance periods" -> I would suggest: "Targets can be exchanged during regular maintenance periods as part of standard operation."

c)"Reactor based- or spallation neutron sources use mostly only one single cold moderator."->I would suggest: "Most reactor-based or spallation neutron sources use only one single cold moderator"

d)"This cold moderator is designed accordingly to deliver a specific cold neutron spectrum, which is used by several instruments independent of their specific spectral requirements."
->I would suggest: "This cold moderator is designed for one specific cold neutron spectrum, which then has to be used by several instruments independent of their specific spectral requirements."

e)"at the end a long vacuum tube (Figure 6)."->perhaps: "at the end of a long vacuum tube (Figure 6)."

f)"Through the extraction channel the cold neutrons are emitted free in the direction of the instrument and views the full volume of the cylinder, where the mean free path of cold neutrons matches the length of the cylinder. By this approach future developments in cold moderator devices and materials can be adopted flexible."
-> I suggest:
"Through the extraction channel the cold neutrons are then emitted in the direction of the instrument and occupy the full volume of the cylinder, where the mean free path of cold neutrons matches the length of the cylinder. Using this approach future developments in cold moderator devices and materials can be easily adopted."

g)"(indicated in yellow in Table 1)", "shown in light blue in Table 1) " --> I assume the authors mean Fig 7 here? The table doesn't show any color.

h)"scattering, that will " -> no comma, e.g. "scattering that will "

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes

**Is the study design appropriate and does the work have academic merit?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Not applicable

**Are all the source data underlying the results available to ensure full reproducibility?**
No source data required

**Are the conclusions drawn adequately supported by the results?**
Yes

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** My background is in ion sources, particle accelerators, neutron generators and their application.

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Reviewer Report 24 March 2025

https://doi.org/10.21956/nuclscitechnolopenres.18888.r28008



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**Liang Lu**
Sun Yat-sen University, Guangdong, China

This manuscript presents an overview of the High Brilliance neutron Source (HBS) project, which aims to develop a high current accelerator-driven neutron source. The project has progressed from conceptual studies to a detailed technical design, and this paper covers various aspects from accelerator design to potential instrument configurations.

**Academic Merit and Novelty:**

The HBS project represents an innovative approach within the field of neutron sources. The idea of moving away from the traditional "one-size-fits-all" moderator concept to a more tailored approach for different instruments is scientifically sound and offers flexibility in constructing scalable neutron sources. However, the current manuscript is more descriptive and reads like a project report rather than a deeply analytical academic paper. It provides a comprehensive overview but lacks in-depth academic discussion or comparison with existing neutron sources beyond stating that HBS fills a gap between low-power and flagship facilities.

**Technical Details and Clarity:**

The technical details are well-presented, though some sections could benefit from additional data. For instance, while the target and moderator sections are described in good detail, including figures of the target design and moderator assembly, there is no presentation of neutron spectra before and after moderation. Including such data would strengthen the technical validation of the moderator designs. The figures, while informative, could be improved in terms of contrast and clarity, particularly Figures 2 and 5, which are somewhat difficult to interpret in their current form.

**Language and Grammar:**

The language is generally clear, but there are several grammatical errors and awkward phrasings that should be corrected. For example:

"Research with neutrons is usually related to the use of fission-based research reactors or neutron spallation sources to offer neutron beams for science and industry." This sentence is grammatically incorrect and should be rephrased to something like "Research with neutrons usually relies on fission-based research reactors or neutron spallation sources to provide neutron beams for scientific and industrial applications."

"The HBS project will offer open access and services to the various and changing demands the scientific and also the industrial community asks for." This sentence is awkward and could be revised to "The HBS project will provide open access and cater to the various and evolving demands of the scientific and industrial communities."

**Suggestions for Improvement:**

1. To enhance the academic rigor of the paper, include more comparative analysis with existing neutron sources, particularly in terms of performance metrics, cost-effectiveness, and scientific impact.

2. Add figures or tables showing the neutron spectra before and after moderation for different moderator types. This would provide concrete evidence of the effectiveness of the moderator designs.

Overall, the manuscript provides a valuable overview of the HBS project and its potential contributions to neutron science. With some revisions to improve academic depth, technical validation, it would be well-suited for indexing in academic databases.

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes

**Is the study design appropriate and does the work have academic merit?**
Partly

**Are sufficient details of methods and analysis provided to allow replication by others?**
No

**If applicable, is the statistical analysis and its interpretation appropriate?**
Not applicable

**Are all the source data underlying the results available to ensure full reproducibility?**
Yes

**Are the conclusions drawn adequately supported by the results?**
Yes

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** Accelerator physics and its applications

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

Reviewer Report 17 March 2025

https://doi.org/10.21956/nuclscitechnolopenres.18888.r28014

**Dong Won Lee**
Korea Atomic Energy Research Institute (KAERI), Daejeon, South Korea

It is considered to be a well-organized paper that can be indexed without any problems. However, it seems necessary to correct some errors, such as the ones below, before indexing.

1) in The concept of the HBS facility, The High Brilliance neutron Source (HBS) represents ~: the abbreviation is already shown, so HBS is enough here.

2) in Neutron target and moderators, author explained the target to be affected by protons, high neutron, and gamma radiation, but the life-time of the tantalum target has been estimated considering only high proton induced displacement per atom (DPA).

3) in Conclusions, The High Brilliance neutron Source (HBS) project represents ~: the abbreviation is already shown, so HBS is enough here.

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes

**Is the study design appropriate and does the work have academic merit?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Yes

**Are all the source data underlying the results available to ensure full reproducibility?**
Yes

**Are the conclusions drawn adequately supported by the results?**
Yes

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** Fusion/Nuclear engineering, neutron source development and application

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Author Response 21 Mar 2025

**Thomas Gutberlet**

We greatfully acknowledge the comments and suggestions by the reviewer which helped us to correct and clearify a few statements

***Competing Interests:*** No competing interests were disclosed.

Reviewer Report 14 March 2025

https://doi.org/10.21956/nuclscitechnolopenres.18888.r28009



**Goran Skoro**
Science and Technology Facilities Council, Rutherford Appleton Laboratory, Oxon, UK

This manuscript explores one of the possible concepts of the high current accelerator-driven neutron source (HICANS), so-called High Brilliance neutron Source (HBS). The HBS project is underway for a number of years already at Forschungszentrum Jülich and it has reached the stage where detailed Technical Design Report has been published. In this paper the overview of the project specifications, covering main ideas from the accelerator design to the potential instruments configurations and expected neutron brightness/flux values, has been presented.

The study described in this paper is of great interest, especially in the light of current developments in the field. The idea to change the standard concept of "one-size-moderator-to-fits-all-instruments" and design a moderator that will serve a few instruments only while the different moderators (some of them at different "target stations") will serve the instruments with different neutron spectrum requirements, is scientifically sound and definitely innovative. This offers then the possibility to construct flexible and scalable (sets of) neutron sources at a user facility.

**As noted above, this manuscript is an overview of the huge project but it is very comprehensive so it should be accepted for indexing after a few minor revisions (and clarifications) listed below:**

(1) First sentence in Introduction should read "Research with neutrons is usually related to fission in research reactors or to spallation in accelerator-based neutron sources as the basic nuclear reactions to create free neutrons from the nucleus of the atom".

(2) Figure 2 should be improved (if possible) - the contrast and visibility of the current version is not good enough.

(3) Figure 5 (on the right-hand side) should be checked. It seems, for example, that two different lengths/dimensions are denoted with the same (130 mm) value.

(4) Instrumentations section: Different group of instruments are "color-coded" in Figure 7 not in Table 1 (as noted in the corresponding paragraph).

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes

**Is the study design appropriate and does the work have academic merit?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Not applicable

**Are all the source data underlying the results available to ensure full reproducibility?**
No source data required

**Are the conclusions drawn adequately supported by the results?**
Yes

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** The design of the neutronics models of accelerator-driven neutron sources; applied nuclear physics, applied material physics (material properties under extreme conditions), particle physics, etc...

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Author Response 21 Mar 2025

**Thomas Gutberlet**

We greatfully acknowledge the commnets and suggestions by the reviewer which helped us to correct an error in one figure and clearify a few statements made.

***Competing Interests:*** No competing interests were disclosed.