WR
WISSENSCHAFTSRAT

Drs. 5365/02
Berlin, July 12, 2002

High Magnetic Field Facility for Neutron Scattering Research

<u>Note:</u>

This statement given by a subgroup of the steering committee „Large research facilities for basic research“ of the German Science Council concentrates on the scientific and technical investigation of the project. The statement if the project should be funded or not is given by the Science Council itself by a final evaluation of all nine projects. This statement is given in a seperate report.

A. Introduction and Background

A.I Field of Research

The proposed High Magnetic Field Facility will use very high static (DC) magnetic fields for neutron scattering research and thus combines for the first time two conventional research techniques.

I.1 Neutron Scattering

Over the last fifty years neutron scattering has been a valuable tool in solid state physics for probing the microscopic structure and processes in complex matter. Neutrons have both comparable wavelength and frequency to the relevant microscopic-mesoscopic time and length scales characterizing structure and dynamics in condensed matter. In addition, due to its magnetic moment, the neutron interacts with the atomic magnetic moments as strongly as with the nuclei. Neutron scattering has decisively contributed to our knowledge of most magnetic phenomena from the experimental discovery of antiferromagnetism in the early 1950s to the first observation of spin fluctuations in high T_c superconductors most recently.

Different experimental techniques for studying the static and dynamic properties of microscopic structures have been developed. Among these techniques X-ray, nuclear magnetic resonance (NMR) and particle-based spectroscopy (Mössbauer spectroscopy, muon spin rotation spectroscopy, positron annihilation spectroscopy, etc.) are the most important ones. However, one cannot consider them as alternative technologies to neutron scattering but rather as complementary sources of information due to partial overlap in the time scale of experiments and different sensitivity to various properties.

A main area of research in which neutron scattering will continue to play a crucial role is solid state physics including studies of strongly correlated and heavy electron systems, magnetic materials, spin liquids, colossal magnetoresistance materials, low-dimensional systems, multi-layer, granular or other artificial materials. For these materials neutrons are the privileged probe due to their ability to sense both structural and magnetic aspects of the material. Also, studies of soft-matter materials (polymers, membranes, liquid crystals, colloids, emulsions and molecular complexes) are important fields of research as well as biology and biotechnology because neutrons are able to locate the positions of light elements in the presence of heavy ones - a task that is difficult to fulfill with X-rays. In addition, neutron scattering is an important research tool for studies of liquids, amorphous and glass-related materials, environmental studies, time resolved studies of chemical reactions and fundamental particle physics.

Europe and especially Germany is at the frontier of international neutron related research.[1] Germany participates in running the world's most powerful neutron source, the ILL in Grenoble and is also strongly involved in the next generation neutron source project of an European Spallation Source (ESS). However, despite of envisaged new projects the total number of neutron sources in Europe will decrease by about one third within the next 15 years due to aging of the reactor sources.[2] Particularly, many medium-size reactor sources will be shut down. Among German sources the research reactor BER II at the Hahn-Meitner-Institute (HMI), refurbished in 1992, will have, however, a secure future for another 20 years of operation.

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[1] See Komitee für die Forschung mit Neutronen: Forschung mit Neutronen in Deutschland – eine Strategie für die nächsten 15 Jahre. 1996-1999; ESF/OECD: A Twenty Years Forward Look at Neutron Scattering Facilities in the OECD Countries and Russia. 1998; ESF/ENSA: Survey of the Neutron Scattering Community and Facilities in Europe. 1998.

[2] See Proceedings of the ESF-SAC/ENSA workshop: Scientific Trends in Condensed Matter Research and Instrumentation Opportunities at ESS. Engelberg, Switzerland, 3.-5. May 2001; ESS Council: ESS – A next Generation Neutron Source for Europe. Vol. II: The Scientific Case. 1997; ESF: Scientific Prospects for Neutron Scattering with Present and Future Sources. Report from the workshop in Autrans, France, 11.-13. January 1996.

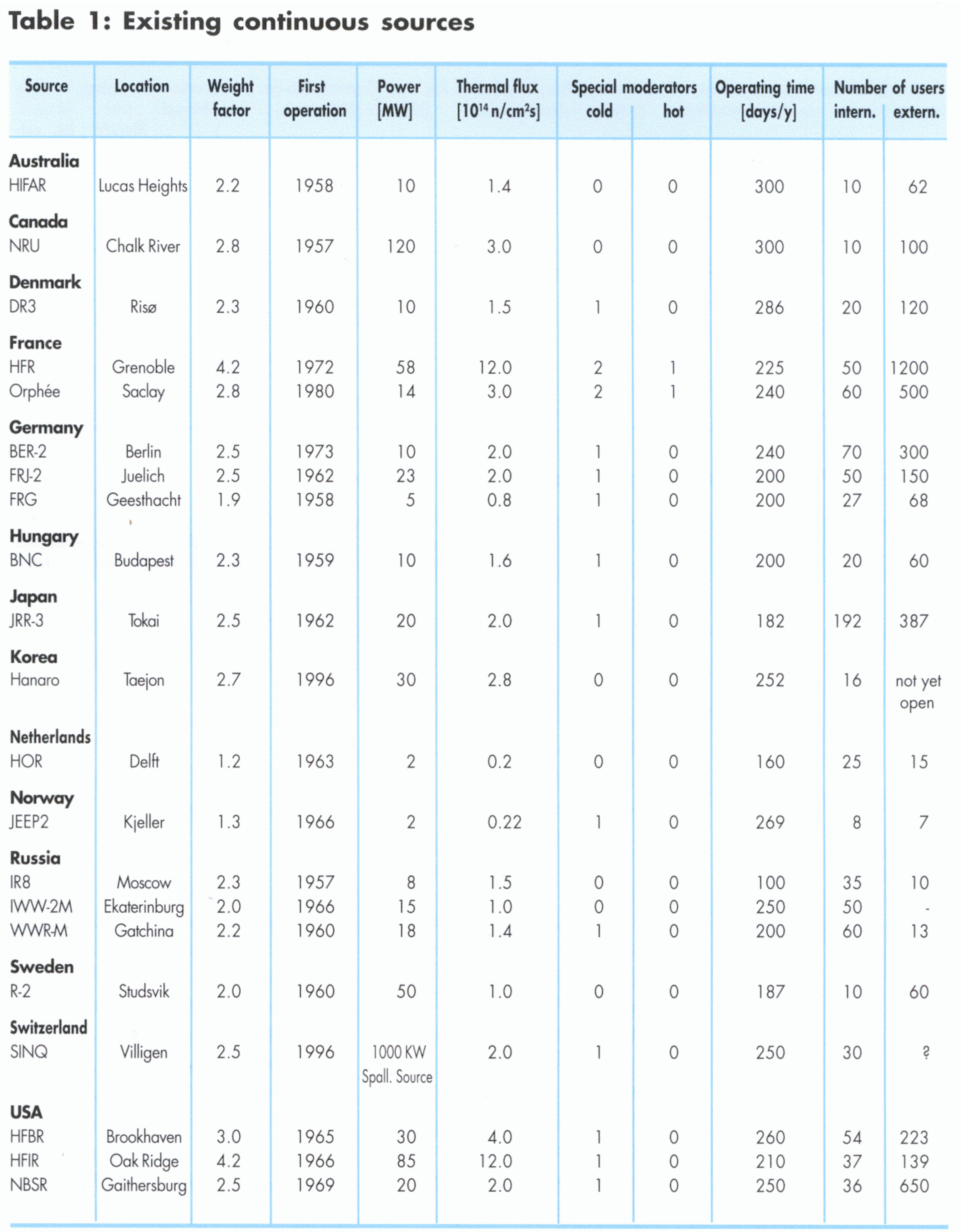

Table 1: Existing continuous sources

Source	Location	Weight factor	First operation	Power [MW]	Thermal flux [10^{14} n/cm²s]	Special moderators		Operating time [days/y]	Number of users	
						cold	hot		intern.	extern.
Australia										
HIFAR	Lucas Heights	2.2	1958	10	1.4	0	0	300	10	62
Canada										
NRU	Chalk River	2.8	1957	120	3.0	0	0	300	10	100
Denmark										
DR3	Risø	2.3	1960	10	1.5	1	0	286	20	120
France										
HFR	Grenoble	4.2	1972	58	12.0	2	1	225	50	1200
Orphée	Saclay	2.8	1980	14	3.0	2	1	240	60	500
Germany										
BER-2	Berlin	2.5	1973	10	2.0	1	0	240	70	300
FRJ-2	Juelich	2.5	1962	23	2.0	1	0	200	50	150
FRG	Geesthacht	1.9	1958	5	0.8	1	0	200	27	68
Hungary										
BNC	Budapest	2.3	1959	10	1.6	1	0	200	20	60
Japan										
JRR-3	Tokai	2.5	1962	20	2.0	1	0	182	192	387
Korea										
Hanaro	Taejon	2.7	1996	30	2.8	0	0	252	16	not yet open
Netherlands										
HOR	Delft	1.2	1963	2	0.2	0	0	160	25	15
Norway										
JEEP2	Kjeller	1.3	1966	2	0.22	1	0	269	8	7
Russia										
IR8	Moscow	2.3	1957	8	1.5	0	0	100	35	10
IWW-2M	Ekaterinburg	2.0	1966	15	1.0	0	0	250	50	-
WWR-M	Gatchina	2.2	1960	18	1.4	1	0	200	60	13
Sweden										
R-2	Studsvik	2.0	1960	50	1.0	0	0	187	10	60
Switzerland										
SINQ	Villigen	2.5	1996	1000 KW Spall. Source	2.0	1	0	250	30	?
USA										
HFBR	Brookhaven	3.0	1965	30	4.0	1	0	260	54	223
HFIR	Oak Ridge	4.2	1966	85	12.0	1	0	210	37	139
NBSR	Gaithersburg	2.5	1969	20	2.0	1	0	250	36	650

Table 2: Existing pulsed sources

Source	Location	Weight factor	First operation	Beam power [KW]	Pulse length [µs] (Proton pulse)	Rep. rate [Hz]	Thermal peak flux [10^{14} n/cm²s]	Moderators		Operating time [days/y]	Number of users	
								cold	thermal		int.	ext.
Japan												
KENS/KEK	Tsukuba	1.3	1980	3	0.1	20	3	1	1	80	14	400
Russia												
IBR2	Dubna	2.9	1984	2000 fission	305 (therma n)	5	100	1	3	104	50	150
UK												
ISIS	Abingdon	3.4	1985	160	0.4	50	20-100	2	2	168	30	1200
USA												
LANSCE	Los Alamos	3.0	1985	56	0.27	20	34	1	3	100	21	41
IPNS	Argonne	1.5	1981	7	0.1	30	5	3	0	175	58	143

Table 3: Planned research reactors and upgrades

Project	Location	Weight factor	Status	Decision date	Anticipated starting date	Power [MW]	Thermal flux [10^{14}n/cm²s]	Special moderators	
								cold	hot
Australia									
HIFAR1	Lucas Heights	2.8	Preproject	1998	unknown	13- 20	3	1	1
Canada									
IRF	?	2.8	Preproject	1998	2006	40	3	1	–
Germany									
FRM II	München	3.6	under constr.	-	2001	20	7	1	1
Russia									
PIK	St. Petersburg	4.2	under constr.	-	2000	100	12	1	1
USA									
HFBR (upgrade)	Brookhaven	3.7	Preproject	1998 or later	2005	60	8	1	0
HFIR (upgrade I)	Oak Ridge	4.2	under constr.	-	2000	100	12	1	0
HFIR (upgrade II)	Oak Ridge	4.2	Calcul.	1998	2001	100	12	1	0

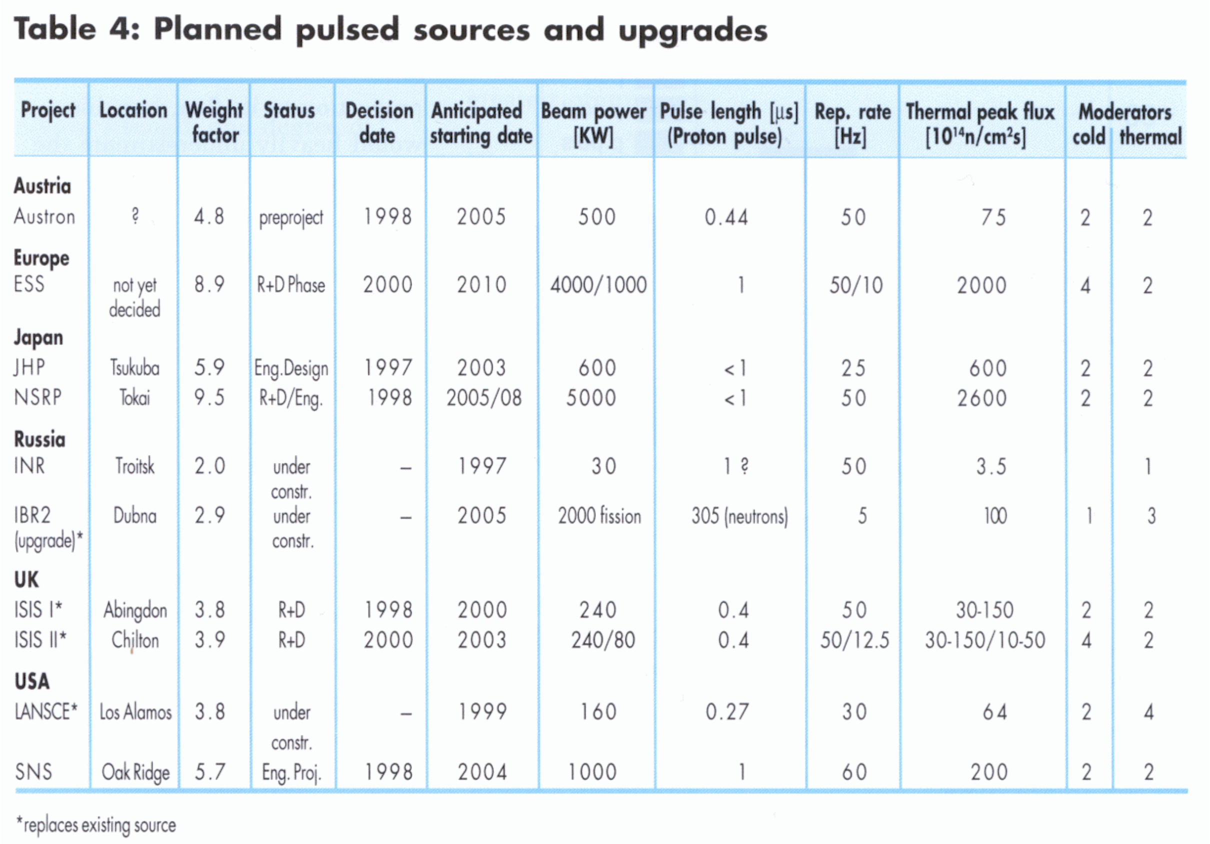

Table 4: Planned pulsed sources and upgrades

Project	Location	Weight factor	Status	Decision date	Anticipated starting date	Beam power [KW]	Pulse length [µs] (Proton pulse)	Rep. rate [Hz]	Thermal peak flux [10^{14}n/cm^{2}s]	Moderators cold	thermal
Austria											
Austron	?	4.8	preproject	1998	2005	500	0.44	50	75	2	2
Europe											
ESS	not yet decided	8.9	R+D Phase	2000	2010	4000/1000	1	50/10	2000	4	2
Japan											
JHP	Tsukuba	5.9	Eng.Design	1997	2003	600	< 1	25	600	2	2
NSRP	Tokai	9.5	R+D/Eng.	1998	2005/08	5000	< 1	50	2600	2	2
Russia											
INR	Troitsk	2.0	under constr.	–	1997	30	1 ?	50	3.5		1
IBR2 (upgrade)*	Dubna	2.9	under constr.	–	2005	2000 fission	305 (neutrons)	5	100	1	3
UK											
ISIS I*	Abingdon	3.8	R+D	1998	2000	240	0.4	50	30-150	2	2
ISIS II*	Chilton	3.9	R+D	2000	2003	240/80	0.4	50/12.5	30-150/10-50	4	2
USA											
LANSCE*	Los Alamos	3.8	under constr.	–	1999	160	0.27	30	64	2	4
SNS	Oak Ridge	5.7	Eng. Proj.	1998	2004	1000	1	60	200	2	2

*replaces existing source

I.2 High Magnetic Fields

Magnetic fields up to 15 to 20 Tesla can be produced by superconducting magnets and such equipment is common in many laboratories not specialized in high magnetic fields. In specialized high magnetic field laboratories fields up to 2800 Tesla can be achieved by essentially three different approaches:

a) The highest fields can be produced in "short" pulses of a few µs duration. Without destroying the sample, about 100 Tesla can be achieved.

b) In 3-100 ms "long" pulses fields in the 50 – 80 Tesla range have been achieved by now.

c) Continuous fields up to 45 Tesla are being produced to date by a combination of resistive and superconducting magnets.

Technical experimental complexity decreases, while the costs of the facility increases for all three approaches. The longer the high field can be made available, the larger is the number of types of experiments that can be performed and the variety of samples. For example, pulsed fields are not adequate for the study of most metallic samples and samples with hysteretic behaviour etc. Experimental probes such as Electron Spin Resonance or neutron scattering also require continuous fields for best efficiency.

For further information see the equivalent chapter on the High Field Laboratory Dresden (HLD) Project.

I.3 Combination of Neutron Scattering and High Magnetic Fields

In exploring matter in the fundamental thermodynamic parameter space including high magnetic fields, neutron scattering is, according to the proponents, more suited than any other research technique because of the neutron's sensitivity to light elements as well as its magnetic properties that make it the most pertinent microscopic probe of magnetism.

Up to now there are only two places in the world where a combination of a neutron scattering facility and a high magnetic field laboratory has actually been realized. At the pulsed spallation source KENS/KEK (Tsukuba, Japan) a repetitively pulsed magnet is operated to generate pulsed fields up to 26 Tesla. At LANSCE (Los Alamos, USA) a project to build a 30 Tesla pulsed magnet is in the exploratory design phase since several years. However, pulsed magnetic fields in combination with neutron scattering are, according to the applicants, much less favorable than DC fields. They expect that the pulsed high field magnets for neutron scattering research under development, which have partially been tested in Japan and are in the design phase at Tallahassee, would at best achieve a 30 Tesla field and would only provide a duty factor of less than 1 % for the use of the neutron flux. Since neutron intensity is a fundamental factor in neutron scattering research this low utilization efficiency of the available flux is judged to be a decisive disadvantage of the pulsed magnetic field approach compared to the continuous field approach of the proposed High Magnetic

Field for Neutron Scattering project. Thus, the applicants conclude that pulsed fields only enable a small fraction of experiments that are feasible with a continuous field.

Concerning the primary goal of the proposed facility, neutron scattering at very high DC magnetic fields, there is no similar project in preparation.

On the other hand, there is an overlap in the conventional, non-neutron scattering use of the proposed power and the work at other high magnetic field laboratories outside Germany. The 40 MW power to be installed in order to combine high fields and neutron scattering is about twice as high as what is available at the two European facilities, which provide continuous high magnetic fields (HMFL, Grenoble; HMFL, Nijmegen) and equal to the power installed at NHMFL Tallahassee (USA), which is the highest in the world (see table in the equivalent chapter on the HLD project). Thus the proposed facility will also open up the possibility for Europe to catch up the USA lead in this field.

A.II The Proposed Facility

II.1 Scientific Objectives and Research Prospects

The proposed facility is planned to be established at the Berlin Neutron Scattering Center (BENSC) which is part of HMI. It combines state-of-the-art neutron scattering capabilities and state-of-the-art continuous high magnetic fields, using a new approach conceived at the HMI. Instead of mounting mobile superconducting magnets on neutron scattering instruments, the neutron scattering experiments will be built up around large, rigidly installed normal conducting magnets driven by DC currents of up to 80.000 A at a conveniently large distance from the neutron source. Two magnets are planned: a tapered horizontal field solenoid for up to 40 Tesla and a split pair vertical field magnet up to 30 Tesla. It is proposed to install a state-of-the-art 40 MW highly stabilized power supply and a corresponding water cooling system next to the neutron scattering research reactor BER II at HMI. Versatile neutron scattering capacities will be build up for thermal and cold, elastic and inelastic neutron scattering work in continuous magnetic fields up to 35-40 Tesla which is more than twice as high as the highest magnetic fields available today for this purpose.

The proposed facility will enable for the first time neutron scattering exploration in the vast thermodynamic variable range of 17 to 40 Tesla continuous magnetic fields - compared to 17 Tesla DC magnetic fields presently available at HMI (12 Tesla at other centers) - and pulsed fields up to 25 Tesla. Important discoveries are expected in many fields of condensed matter research, including magnetism, superconductivity, new materials, soft and biological matter.

II.1.1 Research Program

In May 2001 and January 2002 the HMI held international workshops on scientific prospects of the envisaged facility. The participants concluded that the project goal to provide 30 to 40 Tesla magnetic fields for neutron scattering experiments is of great scientific importance and potential.[3] According to the proponents the proposed High Magnetic Field Laboratory for Neutron Scattering will enable exploration of structures on the atomic level and its dynamics in all kinds of matter. Many magnetic phenomena, for example those related to high temperature superconductivity, are not accessible at lower magnetic fields. In other cases, such as inducing order in paramagnetic and diamagnetic materials, very high fields are required to produce signals above noise level. Thus, the new facility is expected to open up the opportunity to reveal the underlying neutron scattering information and to study all kinds of magnetic and magnetic field induced phenomena in an extremely wide variety of matter relevant for solid state physics (quantum solids, heavy fermion systems, molecular conductors), chemistry, environmental research, material sciences, engineering, geology, archaeology and the life sciences. The application of high magnetic fields in neutron scattering allows, for instance, to grow much larger

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[3] See HMI: The Present Status of High Magnetic Field Technology and the Prospects for Applications to Neutron Scattering Experiments, Berlin 2001; Research Opportunities in Condensed Matter and Life Sciences at High Magnetic Fields, Berlin 2002.

protein crystals of higher quality and to study in-situ the growth process, which in turn stimulates advances in soft condensed matter research and life sciences.

Neutron scattering experiments at very high magnetic fields require meticulous preparation and extensive preliminary checks. Thus during preparation times and periods of maintenance of the neutron source the 40 MW power supply and the cooling system could be made available to additional non-neutron research at continuous magnetic fields of up to 45 Tesla. This could open up the way to supplement the planned neutron scattering research by offering additional experimental opportunities conventionally available at high magnetic field laboratories, such as the study of transport properties, optical properties, specific heat, solid state NMR, electron spin resonance, etc. According to the applicants, these fields of research will aim at experimental techniques and samples which require not pulsed but continuous magnetic fields similarly to neutron scattering.

II.1.2 National/International Networks

BENSC at HMI is part of an European network of neutron scattering user facilities ("Neutron Round Table") and has received EU funding for several years to support access to its research services for the European research community.

The project proposal for the High Magnetic Field Laboratory for Neutron Scattering has been developed in collaboration with and using information of the leading high magnetic field laboratories in Tallahassee (USA), Nijmegen (Netherlands) and Grenoble (France). The workshop on scientific prospects of the envisaged facility held at HMI in Mai 2001 was attended by 35 scientists from 9 countries, the workshop in January 2002, held in Potsdam, was attended by 21 external scientists from 8 countries and 26 HMI researchers.

According to the applicants, the proposed continuous magnetic field facility will complement other existing and planned high magnetic field facilities in Germany, namely the short pulse (µs) >1000 Tesla laboratory at the Humboldt University, Berlin, and the proposed long (ms) pulse 100 Tesla facility (HLD) at the FZ Rossendorf. The applicants propose to establish a strong collaboration and co-ordination between those complementary facilities, in order to optimize the use of resources and expertise and to provide access to different approaches in high magnetic field research.

II.2 Technology

II.2.1 Neutron Scattering

The project is based on a new concept of providing high magnetic fields for neutron scattering research. High magnetic field systems, namely superconducting magnets, have been built so far as mobile units that can be transported to and installed on a number of stationary neutron scattering instruments. In the proposed project the high field magnet is installed for the first time as a stationary equipment while the neutron scattering apparatus is assembled around the magnet in a number of possible modes of operation and configurations. This approach was made possible by new technical developments in neutron scattering, which enable different neutron experiments without the need to turn or move the magnet containing the sample and also in a geometry of limited beam access.

The first important technical innovation in neutron scattering is a time-of-flight (TOF) monochromator that is used instead of a crystal monochromator on a continuous neutron source. This method has recently been tested by HMI scientists in a collaborative effort at the Budapest Research Reactor. It was demonstrated that with an adequate mechanical chopper system the TOF monochromator can provide data collection rates comparable or even superior to most of the currently used focussing crystal monochromator instruments.

The second technical innovation is a supermirror coated so-called ballistic neutron guide, which can transport high flux thermal neutron beams over distances of 50 to 100 m from the neutron source without substantial losses in the neutron flux.

Conventional neutron guides have successfully been used for this purpose for cold neutron beams only. The applicants state that in order to observe a sufficient number of Bragg peaks for the determination of the structure, many experiments envisaged in high magnetic fields require, however, thermal neutrons (wavelengths in the range of 1 - 2 Å). Without an advanced supermirror neutron optical beam delivery system for thermal neutrons substantial beam intensity losses would occur for distances larger than typically 10 m between the magnet and the neutron source. The size of the magnet system and its stray field do not allow for installing the magnet too close to any existing neutron source. Using a ballistic supermirror guide a distance of 60 to 70 m is planned at HMI in order to optimize the available space, to minimize the interference with other equipment and to place the high field magnet at a position with very low neutron background noise.

A third innovation, made possible by the particular geometry of the cold neutron beam NL4 at the HMI reactor, is the capability to deliver both thermal or cold neutrons to the magnet positions. At first it was proposed to achieve this in a time shared fashion by switching off the cold source, the beam line faces a rather high thermal flux region of the reactor reflector structure. With the cold source in operation the beam line only faces the dense cooled H_2 gas in the cold source emitting cold neutrons. At the Wissenschaftsrat's sub-group's visit at HMI the applicants proposed a newly invented concept to extract cold and thermal neutrons simultaneously with the cold source in operation by installing a so-called multi-spectral neutron guide.

II.2.2 Combination of Neutron Scattering and High Magnetic Fields

Currently, there are two technologies that can be considered for producing continuous fields: superconducting or normal conducting (resistive) magnets. Until now the maximum field realized by superconducting technology is 17 Tesla. Expected progress might increase this limit by 20-25% over the next decade at rapidly growing costs. According to the applicants at the current state of science and technology, only the resistive technology is capable of fields up to 40 Tesla. This point of view has been confirmed by the international workshops held in May 2001 and January 2002.[4]

The applicants state that 30 to 40 Tesla could be achieved most efficiently by circulating very high currents in resistive copper-like conductors. Thus, it is proposed to install a state-of-the–art 40 MW high stability power supply together with an adequate cooling system close to the neutron source BER II.

II.2.3 Main strengths and weaknesses

The main strength of the facility is that it will significantly extend the thermodynamic parameter space accessible to neutron scattering exploration up to 40 Tesla.

Although the project involves a new approach and several technical innovations, the applicants state that the technical risks are low. The technology for producing high magnetic fields by resistive coils is well established at the existing high field laboratories. Also, the new neutron instrumentation techniques have been developed and experimentally tested at HMI.

A disadvantage of the resistive technology is the installation costs of the power supply and the cooling equipment, as well as the high power consumption during operation, while the costs for the magnets themselves amount to less than 10 % of the total investment.

The high costs for the power supply and the cooling equipment are a certain weakness of the project but are in the applicants point of view in full proportion with the expected new scientific results and the significant enhancement of neutron research. The installation of the equipment would not lead to essential loss of operational time at the BER II neutron source.

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[4] See footnote 3.

Another potential weakness of the project could be seen in the fact that the BER II reactor at HMI is a medium flux neutron source, with about 10 times lower source intensity than the best in the world (ILL, Grenoble) and about 3 times lower than the future FRM-II reactor in Munich. However, HMI's innovative instrumentation approaches are expected to compensate lower flux of the source by more efficient instrument design.

II.2.4 Enlarging/upgrading

The proposed High Magnetic Field Laboratory for Neutron Scattering is planned to use two beam lines of the reactor BER II at HMI, one facing the cold source and equipped with an innovative multi-spectral ballistic neutron guide and one dedicated thermal beam line. Technically it is feasible to operate a magnet cell up to 100 m from the power supply, a distance that will be sufficient to reach the end of a ballistic guide to be installed on the available thermal neutron beam.

The total period of operation without any expansions to the facility is expected to be 15 years.

A final upgrade potential is to enhance the magnetic field by placing the resistive magnet inside a large bore superconducting magnet. This "hybrid magnet" technology is currently rather cumbersome and expensive but is expected to enhance the magnetic field by 7-8 Tesla beyond the limits of resistive technology at a given power supply. Since the magnetic field generated with resistive magnets is limited by the installed electrical power, only hybrid magnets are capable of further increasing the available fields. This potential upgrading could be envisaged in a few years time, especially if higher performance superconductors become available.

In the more distant future, when the next generation neutron source ESS becomes available in Europe after 2012 with an effective flux nearly two orders of magnitude higher than that of the ILL reactor, HMI will have the option to instrument and operate an ESS beam line as a collaborating research team. The lifetime of the power supply and the cooling system of the proposed facility can be estimated to substantially exceed 15 years. If the ESS would be realized in Germany, HMI proposes to transfer the neutron instrumentation and the magnets to ESS. The applicants expect that particularly cost effective as well as advantageous technical solutions could be envisaged if the experience with the HMI High Magnetic Field Laboratory for Neutron Scattering would be considered during the construction phase of ESS.

II.3 Transfer of Research Results

Research results obtained at the proposed facility are expected to have a direct as well as an indirect impact on the development of new technologies and new materials. A likely potential direct impact could be the elaboration of new production techniques for novel materials in high magnetic fields. Indirect technological impact can be expected from the contribution of neutron scattering studies in high magnetic fields to the general progress in condensed matter science which will enhance our understanding of the broadest variety of materials, both magnetic and non-magnetic. The development of high T_c superconducters for high field and high power applications is a most likely example.

HMI considers the transfer of technology (TT) to industrial use as a high priority task. This includes selling of patents and licenses, offering its highly specialized research capacities to proprietary research and helping start-up companies to enter the market. To support this transfer of knowledge HMI runs a patent service and a special task force to contact potential clients in industry. For internal motivation the directors have announced special funds to support the additional work necessary to present promising TT ideas to potential partners.

The realization of the project does not require the development of new industrial technologies. It will rather be fully realized by industrial contractors applying state-of-the-art industrial technology. Thus, no spin-offs are expected during the period of construction.

A.III The Institutions Participating in the Project

The Berlin Neutron Scattering Center BENSC at HMI is a highly recognized institution which has been open to national and international users for about 10 years.[5] Since 1973, when HMI started BER II, the institute has gained substantial experiences in planning, large-scale upgrading and operating a neutron source. HMI is also internationally recognized for its development of advanced neutron scattering techniques. In this respect, the particular expertise of HMI is e.g. underlined by the fact that supermirrors were invented in 1976 by one of the leaders of the proposed High Magnetic Field Laboratory for Neutron Scattering project. Neutron supermirrors are now widely used at all neutron scattering facilities.

HMI has also gained international reputation for its developments of novel instrument concepts for high magnetic fields. BENSC presently operates six superconducting cryomagnets, which are designed for the special needs of neutron scattering experiments. Since 1998 the worldwide unique possibility to carry out neutron scattering experiments at high magnetic fields up to 14.5 Tesla, respectively 17 Tesla is available at BENSC. This cryomagnetic system is based on a 14.5 Tesla split-pair superconducting magnet developed by Oxford Instruments in collaboration with the Sample Environment Group at BENSC. The design was extended by a field enhancement of 2.5 Tesla by adding ferromagnetic Dy-boosters.

The one experience HMI lacks is designing and operating very high field resistive magnets. However, HMI points to fact that the proposed project has been prepared with extensive expert advice from NHMFL Tallahassee. Also, HMI states that magnet design and manufacturing capacities are available at NHMFL, either in form of fully paid contract work or scientific collaboration. In addition, a collaboration with the European high field facilities in Grenoble and Nijmegen has been initiated.

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[5] At BENSC 70% of the beamtime is used by external users (thereof 45% national users and 55% international users).

A.IV Users of the Proposed Facility

The proposed facility is expected to initiate new research opportunities for a wide user community by adding an additional parameter – high magnetic fields – to the well-established neutron scattering technology. It is also suggested to make the facility available to the high-magnetic-field community. Accordingly, the proposed facility is expected to attract two large user communities. The proponents also expect synergy effects, e.g. for experiments in solid state physics, chemistry or biology that could be performed with and without the impact of neutron scattering, thereby potentially providing new insights in the complex microscopic structure of matter. Hence, the proposed facility will significantly extend the present user program of BENSC.

The German neutron scattering community amounts to over 1100 scientists.[6] At BENSC currently about 75 % of external users come from universities and 25 % from other research institutions. About 25 % of the proposed user experiments at BENSC require high magnetic fields, often in combination with low temperatures. From the overload factor of 4 and more for the highest magnetic field system presently in operation at BENSC the applicants conclude a strong tendency for the need of much higher magnetic fields.

IV.1 Services

Access to the new facility will be made available to the national and international research community via a peer reviewed user proposal system that is already established at BENSC for neutron scattering research. The selecting BENSC User Committee meets every 6 months and has 14 members representing the user community. 70 % of them are external scientists. In addition, user operation at the high field neutron scattering station is planned to be controlled by a peer review committee as well.

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[6] See ESF/ENSA: Survey of the Neutron Scattering Community and Facilities in Europe. 1998. According to this study, 46 % of the experiments concern physics, 31% chemistry and 13% material

The external users will receive expert support by HMI staff both in neutron scattering and high magnetic field, low and high temperature as well as high pressure techniques. These services will be free of charge for research work carried out by national or international users under the condition that the results will be made available to the scientific community in form of a regular publication. They also receive financial support for their travel to HMI funded either by grants to BENSC in the framework of European Union programs or provided by HMI to support German users. For applied and industrial research groups, who intend to keep their results proprietary and confidential, these services will be offered at full costs.

In view of the necessary preparation, calibration, in-situ control, sample and control equipment, mounting times for extreme high field conditions, the realistic yearly operational time of one neutron scattering station is estimated to 1.200–1.400 hours, i.e. some 2.500 hours per year for the two stations. In addition, the 40 MW power supply could be available for up to another 2.500 hours per year service for non neutron scattering users (25 weeks of two 8-hours shifts). For usage in the neutron free time the facility could provide space for five additional magnet stations, i.e. laboratory space with connection to the power supply and cooling circuit and the usual laboratory utilities. These stations could be allocated to research groups, who on the basis of peer reviewed proposals would build or buy their magnets and run high magnetic field experiments at their own costs. It is conceivable that power supply and cooling systems could be provided free of charge for these groups. HMI will provide specific technical support relevant for the use of high electric power and cooling.

Data reduction software and access to computing facilities as well as an on-site guest house can be provided to all users during their stay at HMI.

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science. Presently biology represents only 5% of the total research, but it is expected that this area will dramatically increase in future.

IV.2 Scientific Education

Many university groups participate in the operation of the 15 scheduled neutron scattering instruments at BENSC. Two of the 15 instruments are essentially operated by university groups. About 10 % of BENSC users are collaborating university groups that usually perform their research programs over a longer term of several years. The strong involvement of students in the research at BENSC proved to be successful, which is e.g. indicated by the high proportion of young scientist prizes at the last two European Conferences on Neutron Scattering.[7]

The new facility with its additional science and technology potential is expected to broaden the field of educational opportunities at HMI. There are e.g. planned dedicated workshops and a new conference series on neutron scattering in high magnetic fields.

IV. 3 Public Relations

HMI plans to continue informing the general public by seminars and other public presentations, such as "Tage der offenen Tür". Bi-annual "Tage für die Industrie" are also common practice. In addition, several public presentations and seminars on the combination of neutron sources and magnetic fields are planned that should cover different educational levels. It is intended to increase the public understanding and awareness of science in general and to create a favorable climate, especially regarding future investments such as the ESS.

A.V Project Management, Location, Costs and Schedule

V.1 Project Management

A Facility Construction Board (FCB) is planned to be established. Members will be selected by the Project Leader in consultation with the Scientific Director (Wissenschaftlicher Geschäftsführer) of HMI and the BMBF. The FCB is responsible

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[7] See European Neutron Scattering Conferences, Interlaken ECNS 1996 and Budapest ECNS 1999.

for planning, design and construction of the envisaged facility as well as quality assurance.
Ultimate budget responsibility is within HMI and follows its well-established procedures of the German federal administrative system.

The HMI Scientific Council (Scientific Advisory Board) with international members advises the HMI in issues regarding the High Magnetic Field Laboratory for Neutron Scattering. The Scientific Council will comment on the activities of the FCB in a broader perspective and review the activities and progress of the project.

V. 2 Location

It is the basic idea of the project that the availability of very high magnetic fields as extreme sample environment for neutron scattering will add a new dimension to the scientific program of HMI, and to the field of neutron scattering in general. The reactor BER II, refurbished in 1992, will have a secure future for at least 20 years of operation and is thus expected to provide a sound basis for the proposed facility. No alternative sites are considered.

However, detailed planning is in progress to optimize the facility design for maximum use of the available space at HMI. The facility will consist of a 40 MW power supply, the cooling circuit including chillers, pumps and heat exchangers, infrastructure and a control room housing the computers of the operating system. The distance between the power supply and the magnet sites should be kept as short as possible (not longer than 100 m), because that makes hydraulic and electric losses easier to handle.

V. 3 Costs

The following estimates of the total costs are based on figures of the NHMFL Tallahassee (USA) that was built in 1992 and from the new 20 MW laboratory at the University in Nijmegen, which is currently under construction.

R&D costs, capital costs and operational costs of the neutron scattering instrumentation and the fractional costs of the research reactor BER II, that will be covered by HMI budget, are not included in the following cost estimates. Also the expenses for developing the neutron instrumentation is not included in the project, but will be covered by the regular R&D budget of the HMI.

V.3.1 Cost Estimates for Development

Components	**Total Staff (FTE[1])**	**Capital Cost (million €)**	**Staff Cost incl. overhead (million €)**	**Total Cost incl. Staff (million €)**
R&D	2,0		0,1	0,1

V.3.2 Cost Estimates for Construction

Components	**Total Staff (FTE)**	**Capital Cost (million €)**	**Staff Cost incl. overhead (million €)**	**Total Cost incl. Staff (million €)**
Power Supply, Circuit		15,4		15,4
Water Circuit, Cooling		7,5		7,5
Building		7,5		7,5
Magnet Station		5,8		5,8
Power Grid Connection		10,0		10,0
Consultants, Architect etc		1,2		1,2
Project Team	12,0		1,0	1,0
Construction Total	**12,0**	**47,4**	**1,0**	**48,4**
Construction Total (according to proposal)		**47,4**		**47,4**
Development and construction Total	14,0	47,4	1,1	48,5

V.3.3 Cost Estimates for Operation

The operation costs of the cooling circuit are included in the following table.

Operation	**Capital Cost (1.000 €)**	**Staff Cost (1.000 €)**	**Total Cost incl. Staff (1.000 €)**
Staff		810	810
Electricity		2.500	2.500
Regular replacement or refurbishing of magnets	500		500
Maintenance of power supply and cooling circuit		500	500
Operation Total/a	500	3.810	4.310
Operation Total/a (according to proposal)	500	3.810	4.310

V. 4 Schedule

In the first year a Technical Design Report (TDR) has to be worked out. During this period the standard technical performance specifications will be defined, offers for different options will be obtained, decisions will be made for the final, optimized project definition, the ordering and purchase process will be started, and contracts will be signed with the companies selected in cooperation with an engineering consultant company and/or in-house HMI staff.

In the first year the ordering of the magnets will be started. The preparation of construction of the buildings should also be started in the first year. After the buildings are finished, presumably in the end of the second year the installation of equipment can be started. Because of their distribution over different sites, all installation activities can be started at the same time and be pursued in parallel without interference. Installation activities at the site are expected to be accomplished no later than 12 months after they started, i.e. in the second half of the third year. The remaining months are scheduled for reception, modifications, installation of the magnets and tests.

All equipment will be manufactured, delivered and installed by industry. The applicants expect that the contracts with industry can be specified in such a way that a precise follow-up of schedule, performance and quality assurance is possible.

Item	**Year 1**		**Year 2**		**Year 3**	
Project Definition/Planning (TDR)	xxxxxx	xxxxxx				
Building		xxx	xxxxxx			
Connection to 100 kV Grid			xxxxxx	xxxxxx	xxxxxx	
DC Power Supply and Bus			xxxxxx	xxxxxx	xxxxxx	
12 kV Switchgear			xxxxxx	xxxxxx	xxxxxx	
Harmonics Filter, Power Factor			xxxxxx	xxxxxx	xxxxxx	
AC power distribution for above			xxxxxx	xxxxxx	xxxxxx	
Control System for Plant			xxxxxx	xxxxxx	xxxxxx	
Deionized Water Circuit			xxxxxx	xxxxxx	xxxxxx	
Chilled Water Circuit			xxxxxx	xxxxxx	xxxxxx	
Cooling Tower			xxxxxx	xxxxxx	xxxxxx	
Other (cooling, well, waste water, valves)			xxxxxx	xxxxxx	xxxxxx	
Magnets	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	
Reception, Modifications					xxxxxx	xxxxxx
Tests						xxxxxx

B. Statement and Recommendations

B.I Field of Research

Over the last fifty years, neutron scattering has been an important tool in solid state physics for probing the microscopic structure and processes in complex matter. Neutrons have wavelengths and frequency that are comparable to both the relevant microscopic-mesoscopic time and length scales characterizing structure and dynamics in condensed matter. In addition, due to its magnetic moment, the neutron interacts with the atomic magnetic moments just as strongly as with the nuclei. Neutron scattering, by virtue of providing tunability in both energy and wavelength, enables to directly measure the structure factor $S\ (q,\ \omega)$ which is a quantity that is very amenable in comparison with calculations. Thus, neutrons provide a powerful tool to test theoretical predictions in condensed matter physics.

The proposed combination of neutron scattering and static high magnetic fields of up to 35-40 Tesla is an innovative and promising approach which would enable substantial progress in condensed matter physics and material sciences. The sub-panel expects that the following important questions can be tackled with neutrons and magnets in the magnetic field range between 20 to 40 Tesla:

- Correlated electron systems, e.g. heavy fermion systems, high Tc-superconductors, collosal magnetic resistance (CMR)-materials, low dimensional and low spin antiferromagnetic systems;
- Dynamic antiferromagnetic correlations;
- Quantum liquids, e.g. superfluid helium, superconductivity, vortex states and dynamics;
- Materials science aspects, e.g. pinning in High-Tc superconductors, superhard magnets;
- Studies at the interface between soft and hard matter.

Neutron related research in Germany is very successful on an international scale. Within Europe, Germany has the second largest neutron scattering community of over 1100 scientists. The envisaged laboratory would clearly strengthen the neutron scattering community in Germany. It would also be a world-wide unique facility combining high magnetic fields and neutrons, thereby significantly enhancing current possibilities in neutron scattering research. However, it would not replace existing or planned high magnetic field laboratories.

B.II Scientific Program

HMI runs a first-rate neutron user program and the sub-panel appreciates its well-established service oriented policy. The scientific program of the proposed facility addresses scientific topics that are very appropriate. However, the program needs to be further developed and expanded. Also, in order to strengthen HMI's in-house research capability for the proposal a strong group devoted to magnetism will be needed. Thus the current efforts to attract a Division Director for Magnetism is fully supported by the sub-panel.

Because neutron scattering experiments require long preparation times and periods of maintenance of the neutron source, HMI proposed to also make the 40 MW power supply of the facility available for additional non-neutron-based research at continuous magnetic fields of up to 45 Tesla. However, in the sub-panel's opinion it would be difficult to handle different research techniques and serve different user communities almost simultaneously. Thus, the sub-panel strongly recommends to concentrate on neutron scattering and high magnetic fields at least at the beginning.

B.III Technology

HMI is well recognized for its developments of advanced neutron scattering instrumentation. Especially their first-rate beam technology of ballistic neutron guides as well as their time-of-flight techniques are internationally acknowledged. Also, the possibility to alternatively deliver thermal or cold neutrons to stationary magnet positions is a very promising option. The solution presented for beam delivery to the magnets is convincing.

HMI plans to use state-of-the-art magnet technology developed in the USA which is proven to be technically feasible. The sub-panel expects that a 30-35 Tesla split gap magnet as well as a 40-45 Tesla tapered bore magnet built with the proposed technology will perform at 90%-100% of the quoted field. Thus, it is not required to develop a new magnet technology for the facility. Although it is planned to purchase the magnets, technical expertise in magnet technology will be also needed at HMI.

The sub-panel is convinced that the proposed resistive magnet technology is the most promising approach for a neutron scattering facility. DC magnets - compared to pulsed magnets - offer additional advantages for experimentation with neutron beams, such as a larger magnet bore and split gaps as well as the use of time of flight.

B.IV Project Management, Location, Costs, Schedule

The basic motivation for the project is highly innovative. However, there are technical as well as scientific aspects of the submitted proposal that necessarily need to be further specified. So far, the number of magnet stations is not defined; the instrumentation of the sample environment is not addressed; a plan for installations of the connection to the power grid is missing; while the costs for the magnets are reasonable, the cost of the power grid connection is not calculated and the level of HMI investment is not clearly stated. Also, supporting letters from collaborators as well as a list of potential users are still missing. In addition, further planning will be necessary to optimize the facility design for maximum use of the available space at HMI. For these reasons, the sub-panel recommends to work out a detailed technical design report. This report should be evaluated again before a funding decision is made.

With regard to future strategies of HMI research, the sub-panel recommends that the External Advisory Committee should be involved to better effect. It could play the role of a scientific, technical and financial sounding board giving advise to HMI

Management how the proposed facility would fit into an overall strategic plan for the laboratory.

BENSC at HMI is an important German neutron scattering user facility. The recently refurbished BER II reactor provides a sound technical basis and a long-term perspective for the planned facility. Although there are brighter neutron sources in Europe than the one run by HMI, the sub-panel expects that HMI's excellent instrumentation developments will enable experiments that can compete e.g. with the 10 times higher neutron flux intensity of the ILL, Grenoble. The development of a European Magnet Laboratory for neutron scattering research at HMI is judged to be possible. It would, however, require new scientific and technical expertise associated with magnetism and magnet technology at HMI. In the more distant future, when the next-generation neutron source ESS is implemented, it would be a logical next step to also integrate a high magnetic field laboratory into that facility. The experiences gained at the HMI facility could be very useful for such a further development.

The proposed laboratory for neutron scattering in combination with DC high magnetic fields will be a world-wide unique installation. The proposal, while undoubtedly very attractive internationally, will not require international but only national funding.

Regarding the relatively high investment cost it would not be cost effective to start with only one neutron beam line dedicated to research in high magnetic fields - as currently proposed by HMI. For this reason the sub-panel recommends to directly go for two beamlines.

The presented project schedule is judged to be reasonable, although the assumed timeframe for constructing the new buildings seems to be tight.

B.V Users of the Facility

The planned facility will provide unique conditions for new measurements and new experimental techniques which certainly will attract a broader European and international user community. Also, HMI's innovative time-of-flight design will allow a multi-purpose use of the facility.

The sub-panel is convinced that there is substantial demand for the present 14.5 Tesla split gap magnet installed at HMI for neutron scattering research. Also, there is a strong demand for access to higher magnetic fields than currently are available.

Ten to fifteen different experiments are judged to be feasible per year. Each magnet can only serve a few dozen users. Due to the limited number of experiments, particular attention has to be paid to the quality selection of submitted proposals.

BENSC at HMI is an internationally recognized institution that very successfully runs a national (45%) and international (55%) user program. The sub-panel expects that HMI will be able to provide the technical and scientific support for studying magnetic systems using neutrons with high field magnets, provided that scientific and technical expertise in magnetism and magnet technology will also be established.

The training of students and young scientists is well established at HMI. Summer schools, and special training courses are carried out; and about 60% of BENSC users usually come from universities. The new facility would certainly broaden the educational opportunities at HMI.

B.VI Transfer of Research Results

Neutron scattering studies together with other research techniques will continue to play an important role in condensed matter physics and in the development of new materials for a broad field of applications. The combination of neutrons and higher magnetic fields will be particularly powerful in investigations of magnetism, structures and excitations in those condensed matter systems with characteristic energies or critical fields that match the higher fields.

The development of a high magnetic field laboratory at BENSC would significantly strengthen the European efforts on developments of new instrumentation for neutron scattering research, especially with regard to the envisioned project of a European Spallation Source (ESS). It would in fact make HMI a world-wide unique center in neutron scattering research.

C. Conclusion

HMI proposes a high-magnet field facility comprised of two DC magnets with fields up to 40 Tesla as part of the Berlin Neutron Scattering Center (BENSC). The combination of DC magnets of such high field strengths with the recently upgraded neutron beams of the BER II reactor would open up a some leading-edge science, mostly in material science and condensed matter for a focused international research community. The experimental opportunities would be world-wide unique, and the proposal presents an imaginative combination of new and existing capabilities. HMI is well known for its expertise in neutron instrumentation and neutron beam guides and already operates a 17 Tesla magnet. Since state-of-the-art magnet technology would be used, there is little question that the technical goals of the proposal can be reached. However, the present proposal lacks a full description of the science that will be conducted and a detailed evaluation and costing of the infrastructure that will be required. In addition, a plan how the new facility would fit into the HMI Laboratory in terms of its institutional priorities and capabilities, in particular in operational and scientific staff, needs to be developed. Finally, while BENSC is currently running a very good users program, a national facility of the proposed scope will require establishing research agreements with supporting universities, as well as with other national and international research laboratories.