MLZ
Heinz Maier-Leibnitz Zentrum

Experimental facilities

Heinz Maier-Leibnitz Zentrum (MLZ)

MLZ is a cooperation between:

JÜLICH
FORSCHUNGSZENTRUM

Helmholtz-Zentrum
Geesthacht
Zentrum für Material- und Küstenforschung

Technische Universität München

Bayerisches Staatsministerium für
Bildung und Kultus, Wissenschaft und Kunst

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of Education
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The Heinz Maier-Leibnitz Zentrum (MLZ):
The Heinz Maier-Leibnitz Zentrum is a leading centre for cutting-edge research with neutrons and positrons. Operating as a user facility, the MLZ offers a unique suite of high-performance neutron scattering instruments. This cooperation involves the Technische Universität München, the Forschungszentrum Jülich and the Helmholtz-Zentrum Geesthacht. The MLZ is funded by the German Federal Ministry of Education and Research, together with the Bavarian State Ministry of Education, Science and the Arts and the partners of the cooperation.

The Forschungs-Neutronenquelle Heinz-Maier-Leibnitz (FRM II):
The Forschungs-Neutronenquelle Heinz-Maier-Leibnitz provides neutron beams for the scientific experiments at the MLZ. The FRM II is operated by the Technische Universität München and is funded by the Bavarian State Ministry of Education, Science and the Arts.

Welcome to the MLZ!

The Heinz Maier-Leibnitz Zentrum (MLZ) offers beam time at high-class instruments hosted at the Research Neutron Source FRM II at Garching. The source provides the complete spectrum of neutrons: cold, thermal, hot neutrons as well as fast neutrons from the converter facility and in addition, the world's highest flux of mono-energetic positrons. An ultra cold source is under construction. Structure research, large scale structures, spectroscopy, imaging and analysis as well as particle physics are topics our instrument suite is equipped for.

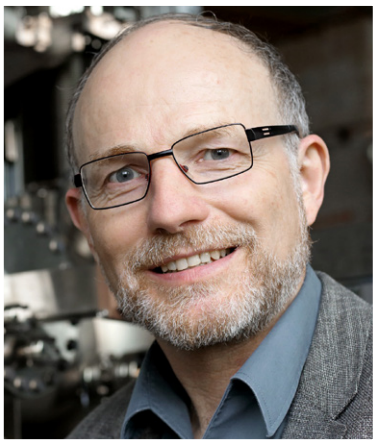
Continous improvements on our instrument suite make it necessay to revise this brochure regularly - in your hands you are holding the third edition! Find all details about our instruments, laboratories, and sample environment here, get in touch with our scientists, discuss your ideas, and become part of our user community: Just submit your proposal to the next deadline after which it will be reviewed by our international referees based solely on the scientific merit of the proposed experiment. The mayor part of the available beam time is distributed to external users.

On February 21st, 2013, the MLZ was inaugurated in order to present a cooperation that had been established in 2011. The partners are the TUM and neutron centres of the Helmholtz Association in Jülich and Geesthacht. They receive additional funds for the cooperation from the Federal Ministry of Education and Research. The source FRM II itself is funded by the Bavarian State Ministry of Sciences, Research and the Arts via the Technische Universität München (TUM).

At the MLZ, not only the cooperation partners assemble, but also institutes of the Max-Planck-Gesellschaft and many university institutes, merging their knowledge and substantial resources with the intention to serve the German and international neutron community the best. A list of them is given at this brochure's end.

The MLZ looks forward to your compelling ideas and experiments!

Yours,



Prof. Dr. Winfried Petry

Scientific Director MLZ
Scientific Director FRM II
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Scientific Director MLZ
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and
Peter Grünberg Institute (PGI)
Forschungszentrum Jülich GmbH

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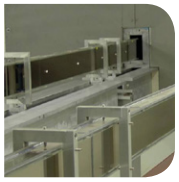
The neutron source FRM II

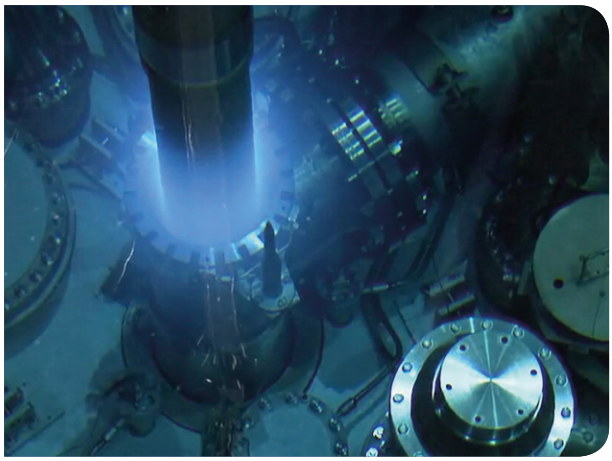
Secondary neutron sources



Neutron guides

Neutron Source

The neutron source FRM II



Powerful neutron source

The neutron source Heinz Maier-Leibnitz (FRM II) is a multipurpose research reactor with a particular focus on beam tube experiments. It has been designed for providing neutrons to scientific users from all over the world as well as for medical and industrial applications. The FRM II is operated as a Corporate Research Center by the Technische Universität München (TUM) in Garching near Munich, Germany. Its first criticality was achieved in March 2004.

The FRM II is the most powerful neutron source in Germany and reaches the highest neutron flux density ($8 \cdot 10^{14}$ n/cm^{-2}s^{-1}, max. undisturbed flux density) relative to its thermal power (20 MW) throughout the world. More than 30 experimental facilities are operated by scientific teams from German universities, research institutes of the Helmholtz Association, and the Max Planck Society at the neutron source. Today, 26 beam tube facilities are operational. Further seven irradiation facilities mainly for medical and industrial application are in service, an irradiation facility for the production of the medical isotop ^{99}Mo is under construction. The FRM II is equipped with cold, thermal, hot, and fast neutron sources and thus covers a broad range of applications, including a device for the continuous production of an intense positron beam.

Fuel element

The FRM II was designed for an exclusive purpose: the production of neutrons for basic research and applied physics. Its high performance is based on the concept of a compact core: a single, cylindrical fuel element with a diameter of just 24 cm is sufficient for 60 days of reactor operation. The fuel zone measures 70 cm in height and contains about 8 kg of uranium in the form of U_3Si_2. Like other high-performance neutron sources around the world, the FRM II uses highly enriched uranium.

The fuel element is located in the centre of a moderator tank filled with heavy water (D_2O). The tips of the beam tubes are placed in the region of the maximum thermal neutron flux density. Various vertical irradiation channels are arranged in the moderator tank. The beam tubes guide the neutrons to the experiments in the Experimental Hall and Neutron Guide Hall West.

The Experimental Hall hosts scientific instruments exhibiting high neutron flux densities and gives access to the positron beam lines, whereas the Neutron Guide Hall West is connected via six neutron guides to the cold neutron source. A second guide hall will be connected to the reactor building soon in order to extend the number of available instruments.

Safety first

The highest priority is always given to safety at the FRM II. The inherent safety stems from its principle design, with a compact fuel element built into the centre of the moderator tank filled with heavy water. Fuel element, moderator tank, and beam tubes are located in the reactor pool filled with 700 m³ of highly purified water. While passing the fuel element, the temperature of the cooling water only increases from 37°C to a maximum of about 53°C. Neither steam nor high pressures are produced. Three subsequent cooling circuits guarantee the safe dissipation of the 20 MW via the air path.

Redundant safety installations (i.e. multiple, independently constructed units) are a key feature of the safety concept of the FRM II. The single central control rod inside the fuel element is sufficient to regulate and shut down the reactor. Additionally, a redundant set of five shut-down rods is available. Each of these systems is constructed such that the

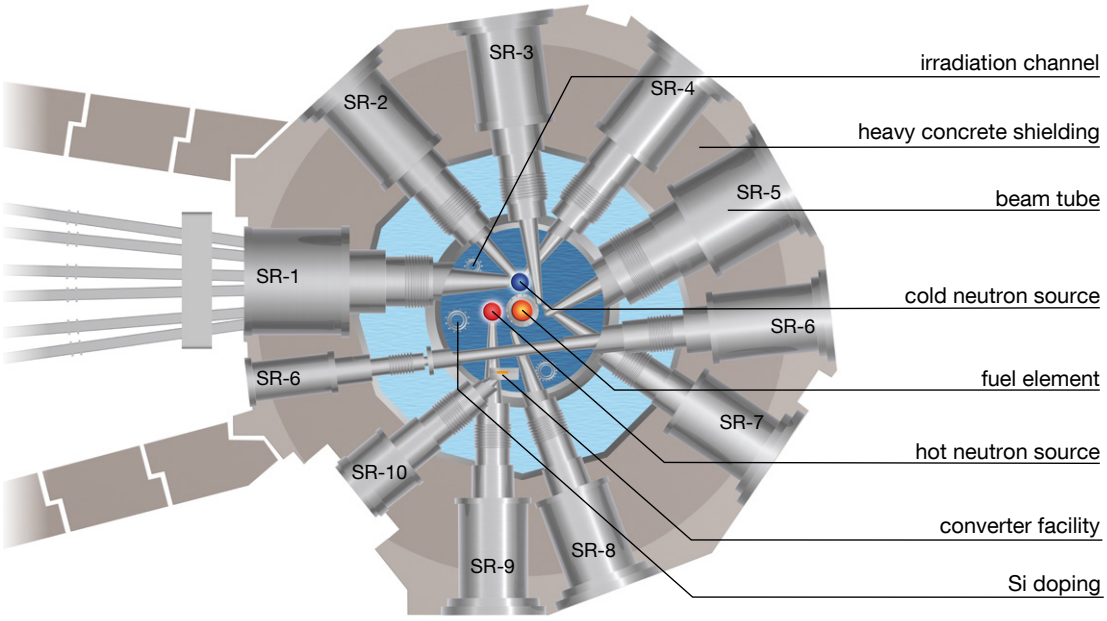


Figure 1: Horizontal section of the reactor pool showing the beam tubes, fuel element, as well as cold and hot neutron source. Beam tubes SR-1, -2, and -4 are fed by the cold source, SR-9 by the hot source. The through-going beam tube SR-6 will be used by the ultra cold neutron source. The converter plate for fast neutrons supplies beam tube SR-10 with the tumour treatment facility. The remaining beam tubes are placed into the highest neutron flux taking up the thermal neutrons.

reactor can be shut down in a fast and durable manner, completely independently.

The 1.8 m thick outer concrete wall of the reactor building protects the reactor against all impacts from outside. It was designed to resist the crash of a fast military as well as a civilian aircraft. This feature has been approved by independent experts. Furthermore, the building can withstand earthquakes up to level VI ½ (MSK), which is beyond the strength of possible earthquakes in the region, or a high floodwater from the nearby river Isar with a height that might occur once every 10,000 years.

Technical Data

Reactor main parameters

- Thermal power: 20 MW
- Max. undisturbed thermal neutron flux density: $8 \cdot 10^{14}$ n/cm^{-2} s^{-1}
- 10 horizontal; 2 tilted beam tubes
- D_2O moderator
- H_2O cooling water

Staff and money

- 435 Mio€ construction costs (2003)
- ~ 400 employees on-site (MLZ + FRM II)

Instruments

- 26 instruments in routine operation (2015)
- 6 instruments under construction

Fuel element

- Dimensions:
  height: 133 cm; outer diameter: 24 cm;
  active zone: 70 cm
- 8 kg HEU in U_3Si_2 alloy in 113 fuel plates
- Enrichment: 92.5% in ^{235}U
- 60 days in a row/ fuel element – typical 240 days of operation per year

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www.frm2.tum.de/en/the-neutron-source

Secondary neutron sources

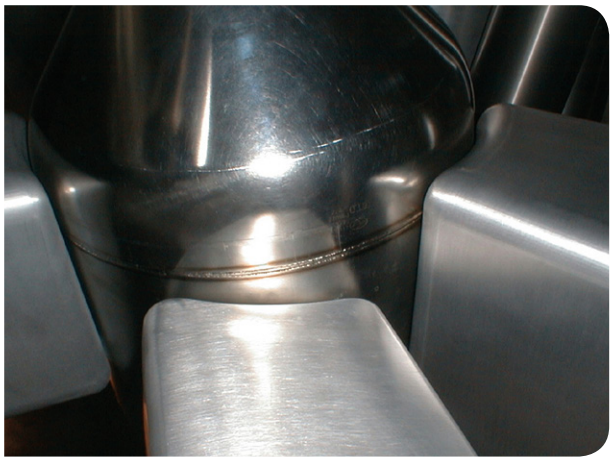

Figure 1: The cold source vessel surrounded by the beam tubes SR-1, -2, -4. View into the moderator tank of the FRM II before operation.

The different instruments at the neutron source FRM II are supplied by various secondary sources slowing down or speeding up the neutrons after thermalisation in the moderator tank. This allows a large variety of applications. Furthermore, beam tube SR-11 hosts the positron source NEPOMUC, which is described in the chapter *Positrons*.

The cold source

At FRM II, a major part of the experiments is carried out using low energy ("cold") neutrons. For this purpose the beam tubes SR-1, -2, and -4 are fed from a special secondary source, the so-called cold neutron source, which is located within the moderator tank close to the maximum of the thermal neutron flux density.

The major component of the cold neutron source is the moderator chamber containing about 12 l of liquid deuterium (D_2) at a temperature of approximately 25 K. Neutrons interacting with the liquid D_2 in the moderator chamber are slowed down at this low ambient. Consequently their energy spectrum is shifted considerably into the low energy range (see fig. 2).

Within the moderator tank, the deuterium is available in a closed circuit driven by natural convection. The liquefaction of the deuterium is achieved by means of a He refrigerator acting as the heat sink of a heat exchanger which is installed above the moderator chamber. The liquefied D_2 rinses into the moderator chamber where it is evaporated again due to neutron moderation and gamma heating.

The moderator chamber and the heat exchanger form the inpile section of the cold neutron source. Important components outside the moderator tank are the refrigerator, a buffer tank and a metal hydride storage unit used to keep the deuterium during periods when the cold neutron source is out of operation and warmed to room temperature e.g. during maintenance periods of the reactor. The subsequent preparation of the cold source for low temperature operation takes approximately one week.

The energy distribution of the neutrons moderated by the cold neutron source is shown in fig. 2. It has its maximum at 40 meV corresponding to a wavelength of 1.4 Å. From the figure it is clearly visible that the corresponding intensity of neutrons exhibiting very long wavelengths is considerably increased as compared to the thermal spectrum generated in the moderator tank at an ambient temperature of about 70°C.

The hot source

Neutrons of short wavelengths in the range of 0.1 eV to 1 eV are used to investigate the structure of condensed matter. As only a small fraction of this spectral range is present in the thermal neutron distribution, the neutrons are moderated upwards from about 300 K to 2200 K. This spectrum shift is performed by the hot neutron source.

The hot moderator consists of a graphite block thermally insulated and positioned in the moderator tank next to the maximum thermal neutron flux density. The graphite cylinder is heated by gamma radiation from the reactor. A double-skinned zircaloy container with interposed insulating graphite felt insulates the graphite block, ensuring a secure containment of the hot graphite. At a reactor power of 20 MW, the temperature inside the container rises to about 2000°C. The hot source provides neutrons to beam tube SR-9, which supplies the single crystal diffractometers HEiDi and POLI.

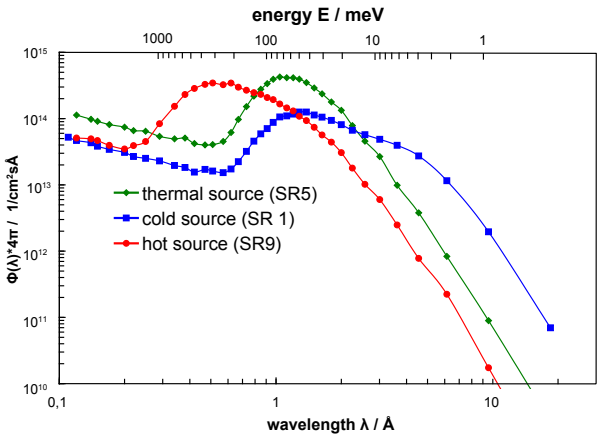

Figure 2: Neutron spectra at the entrance of the beam tubes at 20 MW reactor power.

Converter facility for fast neutrons

In order to obtain a high-intensity neutron beam with an unmoderated fission spectrum, an arrangement of uranium plates is inserted as a secondary source (so-called converter) in front of the tip of beam tube SR-10. It supplies the tumour treatment facility MEDAPP and the radiography and tomography station NECTAR with fast neutrons. Slow neutrons induce nuclear fission in the uranium plates causing the emission of neutrons with an average energy of 1.9 MeV. Without moderation, the fast neutrons are led through a horizontal beam tube to the experiments. The two converter plates deliver a thermal power of about 80 kW.

Figure 3: The moderator of the hot source in the reactor pool of the FRM II during installation.

Technical Data

Cold source

- T = 25 K
- Volume of moderator chamber: 25 l
- Volume of liquid D_2: 12 l
- Mass of D_2 in cold source: 2.4 kg
- Cold moderator pressure: 1.5 bar
- 18 instruments fed by cold source

Hot source

- Mass of graphite in hot source: 14 kg
- Temperature at 20 MW reactor power: ~ 2000°C

Converter facility

- Mass of uranium in converter plates: 540 g
- Thermal power: 80 kW
- Degree of enrichment: 92.5% in ^{235}U

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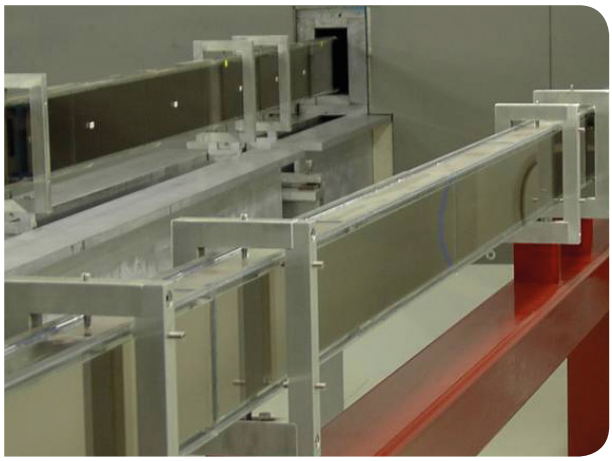
Neutron guides



The MLZ makes extensive use of modern neutron guides to transport and distribute the neutrons over large distances in the Experimental Hall (SR-2, -5, -8) as well as in the Neutron Guide Halls. Adapted to the needs of the instruments with respect to wavelength distribution and angular dispersion the guide elements are coated with 58Ni or supermirror coatings with m values up to 3.0; on focussing sections up to m = 3.6.

Cold neutron guides

Beam tube SR-1 facing the cold neutron source delivers the neutron beams for the entire Neutron Guide Hall West. The in-pile unit of SR-1 consists of a mirror box with m = 2.2 supermirror coating on Al-plates and a dividing section of 2.1 m length, where the beam is divided into the six principal neutron guides. Fig. 1 shows schematically how the neutron guides are further split in order to serve a maximum number of instruments, especially with terminal positions.

Besides SR-1, the cold neutron three axes spectrometer PANDA at beam tube SR-2 has also supermirror inserts in the the primary beam‘s in-pile section. In the near future, SR-4b will be equipped with a neutron guide for the nuclear and particle physics beam line MEPHISTO in the Neutron Guide Hall East. Until now, almost 500 m of cold neutron guides have already been installed.

Thermal neutron guides

Beam tubes SR-8a and SR-8b are equipped with supermirror guides with coatings up to m = 3. At SR-5b a polarising supermirror bender provides the instrument TRISP with polarised neutrons. In total, roughly about 50 m of thermal guides are installed. In the near future, elliptical focussing thermal guides will provide neutron beams for the instruments in the Neutron Guide Hall East.

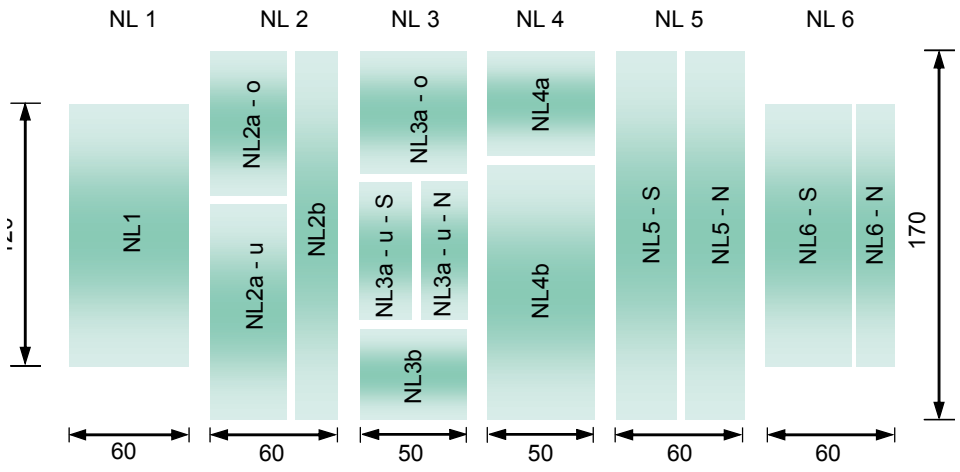


Figure 1: The sectioning of the six principal neutron guides of SR-1. The subsections are indicated by the letters a, b, u, o, S, N.

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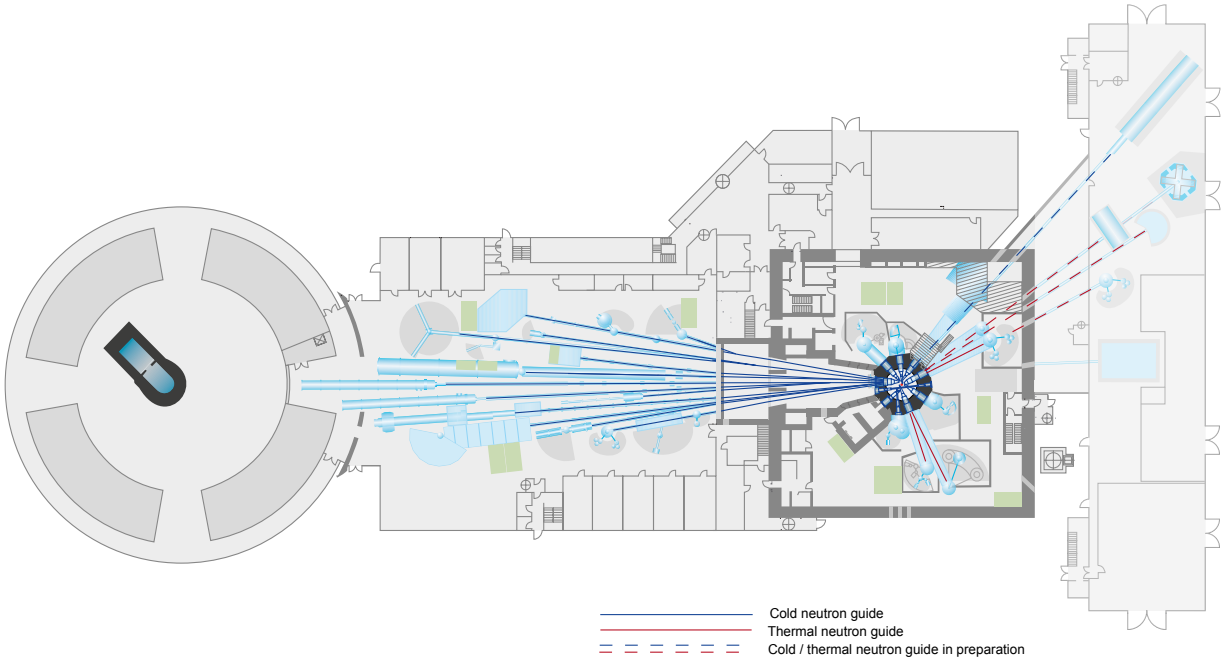

Figure 2: Floorplan of the FRM II with the neutron guide system.

Technical Data

Guide	NL1	NL2a-o	NL2a-u	NL2b	NL3a-o	NL3a-uS	NL3a-uN	NL3b
Length (m)	40	48	60	57	46	30	29	51
Section (mm²)	60 × 120	44 × 60	44 × 100	12 × 170	50 × 50	10 × 56	38 × 56	50 × 45
Coating up to	m = 2.5	m = 3.0	m = 2.0	m = 2.0	m = 3.0	m = 3.0	m = 3.0	m = 2.0
Curvature (m)	1000	160	2000	400	460	30	460	800
Instrument(s)	BIODIFF NREX	J-NSE	TOFTOF	REFSANS	KWS-2	KWS-3	unused	KWS-1

Guide	NL4a	NL4b	NL5-S	NL5-N	NL6-S	NL6-N
Length (m)	34	52	70	35	54	35
Section (mm²)	50 × 50	50 × 110	29 × 170	29 × 170	60 × 120	10 × 120
Coating up to	m = 2.0	m = 3.0	m = 2.0	m = 2.0	m = 2.2	m = 2.0
Curvature (m)	480	390	1640	400	1000	84
Instrument(s)	SANS-1	PGAA	RESEDA TREFF	MARIA	MIRA-2 DNS SPHERES	MIRA

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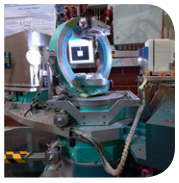
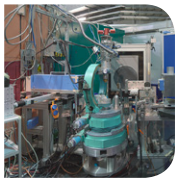
BIODIFF
diffractometer for large unit-cells



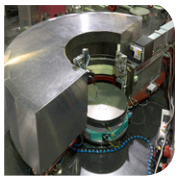
HEIDI
single-crystal diffractometer with hot neutrons

MIRA
dual wavelength band instrument

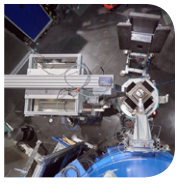
POLI
polarised hot neutron diffractometer



RESI
thermal neutron single crystal diffractometer



SPODI
high resolution powder diffractometer



STRESS-SPEC
materials science diffractometer

Structure Research

BIODIFF

diffractometer for large unit cells

The monochromatic single crystal diffractometer BIODIFF is a joint project of the FRM II (TUM) and JCNS (Forschungszentrum Jülich).

BIODIFF is designed to handle crystals with large unit cells and is dedicated to the structure determination of biological macromolecules. In biological macromolecules, like proteins and nucleic acids, hydrogen atoms play an important role. Hydrogen atoms take part in the substrate binding process and are essential for proton transfer reactions during the catalysis in many enzymes. Therefore, the knowledge about the protonation states of amino acid residues in the active centre of proteins is often crucial for the understanding of their reaction mechanisms. However, hydrogen atoms, especially rather flexible ones, are barely detectable in X-ray structure determinations of proteins. On the other hand, hydrogen atoms are clearly visible in neutron crystallography experiments even at moderate resolutions (d_{min} < 2.0 Å).

BIODIFF is the first instrument along the cold neutron guide NL1 and is positioned in a distance of about 32.5 m from the cold source. Using a pyrolytic graphite monochromator PG(002) the diffractometer covers a wavelength range of 2.4 Å to about 5.6 Å. Higher order wavelength contaminations are removed by a neutron velocity selector. The main detector of the diffractometer consists of a neutron imaging plate system in a cylindrical geometry to cover a large solid angle. A fast LiF/ZnS scintillator CCD camera is foreseen for additional detection abilities. The main advantage of this instrument is the possibility to adapt the wavelength to the size of the sample crystal's unit cell while operating with a clean monochromatic beam that keeps the background level low.

Typical Applications

The main field of application is the neutron structure analysis of proteins, especially the determination of hydrogen atom positions. Typical questions in this field of interest are:

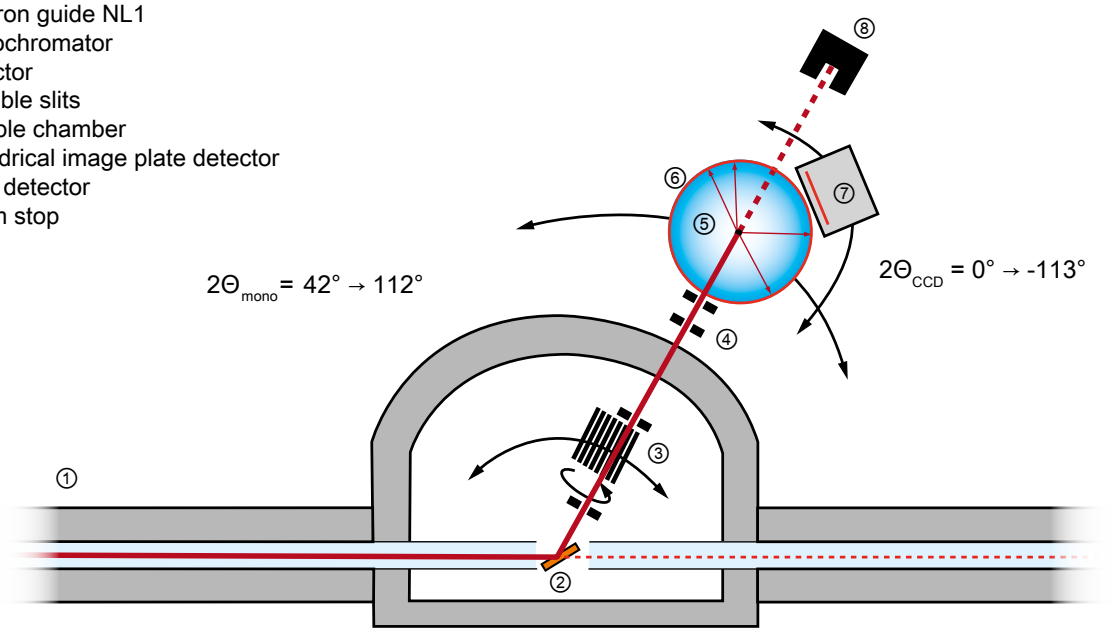
- Enzymatic mechanism (protonation states of amino acids)
- Ligand binding mediated by hydrogen bonds
- Investigation of the hydration shell of proteins
- H/D-exchange pattern as a monitor of structural stability/flexibility

Sample Environment

Besides standard sample environment BIODIFF provides:

- Oxford Cryosystems Cryostream 700 plus with a temperature range of 90 K to 500 K
- Closed cycle cryostat 3.5 - 325 K

① Neutron guide NL1
② Monochromator
③ Selector
④ Variable slits
⑤ Sample chamber
⑥ Cylindrical image plate detector
⑦ CCD detector
⑧ Beam stop



Technical Data

Primary beam

- Neutron guide NL1; supermirror m = 2
- Monochromator:
  PG(002) mosaicity: 0.4 – 0.5°
- Higher order filter:
  Astrium type velocity selector
  transmission 87 % for 2.4 Å
- Wavelength range:
  2.4 – 5.6 Å with selector
  2.4 – 6.1 Å without selector
- Collimation by adjustable slits down to
  Ø = 1 mm

Beam properties at the sample position

- Wavelength resolution at sample position:
  $\Delta\lambda/\lambda$ = 2.9% at 2.4 Å
- Beam divergence (no slits)
  0.8° FWHM horizontal
  0.7° FWHM vertical

Main detector

Neutron image plate (cylindrical)

- $BaFBr:Eu^{2+}$ mixed with Gd_2O_3
- Dimensions:

radius	200 mm
angular range	±152° horizontal
	±48° vertical

- Pixel size (quadratic) 125, 250, 500 µm
- Readout time (with erasing):
  5 min (for 500 µm pixel size)

Auxiliary detector

CCD camera with scintillator

- ZnS mixed with ^6LiF
- Dimensions:

Active scintillator area (flat)	200 x 200 mm²
Distance to sample	100 mm

- 2Θ-angle around sample position 0° – 113°
- CCD chip with 2048 x 2048 pixels
- Pixel size: 13.5 x 13.5 µm²
- Overall spatial resolution ≈ 300 x 300 µm²
  (limited by scintillator thickness)
- Minimum readout time
  ≈ 1 sec (full resolution); < 1 sec (binning mode)

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www.mlz-garching.de/biodiff
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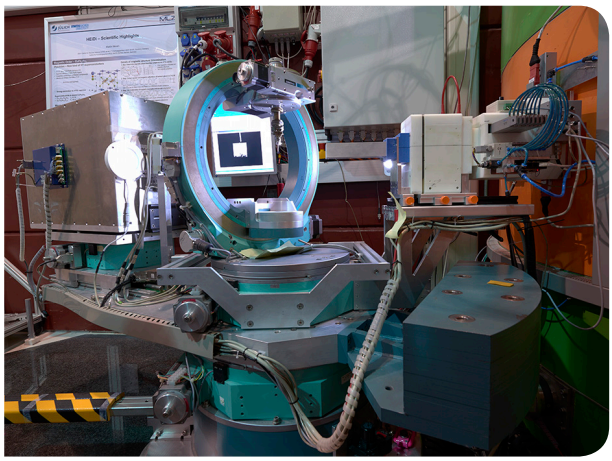
HEIDI

single crystal diffractometer on hot source



The single crystal diffractometer HEiDi is designed for detailed studies on structural and magnetic properties of single crystals using unpolarised neutrons and Bragg's Law:

$$2\, d_{hkl} \sin(\Theta) = \lambda$$

Because of the large variety of short wavelengths and resolutions, HEiDi is suitable for studies on a lot of crystalline compounds – many of them of potential interest for energy or data storage technologies – like:

- HT superconductors (e.g. cuprates, FeAs-pnictides)
- Multiferroics (e.g. manganates) and other complex ferro- and antiferromagnetic compounds (e.g. olivines)
- Ionic conductors (e.g. nickelates)
- Ferroelectrics (e.g. KDP family)
- Mixed crystals (e.g. AsSe compounds)
- Highly absorbing compounds (e.g. with Gd, Sm, Eu, Dy)
- Frustrated magnetic materials (e.g. pyrochlores)

Applications (in general)

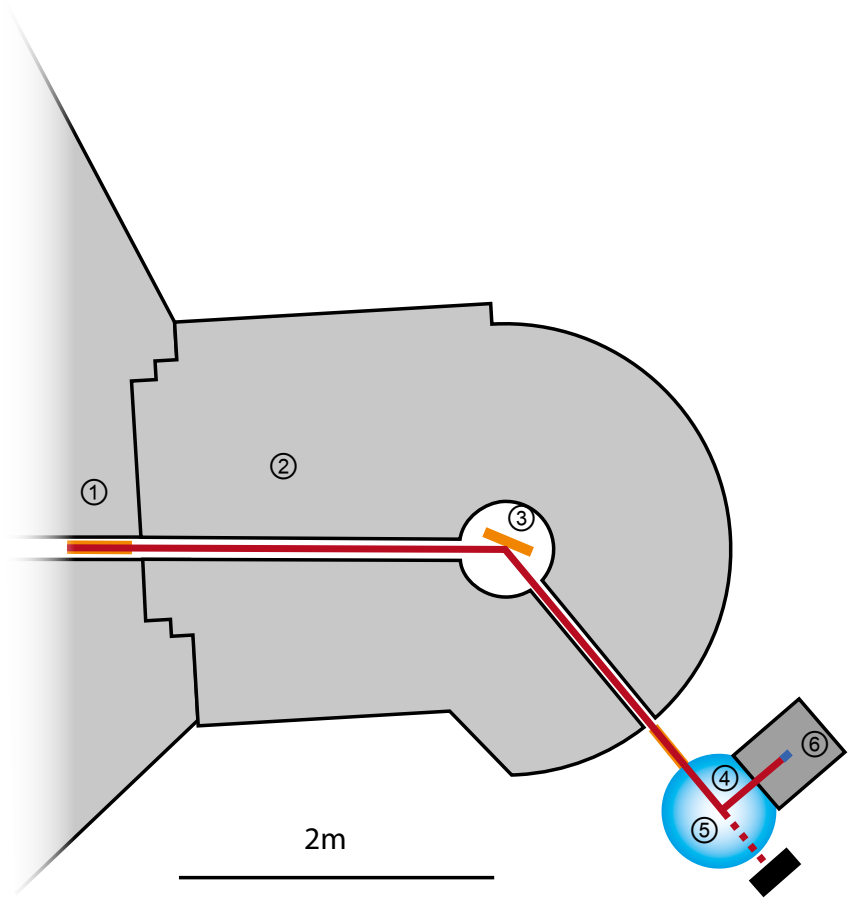
- Structure analysis
- Hydrogen bonds
- Static and dynamic disorder
- Harmonic and anharmonic mean square displacements
- Twinning
- Magnetic structure and order
- Structural and magnetic phase transitions
- Incommensurate structures

Applications (in detail)

- Studies of atomic positions and bond distances in compounds with heavy and light elements or elements of similar electron shells
- Temperature dependent studies for determination of phase transitions
- Studies of order – disorder phase transitions, e.g. H bonds by determination of anisotropic mean square displacements using large Q range up to $\sin(\Theta)/\lambda > 1$
- Structure determination of compounds with highly absorbing elements (Gd, Sm, Cd, Dy) with short wavelengths
- Studies on magnetic phase transitions and T dependencies (ferri, ferro and antiferro magnets, multiferroics)
- Studies on HT superconductors (e.g. cuprates, FeAs pnictides)
- Sample characterisation by profile analysis
- Determination of sample orientation, e.g. for preparation of experiments on three axes instruments
- Presentation of fundamentals of crystallography and structure analysis for education

Sample Environment

- Closed cycle cryostat (2 K – RT)
- Mirror furnace (RT – 1500 K)
- Micro furnace (RT – 500 K)
- Uniaxial pressure cell (from PUMA)



Technical Data

Beam-tube

- SR-9b (hot source)
- Flux at sample $1.4 \cdot 10^7$ $cm^{-2}s^{-1}$ ($\lambda \approx 1.17$ Å)
- Gain by hot source x 10 ($\lambda \approx 0.6$ Å)

Wavelength

$2\Theta_M$	Ge(311)	Cu(220)	Ge(422)	Cu(420)
20°	0.503	0.443	0.408	0.280
40°	1.168	0.870	0.793	0.552
50°	1.443	1.079	0.993	0.680

Q-range

$2\Theta_M$	Ge(311)	Cu(220)	Ge(422)	Cu(420)
20°	1.46	1.95	2.12	3.09
40°	0.74	0.99	1.09	1.57
50°	0.60	0.80	0.87	1.27

Optical components

- Single detector optimised for small wavelengths (sensitivity > 90% at 0.3 Å)
- Analyzer PG(002); optional for studies of purely elastic scattering and background suppression
- Neutron filters for suppression of λ/2- or λ/3-contamination of the monochromatised beam

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MIRA

dual wavelength band instrument

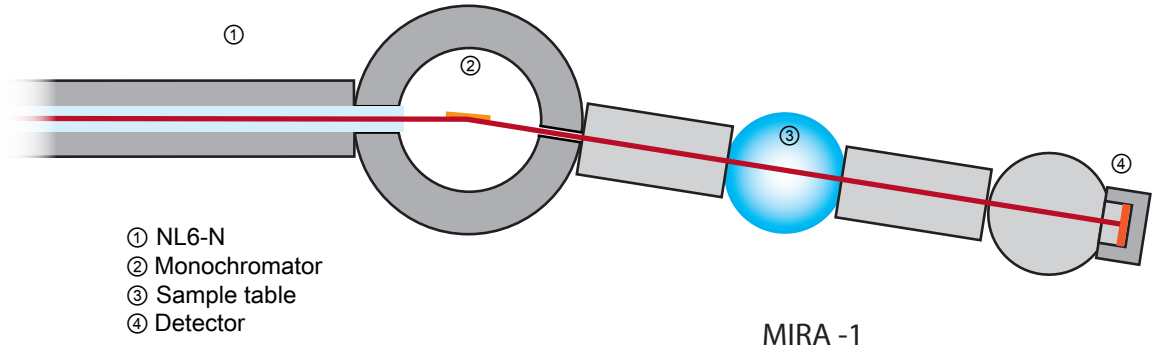
MIRA is a multipurpose instrument. With its two beam ports, namely MIRA-1 and MIRA-2, it provides neutrons over a wide range of wavelengths 3.5 Å < λ < 20 Å. The instrument can easily be moved from one port to the other without changing the sample environment. The large variety of different options offered can also be combined in most cases. This allows for a fast realisation of experiments in a very flexible way using a number of available options:

- Cold diffraction
- Cold three axes spectroscopy for extreme environments
- Small angle neutron scattering (SANS)
- MIEZE
- Reflectometry
- 3D-Polarimetry

All options can be measured in polarised mode. Using the finger detector, the instrument has a very low background of less than 0.1 cps. For MIRA-2 a q-range up to 2.5 A^{-1} with an q-resolution of 0.01 A^{-1} can be reached. Vertical and horizontal B-fields up to 2.2 T and vertical B-fields up to 7.5 T are available. Temperatures from 50 mK to 1500 K can be applied using the standard sample environment.

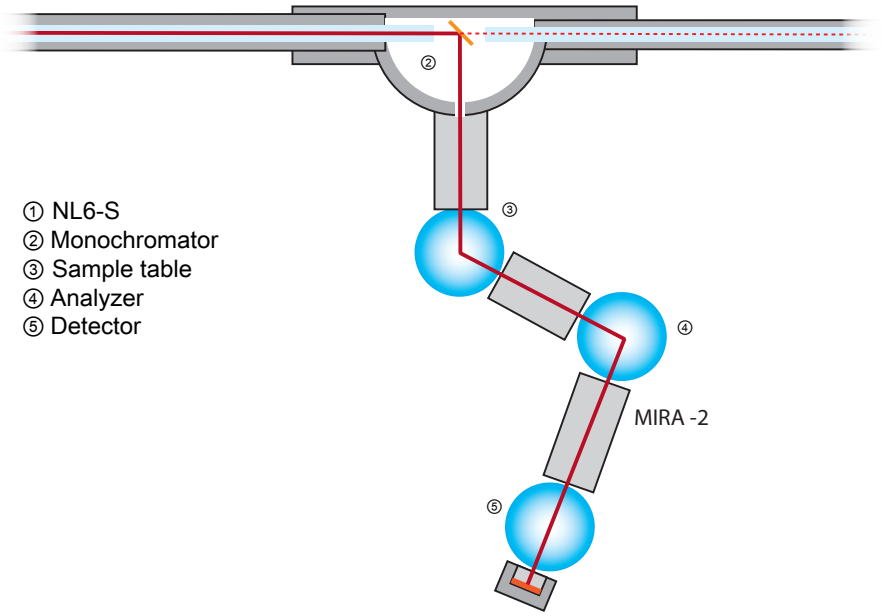
Typical Applications

- Dynamics of magentic excitations
- Determination of magnetic structures, especially large scale structures, i.e. helical spin density waves or magnetic lattices
- Quasi-elastic measurements in magnetic fields with high resolution
- Determination of structures and dynamics in extreme environments, like pressure
- Determination of layer thickness of films, for instance in polymer physics
- Reflectometry from magnetic multilayers
- Polarisation analysis



① NL6-N
② Monochromator
③ Sample table
④ Detector

MIRA -1



Technical Data

MIRA-1

Primary beam

- Neutron guide: NL6-N
- Dimensions: 10 x 120 mm² (width x height)
- Curvature: 84 m
- Coating: sides m = 2, top/bottom m = 2

Monochromator

- Intercalated HPGO $\Delta\lambda/\lambda = 2\%$
- Multilayer $\Delta\lambda/\lambda \approx 3\%$ (5% polarised)
- 6 Å < λ < 20 Å

Max. differential flux at sample

- $5 \cdot 10^5$ neutrons s^{-1} cm^{-2} at 10 Å
- $2 \cdot 10^5$ neutrons s^{-1} cm^{-2} polarised

Analyzer

- 2 cavities
- 2 bender
- ^{3}He-spin filter

Detector

- 20 x 20 cm² 2-D PSD with 1 x 2 mm² resolution
- 1 inch ^{3}He finger detector
- 20 x 20 cm² 2-D PSD, time resolution < 1 ps

MIRA-2

Primary beam

- Neutron guide: NL6-S
- Dimensions: 60 x 120 mm² (width x height)
- Coating: sides m = 2.0, top/bottom m = 2

Monochromator

- Horizontal focussing HOPG $\Delta\lambda/\lambda \approx 2\%$
- 3.5 Å < λ < 6 Å

Max. differential flux at sample

- $1 \cdot 10^7$ neutrons s^{-1} cm^{-2} at 4.7 Å (2015)
- $1 \cdot 10^6$ neutrons s^{-1} cm^{-2} polarised

Analyzer

- 2 cavities
- S-bender, transmission polariser
- ^{3}He-spin filter

Detector

- 20 x 20 cm² 2-D PSD with 1 x 2 mm² resolution
- 1 inch ^{3}He finger detector
- 20 x 20 cm² 2-D PSD, time resolution < 1 ps
- with low background < 0.1 cps

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POLI

polarised hot neutron diffractometer

POLI is a versatile two axes single crystal diffractometer mostly dedicated to the investigation of magnetic structures in single crystals using neutron spin polarisation. The using of the separate non-polarising variably focussing monochromators and optimised polarisers allows the structural investigations using polarised and non-polarised neutrons with short wave length and high resolution. Two standard options are currently implemented on POLI:

- Zero-field **s**pherical **n**eutron **p**olarimetry (SNP) using third generation polarimeter CRYOPAD;
- Non-polarised diffraction under special conditions e.g. very low temperatures (< 3 K), magnetic and electric fields, high pressures, high temperatures, etc. using dedicated sample environments and out-of-plane lifting counter.

A third measurement method named flipping-ratio is under development and planned to be operational using a new 8 T magnet in 2016.

SNP allows distinguishing between the depolarisation and polarisation rotation occurring during the scattering in the sample. X, Y, Z components of the scattered polarisation are measured for each orientation of the incoming polarisation and hence a polarisation matrix of 9 elements for an individual Bragg reflection can be found. Determining the relationship between the directions of incident and scattered polarisations gives access to the 16 independent correlation functions involved in the most general nuclear and magnetic scattering processes. Generally, this leads to the direction's determination of the magnetic interaction vector of magnetic structures. For those structures coinciding nuclear and magnetic reflections in reciprocal space, SNP leads to the amplitude's determination of the magnetic interaction vectors, and hence to the magnetisation distribution. SNP could also be employed to study the magnetic domain distribution.

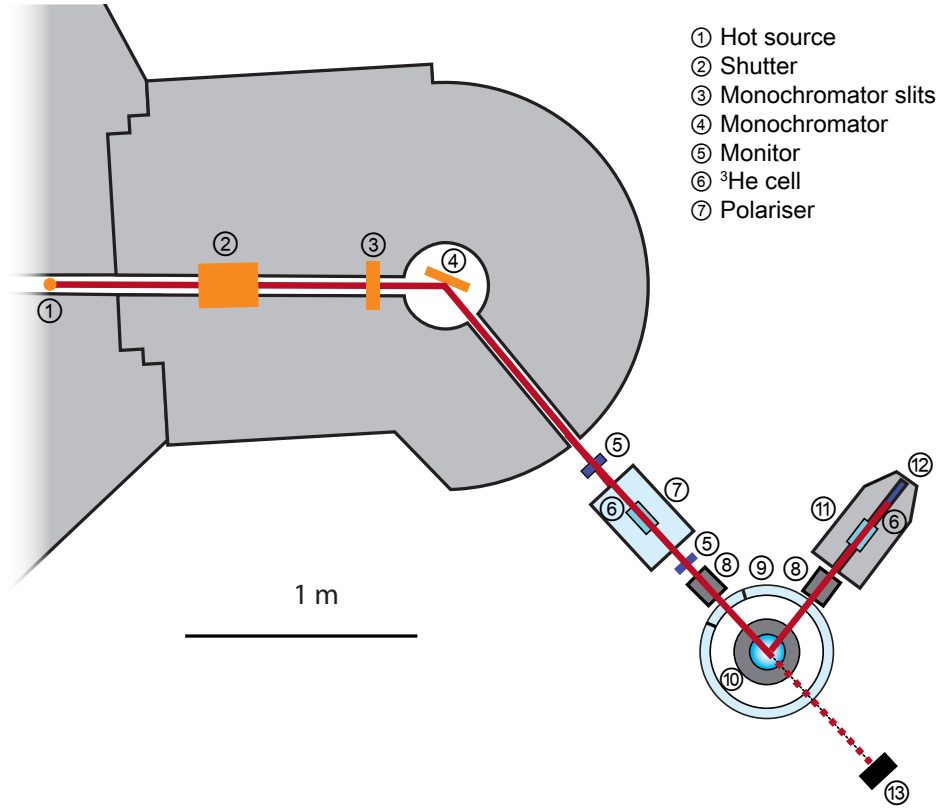
Actually, polarised ^{3}He spin filters are used on POLI in order to produce and to analyse neutron polarisation. This method offers best performance in the polarising of hot neutrons. Tuning the pressure of ^{3}He in the filter cell it is possible to optimise the polariser's performance depending on wave length or experimental needs. The automatic correction of the time-dependent polarisation is applied. Because of the ^{3}He filters' sensitivity about non-homogeneous magnetic fields, a dedicated solid state supermirror bender will be used in the future for experiments with high magnetic fields.

Typical Applications

- Complex commensurate and incommensurate magnetic structures studied in ground state (zero-field) – very useful especially for superconductors.
- Studies of magnetic or magneto-electric domains using SNP on samples cooled in zero-field as well as in external magnetic field (up to 7.5 T).
- The combination of magnetic and electric fields applied on the sample – important for the studies on multiferroic materials.
- Determination of magnetic form factors (sometimes also in antiferromagnets).

Sample Environment

- Standard closed-cycle cryostat (4 K – 425 K)
- Variox LHe cryostat (1.5 – 300 K)
- Lower temperature inserts on request
- 2.2 T HTS magnet / 7.5 T magnet on request
- 8 T dedicated magnet planned from 2016
- Electric field up to 10 kV



Technical Data

Primary beam: SR-9a on hot source

- Focussing monochromators

Crystal	λ Å	flux n/s/cm²	λ Å	flux n/s/cm²
Cu (220)	0.55	$4 \cdot 10^6$	0.9	$2.4 \cdot 10^7$
Si (311)	0.7	$7 \cdot 10^6$	1.15	$2.8 \cdot 10^7$

Diffractometer angles

with Cryopad	without Cryopad
$-10° < 2\theta < 120°$	$-30° < 2\theta < 130°$
$-180° < \omega < 180°$	$-180° < \omega < 180°$
$-4° < \xi_1 < 4°$	$-5° < \xi_1 < 5°$
$-4° < \xi_2 < 4°$	$-5° < \xi_2 < 5°$
$\nu = 0$	$-4.2° < \nu < 30°$

Neutron polarisation: ³He spin filter

- ³He polarisation: 0.75 – 0.7
- Neutron polarisation: 0.93 – 0.8
- Cell holding time: 2 days
- Cells replacement time: 5 – 10 min

Cryopad (zero-field polarimeter)

- Precision in polarisation control: better 1°
- Low background / low absorption
- LHe autonomy: 10 days
- LN_2 refill (automatic): daily
- Sample space for closed cycle cryostat or orange type cryostat

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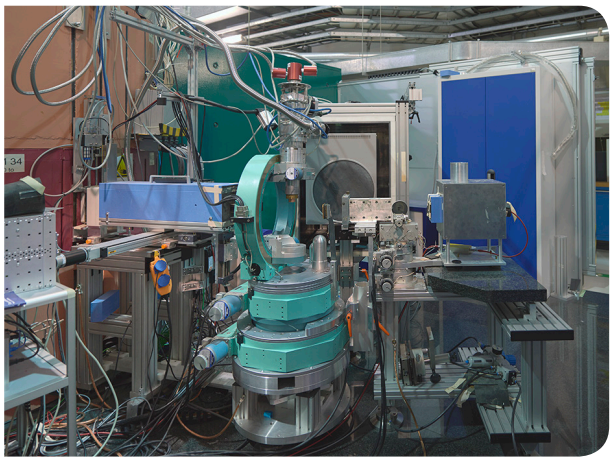
RESI

thermal neutron single crystal diffractometer



The diffractometer RESI is designed for using a maximum of thermal neutron intensity, allowing optimum measurements of weak diffraction phenomena in a large portion of the reciprocal space on single crystalline samples.

Typical Applications

Structure analysis with thermal neutrons (λ = 0.8 Å to 2 Å) is complementary to structure analysis with X-rays. The measurement possibilities provided by this instrument are crucial for many scientific questions:

- **Structure analysis, bonding theory, electron densities:** Due to the interaction with atomic cores and the diffraction angle independence of the atomic form factor, it is possible to measure Bragg scattering up to high diffraction angles.
- **Real crystals** and compounds of interest for material science are often not perfectly ordered. The elucidation of these real structures requires the analysis of the corresponding diffuse scattering. The diffuse scattering - off the Bragg reflections - is normally differentially weak and distributed continually (anisotropic) in the reciprocal space.
- **Partially crystalline** compounds, like **fibre structures,** show a specific scattering, which is highly anisotropic and continously distributed in the reciprocal space. Therefore, diffractometers with area detectors like RESI are best suited for this kind of problems.
- A new class of **aperiodic crystals** (“quasi crystals”) show dense, but discrete reflex patterns, where more than 90% of the reflexes are very weak. Additionally, due to the fact that quasi crystals often contain two or more transition metals (which are almost isoelectronic), neutrons offer much higher contrast than X-ray methods.
- **Structural phase transitions** can be accompanied by continuous reflection shifting.
- **Modulated structures** show satellite reflections at “incommensurable” positions. Both areas require analysis of large portions of the reciprocal space.
- **Twinned crystals** and **multi-domain/multi-phase crystals** are often difficult to measure on single-counter instruments. The area detector at RESI allows for easy detection and in many cases separation of reflections in such systems.

The advantages of the high-resolution area detector can be utilised best, if the reciprocal space is not too empty. That means, that RESI is optimal for cells of ca. 1000 Å^3 to ca. 20000 Å^3. Typical crystal sizes range from 5 mm^3 to 25 mm^3.

Sample Environment

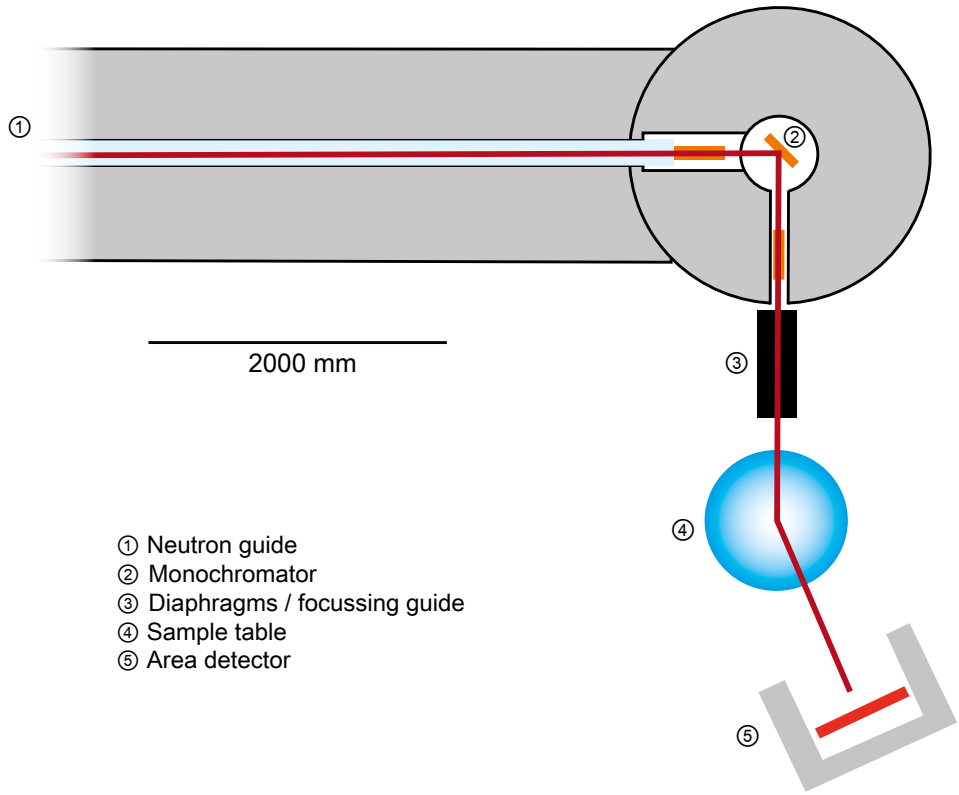
Dedicated sample environment of RESI:

- Oxford Cryosystems Cryostream 700
  temperature range 100 K - 400 K
  consumption ~ 20 l L-N_2/d

- Oxford Instruments Helijet
  temperature range 15 K - 100 K
  consumption ~ 2 l L-He / h
  sample size 1 × 1 × 1 mm³ max.

Standard sample environment usable with RESI

- Closed-cycle cryostat CC, 2.5 K – 300 K
- Closed-cycle cryostat CCR, 3 K – 100 K
  using ^{3}He insert, 500 mK – 4 K
  using ^{3}He/^{4}He dilution, 50 mK – 1 K
- Vacuum furnace, 340 K – 2100 K
- Mirror furnace, RT – 1250 K



Technical Data

Primary beam

- Beam tube SR-8b
- Neutron guide
  Length: 12 m, focussing vertical / horizontal
  section: 70 × 40 mm → 60 × 30 mm
- Coatings: m = 3 top/bottom; m = 1 side

Monochromators

Vertically focussing lamella type, fixed take-off 90°

- Cu-422, 20' mosaic, 1 Å : $2 \cdot 10^6$ n $cm^{-2}s^{-1}$
- Ge-511, 25' mosaic (deformed wafer stack)
  1.5 Å : $6 \cdot 10^6$ n $cm^{-2}s^{-1}$

Secondary neutron guide

Vertically focussing ellipitical guide-in-guide

- Length: 1 m
- Focus 400 mm after guide exit
- Coating: m = 5

Available goniometers

- Kappa-Goniometer:
  Bruker-Nonius Mach3
  carrying capacity: max 100 g
- Eulerian cradle Huber 420:
  higher carrying capacity, e.g. for closed-cycle cryostat
- Huber 2-circle goniometer with tilting head
  highest carrying capacity, e.g. for CCR with ^{3}He insert

Available detectors

- MAR345 image plate detector:
  345 mm diameter, N-sensitive image plate
- Single counter ^{3}He with optional analyzer
  for pure elastic scattering

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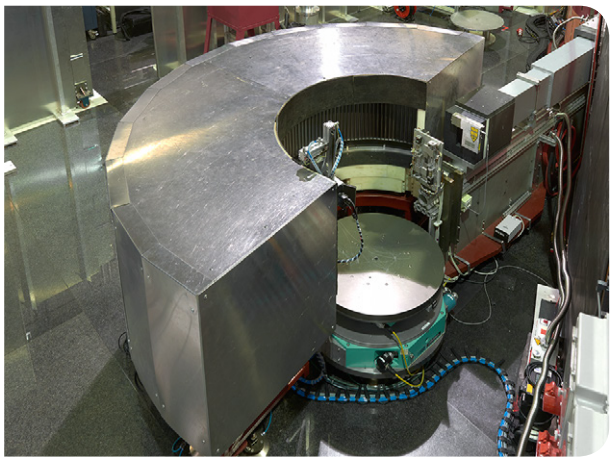
SPODI

high resolution powder diffractometer



The high resolution powder diffractometer SPODI is designed for structure solution and Rietveld refinement of structural parameters on crystalline powders. The instrument is characterised by a very high monochromator take-off angle of 155° (standard configuration). Optionally, a take-off angle of 135° is available.

The detector array consists of 80 ^{3}He position sensitive detector tubes (300 mm active height) with fixed Soller collimators of 10' horizontal divergence. The multidetector of SPODI spans an angular range of 2θ = 160°. Each detector covers 2° corresponding to 160°/ 80 detectors. Therefore the data collection is performed via stepwise positioning of the detector array to obtain a diffraction pattern of the desired step width (typically 2°/ 40 steps resulting in Δ(2θ) = 0.05°).

The two-dimensional raw data are evaluated to provide diffraction patterns corresponding to different detector heights ranging from 10 mm to 300 mm and variable detector height, accounting for vertical beam divergence effects. Thus, asymmetric broadenings at quite low and high scattering angles are overcome, while the full detector height in the medium 2θ regime can be used [1].

Various sample environmental devices enable the characterisation of materials under special conditions: A rotatable tensile rig allows in-situ studies under tensile stress, compression stress or torsion while the load axis can be oriented with respect to the scattering plane. A potentiostat for charging/ discharging of Lithium ion batteries is available as well as a device to apply high electric fields on ferroelectrics.

Typical Applications

- Determination of complex crystal and magnetic structures
- Structural evolutions and phase transformations under various environmental conditions.
- Static and thermal disorder phenomena

Research Areas

- Ionic conductors
- Materials for lithium ion batteries
- Ferroelectrics, multiferroics
- Hydrogen storage materials
- Shape memory alloys
- Superalloys
- Correlated electron systems
- Superconductors
- Minerals

Sample Environment

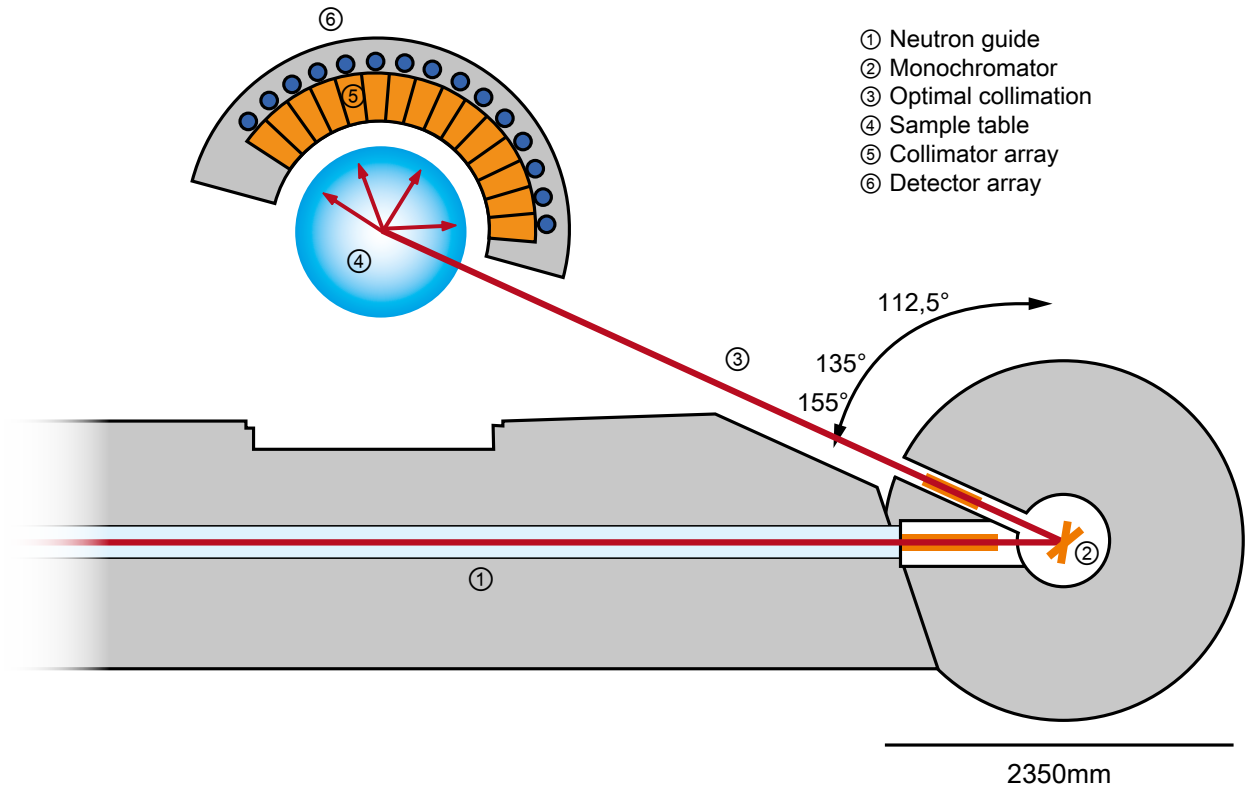
Standard sample environment of FRM II

- Closed cycle cryostat 3 – 550 K
  (with ^{3}He insert: T_{min} = 500 mK)
- Vacuum high temperature furnace
  T_{max} = 1900°C
- Cryomagnet
  B_{max} at SPODI: 5 T
- Sample changer (six samples, ambient temperature)

Special sample environment

- Rotatable tensile rig
  F_{max} = 50 kN, M_{max} = 100 Nm
- Device for electric fields
  V_{max} = 35 kV
- Potentiostat for electrochemical treatment of materials VMP3 and SP240

[1] Hoelzel, M. et al., Nucl. Instr. A 667, 32-37 (2012).



Technical Data

Monochromator

- Ge(551) wafer stack crystals
- standard configuration: take-off angle 155°
  - Ge(551): 1.548 Å
  - Ge(331): 2.436 Å
  - Ge(711): 1.111 Å

Collimation

- α1 ≈ 20’ (neutron guide)
- α2 = 5’,10’, 20’, 25’ nat. (for 155°)
  α2 = 10’, 20’, 40’ nat. (for 135°)
- α3 = 10’

Detector array

- 80 position-sensitive ^{3}He tubes,
  - angular range 2θ = 160°,
  - effective height: 300 mm

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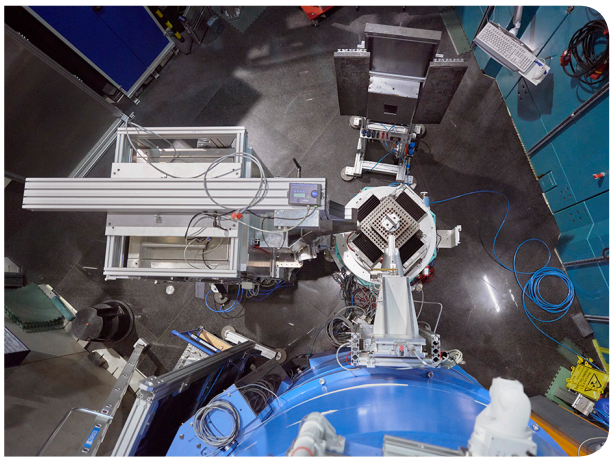
STRESS-SPEC

materials science diffractometer



In response to the development of new materials and the application of materials and components in new technologies the direct measurement, calculation and evaluation of textures and residual stresses has gained worldwide significance in recent years.

STRESS-SPEC, the materials science diffractometer is located at the thermal beam port SR-3 of the FRM II and can easily be configured either for texture or stress analysis.

The set-up utilises three different monochromators: Ge (511), bent silicon Si (400) and pyrolitic graphite PG(002). This selection of monochromators and the possibility to vary automatically the take-off angles from $2\theta_M$ = 35° to 110° allows to find a good compromise between resolution and intensity for each measuring problem.

The gauge volume defining optical system of primary and secondary slits is designed with regard to reproducibility of geometrical alignment and sturdiness. Both slit systems are linked to the sample table and the detector in such a way that the center of the beam remains the same under all conditions. Samples can be aligned using theodolites and a camera system. In addition the possibility to scan surfaces of components offline using a CMM laser scanner is available at STRESS-SPEC.

Typical Applications

Residual stress analysis [1]

- Industrial components
- Welds
- Superalloys
- Strain mapping
- Surface measurements from 150 µm possible [2]

Texture determination [3]

- Global textures
- Local textures
- Strain pole figures
- FHWM pole figures

Structural applications

- Phase transformation dynamics
- Spatially resolved phase analysis (e.g. batteries)

Sample Environment

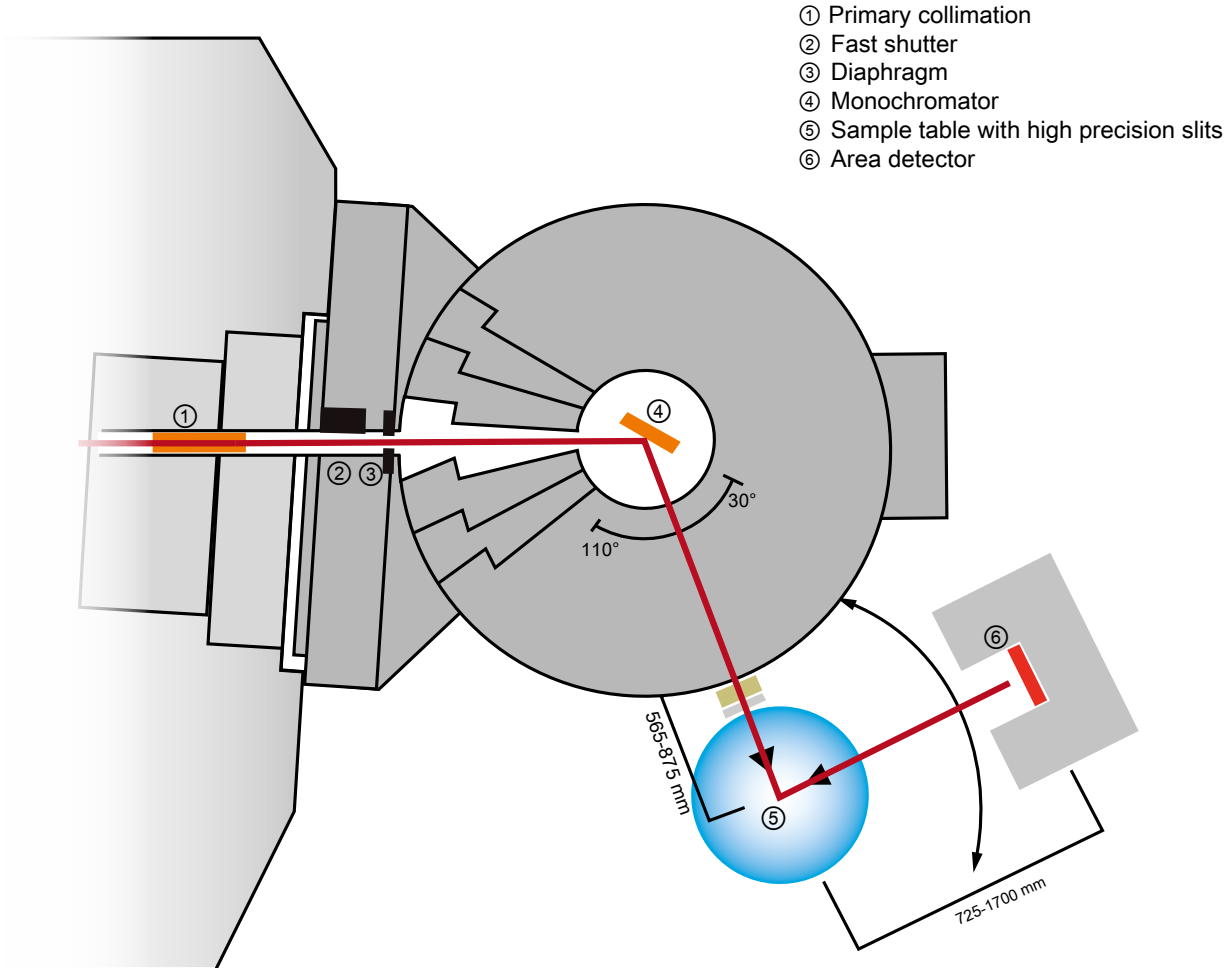
- XYZ-table
  capacity 300 kg, Travel xy = ±120 mm,
  z = 300 mm, accuracy ~ 10 µm
- Load frame
  +/- 50 kN, heatable to 1000°C
- Full circle Eulerian cradle (max. load 5 kg)
- ¼ circle Eulerian cradle for heavy samples
- Standard sample environment (e.g. furnace, cryostat)

A positioning system consisting of a Stäubli-6-axes robotic arm for texture and strain measurements (payload up to 30 kg) can be mounted instead of the standard sample table. It offers more flexibility than an Eulerian cradle and can be also used as automatic sample changer for texture measurements.

[1] Hofmann, M. et al., Physica B, 385-386, 1035-1037 (2006).

[2] Saroun, J. et al., J. Appl. Cryst., 46, 628-638 (2013).

[3] Brokmeier, H.-G. et al., Nucl. Instr. Meth. A, 642, 1, 87-92 (2011).



Technical Data

Neutron beam

- SR-3 thermal neutrons
- Collimators (‘in-pile’) 15’, 25’, open

Monochromators

- Ge(511), Si(400), PG(002)
- $2\theta_M$ 35° – 110° continuous
- Wavelength 1 Å – 2.4 Å ; (2.5 $Å^{-1}$ < Q < 10.5 $Å^{-1}$)

Possible slit size - Residual Stress

- Primary slit: automatic continously variable up to 7 x 17 mm^2 (W x H)
- Secondary slit: continuously variable up to 15 mm
- Radial collimators (FWHM = 1 mm, 2 mm, 5 mm, 10 mm)

Possible slit size – Textures

- Primary slit: max. 30 x 40 mm^2 (W x H)
- Secondary slit: continuously variable up to 15 mm or open

Detector

- ^{3}He-PSD, 25 x 25 cm^2; 256 × 256 pixel

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www.mlz-garching.de/stress-spec

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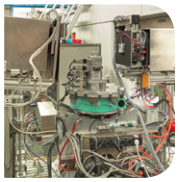
KWS-1
small angle scattering diffractometer

KWS-2
small angle scattering diffractometer

KWS-3
very small angle scattering diffractometer with focusing mirror

MARIA
magnetic reflectometer with high incident angle



NREX
neutron reflectometer with X-ray option

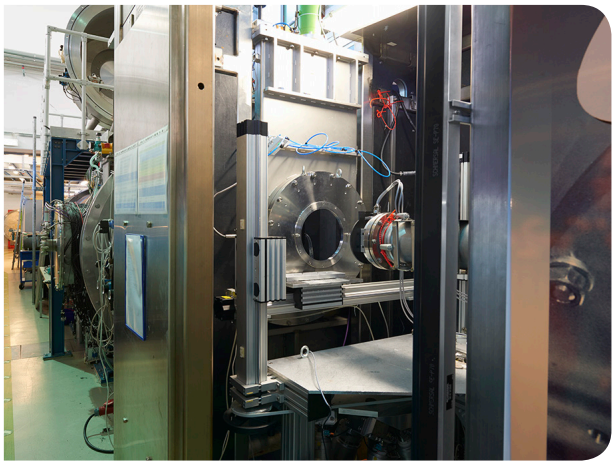
REFSANS
horizontal time-of-flight reflectometer with GISANS option

SANS-1
small angle neutron scattering

Large Scale Structures

KWS-1

small angle scattering diffractometer



The KWS-1 is dedicated to high resolution measurements [1] due to its 10% wavelength selector. This property is interesting for highly ordered or highly monodisperse samples. With the foreseen chopper the wavelength uncertainty can be reduced further to ca. 1%. The scientific background of KWS-1 is placed in magnetic thin films. Magnetic samples will be studied with the full polarisation analysis including incident beam polarisation and polarisation analysis of the scattered neutrons. In front of the collimation, a 3-cavity polariser with V-shaped mirrors is placed. The full bandwidth of 4.5 to 20 Å will be covered with min. 90% (95% typical) polarisation. A radio frequency spin flipper allows for changing the polarisation. The polarisation analysis will be realised with ^{3}He-cells which will be optimised for the used wavelength and scattering angle. Vertical magnets will be provided to render the magnetic field at the sample position. Thin films can be well studied in the grazing incidence geometry – the method is called **g**razing **i**ncidence **s**mall **a**ngle **n**eutron **s**cattering (GISANS). A newly installed hexapod will allow for positioning the sample with 0.01 mm and 0.01° precision.

Classical soft-matter systems will be investigated on KWS-1 if the resolution is needed. Biological samples can be handled due to the detector distance of ca. 1 m, which will allow for maximal scattering angles of Q = 0.5 Å^{-1}.

The MgF_2 lenses are used for the high flux mode with large sample areas, while the resolution stays in the classical SANS range. These enhanced intensities allow for real time measurements in the 1/10 second region (typical 1 s).

The chopper in parallel allows for studying faster dynamics in the ms range. The so-called TISANE mode interlocks the chopper frequency with the excitation field frequency and with the detection binning. The precise consideration of the flight times allows for higher precision compared to classical stroboscopic illuminations.

Typical Applications

- Grain boundaries
- Alloys
- Magnetic structures
- Flow lines
- Soft matter and biology (as for KWS-2)
- Complex fluids near surfaces
- Polymer films
- Magnetic films
- Nanostructured films

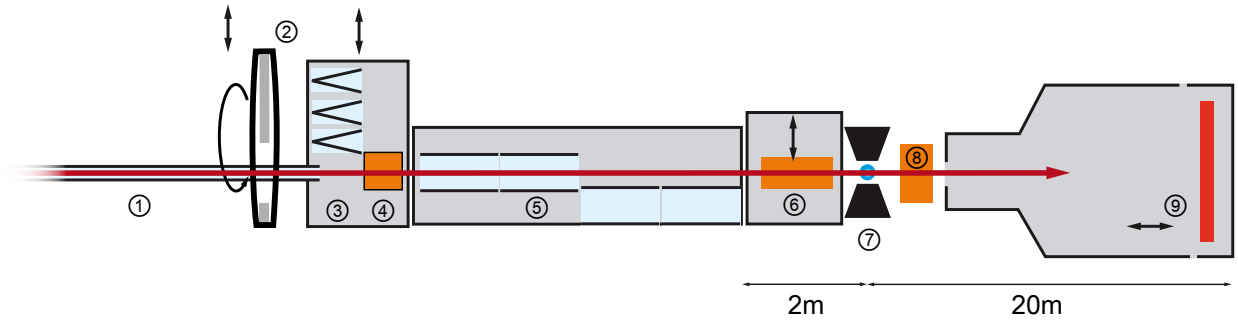
Sample Environment

- Rheometer shear sandwich
- Rheowis-fluid rheometer (max. shear rate 10000 s^{-1})
- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders: 9 horizontal x 3 vertical (temperature controlled) for standard Hellma cells 404-QX and 110-QX
- Oil & water thermostats (range -40 – +250) electric thermostat (RT – 200°C)
- 8-positions thermostated (Peltier) sample holder (-40°C – 150°C)
- Magnet (horizontal, vertical)
- Cryostat with sapphire windows
- High temperature furnace
- Pressure cells (500 bar, 2000 bar, 5000 bar)

[1] Feoktystov, A. et al., J. Appl. Cryst. 48 (2015), 61-70.

Jülich Centre for Neutron Science

Email:
Office:
Instrument:



① Neutron guide NL3
② High-speed chopper
$\Delta\lambda/\lambda$=1%
③ Changeable polarisers
④ Spin flipper
⑤ Neutron guide sections 18 x 1m
⑥ MgF_2 focussing lenses
⑦ Sample position with magnet
⑧ ^{3}He spin filter
with reversable polarisation
(to be implemented)
⑨ Anger-type scintillation detector

Technical Data

Overall performance

- Q = 0.0007 – 0.5 Å^{-1}
- Maximal flux: 1.5·10^8 n cm^{-2} s^{-1}
- Typical flux: 8·10^6 n cm^{-2} s^{-1} (collimation 8 m, aperture 30 x 30 mm², λ = 7 Å)

Velocity selector

- Dornier, FWHM 10%, λ = 4.5 Å – 12 Å, 20 Å

Chopper

- For TOF-wavelength analysis, FWHM 1%

Polariser

- Cavity with V-shaped supermirror, all wavelengths
- Polarisation better 90%, typical 95%

Spin-flipper

- Radio-Frequency spin flip probability better than 99.8%

Active apertures

- 2 m, 4 m, 8 m, 14 m, 20 m

Aperture sizes

- Rectangular 1 x 1 mm² – 50 x 50 mm²

Sample aperture

- Rectangular 1 x 1 mm² – 50 x 50 mm²

Neutron lenses

- MgF_2, diameter 50 mm, curvature 20 mm
- Packs with 4, 6, 16 lenses

Sample stage

- Hexapod, resolution better than 0.01°, 0.01 mm

Detector 1

- Detection range: continuous 1.5 m – 20 m
- ^{6}Li-Scintillator 1 mm thickness + photomultiplier
- Efficiency better than 95%
- Spatial resolution 5.3 x 5.3 mm², 128 x 128 channels
- Max. countrate 0.6 MHz (τ_{dead} = 0.64 µs)

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KWS-2

small angle scattering diffractometer

KWS-2 [1] represents a classical pinhole SANS instrument where, combining the pinhole mode using different neutron wavelengths and detection distances with the focusing mode using MgF_2 lenses, a wide Q-range between 1 x 10^{-4} and 0.5 $Å^{-1}$ can be explored. It is dedicated to high intensity/ wide-Q investigation of mesoscopic structures and structural changes due to rapid kinetic processes in soft condensed matter, chemistry, and biology. The high neutron flux, comparable with that of the world leading SANS instruments, which is supplied by the neutron delivery system (cold source, selector, guides) [2, 3], and the possibility to use large sample area using focussing lenses, enable high intensity and time-resolved studies. On demand, the instrument resolution can be tuned using the double-disc chopper with adjustable opening slit, which allows the variation of the wavelength spread between 2 and 20%. This offers a high flexibility in optimising the instrument performance towards improved characterisation of structural details and accurate beam characteristics (avoid the gravity and chromatic effects while using the lenses).

Typical Applications

- Colloids, nanocomposites, polymer gels, networks
- Polymer blends, diblock copolymers
- Microemulsions, complex fluids, micelles
- Membranes, films; in-situ adsorption – desorption/ humidifying – drying phenomena
- Kinetics of demixing, formation, aggregation
- Shear induced micelle deformation, rubber network deformation, nanocomposite ordering
- Protein structure and folding/ unfolding
- Pressure dependence of phase diagrams, fluctuations, molecular interactions
- In-situ crystallisation semi-crystalline polymer

Self-assembly of block-copolymers in micellar structures is a widely studied topic at KWS-2. The properties of block-copolymer micelles tuned by changing e.g. solvent quality, temperature, solvent selectivity, block copolymer composition, and molecular weight are investigated thoroughly benefiting from the adjustable instrumental resolution between 2 and 20%.

Another kind of typical application relate to fast structural changes of micellar systems (formation, transformation or chain exchange at equilibrium) or polymer crystallisation which are investigated by time-resolved SANS in the second or sub-second (up to 50 ms) regimes. More recently, the determination and control of the morphological parameters of biocompatible gels and amphiphiles became an important topic of study stimulated by the demands from nanomedicine related to the design of new functional drug delivery vehicles.

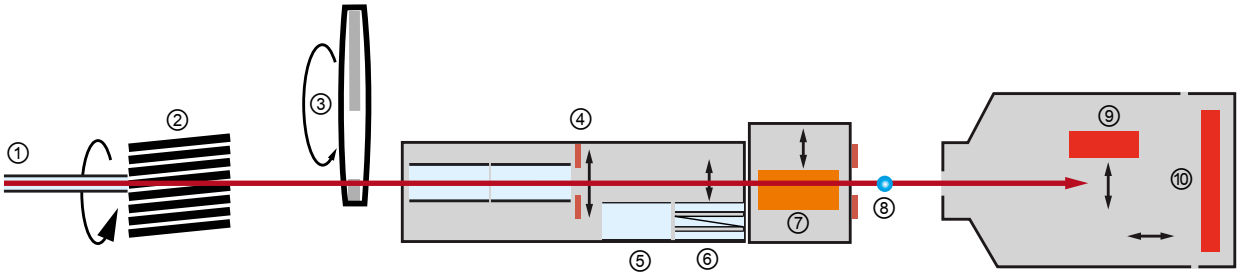
Sample Environment

- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders: 9 horizontal x 3 vertical (temperature controlled) for standard Hellma cells
- Oil & water thermostats (typical 10 ...100°C)
- 8-positions thermostated (Peltier) sample holder (-40°C ... 150°C)
- Magnet (1.5 T, vertical)
- Cryostat with sapphire windows
- Pressure cells (500 bar, 5000 bar)
- Humidity chamber, 5% … 95% for 10°C … 60°C

Complementary in-situ techniques (optional at sample aperture, see instrument plan)

- FT-IR spectroscopy
- DLS & SLS
- ^{3}He spin analyzer (SEOP)

[1] Radulescu, A. et al., J. Phys. Conf. Series 351, 012026 (2012).
[2] Radulescu, A ., Ioffe, A., Nucl. Inst. Meth. A, 586 , 55 (2008).
[3] Radulescu, A. et al., Nucl. Inst. Meth. A 689, 1 (2012)



① Neutron guide
② Velocity selector Δλ/λ=20%
③ High-speed chopper Δλ/λ=1%
④ Entrance aperture
⑤ Neutron guide sections 18 x 1m
⑥ Transmission polariser
⑦ MgF_2 focussing lenses
⑧ Sample aperture
⑨ High resolution position-sensitive detector
⑩ ^{3}He tubes array detector

Technical Data

Overall performance

- Q = 0.0001… 1 $Å^{-1}$
- Maximal flux: 2 x 10^8 n cm^{-2} s^{-1}
- Typical flux: 2.5 x 10^7 n cm^{-2} s^{-1} (collimation 8 m, 50 x 50 mm^2, λ = 5 Å)

Velocity selector

- Astrium, Δλ/λ = 20%, λ = 3… 20 Å;

Chopper

- Tunable Δλ/λ: 20%... 2% (TOF analysis)

Active apertures

- 2 m, 4 m, 8 m, 14 m, 20 m, sample position

Aperture sizes

- Rectangular 1 x 1 mm^2 – 50 x 50 mm^2

Neutron lenses

- MgF_2, diameter 50 mm, curvature 20 mm
- Packs with 4, 6,16 lenses

Polariser

- Transmission, P > 95% for λ > 4.5Å

Sample stage

- XYZθ translational-rotational stage + craddle
- Accuracy better than 0.01°, 0.01 mm

Detector 1

- Detection range: continuous 1 – 20 m
- ^{3}He tubes array, active area ~0.9 m^2, count rate for no deadtime >2 MHz, resolution = < 8 mm, stability of pixel response ~0.1%, efficiency 85% for 5 Å

Detector 2 (high res.)

- Spatial resolution 0.45 x 0.45 mm^2
- Active area: Ø = 8.7 cm
- ^{6}Li-Scintillator 1 mm thickness
- Fixed position: 17 m after sample position

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www.mlz-garching.de/kws-2
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KWS-3

very small angle scattering diffractometer with focusing mirror

KWS-3 is a **v**ery **s**mall **a**ngle **n**eutron **s**cattering (VSANS) instrument running on the focussing mirror principle. The principle of this instrument is a one-to-one image of an entrance aperture onto a 2D position sensitive detector by neutron reflection from a double-focussing toroidal mirror.

The instrument's standard configuration with a 9.5 m sample-to-detector distance allows performing scattering experiments with a wave vector transfer resolution between $4.0 \cdot 10^{-5}$ and $2.5 \cdot 10^{-3}$ Å^{-1}, bridging a gap between Bonse-Hart and pinhole cameras. A second sample position at 1.3 m sample-to-detector distance extends the Q-range of the instrument to $2.0 \cdot 10^{-2}$ Å^{-1} and reaches more than one-decade overlapping with the classical pinhole SANS instruments. Another "mobile" sample position can be installed to adept sophisticated sample environment between 8 and 2 m sample-to-detector distance according to the requested instrumental resolution.

The instrument covers the Q range of small angle light scattering instruments. Especially when samples are turbid due to multiple light scattering, V-SANS gives access to the structural investigation. Thus, the samples do not need to be diluted. The contrast variation method allows for highlighting of particular components.

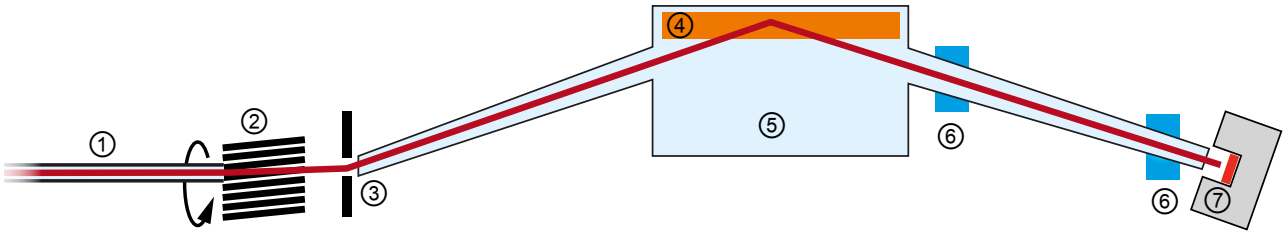
Small-angle scattering is used for the analysis of structures with sizes just above the atomic scale, between 1 and about 100 nm, which can not be assessed or sufficiently characterised by microscopic techniques. KWS-3 is an important instrument extending the accessible range of scattering angles to very small angles with a superior neutron flux when compared to a conventional instrumental set up with pinhole geometry. Thus, the length scale that can be analysed is extended beyond 10 µm for numerous materials from physics, chemistry, materials science, and life science, such as alloys, diluted chemical solutions, and membrane systems.

Typical Applications

- High-flux bridge between Bonse-Hart and conventional SANS diffractometers
- Colloid science: mixtures of particles, particles of micron size, silicon macropore arrays
- Materials science: filled polymers, cements, microporous media
- Polymer science: constrained systems, emulsion polymerisation
- Bio science: aggregations of bio-molecules, protein complexes, crystallisation of proteins
- Hierarchical structures
- Multilamellar vesicles

Sample Environment

- Anton-Paar fluid rheometer
- Stopped flow cell
- Sample holders:
  - 4 horizontal x 2 vertical (temperature controlled) for standard Hellma cells 404-QX
  - 9 horizontal x 2 vertical (room temperature) for standard Hellma cells 404-QX
- Oil & water thermostats (typical 10 – 100°C)
- Electric thermostat (RT - 200°C)
- 6-positions thermostated (Peltier) sample holder (-40 – 150°C)
- Magnet (2 T, vertical)
- Magnet (5 T, horizontal)
- Cryostat with sapphire windows
- High temperature furnace
- Pressure cells (500 bar, 2000 bar, 5000 bar)



① Neutron guide NL3a
② Velocity selector
③ Entrance aperture
④ Toroidal mirror
⑤ Mirror chamber
⑥ Sample positions
⑦ Detector

Technical Data

Overall performance

- Resolution:
  $\delta Q = 10^{-4}$ Å^{-1} (extension to $4 \cdot 10^{-5}$ Å^{-1} possible)
- Q-range:
  $1.0 \cdot 10^{-4} – 3 \cdot 10^{-3}$ Å^{-1} at 9.5 m distance
  $1.5 \cdot 10^{-3} – 2 \cdot 10^{-2}$ Å^{-1} at 1.3 m distance
- Neutron flux:
  high-resolution mode: > 10000 n s^{-1}
  high-intensity mode: > 60000 n s^{-1}

Monochromator

- MgLi velocity selector
- Wavelength spread $\Delta\lambda/\lambda = 0.2$
- Wavelength range λ = 10 - 30 Å (maximal flux at 12.8 Å)

Aperture size (focus)

- 1 × 1 mm^2 – 5 × 5 mm^2

Beam size at 9.5 m

- 0 × 0 mm^2 – 100 × 25 mm^2

Beam size at 1.3 m:

- 0 × 0 mm^2 – 15 × 10 mm^2

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www.mlz-garching.de/kws-3
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MARIA

magnetic reflectometer with high incident angle

The neutron reflectometer MARIA with polarisation analysis was designed for the investigation of thin magnetic layered structures down to the monolayer scale and lateral structures. The reflection of polarised neutrons allows to determine individually the density and the modulus and the direction of the magnetisation vector of buried layers.

MARIA is optimised for layer thicknesses between 3 – 300 Å and lateral structure sizes from nm to µm sizes. Consequently the instrument is designed for small focused beam and sample sizes of 1 cm^2 at λ = 4.5 Å (available: 4.5 Å < λ < 40 Å) in a vertical orientation with a maximum incident angle of 180° and outgoing angle ranging from -14° to 100°. MARIA provides polarisation analysis in standard operation, where the beam is polarised by a polarising guide (z-geometry; 4.5 Å < λ < 10 Å) and analysed by a wide angle ^{3}He-cell.

Beside the above described reflectometer mode with good resolution in the horizontal scattering plane, MARIA can be used in the GISANS mode with additional resolution in the vertical direction. The latter mode allows for measuring lateral structures down to the nm scale.

At the sample position, a Hexapod with an additional turntable (360°) is installed, which can take a load up to 500 kg. In the standard configuration magnetic fields are provided up to 1.3 T (Bruker electromagnet) and cryogenic temperatures down to 4 K (He closed cycle cryostat). Beside this standard setup the complete sample environment of the JCNS can be adopted to MARIA so that magnetic fields up to 5 T and temperatures from 50 mK to 500 K are available.

All parts of MARIA are controlled by a computer system according to the “Jülich-Munich” standard based on a Linux workstation. This allows a flexible remote control with automatic scan programs, including the control of sample environment as cryostat and electromagnet.

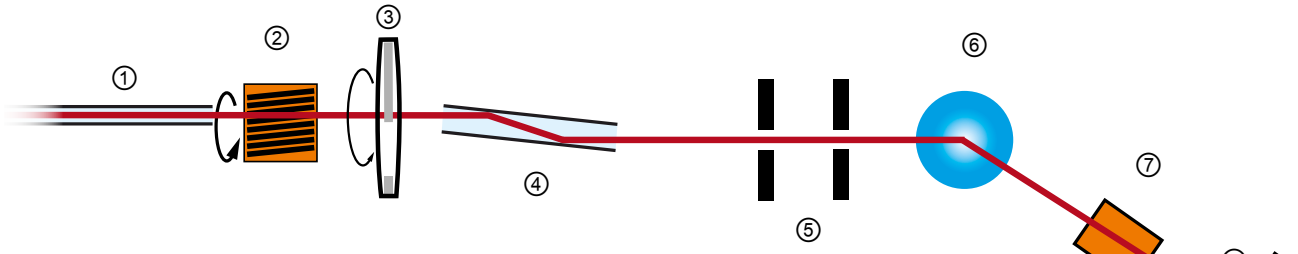
Typical Applications

With scattering under grazing incidence we investigate depth-resolved the laterally-averaged magnetisations and the correlations between their lateral fluctuations. With an additionally polarised neutron beam we derive a vector information on the laterally-averaged magnetisation (reflectivity) and on the correlations between their lateral fluctuations (off-specular scattering – µm length scale, GISANS – nm length scale).

In general, MARIA can be used for measurements of magnetic roughness, the formation of magnetic domains in thin layered structures, lateral structures, etc. (polarised mode) and density profiles, structures of solid polymer layers, etc. (unpolarised mode with higher intensity).
Furthermore possible without the need for multilayers investigation of:

- Diluted semiconductors
- Influence of the substrate
- Interfaces between oxide materials

Additionally the instrument in non-polarised beam mode can be used for reflectometry and GISANS studies of “soft” layers at the solid/ liquid interface by the use of appropriate liquid cells that are available at the beamline. Candidate systems for such investigations include polymer brushes, polyelectrolyte multilayers, biomimetic supported membranes, adsorbed proteins etc. For typical applications involving deuterated solvents the dynamic range that can be expected covers 7 order of magnitude.



① Neutron Guide NL5-N
② Velocity selector
③ Fermi chopper
④ Polariser
⑤ Slit pair
⑥ Hexapod sample table
⑦ Polarisation analyzer (^{3}He)
⑧ Detector

Sample Environment

The optimal sample size for MARIA is 10 × 10 mm² with the following parameters:

- Thin magnetic layers down to sub mono layers
- Polarisation analysis as standard
- Layer thickness of 1 – 300 Å optimised, but – 1000 Å (multi layers) should be feasible
- Lateral structures of nm to µm
- Temperature controlled liquid cells for soft matter, accomodating various substrates

Besides the described cryogenic temperatures and magnetic fields MARIA can provide users with a fully equipped Oxid-MBE (**M**olecular **B**eam **E**pitaxy). The typical sample sizes are 10 × 10 mm² and as targets we can provide Al, Cr, Pr, Fe, La, Nb, Ag, Nd, Tb, Sr, Mn, Ti and Co.

Technical Data

Primary beam

- Neutron guide NL5-N:
  vertically focussing elliptic guide
- Monochromator: Velocity selector
- Wavelength:
  4.5 Å – 10 Å (polarised)
  4.5 Å – 40 Å (unpolarised)
- Resolution:
  10% velocity selector
  1%, 3% Fermi chopper
- Double reflection polariser
- Horizontal scattering plane

Flux at sample

- Expected pol. flux $5 \cdot 10^7$ n cm^{-2} s^{-1} for 3 mrad collimation

Distances and angles

- 4100 mm distance S1 – S2 (collimation)
- 400 mm distance S2 – sample
- 50 mm × 40 mm (w × h) max. opening S2
- 1910 mm distance sample – detector
- 120° maximum detector angle
- GISANS option: 4 m collimation length

Accessible Q-range

- Reflectometry:
  Q_z- range 0.002 Å^{-1} – 3.2 Å^{-1}
  Q_x- range $6 \cdot 10^{-5}$ Å^{-1} – 0.001 Å^{-1}
  α_f -14° – 100°
- GISANS option:
  Q_y- range 0.002 Å^{-1} – 0.2 Å^{-1}

Polarisation analysis

- ^{3}He cell

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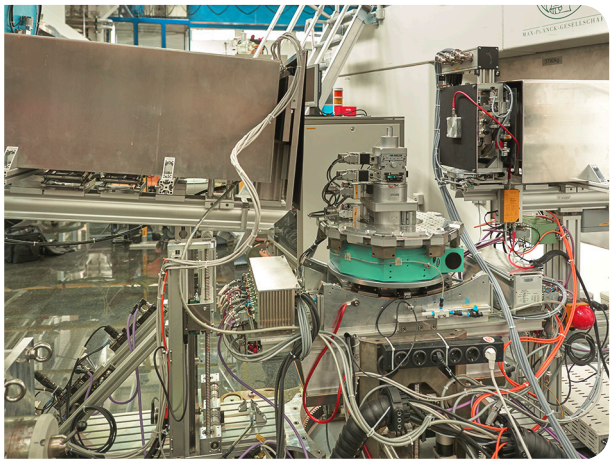
NREX

neutron reflectometer with X-ray option



The neutron/ X-ray contrast reflectometer NREX, operated by the Max Planck Institute for Solid State Research, is designed for the determination of structural and magnetic properties of surfaces, interfaces, and thin film systems.

The instrument is an angle-dispersive fixed-wavelength machine with a default wavelength of 4.3 Å. A horizontal focussing monochromator gives the possibility to switch between modes “high intensity/ relaxed resolution” and “high resolution/ reduced intensity” and provides a beam especially for small samples (down to 5 x 5 mm²). A Beryllium filter attenuates higher order reflections. Transmittance supermirrors m = 3.5 with a polarising efficiency of P = 99% and high efficiency gradient RF field spin flippers are used for a full 4 spin channel polarisation analysis.

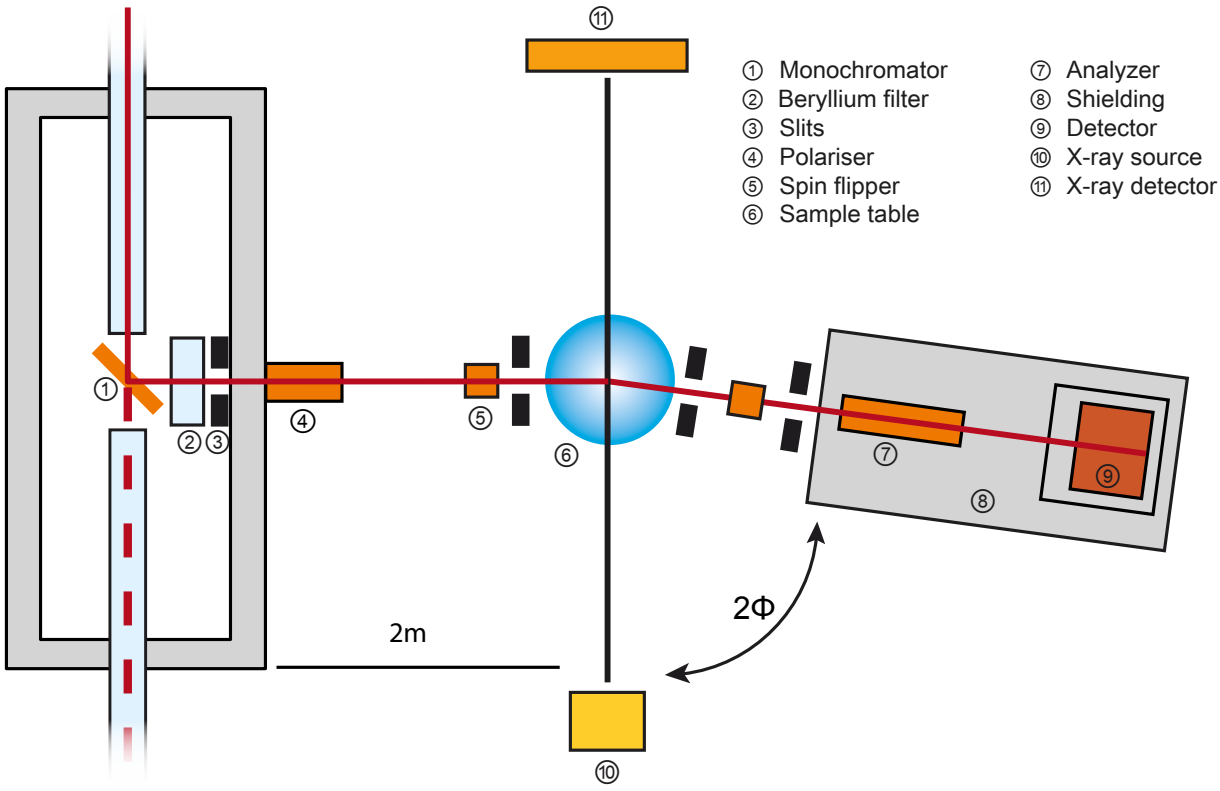
The sample is aligned horizontally. By tilting the sample the incident angle is varied. The detector arm can move for GISANS horizontally as well as vertically for specular and diffuse scattering measurements. Neutrons are detected with a 20 x 20 cm² position sensitive or a pencil detector. An X-ray reflectometer can be mounted on the sample table orthogonal to the neutron beam. It allows for the in-situ characterisation of sensitive soft matter samples and neutron/ X-ray contrast variation experiments.

Typical Applications

The instrument provides specular and off-specular reflectometry as well as grazing incidence small angle diffraction both in polarised and non-polarised modes. While the specular reflectivity allows determining the scattering length density profiles (20 – 1500 Å) with nm precession along the surface normal, the off specular reflectivity is sensitive to in-plane-inhomogeneity like roughness, (magnetic) domains, vortices in superconductors- and clusters- in the µm-range. To probe lateral (in-plane) structures in the order of atom distance (down to few Å) at the surface, grazing incidence diffraction is provided.

Sample Environment

A closed cycle crystat (down to 3.5 K) and an electromagnet for fields up to 3.5 T applicable in all three space-directions are provided. Additionally the standard sample environment (magnets up to 7.5 T and ^{3}He inserts for the cryostat down to 50 mK) are available. To the instrument pool belong a cell for investigations at the solid/ liquid interface and a gastight chamber for experiments under defined environmental conditions (arbitrary atmospheres: for example defined relative humidity) at the solid/ air interface.



Technical Data

Monochromator

- Type: 7 × 5 HOPG crystals, Horizontal focussing
- Wavelength: 4.3 Å
- Wavelength resolution: 1…2%
- Distance to sample: 2500 mm
- Higher order filter: cooled Be

Collimation

- Vertical
  - Slit sizes: 0.2 – 6 mm
  - Divergence: 0.05 – 1.4 mrad
- Horizontal
  - Slit: 0.2 – 100 mm

Polarisation

- Beam polarisation: > 99%
- Flipper efficiency: > 99%

Detector

- 2 pencil detectors: ^{3}He
- 2D area detector: ^{3}He wire chamber
  - Active area: 200 × 200 mm²
  - Lateral resolution: 3 mm
- Distance to sample: 2465 mm

Dynamical- and Q-Range

- Specular reflectivity: 1 : 1 x 10^{-6} (@ 5 × 5 mm² sample and full polarisation)
- Q_z: 0.005 - 0. 5 Å^{-1}
- δQ_z ($0 < Q_z < 0.2$ Å^{-1}) < 0.002 Å^{-1}

X-rays

- Source: Cu-Kα fixed anode (1.54 Å)
- Monochromator: Goebel Mirror & Double Ge-Crystal
- Detector: 0-dimensional NaI scintillation counter

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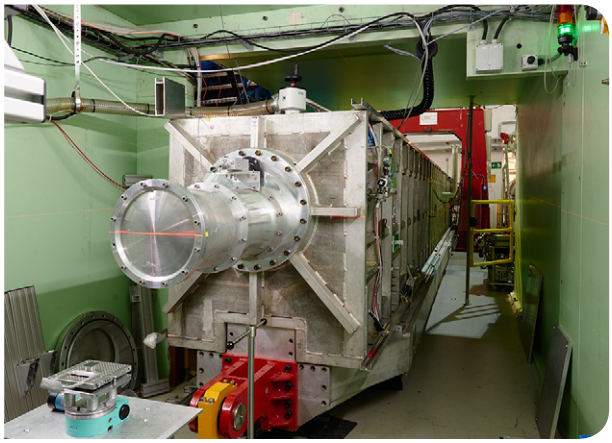
REFSANS

horizontal time-of-flight reflectometer with GISANS option



The horizontal reflectometer REFSANS was designed to enable specular reflectometry as well as grazing incidence neutron scattering studies of both solid samples and liquid-air interfaces.

By using a polychromatic incident neutron beam and **t**ime-**o**f-**f**light (TOF) wavelength resolution, REFSANS gives simple access to a large Q range. Typical reflectometry curves are recorded using three incident angles to cover the 0 – 2 nm^{-1} Q_z domain. In the case of GISANS, the TOF mode provides direct information about the full penetration curve from a single incident angle.

The instrument versatility relies on the one hand on the fact that the wavelength resolution can be tuned between 0.2 and 10%, on the other hand on the possibility to independently control the horizontal and vertical divergence by means of a complex optic. These two characteristics make it possible to optimally perform reflectometry and GISANS. One can easily switch between these two configurations for a given sample and thereby fully investigate its structure without having to alter externally applied fields or constraints (temperature, chemical environment).

For reflectometry, a horizontally smeared out beam of up to 80 mm width is used in order to maximise intensity. For GISANS, up to 13 point beams are impinging on the sample and point focused on the 2D position sensitive detector placed at a distance of 9 m. This setup allows to resolve lateral structures with dimensions up to several micrometer. In all other cases the detector can be placed at any distance between 1.5 m and 12 m from the sample, thereby making it easy to control the explored angular range and optimise the resolution/ background intensity trade-off.

Typical Applications

The TOF reflectometry and GISANS techniques can be used to characterise thin films in general. Reflectometry provides information about the structure along the sample's normal, while GISANS gathers information about the in-plane correlations. Typical reflectometry experiments include:

- Characterisation of polymer thin film structure and their swelling behaviour in presence of various vapors
- Biological systems such as solid or liquid supported membranes (e.g determination of the morphology and localisation of proteins at interfaces)
- Metallic multilayers (e.g magnetically active films)
- Coatings

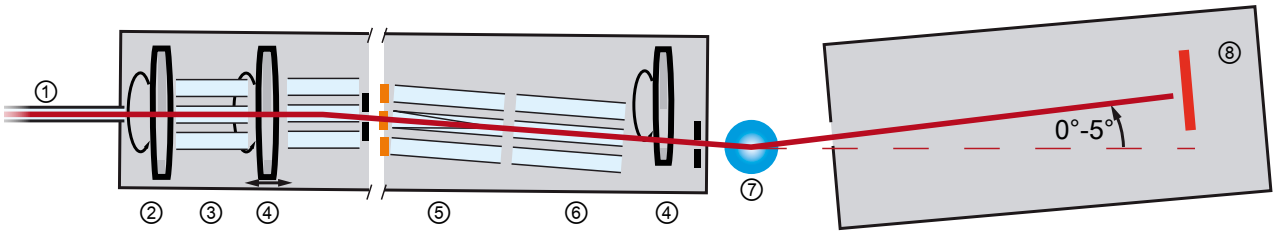
GISANS complements these measurements and has been successfully applied to polymer thin films (lateral correlations e.g in dewetted systems, detection and identification of polymer lamellae in immiscible blends or semicristalline systems), composites, nanopatterned metallic surfaces for which Bragg truncation rods have been reconstructed.

Sample Environment

The optimal sample size is 70 × 70 mm^2. Various environments are available:

- Simple sample changer for three substrates
- Vibration controlled Langmuir trough for liquid-air interfaces studies
- Magnetic fields up to 7 Tesla
- Cryostats

A heavy load Huber goniometer (max. load 200 kg) is normally used to carry the experimental set-up, but it can easily be removed and replaced by custom equipments.



① Neutron guide NL2b
② Master chopper
③ Neutron guide elements
④ Slave chopper 1+2
⑤ Changeable polariser
⑥ Neutron guide elements
⑦ Sample position
⑧ Detector

Technical Data

Primary beam

- Neutron guide NL2b
- Astrium choppers with wavelength resolution to be chosen in the range 0.2 – 10% for wavelengths in the range 2 – 20 Å. Rotation speed up to 6000 rpm
- Collimation: 2 vertical adjustable slits (0 – 12 mm) separated by 8.68 m
- For reflectometry, the horizontal divergence is maximized by use of supermirrors (m = 2 – 3)

Flux at sample

Typical values (ΔQ / Q = 3%):

- $1 \cdot 10^4$ n s^{-1} (incident angle 0.2°)
- $3 \cdot 10^6$ n s^{-1} (at 2.5°)
  in the wavelength range 2 to 6 Å for a 60 × 60 mm^2 sample.

Accessible Q-range

- Reflectometry:
  Q_z up to 0.3 $Å^{-1}$ for reflectivities down to the 10^{-7} range.
- GISANS:
  $Q_y = 9.5 \cdot 10^{-5}$ $Å^{-1}$ to 0.18 $Å^{-1}$ (corresponding to distances from 6 µm down to 3.5 nm)

Detector

- High performance 2D 500 × 500 mm^2 multiwire ^{3}He detector (pixel size 2.7mm, efficiency 80% at 7 Å, gamma sensitivity < 10^{-6}) positioned between 1.5 m and 12 m from the sample. The detector is installed in a liftable vacuum tube in order to reach exit angles up to 6 degrees at the maximum distance.

TOF analysis

- The data are acquired in list mode, each neutron arrival time and impact position being stored for later analysis. This makes it possible to perform various rebinnings in order to tune the resolution/ intensity trade-off.

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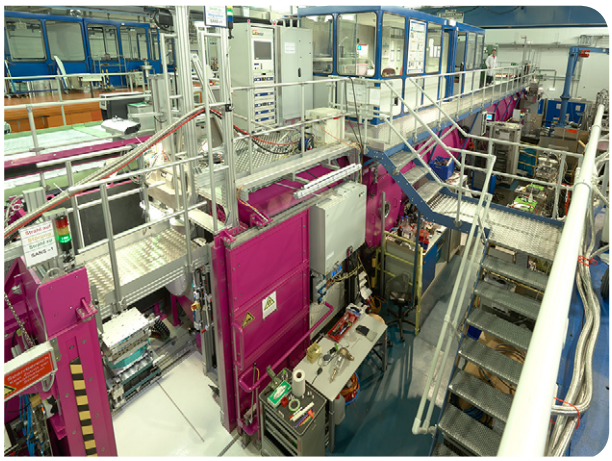
SANS-1

small angle neutron scattering



The new small angle scattering instrument SANS-1, a joint project of TUM and HZG, has completed commissioning and is in regular user service [1]. SANS-1 is located at the end of neutron guide NL4a in the Neutron Guide Hall West.

SANS-1 is a standard pinhole SANS instrument with both 20 m collimation distance and 20 m sample detector distance, respectively. SANS-1 has been optimised by Monte-Carlo simulations to fit the restrictions in both available space and optimal usage of the provided neutron beam [2]. A vertical S-shaped neutron guide with extreme suppression of fast background neutrons is optimised for complementary wavelength packages, followed by the selector tower with two selectors for high and low resolution, respectively. Adjacent to the selector tower, a collimation system with four parallel horizontal tracks provides vast flexibility: The first track is occupied by a neutron guide system, the second track carries the collimation system with additional background apertures on track three. One track remains empty for various future applications such as focussing lenses or a longitudinal spin echo option. Two Fe/Si transmission polarisers have been optimised to cover the whole wavelength band from 4.5 – 30 Å.

The acentric mounting of the detector tube with around 2.4 m inner diameter allows to use a primary detector of 1 × 1 m^2 with lateral movement of more than 0.5 m, significantly expanding the accessible Q-range to around $Q_{max} \approx 1$ $Å^{-1}$. The primary detector is made up of an array of 128 position sensitive tubes to provide 8 mm × 8 mm spatial resolution. A second high resolution (3 mm) detector, installed downstream of the primary detector is foreseen for 2016.

A TISANE chopper disk set-up will be available in 2015 which allows to perform kinetic neutron scattering experiments in the µs regime and simultaneously sets the stage for a later upgrade to a complete time-of-flight option for SANS-1.

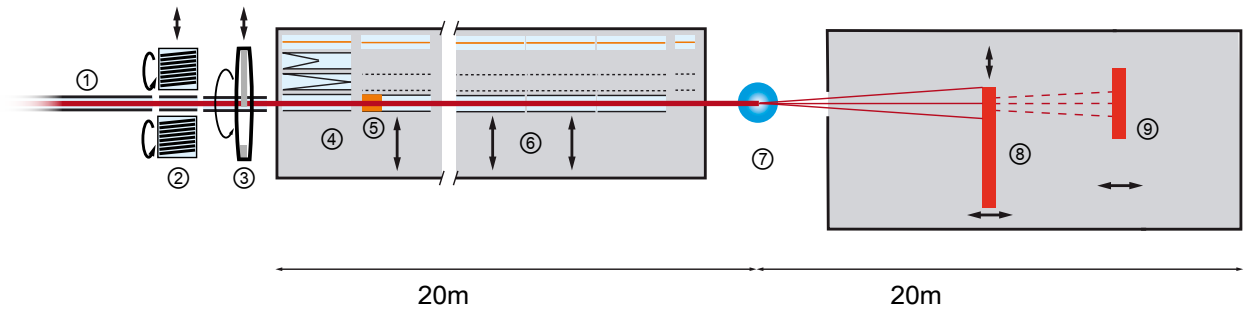
Typical Applications

The instrument SANS-1 is dedicated to study the structure of materials on length scales of 10 to 3000 Å. With its polarised beam option, the flexible sample goniometer, the wide non-magnetic sample space and the specialised set of sample environment, SANS-1 is particularly adapted for the needs of materials research and magnetism. The precise sample goniometer carries various loads up to 750 kg and fulfills the rising demand on diffraction experiments at low scattering angles, for instance for studies of superconducting vortex lattices and other large magnetically ordered systems.

- Precipitates and segregation in alloys
- Chemical aggregation
- Defects in materials, surfactants, colloids
- Ferromagnetic correlations in magnetism
- Magnetic domains
- Polymers, proteins, biological membranes, viruses, ribosomes and macromolecules
- Superconducting vortex lattices
- Large magnetic structures such as helical magnets and skyrmion lattices

[1] Gilles, R. et al., Physica B, 385 386, 1174-1176 (2006).

[2] Gilles, R. et al., J. Appl. Cryst., 40, s428-s432 (2007).



① Neutron guide NL4a
② Velocity selector 1+2
③ TISANE Chopper
④ Changeable polarisers
⑤ Spin flipper
⑥ 4 collimation sections 19 m (neutron guide, collimation slits)
⑦ Sample position
⑧ Position sensitive area detector,1 x 1 m²
⑨ High resolution position-sensitive area detector, 0.5 x 0.5 m² (installation 2016)

Sample Environment

- Standard sample changer with 22 positions
- Different types of high temperature furnaces up to 1900°C
- Deformation-rig with heating
- Set of magnets (5 T horizontal, parallel and perpendicular access, 7.5 T vertical)
- Sample changer with thermostat (-20 +200°C), 11 positions
- Different cryostats with optional ^{3}He insert (460 mK base temp. with 5 T magnet, 50 mK with 7.5 T magnet)
- Polarisation analysis with ^{3}He cell

Technical Data

Primary beam

- S-shaped neutron guide (NL 4a), 50 × 50 mm2
- Mechanical velocity selectors with variable speed
  1) $\Delta\lambda/\lambda$ = 10% medium resolution
  2) $\Delta\lambda/\lambda$ = 6% high resolution
- Wavelength range: 4.5 Å – 30 Å
- TISANE chopper setup with µs time resolution

Polarisation

- Two V-shaped polarisers

Collimation system (source-to-sample distance)

- 1 m, 2 m, 4 m, 8 m, 12 m, 16 m to 20 m in steps via insertion of neutron guide sections

Sample size

- 0 – 50 mm diameter

Q-range

- 0.0005 Å^{-1} < Q < 1 Å^{-1} with primary detector
- Q_{min} = 0.0001 Å^{-1} with secondary high resolution detector

Detectors

- Primary detector: Array of 128 ^{3}He position-sensitive tubes with an active area of 1000 × 1020 mm² and 8 mm resolution. Lateral detector movement up to 0.5 m, counting rate capability up 1 MHz.
- Secondary high resolution detector (3 mm) and an active area of 500 x 500 mm² to be installed 2016.

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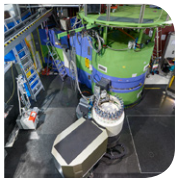
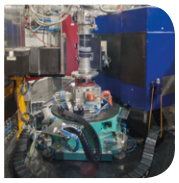
DNS
diffuse scattering time-of-flight spectrometer

J-NSE
neutron spin echo spectrometer

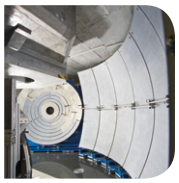


PANDA
cold three axes spectrometer



PUMA
thermal three axes spectrometer

RESEDA
resonance spin echo spectrometer



SPHERES
backscattering spectrometer

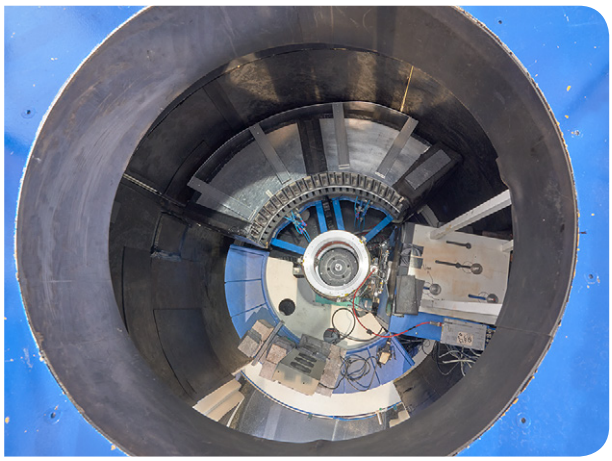
TOFTOF
cold neutron time-of-flight spectrometer

TRISP
three axes spin echo spectrometer

Spectroscopy

DNS

diffuse scattering neutron time-of-flight spectrometer



DNS is a versatile diffuse scattering cold neutron time-of-flight spectrometer with polarisation analysis. It allows the unambiguous separation of nuclear coherent, spin incoherent, and magnetic scattering contributions simultaneously over a large range of scattering vector Q and energy transfer E. With its compact size DNS is optimised as a high intensity instrument with medium Q- and E- resolution.

New chopper, neutron velocity selector, and position sensitive detector systems have recently been installed at DNS. This is expected to largely improve possibilities for single-crystal time-of-flight spectroscopy with efficient measurements in all four dimensions of S(Q,E). With its unique combination of single-crystal time-of-flight spectroscopy and polarisation analysis, DNS is also complimentary to many modern polarised cold neutron three axes spectrometers.

Typical Applications

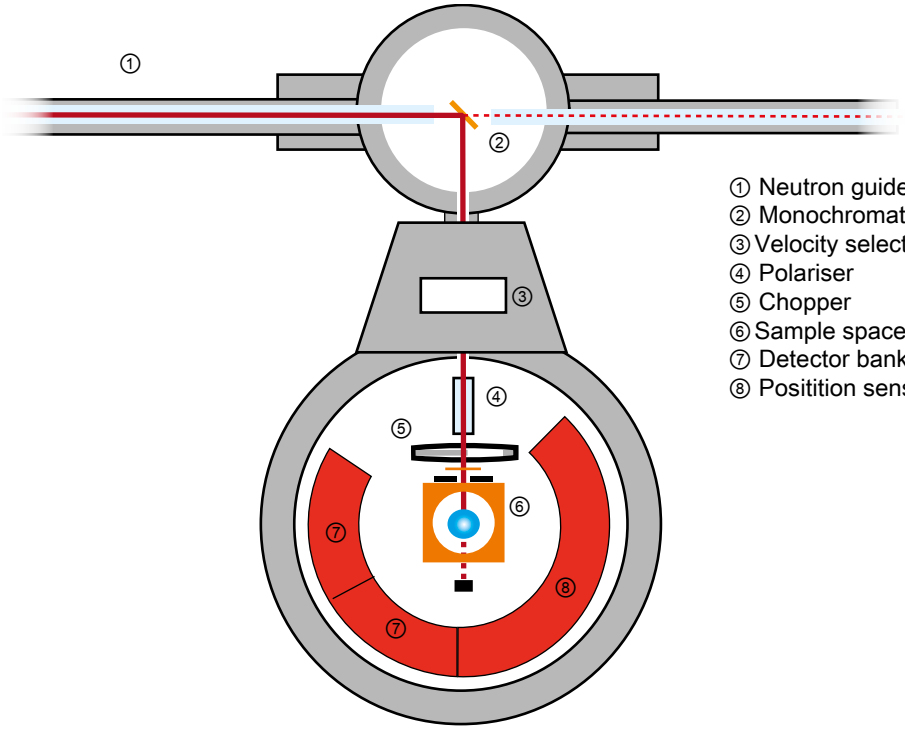
With the increased flux and efficiency delivered by the FRM II, DNS becomes ideal for the studies of complex spin correlations, such as in highly frustrated magnets and strongly correlated electrons, as well as of the structures of soft condensed matter systems, such as the nanoscale confined polymers and proteins, via polarisation analysis. The exploration of unusual magnetic properties can also be efficiently undertaken on single-crystal samples by reciprocal space mapping. In addition to the separation of magnetic cross section from nuclear and spin-incoherent ones, polarisation analysis also allows to distinguish in detail the anisotropy of spin correlations. It has also been well demonstrated that polarised powder diffraction on DNS is complementary to standard neutron powder diffraction and may be extremely useful for magnetic structure refinements, particularly in case of small moments by improving the signal to background ratio. DNS also represents a powerful instrument for the soft condensed matter community for the separation of nuclear coherent scattering from often dominating spin incoherent scattering background. The main applications can be summarised:

- **Application of polarisation analysis**: uniaxial-, longitudinal-, and vector-PA
- **Magnetic, lattice, and polaronic correlations**: geometrically frustrated magnets, strongly correlated electrons, emergent materials
- **Single-crystal and powder time-of-flight spectroscopy**: single-particle excitations, magnons and phonons
- **Soft condensed matters**: separation of coherent scattering from hydrogenous materials, polymer, liquids and glasses

Sample Environment

- Top-loading CCR
- Closed-cycle cold head
- Orange-type cryostat
- Cryo-furnace
- Dilution ^{3}He/ ^{4}He cryostat insert (~20 mK)
- Cryomagnet (self-shielding, vertical field up to 5 T)

Jülich Centre for Neutron Science



① Neutron guide NL6-S
② Monochromator
③ Velocity selector
④ Polariser
⑤ Chopper
⑥ Sample space with XYZ Coils
⑦ Detector banks with polarisation analysis
⑧ Positition sensitive ^{3}He detectors

Technical Data

Monochromator

- Neutron guide NL6-S
  Horizontally and vertically adjustable, double-focusing
- PG(002), d = 3.355 Å
- Crystal dimensions: 2.5 × 2.5 cm² (5 × 7 crystals)
- Wavelength range: 2.4 Å < λ < 6 Å

Neutron velocity selector

- Minimum wavelength: 1.5 Å @ 22000 rpm
- Resolution Δλ/λ: 30 – 40%

Chopper

- Chopper frequency ≤ 300 Hz
- Repetition rate ≤ 900 Hz
- Chopper disc: Titanium, 3 slits, Ø = 420 mm

Flux at sample

- Non-polarised: ~ 10^8 n cm^{-2} s^{-1}
- Polarised: ~ $5 \cdot 10^6$ – 10^7 n cm^{-2} s^{-1}
  (polariser: m = 3 supermirror benders)

Detector banks for non-polarised neutrons

- 128 position sensitive ^{3}He tubes
  Ø = 1.27 cm, height ~100 cm
- Total solid angle covered: 1.9 sr
- Covered scattering angles in the horizontal plane: 0° < 2θ ≤ 135°

Detector banks for polarised neutrons

- 24 detection units:
  Polarisation analysis by m = 3 supermirror benders
  ^{3}He detector tubes, Ø = 2.54 cm, height 15 cm
- Covered scattering angle in the horizontal plane: 0° < 2θ ≤ 150°
- Q_{max}
  λ_i = 2.4 Å (E_i = 14.2 meV): 4.84 Å^{-1}
  λ_i = 6 Å (E_i = 2.28 meV): 1.93 Å^{-1}

Energy resolution

- λ_i = 2.4 Å (E_i = 14.2 meV): 1 meV
- λ_i = 6 Å (E_i = 2.28 meV): 0.1 meV

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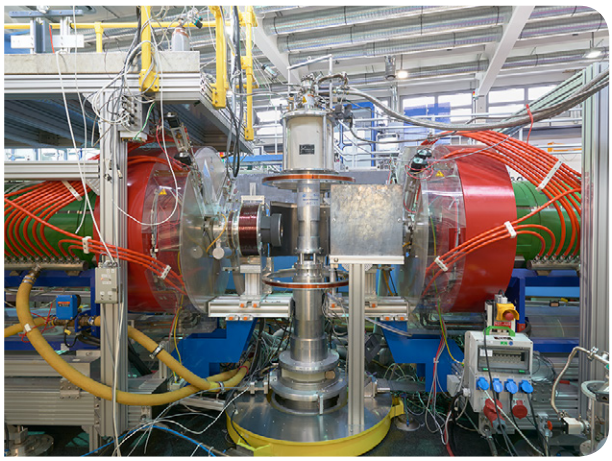
J-NSE

neutron spin echo spectrometer



The neutron spin echo technique NSE uses the neutron spin as an indicator of the individual velocity change the neutron suffered when scattered by the sample. Due to this trick, the instrument accepts a broad wavelength band and at the same time is sensitive to velocity changes down to 10^{-5}. However the information carried by the spins can only be retrieved as the modulo of any integer number of spin precessions as intensity modulation proportional to the cosine of a precession angle difference. The measured signal is the cosine transform S(Q, τ) of the scattering function S(Q, ω). All spin manipulations only serve to establish this special type of velocity analysis. For details see “Neutron Spin Echo”, ed. F. Mezei, Lecture Notes in Physics, Vol. 128, Springer Verlag, Heidelberg, 1980.

Due to the intrinsic Fourier transform property of the NSE instrument it is especially suited for the investigation of relaxation-type motions that contribute at least several percent to the entire scattering intensity at the momentum transfer of interest. In those cases the Fourier transform property yields the desired relaxation function directly without numerical transformation and tedious resolution deconvolution. The resolution of the NSE may be corrected by a simple division.

For a given wavelength the Fourier time range is limited to short times (about 2 ps for J-NSE set-up) by spin depolarisation due to vanishing guide field and to long times by the maximum achievable field integral J. The time is proportional to $J \times \lambda^3$. The J-NSE may achieve a J = 0.5 Tm corresponding to τ = 48 ns at λ = 8 Å.

The instrument itself consists mainly of two large water-cooled copper solenoids that generate the precession field. The precession tracks are limited by the π/2-flippers and the π-flipper near the sample position. The embedding fields for the flippers are generated by Helmholtz-type coil pairs around the flipper locations. After leaving the last flipper the neutrons enter an analyzer containing 60 CoTi supermirrors located in a solenoid set. These mirrors reflect only neutrons of one spin direction into the multidetector. By the addition of compensating loops the main coils and the analyzer coil are designed such that the mutual influence of the different spectrometer components is minimised.

Typical Applications

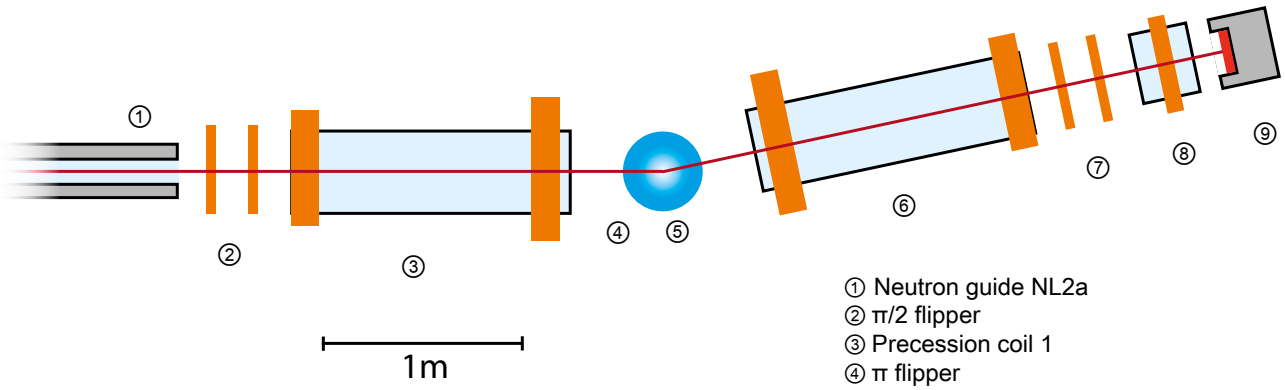
The spin echo spectrometer J-NSE is especially suited for the investigation of slow (~ 1 to 100 ns) relaxation processes. Typical problems from the fields of “soft matter” and glass transition are:

- Thermal fluctuations of surfactant membranes in microemulsions
- Polymer chain dynamics in melts
- Thermally activated domain motion in proteins, which is an important key for understanding the protein function

Sample environment

- Circulation thermostat furnace (260 – 360 K)
- Cryofour (3 – 650 K)
- Furnace (300 – 510 K)
- CO_2- pressure cell (500 Bar)

Other specialised sample environments on request.



① Neutron guide NL2a
② π/2 flipper
③ Precession coil 1
④ π flipper
⑤ Sample space
⑥ Precession coil 2
⑦ π/2 flipper
⑧ Analyzer
⑨ Detector

Technical Data

Main parameters

- Polarised neutron flux at sample position
  7 Å: $1 \cdot 10^{7}$ n cm^{-2} s^{-1}
  12 Å: $6.8 \cdot 10^{5}$ n cm^{-2} s^{-1}
- Momentum transfer range:
  0.02 – 1.5 $Å^{-1}$
- Fourier time range:
  2 ps (4.5 Å) < τ < 350 ns (16 Å)
- Max. field integral: 0.5 Tm

Primary beam

- Neutron guide NL2a
- Polarisation:
  Short wavelength by bent section with FeSi m = 3 remanent supermirror coating
  Long wavelength by FeSi polariser at entrance of the spectrometer
- Cross section of guide: 6 cm × 6 cm
- Max. sample size: 3 cm × 3 cm
- Collimation:
  By source and sample size or wire collimators
  0.5° × 0.5°

Analyzer

- 30 × 30 cm^2 CoTi supermirror Venetian blind

Detector

- 32 × 32 1 cm^2 cells ^{3}He multidetector

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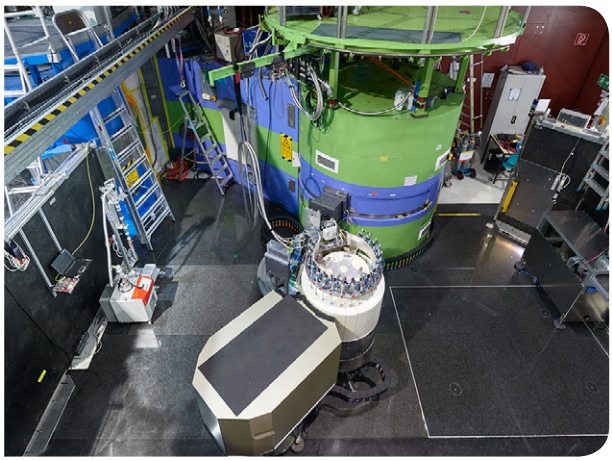
PANDA

cold three axes spectrometer



The cold three axes spectrometer PANDA offers high neutron flux over a large dynamic range keeping the instrumental background comparably low. PANDA is situated on the cold neutron beam-tube SR-2 in the Experimental Hall. The high flux is achieved by neutron guide elements in the beam tube, a short source-to-monochromator distance, and the double-focussing monochromator and analyzer crystals. Options for high energy and high q-resolution are available. With dedicated sample environments for very strong magnetic fields and very low temperatures, PANDA is ideally suited for the studies of magnetism and superconductivity on single crystals. Lattice dynamics and magnetic structures are investigated successfully, too.

A polarised neutron set-up using both Heusler monochromator and analyzer as well as a sample-space Helmholtz-coil set for longitudinal polarisation analysis is available.

Typical Applications

Magnetic properties
- Spin-waves
- Crystal field excitations
- Excitations in low dimensional systems
- Magnetic vs nuclear scattering

Lattice dynamics
- Phonon dispersion
- Anharmonic effects
- Polarisations vectors

General
- Critical scattering at phase transitions
- Magnon - phonon interaction
- Soft mode
- Central peak
- Diffraction:
  - without analyser: integral E method
  - with analyser:
    dE close to 0, high E & Q resolution

Sample Environment

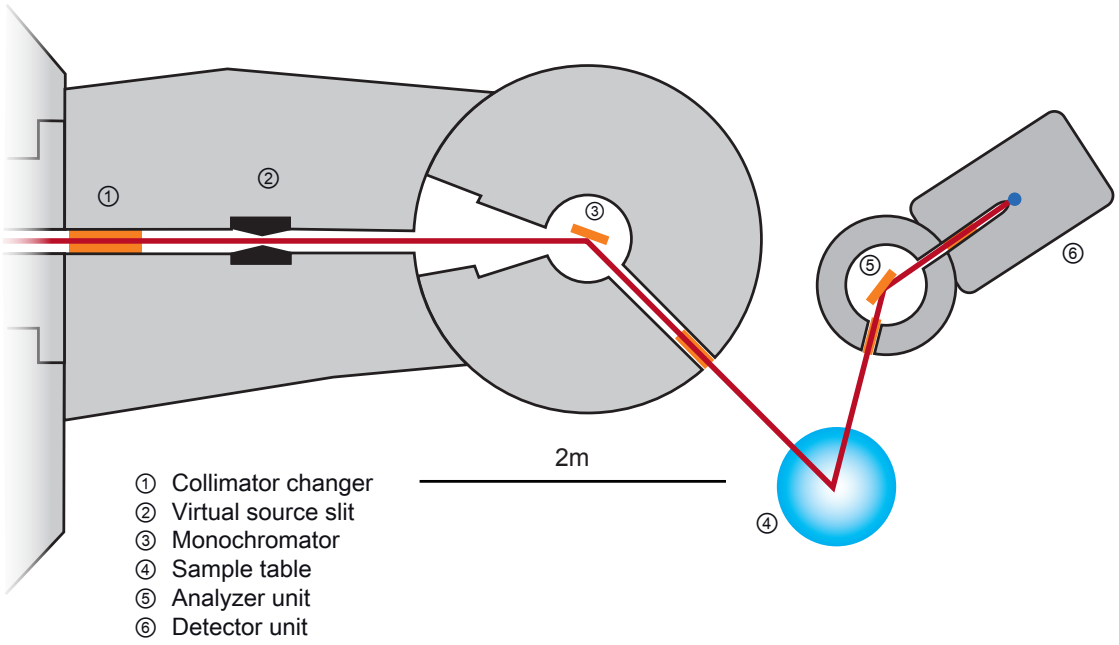
The sample table of PANDA allows for a variety of sample environments, and may easily be adapted to user specific devices. Among other, PANDA disposes routinely operated sample environment for:

Low temperature
- Closed cycle cryostat (3 K < T < 300 K)
- Variox cryostat (1.5 K < T < 100 K)
- ^{3}He insert (0.4 K < T < 300 K)
- Dilution insert (50 mK < T < 6 K)

  typical dimensions for sample space
  Ø 50 mm, h = 70 mm

Vertical magnetic field:
- Cryomagnet V15T with optional ^{3}He-^{4}He-dilution insert; H_{max} = 13.5 T
  (50 mK) 1.5 K < T < 100 K
  max. sample diameter: (12 mm) 19 mm
  split of coils 20 mm
- Closed-cycle magnet V7.5T
  H_{max} = 7.5 T
  field at low and high temperatures available

High temperature
- High temperature furnace
  300 K < T < 2100 K
  sample space: Ø 50 mm, h = 50 mm



Technical Data

Monochromators

- PG(002) (d = 3.355 Å)
  $20° < 2\Theta_M < 132°$
  $1.05\ Å^{-1} < k_i < 4.0\ Å^{-1}$
  variable horizontal and vertical focussing
- Heusler (d = 3.35 Å, polarised neutrons)
  $20° < 2\Theta_M < 120°$
  $1.1\ Å^{-1} < k_i < 4.0\ Å^{-1}$
  variable vertical focussing

Analysers

- PG(002)
  $-130° < 2\Theta_A < 100°$
  $1.05\ Å^{-1} < k_f$
  variable horizontal focussing
- Heusler (polarised neutrons)
  $-130° < 2\Theta_A < 100°$
  $1.05\ Å^{-1} < k_f$
  variable horizontal focussing

Detectors

- 1” ^{3}He tube (focussing mode)
- 2” ^{3}He tube (collimated mode))

Flux at sample

PG monochromator vertically focussed, horizontal flat, no collimation:

- $1.9 \cdot 10^7$ n cm^{-2} s^{-1} for $k_i = 1.55\ Å^{-1}$ Be Filter
- $5.5 \cdot 10^7$ n cm^{-2} s^{-1} for $k_i = 2.662\ Å^{-1}$ PG Filter

Main parameters

- Scattering angle at the sample:
  $5° < 2\Theta_S < 125°$ (moveable beam-stop)
- Energy transfer
  up to 20 meV
- Momentum transfers
  up to $Q = 6\ Å^{-1}$ (depending on k_i)

Filters for higher order suppression:

- PG (l = 60 mm); $k_f = 2.57\ Å^{-1}$ or $2.662\ Å^{-1}$
- Be (closed-cycle cryostat, T ≤ 45 K);
  $k_f = 1.55\ Å^{-1}$
- BeO (liq.-N_2 cooled); $k_f = 1.33\ Å^{-1}$

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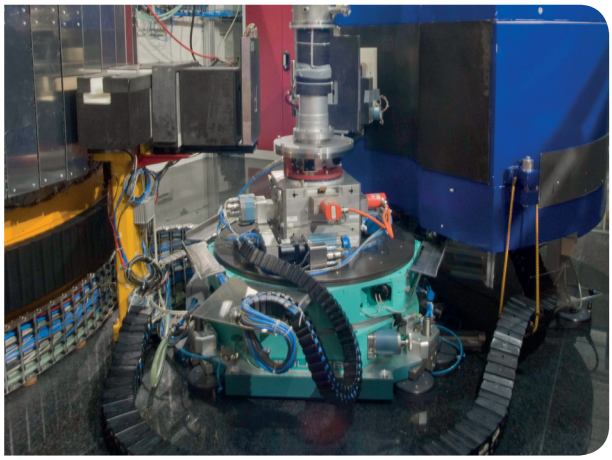
PUMA

thermal three axes spectrometer



Three axes spectrometers allow the direct measurement of the scattering function S(Q, ω) in single crystals at well defined points of the reciprocal lattice vector Q and frequency ω and thus represent the most general instrument type.

PUMA is characterised by a very high neutron flux as a result of the efficient use of focussing techniques. Three different vertical openings and a horizontal slit with a maximum opening of 40 mm define the virtual source, which is two meters before the monochromator. To reduce the primary beam's contamination by epithermal neutrons, a sapphire filter can be placed in front of the monochromator. PUMA has a remote controlled monochromator changing unit which allows to place one out of four different monochromators inside the drum. All of them are equipped with double focussing devices that allow for optimum focussing conditions over a wide range of incident wavevectors k_i. The horizontal divergency of the beam can be defined using a series of four Soller collimators. The two inside the drum, before and after the monochromator, can be remotely changed, whereas the two in the analyzer housing can be changed manually. An Eulerian cradle can optionally be used to access the four dimensional Q-ω-space.

An innovative option of the spectrometer is the multianalyzer/ detector system. It allows a unique and flexible type of multiplexing. Using this option a scattering angle range of 16° can be measured simultaneously and flexible Q-ω paths can be realised without repositioning the instrument. Mapping of excitations is equally well possible as kinetic single shot experiments on time scales that have not been accessible so far.

A unique feature of the instrument is the possibility to perform stroboscopic, time resolved measurements of both elastic and inelastic signals on time scales down to the microsecond regime. Using this technique, the sample is periodically perturbed by an external variable such as temperature, electric field, etc. The signal is then recorded not only as a function of momentum and energy transfer, but also given a time stamp, relative to the periodic perturbation.

Typical Applications

- Phonons
  - Electron-phonon interaction
  - Phonon anharmocities
  - Soft mode phase transitions
- Magnons
  - Spin waves in (anti)ferromagnets
  - Electron-magnon interaction
  - Unconventional superconductors
  - Crystal fields
- Time resolved/ stroboscopic measurements
  - Temperature cycling (excitations during demixing processes)
  - Electrical field cycling (polarisation processes in ferroelectrics)
  - Temperature/ pressure cycling
- Diffraction; purely elastic signals
  - Superstructures/ satellites
  - Diffuse scattering

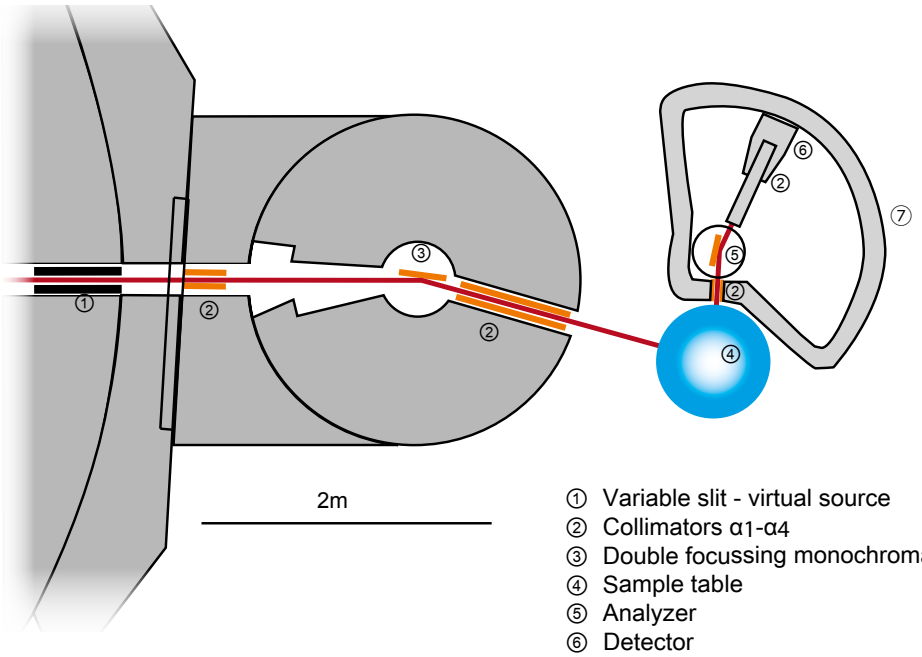
Sample Environment

Besides standard sample environment, we provide:

- Closed-cycle cryostates 3.5 – 300 K;
  – 650 K with adaptable heating device
- Cryofurnace 5 K – 750 K
- Paris-Edinburgh type pressure cell p < 10 GPa

Along with the detector electronics required for time resolved measurements, special sample environment for the rapid cycling is available:

- Furnace for fast temperature jumps (~ 5 K/s cooling rate; < 620 K; ambient atmosphere)
- Switchable HV power supply (< 500 Hz; +/- 10 KV)



① Variable slit - virtual source
② Collimators α1-α4
③ Double focussing monochromators (PG, Si, Cu, Ge)
④ Sample table
⑤ Analyzer
⑥ Detector
⑦ Common analyzer and detector shielding

Technical Data

Primary beam

- Beam tube SR-7 (thermal)
- Beam tube entrance 140 × 90 mm²
- Virtual source dimensions:
  horizontal: 0 – 40 mm
  vertical: (90, 110, 130 mm)

Distances

- Beam tube entrance - monochromator: 5.5 m
- Virtual source – monochromator: 2.0 m
- Monochromator – sample: 2.0 (± 0.1) m
- Sample – analyzer: 1.0 (± 0.1) m
- Analyzer – detector: 0.9 m

Collimation

Remote controlled:
- α1: 20', 40', 60'
- α2: 14', 20', 24', 30', 45', 60'

Manually changeable:
- α3: 10', 20', 30', 45', 60'
- α4: 10', 30', 45', 60'

Monochromators

- Crystals: PG(002), Cu(220), Cu(111), Ge(311)
  size: 260 × 162 mm²;
- Focus vertically and horizontally adaptable to incident energy

Analyzer

- Crystals : PG(002), Ge(311); 210 × 150 mm²
  vertical fixed focus
  horizontally adaptable to incident energy

Sample table

- Diameter 800 mm
- Max. load 900 kg
- Amagnetic goniometer (± 15°)
- Z translation (± 20 mm)
- Optional Eulerian cradle

Main parameters

- Monochromator take-off angle
  -15° < 2Θ < -115°
- Scattering angle sample
  -70° < 2Θ <120°
  (dependent on monochromator take-off angle)
- Analyzer scattering angle
  -120°< 2Θ < 120°
- Incident energy range 5 meV – 160 meV
- Momentum transfer range < 12 Å^{-1}
- Energy transfer < 100 meV

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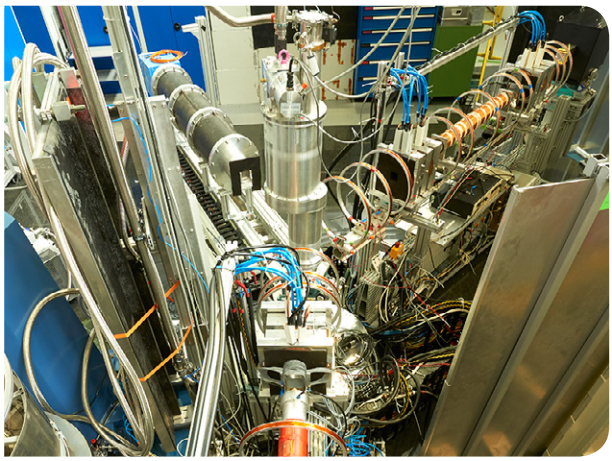
RESEDA

resonance spin echo spectrometer



RESEDA (**re**sonance **s**pin **e**cho for **d**iverse **a**pplications) is a high-resolution resonance spin-echo spectrometer installed at the cold neutron guide NL5-S in the Neutron Guide Hall West. The instrument gives access to a large time and scattering vector range for quasi-elastic measurements.

RESEDA supports **l**ongitudinal **n**eutron **r**esonance **s**pin **e**cho (LNRSE, time range from 0.001 to 20 ns for λ = 8 Å) and **m**odulation of **i**nt**e**nsity with **z**ero-**e**ffort (MIEZE, time range from 0.001 to 20 ns for λ = 8 Å) experiments. At RESEDA, the analysis of S(Q,τ) provides characteristic parameters, e.g. relaxation time and amplitude of the dynamic processes in the sample investigated. The determination of S(Q,τ) is feasible for different Q-values and/ or different temperatures and pressures.

NRSE experiments require non-depolarising sample environment conditions. For MIEZE experiments (and in contrast to NRSE) the spin manipulation and analysis is realised solely before the sample. Therefore, the MIEZE method enables high-resolution study of depolarising samples, under magnetic field and/ or within depolarising sample environments. However, as a consequence of the polarisation analysis before the sample, MIEZE experiments are limited to a smaller Q-range than NRSE measurements.

Next to ^{3}He detectors, a 2D CASCADE detector with an active area of 20 cm x 20 cm characterised by a spatial resolution of 2.6 mm^2 and a time dynamics of the order of a few MHz is available [1, 2].

Hence, RESEDA is in addition suited to (polarised) **s**mall **a**ngle **n**eutron **s**cattering (SANS) applications.

Typical Applications

- Quasi-elastic measurements:
  - e.g. to determine the dynamics of water in porous media, polymer melts, diffusion processes in ionic liquids as well as magnetic fluctuations in single crystals, powder samples and thin films
- (Polarised) SANS:
  - e.g. to investigate the diffraction pattern of magnetic structures and vortex lattices to choose suited reflections for a line-width determination
- Spherical polarisation analysis

Sample Environment

At RESEDA the whole sample environment of the MLZ is applicable. Depolarising conditions are limited to MIEZE experiments.

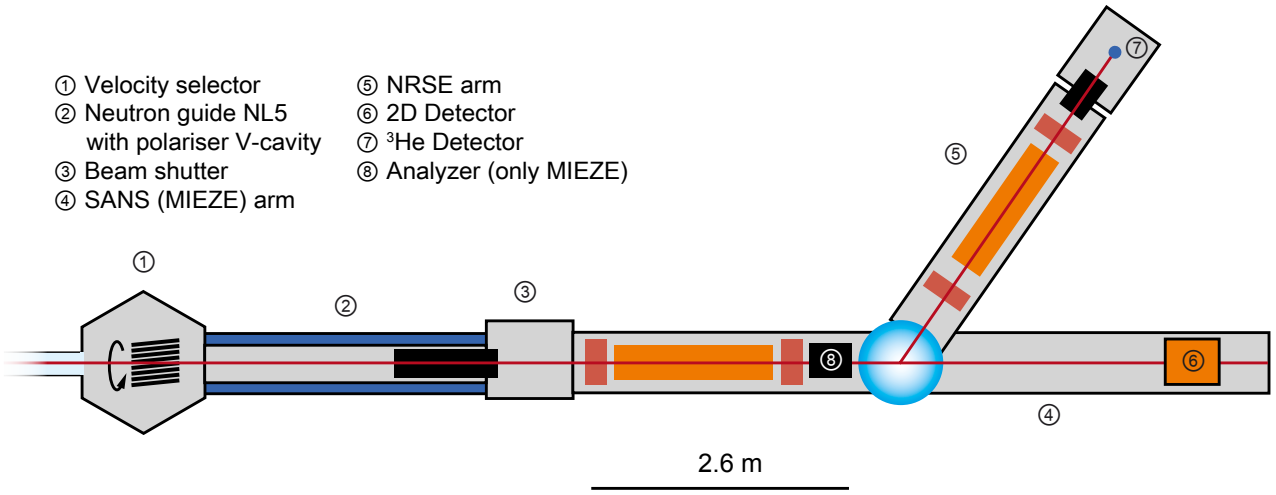
- Available temperature range: 50 mK (dilution insert, see below) up to more than 1300 K (high temperature furnace, non-depolarising)
- Maximal pressure: 7 GPa
- Maximal magnetic field: 7.5 T

Available cryostats:

- Closed cycle cryostat: (3 K < T < 300 K)
- ^{3}He insert: (450 mK < T < 300 K)
- Dilution insert: (50 mK < T < 6 K)

[1] Schmidt, C.J. et al., Journal of Physics: Conf. Ser. 251, 012067 (2010).

[2] Häußler, W. et al., Rev. Sci. Instr. 82, 045101 (2011).



Technical Data

Primary beam

- Neutron guide: NL5-S
- Guide cross section: 29 x 34 mm^2
- Wavelength selection: Velocity selector (max. 28000 rpm)
- Wavelength range: λ = 3 – 12 Å
- Wavelength bandwidth at sample position: $\Delta\lambda/\lambda$ = 9 – 20%
- Polariser: V-cavity (length: 2 m, coating: m = 3)

Spectrometer

- Optional polariser before sample: V-cavity (length: 30 cm, coating: m = 4)
- Length of the spectrometer arms: 2.6 m
- Two secondary spectrometer arms: SANS (MIEZE) arm and LNRSE arm
- For polarisation analysis available: V-cavity, Bender
- Detectors: ^{3}He counter or 2D detector (CASCADE)

Characteristic parameters

- Flux at sample position: $\varphi \geq 10^6$ n cm^{-2} s^{-1} (at λ = 5.3 Å)
- Frequency range of RF coils: 35 kHz – 1.7 MHz
- Maximum scattering angle: $2\theta = 93°$
- Maximum scattering vector: Q = 2.5 $Å^{-1}$ (at λ = 3 Å)
- Spin echo time range: τ = 0.001 – 20 ns for λ = 8 Å
- Energy resolution: 0.03 µeV – 0.1 meV

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SPHERES

backscattering spectrometer

SPHERES (**sp**ectrometer for **h**igh **e**nergy **res**olution) is a third-generation backscattering instrument with focussing optics and a phase-space-transform chopper. It is a versatile spectrometer for the investigation of atomic and molecular dynamics on a GHz scale.

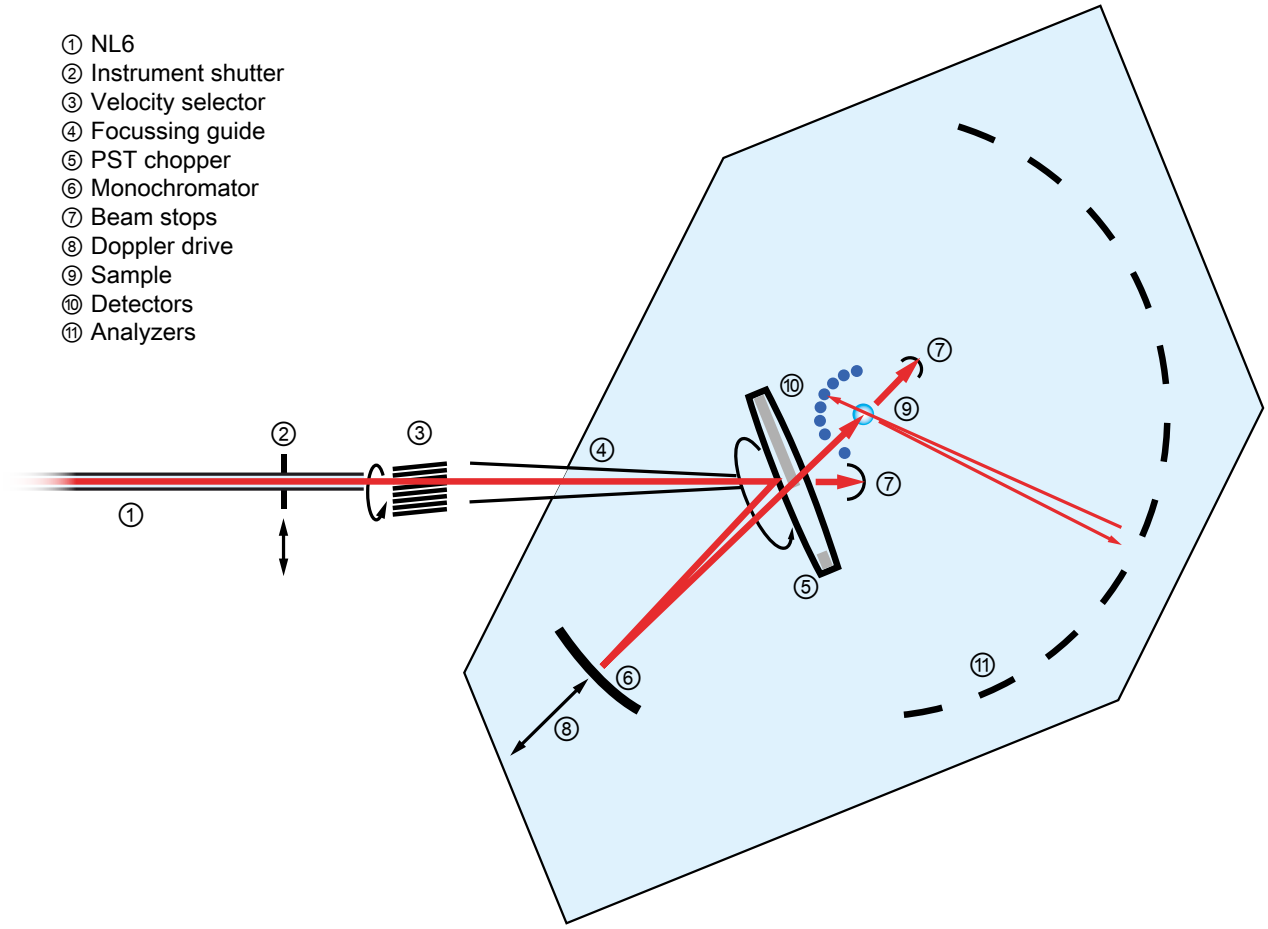
The necessary filtering of neutron energies is achieved by Bragg reflection from perfect monochromator and analyzer crystals under angles close to 180°. The backscattering geometry makes it unavoidable to use a primary beam deflector and a duty-cycle chopper. At SPHERES, these two functions are both realised by a chopper that bears deflector crystals on its circumference. This leads to a particularly compact spectrometer layout so that full use can be made of the focussing neutron guide. As an additional advantage, the fast motion of the deflector crystals achieves a phase-space transform of the primary spectrum, thereby enhancing the flux at the sample.

The principal figures of merit qualify SPHERES as one of the best of its class [1]. Count rates and signal-to-noise ratio have been improved by filling the instrument housing with argon, thereby avoiding air scattering in the secondary spectrometer. Another gain in flux will be achieved by a more efficient phase-space transform chopper which is in the commissioning phase. The new designed chopper will be more efficient due to optimised rotation speed and higher reflectivity and mosaicity of the graphite crystals. The resolution of the small angle detectors have been improved by reducing the azimuth angle range of the analyzers [2].

As a multi-detector instrument with relaxed angular resolution, SPHERES is particularly suited for studying tagged-particle motion by incoherent scattering. Typical applications include for example dynamical processes in polymers and biological systems [3]. The high resolution of the spectrometer allows to investigate the dynamics of water in confined geometry. The unprecedented sensitivity of SPHERES helps us to detect the onset of quasielastic scattering deep in the supercooled state [4]. Other important applications are hyperfine splitting in magnetic materials [5] and rotational tunneling [6]. The high count rates allow inelastic temperature scans [7] and real-time kinetic experiments [8].

Raw histograms are accumulated on an equidistant ω grid. A script driven program, SLAW [9], is provided to normalise the raw counts, to perform optional binning, and to deliver S(q,ω) in a variety of output formats so that users are not bound to any specific data analysis program. In data fitting, it is critcially important to convolute theoretical models with the measured resolution function in an efficient and numerically stable way. We strive to support best practice through our FRIDA package [10].

[1] Wuttke, J. et al., Rev. Sci. Instrum. 83, 075109 (2012).
[2] Wuttke, J. , Zamponi, M., Rev. Sci. Instrum. 84, 115108 (2013).
[3] Gallat, F.-X. et. al., J. Am. Chem. Soc. 134, 13168 (2012).
[4] Doster, W. et al., Phys. Rev. Lett. 104, 098101 (2010).
[5] Chatterji, T. at al., Phys. Rev. B 78, 012411 (2008).
[6] Bator, G. et al., Chem. Phys. 410, 55 (2013).
[7] Häußler, W. et al., Neutron News 22, 24 (2011).
[8] Leon, A., Wuttke, J., J. Phys.: Condens Matter 23, 254214 (2011).
[9] Wuttke, J.: SLAW - a neutron histogram to scattering law converter, http://apps.jcns.fz-juelich.de/slaw
[10] Wuttke, J.: FRIDA - fast reliable interactive data analysis, http://apps.jcns.fz-juelich.de/doku/frida/start



Typical Applications

- Hyperfine splitting
- Molecular reorientations and rotational tunneling
- Dynamic signature of phase transitions
- Hydrogen diffusion
- Liquid dynamics
- Polymer relaxation
- Protein aggregation

Sample Environment

- Cryofurnace 3...700 K
- Dilution inset 20 mK
- Furnace

Technical Data

Primary beam	
Neutron guide	NL6-S
Neutron wavelength	6.27 Å
Neutron energy	2.08 meV

Main parameters	
Resolution FWHM	0.62 – 0.65 μeV
Dynamic range	± 31 μeV
Q range	0.2 – 1.8 $Å^{-1}$
Flux after selector	10^{10} s^{-1}
Flux at sample	$1.8 \cdot 10^{6}$ s^{-1}
Illuminated area	40 × 30 mm^2

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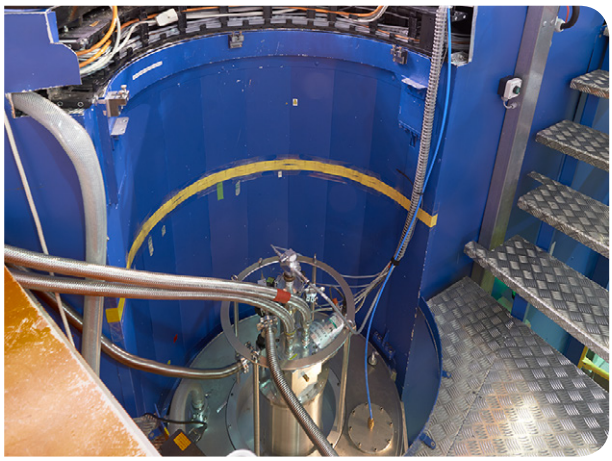
TOFTOF

cold neutron time-of-flight spectrometer



TOFTOF is a direct geometry disc-chopper time-of-flight spectrometer located in the Neutron Guide Hall West. It is suitable for both inelastic and quasi-elastic neutron scattering and the scientific questions addressed range from the dynamics in disordered materials in hard and soft condensed matter systems (such as polymer melts, glasses, molecular liquids, or liquid metal alloys), properties of new hydrogen storage materials to low-energy magnetic excitations in multiferroic compounds, and molecular magnets.

A cascade of seven fast rotating disc choppers which are housed in four chopper vessels is used to prepare a monochromatic pulsed beam which is focussed onto the sample by a converging supermirror section. The scattered neutrons are detected by 1000 ^{3}He detector tubes with a time resolution up to 50 ns. The detectors are mounted at a distance of 4 m and cover 12 m^2 (or 0.75 sr). The high rotation speed of the chopper system (up to 22 000 rpm) together with a high neutron flux in the wavelength range of 1.4 -14 Å allows free tuning of the energy resolution between 3 meV and 2 µeV.

The 60 m primary neutron guide has an s-shape which efficiently suppresses fast neutron background. This enables the investigation of weak signals. The prototype of a new focussing neutron guide has been installed recently, as alternative option in the last section of the guide system. The existing linearly tapered neutron guide yields a beam spot size of 23 x 47 mm^2. Using the focussing guide, an intensity gain up to a factor of 3 (wavelength dependent) is observed on a sample area of 10 x 10 mm^2.

Typical Applications

TOFTOF represents a versatile instrument combining high energy resolution, high neutron flux (also at short wavelengths), and an excellent signal-to-background ratio. It is perfectly suited for both inelastic and quasielastic neutron scattering and scientific topics include e.g.:

- Diffusion in liquid metals and alloys
- Hydrogen dynamics in soft matter systems such as molecular liquids, polymer melts or colloids
- Molecular magnetism, quantum criticality in heavy fermion compounds, low energy excitations in multiferroic materials and novel magnetic phases
- Dynamic properties of energy storage materials, such as solid state hydrogen storage materials, electrolytes for batteries and fuel cells, or gas storage materials
- Energy-resolved quasi-elastic neutron scattering on proteins, vesicles, and biological materials
- Kinetic studies of hydrogen binding, e.g. in concrete
- Aging effects in disordered media and low frequency dynamics in glasses
- Biological activity and functionality of proteins and cells under pressure

Sample Environment

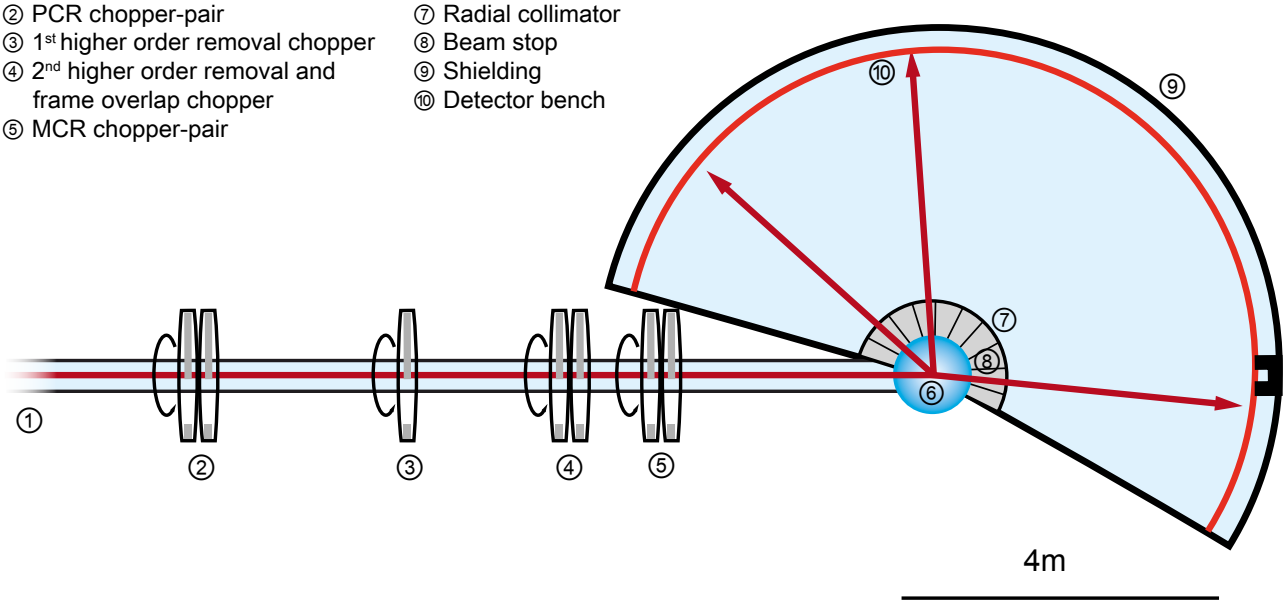
Standard sample environment:

- CCR Cryostat (4 - 600 K)
- ^{3}He insertion device (down to 0.5 K)
- Circulation thermostat furnace (255 - 450 K)
- High temperature furnace (300 – 2100 K)
- 2.5 T magnet

Sample environment provided by collaborators:

- Electromagnetic levitator
- Electrostatic levitator
- Hydraulic pressure cells (up to 3.5 kbar)
- Clamp pressure cells (few GPa)

① Neutron guide NL2a-u
② PCR chopper-pair
③ 1st higher order removal chopper
④ 2nd higher order removal and frame overlap chopper
⑤ MCR chopper-pair
⑥ Sample position
⑦ Radial collimator
⑧ Beam stop
⑨ Shielding
⑩ Detector bench



Technical Data

Primary Beam	
• Neutron guide	NL2a-u
• Number of chopper discs	7
• Chopper frequency range	400 min^{-1} – 22000 min^{-1}
• Diameter of chopper disc	600 mm
• Cross section of neutron guide at the entrance	44 × 100 mm^2
• Cross section of neutron guide, 20 cm in front of sample position	23 × 47 mm^2
• Cross section of focussing guide	minimal 12 × 25 mm^2

Main Parameters	
• Adjustable range of incident neutrons	1.4 – 16 Å
• Elastic energy resolution	2 µeV – 3 meV
• Range of energy transfers	-30 meV – 50 meV
• Integral neutron flux of the white beam at sample position	10^{10} n cm^{-2} s^{-1}
• Angular range of the detector bank	-15° to -7° and 7° to 140°

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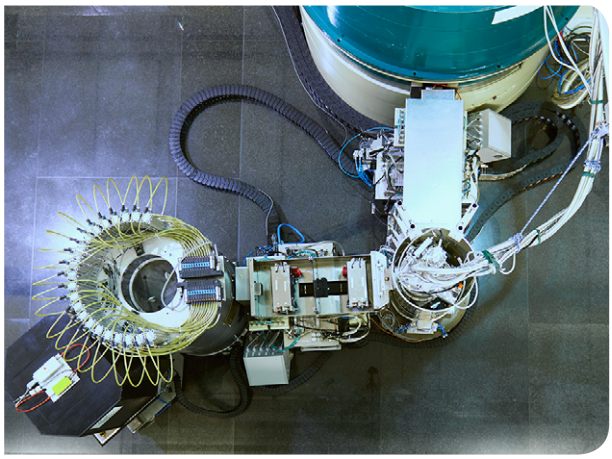
TRISP

three axes spin echo spectrometer



TRISP is a high-resolution neutron spectrometer combining the three axes and **n**eutron **r**esonance **s**pin **e**cho (NRSE) techniques. The design of TRISP is optimised for the study of intrinsic linewidths of elementary excitations (phonons, magnons) with an energy resolution in the μeV region over a broad range of momentum and energy transfers. Compared to conventional **t**hree **a**xes **s**pectrometers (TAS), this corresponds to an improvement of the energy resolution of one to two orders of magnitude.

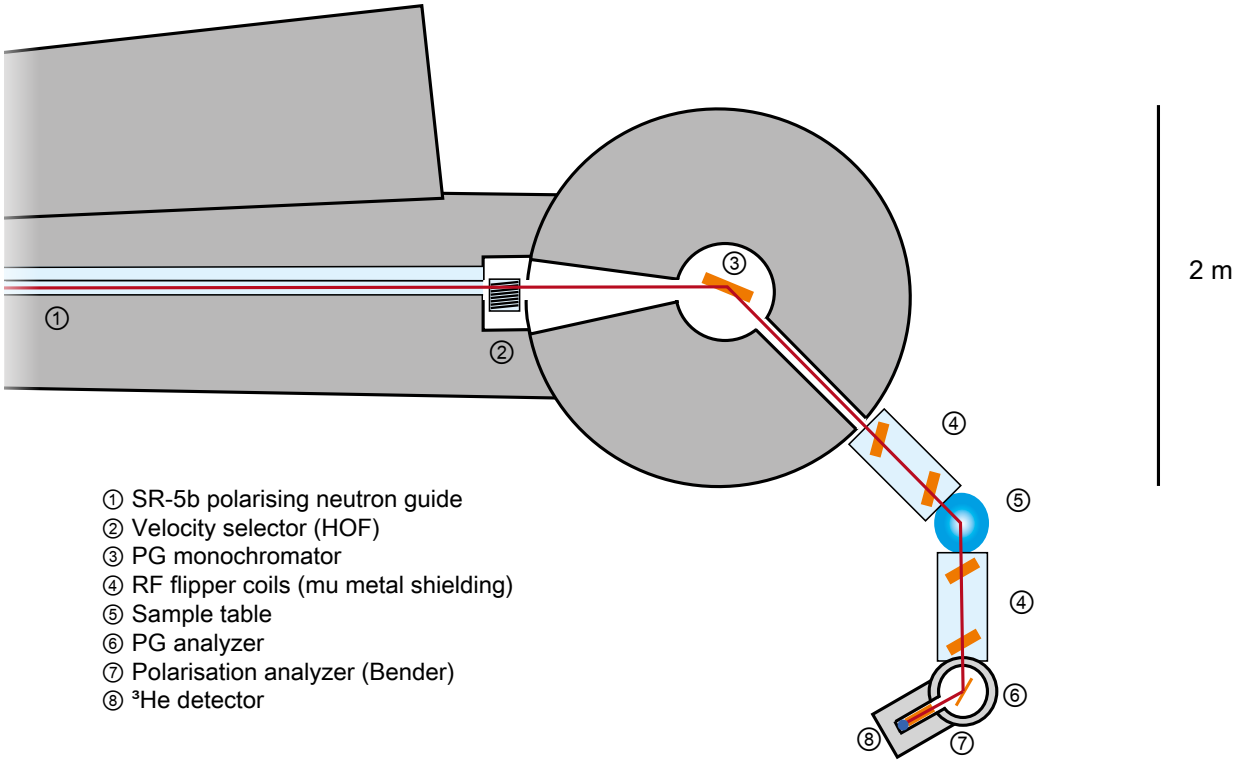
TRISP also incorporates the Larmor diffraction (LD) technique, which allows to measure lattice spacings with a relative resolution $\Delta d/d = 1.5 \cdot 10^{-6}$, i.e. one to two orders of magnitude better than conventional neutron or X-ray diffraction. Absolute d-values can be determined by calibrating the instrument against an Si standard. The main applications of LD include thermal expansion under pressure and low or high temperature, and distributions of lattice constants (second order stresses). LD thus is unique in a parameter region, where standard methods such as dilatometry fail.

Typical Applications

- Measurement of the intrinsic linewidths of phonons
- Measurement of the instrinsic linewidths spin excitations
- Larmor diffraction is used to determine thermal expansion and second order stresses under pressure and at low or high temperature

Sample Environment

Besides the standard sample environment a dedicated dilution cryostat with a base temperature of 6 mK is available.



Technical Data

Primary beam

- thermal beam tube SR-5b
  polarising supermirror bender
  1.3 Å^{-1} < k_i < 7.0 Å^{-1}
- Velocity selector
  Astrium type, as higher order wavelengths filter

Monochromator

- PG(002) or (004)
  variable focussing horizontal and vertical

Analyzer

- PG(002)
  variable horizontal focussing
- Heusler (111) (polarised neutrons)
  variable horizontal focussing

Spin echo

- Resonance spin echo, enclosed by mu-metal magnetic screen.

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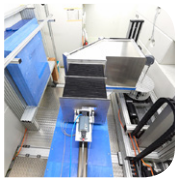
ANTARES
cold neutron radiography and tomography station

MEDAPP
fission neutron beam for science, medicine, and industry



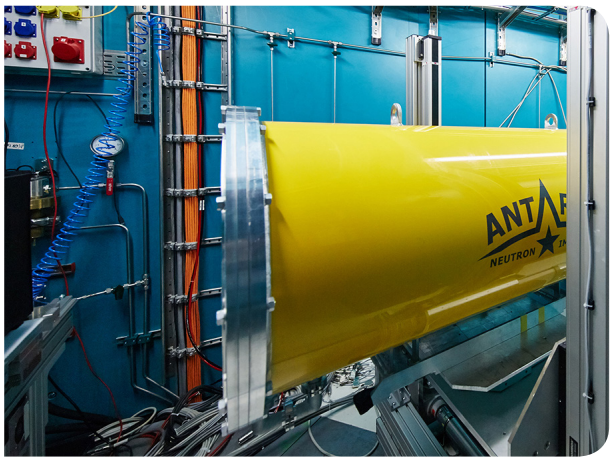
NECTAR
radiography and tomography station using fission neutrons

PGAA
prompt gamma and in-beam neutron activation analysis facility

Imaging & Analysis

ANTARES

cold neutron radiography and tomography station



The neutron imaging facility ANTARES is located at the cold neutron beam port SR-4a. Based on a pinhole camera principle with a variable collimator located close to the beam port, the facility provides the possibility for flexible use in high resolution and high flux imaging. ANTARES offers two different detector positions in chamber 2 and 3, which may be chosen according to the requirements for beam size, neutron flux and spatial resolution. Both chambers offer abundant space for user-provided experimental systems or sample environment.

Chamber 1 is separately accessible for the optional installation of beam and spectrum shaping devices provided by the user. At this position, ANTARES also offers built-in options such as a velocity selector, double crystal monochromator, interference gratings, and a Be-filter which are readily available for standard user operation.

Additionally we can provide access to a 300 kV microfocus X-ray CT setup for complementary investigations with a spatial resolution as good as 1 µm.

Typical Applications

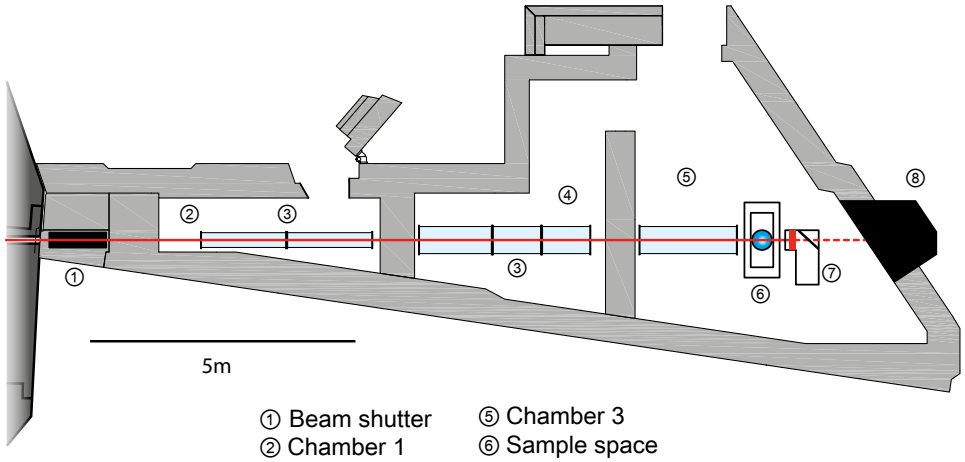
The ANTARES neutron imaging facility is designed to deliver radiographs and computed tomography of samples, similar to an X-ray machine. The resulting information is often complementary to X-ray measurements with its most important features, the high penetration of metals (Fe ~ 4 – 5 cm, Al ~20 – 30 cm, Pb ~10 – 20 cm) and the high sensitivity for hydrogen. These allow to visualise metal machine parts as well as liquids, sealants, and plastics inside of metal parts. Liquid contrast agents can be employed for crack and void detection. Examples of different techniques and their typical applications:

- **Standard neutron radiography**: Moisture in sandstone, O-rings in machine parts, aerospace pyrotechnical components, fuel cells
- **Computed tomography**: Geological samples, mineral phases, voids in carbon fiber structures (using contrast agents), machine parts, biological samples like e.g. lung tissue
- **Continuous radioscopy**: Video speed radiography of dynamic processes like boiling in refrigerators or water boilers
- **Stroboscopic imaging**: Visualisation of repetitive processes with high time resolution: Oil distribution in running combustion engines
- **Phase contrast**: Edge enhancement, aluminium foams, interfaces of similar alloys
- **Energy / wavelength scan**: Scanning for Bragg edges, phase or material identification, examination of welds
- **Polarised neutron imaging:** Metallurgical homogeneity of ferromagnetic materials, fundamental research on ferromagnetic phase transitions, visualisation of magnetic field profiles
- **Neutron Grating Interferometry:** Measurement of the spatially resolved SANS or USANS signal of the sample. Detection of microstructures on length scales of 500 nm – 10 µm, porous materials, magnetic and superconducting vortex lattice domains

Sample Environment

Standard sample environment can be used at ANTARES:

- Closed-cycle cryostats CC, CCR:
  T = 50 mK – 300 K
- Electro magnet: 0 – 300 mT
- Cooling water and pressurised air



① Beam shutter
② Chamber 1
③ Flight tubes
④ Chamber 2
⑤ Chamber 3
⑥ Sample space
⑦ Detector
⑧ Beam stop

Technical Data

Collimation and flux at the sample position

- L/D = 200, $4 \cdot 10^8$ n cm^{-2} s^{-1}
- L/D = 400, $1 \cdot 10^8$ n cm^{-2} s^{-1}
- L/D = 800, $2.6 \cdot 10^7$ n cm^{-2} s^{-1}
- L/D = 8000, $2.6 \cdot 10^5$ n cm^{-2} s^{-1}
- Beam size up to 35 × 35 cm^2

Neutron beam optics (optional)

- Double crystal monochromator:
  1.4 Å ≤ λ ≤ 6.0 Å (1% < Δλ/λ < 3%)
- Neutron velocity selector:
  3.0 Å ≤ λ ≤ 8 Å (Δλ/λ = 10%)
- Neutron grating interferometer:
  Sensitive to length scales 500nm – 10 µm
- Beam Filters:
  Cd filter for epithermal imaging
  Be filter to suppress wavelengths λ < 4 Å
  Sapphire filter to suppress fast neutrons
- ^{3}He neutron spin filter polariser
- polarising supermirror V-cavity

Sample table

XY-Phi-table:

- Capacity: 500 kg
- Travel: x = 800 mm, y = 600 mm
- Rotation table: 360° rotation
- additional high precision 5-axes HUBER table for small samples (< 10 kg)

Detection systems

- various detection systems with spatial resolutions as good as 30 µm
- Camera box with mirror and scintillation screens of different sizes from 6 x 6 cm^2 to 40 x 40 cm^2, screen thickness from 10 µm to 200 µm, plus X-ray screens
- Standard detector: ANDOR cooled CCD camera, 2048 x 2048 pixels, 16 bit
- Fast cooled scientific CMOS camera: ANDOR Neo 2560 x 2160 pixels, 16 bit, up to 50 fps full frame
- Intensified triggerable iStar ANDOR cooled CCD camera, 1024 x 1024 pixels, 16 bit
- Intensified NTSC video camera (30 fps) with analog frame grabber, MPEG-2 and DivX recording
- DürrDental Image Plate scanner for arbitrary imaging plates, focus size 12.5 – 100 µm
- Fuji BAS 2500 Image Plate scanner, focus size 25 – 100 µm
- X-ray and neutron imaging plates
- MAR345 image plate detector, 345 mm diameter, N-sensitive image plate

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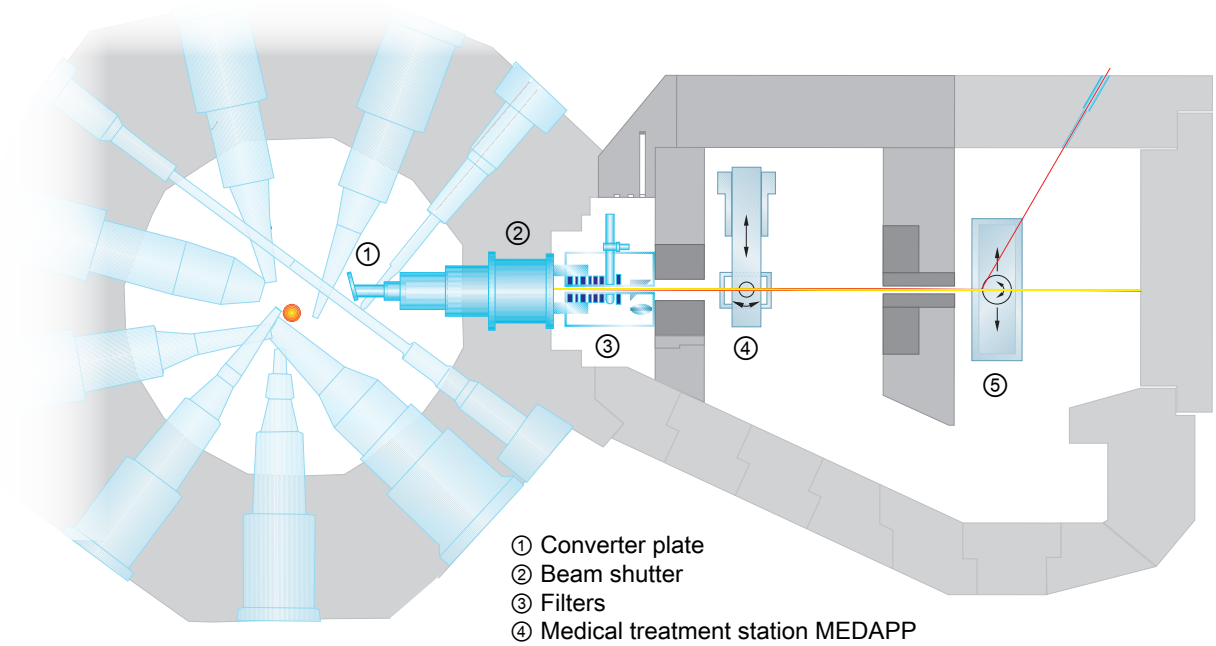
MEDAPP and NECTAR

fission neutron facility for scientific, medical, and industrial applications



① Converter plate
② Beam shutter
③ Filters
④ Medical treatment station MEDAPP
⑤ Sample table NECTAR

Both the instruments MEDAPP (**med**ical **app**lications) and NECTAR (**ne**utron **c**omputed **t**omography **a**nd **r**adiography) are located at beam tube SR-10 to which a uranium converter is attached. Both instruments are operated with fission neutrons and can be used for a broad variety of different applications. For selected tasks, an alternative use with thermal neutrons is possible.

The particularly large beam cross-section of SR-10 allows the irradiation of rather large objects, such as cell culture flasks. In addition, the FaNGas (**fa**st **n**eutron **ga**mma **s**pectrometry) instrument, consisting of a movable shielded HPGe detector system, can be installed within the MEDAPP irradiation chamber to directly measure gamma radiation emitted, e.g., in (n,n'), (n,2n), (n,p), and (n,α) reactions, and for non-destructive qualitative elemental analysis.

MEDAPP

MEDAPP is an instrument for the medical treatment of malignant tumours, as well as for biological research, and technical irradiations. Due to their energy spectrum, fast neutrons have the highest biological effectiveness of clinical neutron beams used in cancer treatment, comparable only to the effectiveness of heavy ions. This advantage comes at the expense of penetration depth, which - due to the relatively low energy of 2 MeV - limits their application to near-surface tumours, typically recurrent breast tumours and melanomas.

NECTAR

NECTAR is a versatile facility for the non-destructive inspection of various objects by means of fission neutron radiography and tomography, respectively. The obtained images often show complementary or additional information compared to other radiography sources such as X-rays or gamma-radiation. Especially for large objects consisting of dense materials, the deep penetration of fission neutrons allows for their non-destructive investigation maintaining the sensitivity for hydrogen containing materials. The acquired radiographs are available as *.tiff and *.fits files and can be processed with any image processing software. On demand, reconstruction and visualisation software is available for data analysis.

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www.mlz-garching.de/medapp-nectar
DOI: 10.17815/jlsrf-1-43

Technical Data

Neutron source

Converter facility, consisting of 2 plates of uranium-silicide. (93% ^{235}U, total 540 g), P = 80 kW

MEDAPP	NECTAR
Neutron spectrum	

• Fission spectrum
  • Mean energy: 1.9 MeV
  • Flux: up to $7 \cdot 10^8$ cm^{-2} s^{-1} (depends on filter used)
• Thermal spectrum of the D_2O moderator
  • Mean energy: 28 meV
  • Flux: ca. $2 \cdot 10^9$ cm^{-2} s^{-1}
	• Fission spectrum
	  • Mean energy: 1.8 MeV
	  • Flux: $8.7 \cdot 10^5$ cm^{-2} s^{-1} – $4.7 \cdot 10^7$ cm^{-2} s^{-1} (depends on filter used)
	• Thermal spectrum of the D_2O moderator
	  • Mean energy: 28 meV
	  • Flux: up to $1 \cdot 10^7$ cm^{-2} s^{-1}

Collimation	
• Multi leaf collimator, individually adjustable	• L/D: ≤ 233 +/- 16 (depending on collimator)
Sample space	
• Max. 40 cm x 30 cm • Max. about 100 kg	• Max. 80 cm × 80 cm, thickness dependent on material • Max. 500 kg • Any standard sample environment • Custom environment can be easily attached (e.g. hydrogen supply)
Detection systems	
• Ionisation chambers for dosimetry in custom-made phantoms • 50%-HPGe detection system shielded with PE, B_4C, and Pb • Custom systems can temporarily be installed by users	• CCD-based (ANDOR DV434-BV, pco. 1600) detection systems with different converters, e.g., pp-converter with 30% ZnS and 30 cm x 30 cm x 0.24 cm available
Typical applications	
• Neutron medical treatment of malign tumours in the MEDAPP-room • Biological dosimetry, e.g., irradiations of cell cultures • Irradiations of electronic components (also on-line tests) • Fundamental physics • In-beam gamma spectrometry	Cultural Heritage • Restauration and conservation of objects • Inner structure of large archaeological objects Technology • Hydrogen storage • Degradation of glue in timber • Water or oil in large metallic objects (e.g. gearboxes) Biology • Water uptake in large wooden samples

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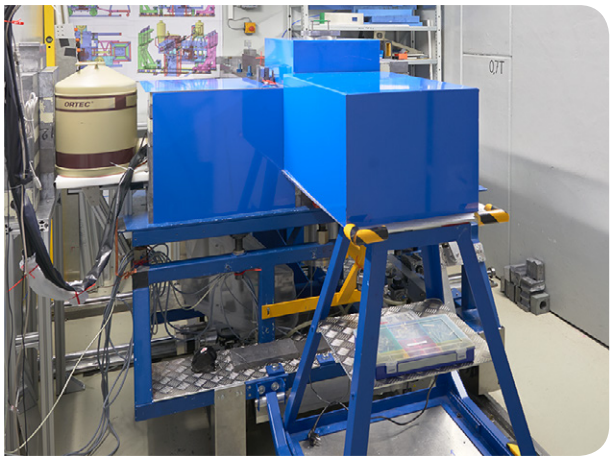
PGAA

prompt gamma and in-beam neutron activation analysis facility



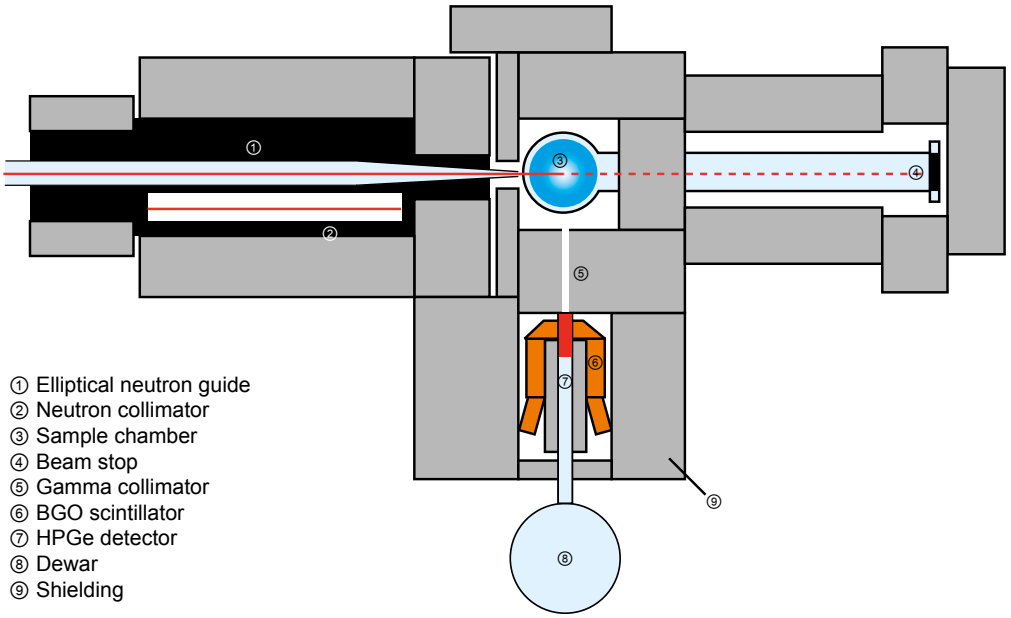
Prompt **g**amma-ray **a**ctivation **a**nalysis (PGAA) is typically used for the determination of elemental composition and concentration of solid samples (ca. down to ppm range). Liquids and gaseous samples can also be measured.

The PGAA method is based on the neutron capture in nuclei of the sample material and the subsequent detection of prompt gamma-rays emitted during de-excitation of the compound nuclei: ${}^{A}Z(n, \gamma)^{A+1}Z$.

PGAA is a non-destructive tool for the analysis of major and minor components, especially advantageous for the assay of light elements (unique for H and B) and certain trace elements (Cd, Hf, rare earths). In the strong neutron beam at FRM II, however, neutron activation can also be performed, and thus many more trace elements can be detected (elements in the 4 – 6 period).

Typical Applications

- Archaeology and cultural heritage objects (ceramics, coins, metals, conditionally bronze objects)
- Cosmochemistry (meteorites)
- Geology, petrology (macerals, sediments)
- Enviromental research (air pollution, river pollution)
- Medicine (B, Li, Cd in tissues, nano-particles for cancer therapy, radiation damage of DNA)
- Semiconductor or superconductor research and industry
- Analysis of new chemical materials (catalysts, clathrates, crystals)
- Reactor physics (shielding material, new fuel element), radiation hardness testing with cold neutrons (chips, scintillators)
- Fundamental research (nuclear data, low-spin excited states in nuclei, partial and total neutron capture cross-section measurements)
- Conditionally NAA after the PGAA irradiation



Technical Data

Neutron beam

- Cold neutron spectrum from NL4b (last section of 5.8 m elliptical focussing) with an average energy of 1.83 meV (6.7 Å)
- Two measuring conditions:
  - for large samples with collimation:
    Beam size: 20 x 30 mm^2
    Neutron flux max.: $2 \cdot 10^9$ n cm^{-2} s^{-1} thermal n. eq.
  - for small samples with 1.1 m elliptical guide:
    Beam size: 11 x 16 mm^2
    Neutron flux max.: $5 \cdot 10^{10}$ n cm^{-2} s^{-1} thermal n. eq.

Detection system

- For the standard PGAA, one Compton-suppressed spectrometer is used (60% HPGe detector surrounded by a BGO scintillator and connected in anticoincidence mode). The signal is processed using a DSpec-50 digital spectrometer manufactured by Ortec.
- A new low-background counting chamber has also been installed next to the PGAA instrument for the acquisition of decay gamma spectra after activating the samples in the beam. A 30% HPGe detector is used with a DSpec-50 unit.
- Energy range is from 30 to 12 000 keV.

Measuring conditions

- Low vacuum (0.3 mbar) possible
- Sample weight: 0.1 mg – 10 g
- Max. sample dimensions:
  ca. 40 × 40 x 40 mm^3
- Automated measurement for max. six samples in a batch (vertical sample holder with six positions)
- Solid samples are usually sealed into thin FEP bags or other suitable material

Data acquisition and analysis

- An in-house software for the automated measurement of up to six samples in a batch run.
- Evaluation of the spectra and the calibration of the spectrometer (efficiency curve and non-linearity) using the software Hypermet PC developed in Budapest
- Determination of the elemental composition of samples using the Excel macro and Excel sheet package ProSpeRo
- Automated data acquisition using DSPEC-50 is currently under development

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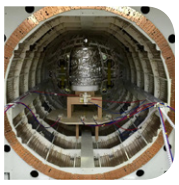


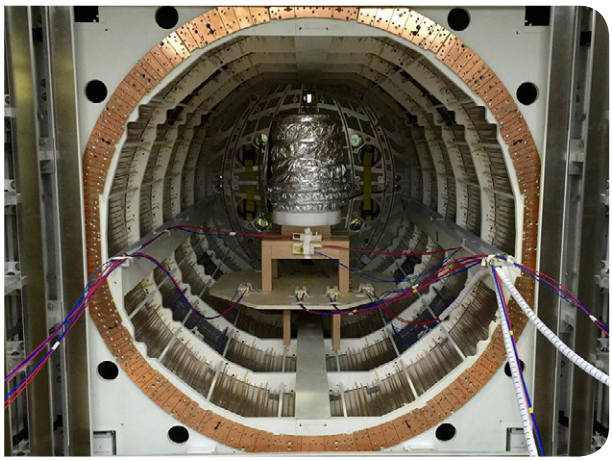
EDM
neutron electric dipole moment measurement

MEPHISTO
facility for particle physics with cold neutrons

Particle Physics

EDM

neutron electric dipole moment measurement



An **e**lectric **d**ipole **m**oment (EDM) of the neutron would be a clear sign of new physics beyond known particle physics. The search for this phenomenon is considered one of the most important experiments in fundamental physics and could provide key information on the excess of matter versus antimatter in the Universe. With high measurement precision, this experiment aims to ultimately achieve a sensitivity of 10^{-28} ecm for a charge distribution within the neutron. This can be interpreted as a probe of the early Universe, less than 10^{-11} s after the big bang, complementary to experiments at CERN and also beyond the reach of accelerators. In the Neutron Guide Hall East, a new instrument to search for the neutron EDM is currently being commissioned.

At a later stage, **u**ltra **c**old **n**eutrons (UCN) will be provided by a source in beam tube SR-6. In the instrument's centre, the UCN are trapped in a box, where Ramsey's method of separated oscillatory fields is used to precisely measure Larmor precession of UCN over hundreds of seconds as an interferometer in time in a small (about 1 µT) magnetic field. A deviation of the Larmor precession in the simultaneous presence of the magnetic field and a strong electrostatic field would be an indication for an EDM. While the UCN source will provide the required neutron density of 1000 per cm^3 in the instrument, it itself is optimised to control any systematic effects.

A dominating issue to achieve this precision is the quality of the magnetic environment. Currently, it provides an extended volume (~0.5 m^3) of 100 pT or less absolute field and a temporal stability of < 10 fT in 1000 s without any active measures. This corresponds to about the magnetic field in between stars in the milky way.

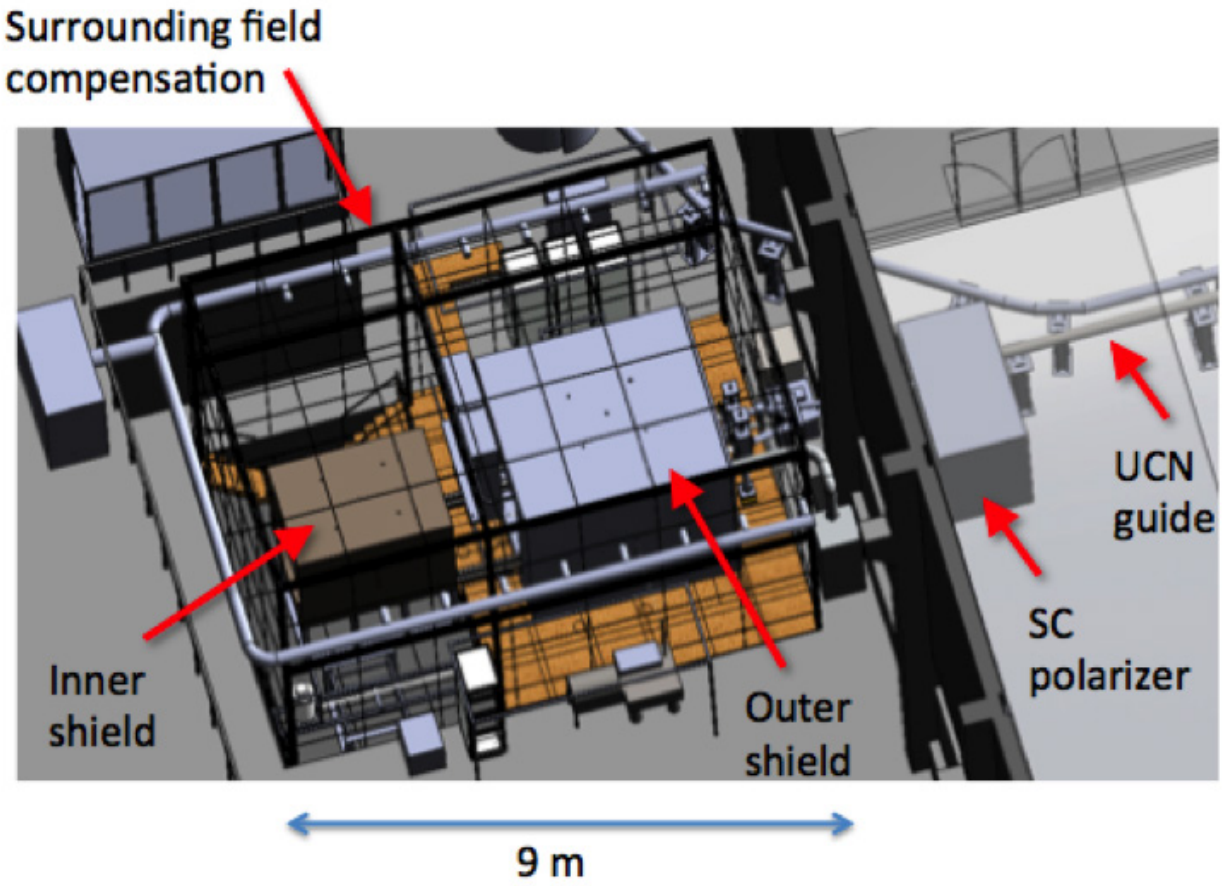
The shielding factor against external distortions of 6 Mio at 1 MHz and > 10^8 at 10 Hz. Inside this volume, magnetic fields of up to few µT can be applied vertically and horizontally with a homogeneity of better than up to 10^{-4} relative precision. During the commissioning phase, the volume is used for optical magnetometry and precision spin-clock measurements, as well as for the comparison of precision magnetometers. To apply electrostatic fields, a bipolar 200 kV source with stabilisation on Pockels effect is implemented. The instrument is a joint activity of several institutions, see nedm.ph.tum.de

Other optional measurements inside the instrument include:

- Ramsey-measurements with trapped ultra cold neutrons
- Probing the isotropy of the Universe and its invariance under Lorentz transformations via clock comparison measurements with polarised gases
- Measuring new forces at short distances: search for dark matter candidates (axions etc.)
- Precision magnetometry and magnetometer development
- Ultra low field NMR
- Magnetic material screening on pT level

Technical data

The EDM facility consists of a magnetically shielded room, surrounded by 180 fluxgate magnetometers and 24 coils for external field compensation. The magnetically shielded room consists of an outer and an inner room, which can be used independently or slided into each other. Experiments with 2 x 2 x 2 m dimension can be placed inside the shields in preassembled state through a door of 2 x 2 m. The furniture inside is non-magnetic and either 3D-printed or made from wood, external equipment can be degaussed on-site. Stable current sources with ppm stability over > 1000 s can provide DC magnetic fields with up to 5 µT.



External compensation

- Size 9 x 6 x 6 m
- Number of coils: 24
- Number of magnetometers: 180
- Field < 5 µT (DC)
- Active feedback frequency: 10 Hz (max.)

Outer shield

- Inner dimension:
  h = 2.3 m, w = 2.5 m, l = 2.8 m
- Residual field: < 0.5 nT in 1 m^3
- Damping factor:
  279 at 0.01 Hz, > 10000 at 10 Hz

Inner shield

- Inner dimension:
  h = 1.5 m, w = 1.5 m, l = 2.1 m
- Residual field: < 0.1 nT in 0.5 m^3
- Damping factor:
  6.000.000 at 0.001 Hz, > 10^8 at 10 Hz

Available magnetometry

- Fully optical Cs magnetometers (< 30 fT in 40 s resolution)
- ^{199}Hg magnetometers (< 20 fT in 100 s)
- SQUID magnetometers and gradiometers
- SEOP polarisation of ^{3}He and ^{129}Xe at the experiment

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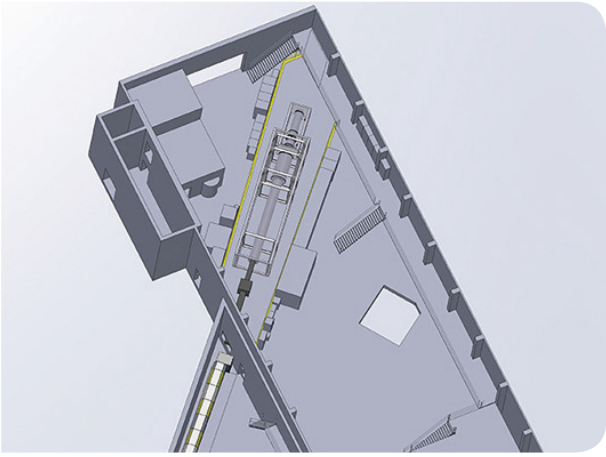
MEPHISTO

facility for particle physics with cold neutrons



Since the start of reactor the FRM II provides a cold white neutron beam for long term user dedicated experimental setups.

Such an experiment is normally planned and built up by external groups but additional help during the commissioning of the experiment at the reactor is necessary. Therefore, this work must be organised in close contact with the local instrument scientist. The desired precision is reached inter alia by good statistics which means long term experiments over several reactor cycles.

The experimental area MEPHISTO, the measurement facility for particle physics with cold neutrons, is dedicated to those experiments in the field of nuclear and particle physics. Currently, the experimental area moves from the Neutron Guide Hall West to the Neutron Guide Hall East. The solely used neutron guide SR-4b will deliver a white cold spectrum for experiments. A removeable 11% velocity selector at the end of the guide will complete the beam line.

The MC-simulation for this beam with a dimension of 60 x 106 mm² proposes a mean wavelength of 4.5 Å and a gold capture flux of $2 \cdot 10^{10}$ n $cm^{-1}s^{-1}$. The experimental area is 5 x 25 m², diagonally built-in in the Neutron Guide Hall East. The spectrum shows a shoulder to smaller wavelengths, the maximum of the spectrum is located at 3.3 Å.

It is planned to install the instrument PERC [1] at the MEPHISTO beam line during the first years of operation in the Neutron Guide Hall East. This instrument is a precise, bright and intense source of protons and electrons from the neutron decay. The instrument PERC itself is open for external user groups with spectrometers to measure the protons and electrons.

Typical Applications

The experiments at MEPHISTO concentrate on induced nuclear reactions of the neutron with atoms or on the free neutron decay with its products.

Some of the experiment types performed at MEPHISTO:

- Free neutron decay and spectroscopy of the decay products
- Spectroscopy of neutron induced fission
- Production of ultra cold neutrons with liquid helium
- Production of ultra cold neutrons with solid gases

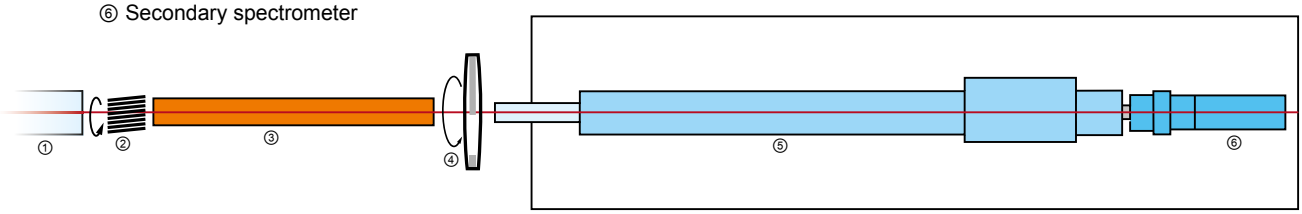
Infrastructure

A removeable neutron velocity selector is placed at the end of the neutron guide. The minimal wavelength is 4.5 Å. The resolution of the passing wavelength is 11%. The selector can be rotated to tune the resolution.

A data system based on VME (ADC, peak ADC, QDC, TDC) is available. For signal forming purpose several NIM inserts exist, a list can be requested from the local instrument scientist. Also available are spectroscopic amplifiers and high voltage sources for detectors.

[1] Dubbers, D. et al., Nucl.Instr.Meth. A, 596, 238-247, (2008).

① Mephisto guide
② Selector
③ PERC polariser
④ PERC chopper
⑤ PERC
⑥ Secondary spectrometer



Technical Data

Neutron beam

- End of the cold neutron guide SR-4b (m = 2.5)
- Cross section of the guide: 60 x 106 mm²
- Thermal capture flux (simulated): $2 \cdot 10^{10}$ n $cm^{-1}s^{-1}$
- Mean wavelength (simulated): 4.5 Å
- Beam height from floor: ~ 1300 mm
- Experimental area: 5 x 25 m²
- Maximum at 3.3 Å
- Standard neutron spectrum with shoulder to smaller wavelengths

Beam attenuators

- By geometrical attenuation, the beam intensity can by reduced to 20%, 4% and 2%

Polarisation

- A bender (vertical direction) is available to polarise the complete cross section of the beam

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NEPOMUC
neutron induced positron source Munich

CDBS
coincident Doppler-broadening spectrometer

PAES
positron annihilation induced Auger-electron spectrometer

PLEPS
pulsed low energy positron system

SPM
scanning positron microscope

Positrons

NEPOMUC

neutron induced positron source Munich

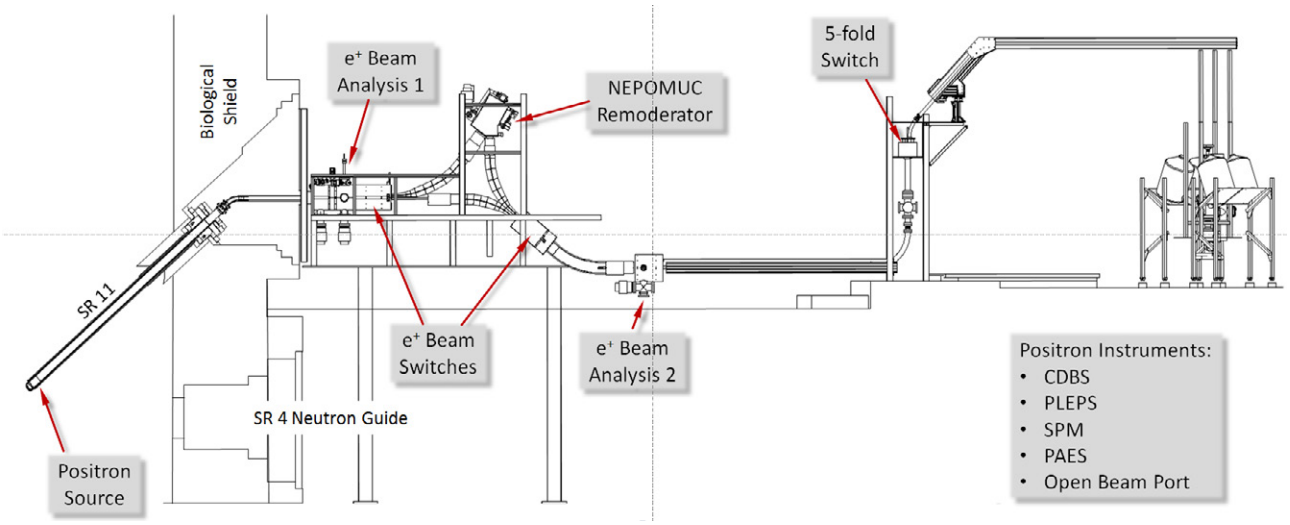


Figure 1: Cross-sectional view of the inclined beam tube SR11: the in-pile positron source is mounted inside the tip. After acceleration, the positron beam is magnetically guided to the remoderation unit outside the biological shield of the reactor.

NEPOMUC provides a high-intensity low-energy positron beam for applications in solid state and surface physics as well as for fundamental research in nuclear and atomic physics.

At NEPOMUC, the positrons are generated by pair production from absorption of high-energy prompt gamma-rays after thermal neutron capture in Cd. A cadmium cap is mounted inside the tip of the inclined beamtube SR11. The released high-energy gamma-radiation is converted into positron – electron pairs in a structure of platinum foils which is mounted inside the cadmium cap. Positive high voltage is applied in order to extract the moderated positrons. The positron beam is magnetically guided in a solenoid field of typically 7 mT.

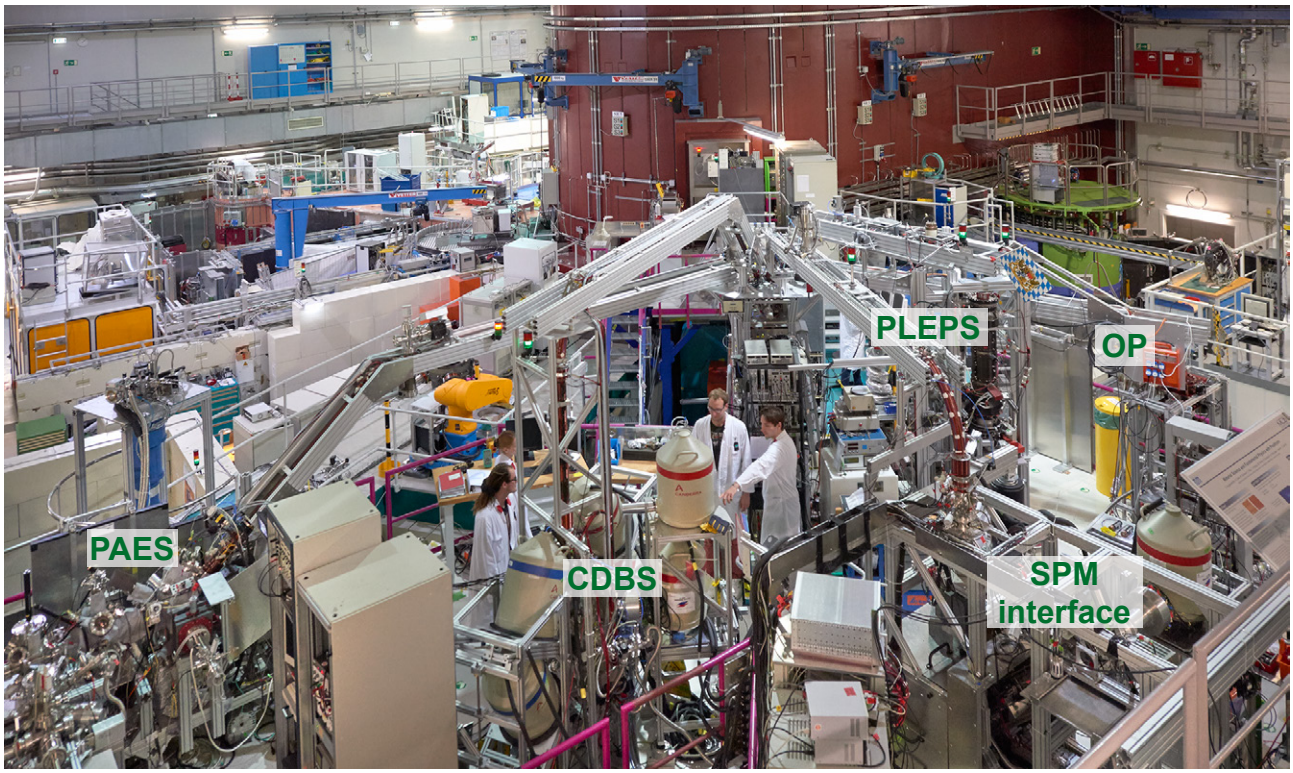
Technical Data

Key values of the primary positron beam

- E = 1 keV
- Intensity:
  > $1.1 \cdot 10^9$ e^+/s moderated positrons per second
- Diameter of beam spot:
  ≈ 9 mm (FWHM) in 7 mT beam guiding field.

Key values of the remoderated positron beam

- E = 10 ... 200 eV
- Intensity:
  $5 \cdot 10^7$ remoderated positrons per second
- Diameter of beam spot:
  1.85 mm (FWHM) in ≈ 4 mT beam guiding field



The positron beam facility

The remoderation device of NEPOMUC enhances the brightness of the positron beam and hence enables positron experiments which are high resolved in space or/ and in the time domain. The remoderator is based on the stochastic cooling of the positrons in a W(110) single crystal and the positron reemission of the thermalised positrons into the vacuum with discrete energy. For most of the measurements the brightness enhanced positron beam is used. However, there are also experiments which are not dependent on a very bright beam but need the full intensity of the primary beam. Therefore the primary beam can be used also unaltered via two beam switches e.g. for experiments at the open beam port.

By the central, fivefold beam switch the positron beam is delivered to one of the five experiment beam lines. Currently, at these beam lines four instruments are permanently installed:

- Pulsed low-energy positron system (PLEPS)
- Coincident Doppler-broadening spectrometer (CDBS)
- Positron annihilation induced Auger-electron spectrometer (PAES)
- Scanning Positron Microscope Interface (SPM Interface)

The fifth beam line is for the multi-purpose open beam port (OP) which is used for transportable short-term experimental set-ups.

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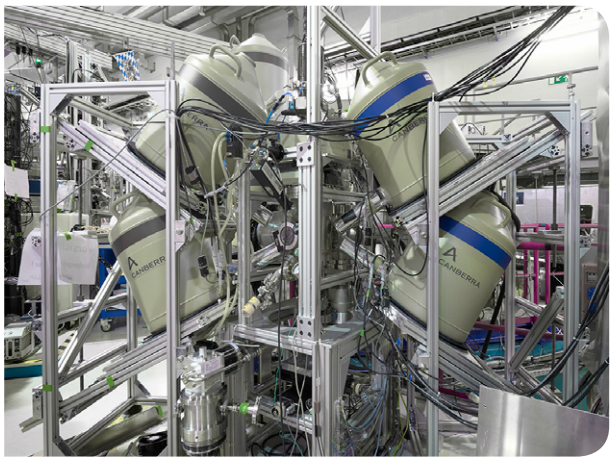
CDBS

coincident Doppler-broadening spectrometer



The Doppler broadening of the 511 keV annihilation line contains information of the electron momentum distribution at the positron annihilation site in the sample. Since the probability of core electron annihilation decreases in open volume defects a narrowing of the annihilation line is observed.

For this reason, DBS with the monoenergetic positron beam allows to determine defect profiles, energy dependent 2D imaging of defects, and defect annealing as a function of temperature. In addition CDBS is applied in order to gain elemental information about the positron annihilation site and hence about the chemical surrounding of defects.

Technical Data

Beam properties

- Positron implantation energy: E = 0.2 – 30 keV
- Mean positron implantation depth: up to several µm (material dependent)
- Beam size: adjustable between 0.3 – 3 mm Ø

2D x-y-scans

- Scan area: 20 × 20 mm^2
- Step size adjustable between 0.1 and 10 mm

High-purity Ge detectors

- 30% efficiency
- Energy resolution: 1.4 keV at 477.6 keV

Sample

- Size up to 20 × 20 × 3 mm^3
- Optimum 4 samples at one sample holder: < 10 × 10 mm^2
- Temperature: 100 K – 900 K

Typical measurement times

- ~ 1 – 2 min / spectrum
- ~ 8 h full 2D overview scan (with $\Delta x = \Delta y = 1$ mm)
- ~1 h depth profile (t = 2 min, 30 energy values)
- ~ 4 – 6 h/spectrum CDBS

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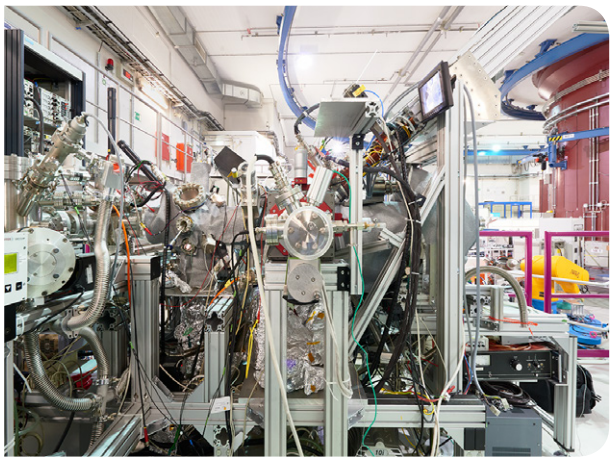
PAES

positron annihilation induced Auger-electron spectrometer



PAES is a newly developed application for surface studies with high elemental selectivity and exceptional surface sensitivity. In PAES, the emission of Auger electrons is initiated by positron-electron annihilation that leads to several major advantages, e.g. topmost layer sensitivity, compared with conventional electron induced AES.

PAES is part of the **sur**face **spect**rometer (SuSpect) which also enables sample preparation in UHV conditions, conventaional AES and XPS.

Examples are surfaces with sub-monolayers of foreign atoms, high resolution determination of Auger line shapes, element selective surface studies.

Technical Data

Beam properties

- Positron implantation energy: 20 eV
- Electron energy resolution: ΔE/E < 1%

Sample

- Sample size: ø 10 mm
- Sample thickness: max. 3 mm

Typical measurement times

- Measurement time (typically): 10 – 15 min

Complementary techniques

- Electron or X-ray induced AES
- XPS
- STM

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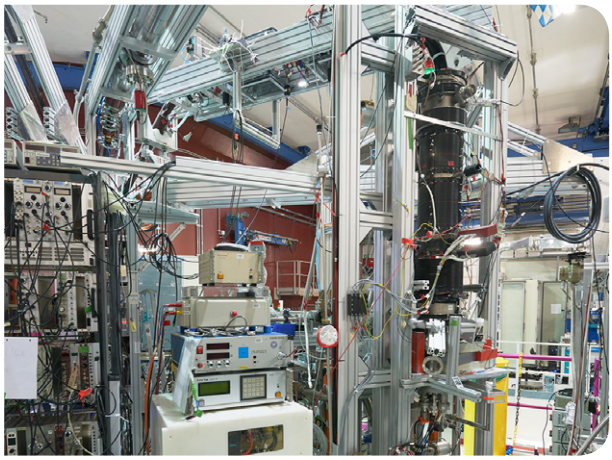
PLEPS

pulsed low energy positron system



PLEPS is a unique tool for depth profiling of defects with positron annihilation lifetime spectroscopy using a pulsed positron beam of variable energy.

Positron lifetime measurements allow to determine type and size of open volume defects (such as vacancies, vacancy-clusters, dislocations, grain boundaries etc., and free volumes in polymers) in a wide variety of materials and provide information on defect-concentration. In combination with a monoenergetic positron beam of variable energy depth-resolved defect analysis becomes possible.

Typical applications

- Defect identification in thin layers and layered structures of semiconductors and insulators
- Radiation induced defects in materials for fusion and fission reactors
- Characterisation of free volumes in polymers and glasses

Technical Data

Beam properties

- Positron implantation energy: 0.5 – 20 keV
- Beam spot Ø ~ 1 mm
- Count rate: ~ 5000 – 10000 cps

Sample

- Limited to 5 × 5 mm^2 – 9 × 9 mm^2

Typical measurement times

- < 10 min per spectrum
  (> $3 \cdot 10^6$ counts in the spectrum)
- Depth-profile: 4 – 5 h
  (15 – 20 implantation energies, > $3 \cdot 10^6$ counts in the spectrum)
- Time-window: 20 ns or 40 ns
- Time-resolution: 260 – 280 ps
- Peak/ background > 50000 : 1

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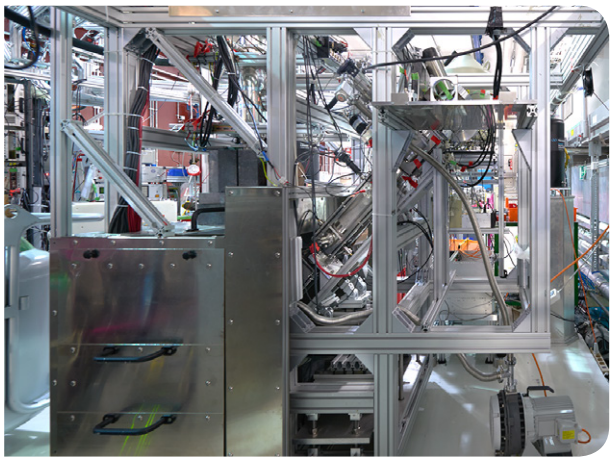
SPM

scanning positron microscope



The Munich scanning positron microscope permits positron lifetime measurements with a lateral resolution in the µm range and within an energy range of 1 – 20 keV. Thus, this instrument enables the measurement of high resolved 3D defect maps. Until today, the SPM was operated only in the laboratory at the Universität der Bundeswehr in Munich and was therefore limited by the long measurement times of several days per 2D-scan due to the low intensity of the positron beam produced by a standard ^{22}Na source. This disadvantage will be overcome by installing the SPM at the high intensity positron beam at NEPOMUC.

Therefore, the SPM interface was designed and tested successfully. This device converts the continuous beam of NEPOMUC to a high-brightness, pulsed positron beam, which matches the demands of the SPM. Recently, a sample chamber was connected to the SPM interface which enables spatially resolved positron lifetime measurements with a lateral resolution in the range of 0.1 mm.

Technical Data

Beam properties SPM / SPM Interface

- Positron implantation energy: < 20 keV / < 10 keV
- Beam-Spot < 1 µm / ≈ 0.1 mm
- Count rate: > 2000 cps / > 4000 cps
- Time-Window: 20 ns
- Time-Resolution: < 250 ps
- Peak/ Background: > 5000 : 1 / > 2000 : 1

Typical measurement times

- SPM: ≈ 1 day for one 2D-Scan (12 x 12 µm^2)
- SPM interface: ≈ 0.5 day for one 2D-Scan (1 x 1 mm^2)

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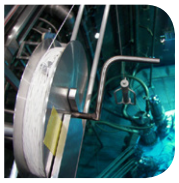
www.mlz-garching.de/spm
DOI: 10.17815/jlsrf-1-53

Silicon doping facility (SDA)

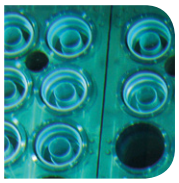
Standard rabbit irradation facility (RPA)

Capsule irradiation facility (KBA)



Mechanical irradiation system

Irradiation position in control rod



Gamma-ray irradiation facility

Irradiation possibilities at beam tube SR-10 using fission neutrons

Irradiation facilities

Irradiation facilities

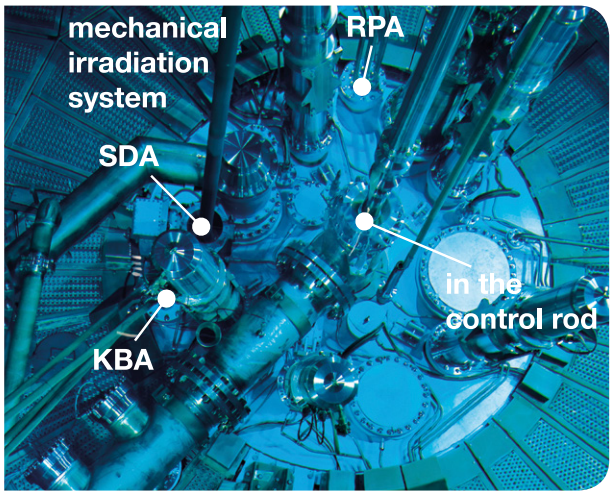


Figure 1: Positions of the different irradiation facilities within the reactor pool: SDA = silicon doping facility, RPA = rabbit irradiation system, KBA = capsule irradiation facility, mechanical irradiation system, and irradiation position in the control rod.

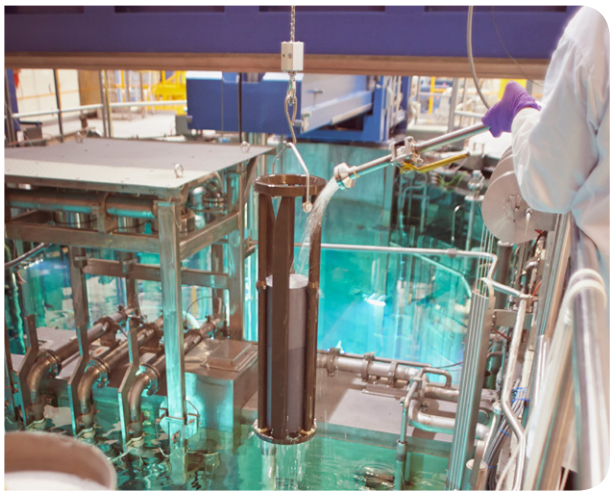


Figure 2: A freshly irradiated Si batch is taken out of the reactor pool.

The irradiation of materials serves many purposes including the doping of silicon and the production of radioisotopes for industry and medicine, as well as the examination of samples with neutron activation analysis.

The neutron source FRM II is equipped with a number of irradiation facilities, which cover a wide range of applications both with regard to the available sample volumes and the achievable neutron fluences.

For proposals and experiments dealing with the irradiation facilities please contact directly the head of the irradiation services Dr. Heiko Gerstenberg.

Silicon doping facility (SDA)

Pure silicon is a poor conductor of electricity. In order to gain the properties which make it interesting for components in the electrical engineering, it needs to be doped with small amounts of host atoms e.g. phosphorous or boron. For high-performance electronic components as thyristors or **i**nsulated-**g**ate **b**ipolar **t**ransistors (IGBTs) the silicon (Si) needs to have a defined content of phosphorous (P) atoms distributed extremely homogeneously within the Si matrix. At the FRM II, silicon ingots up to a diameter of 200 mm and a height up to 500 mm are irradiated in a position within the moderator tank (see fig. 2). The doping is achieved by neutron capture and the resulting conversion of individual ^{30}Si atoms into ^{31}P. Due to the neutron moderation by heavy water the facility is particularly useful for the production of high resistivity (up to 1200 Ωcm) **n**eutron **t**ransmutation **d**oped (NTD) Si. The silicon doping facility is automated and operated in two working shifts. The typical yearly output sums up to about 15 tons. The customers of the doped ingots are semiconductor producers from Europe and Asia.

Standard rabbit irradiation system (RPA)

Six independent irradiation channels are available within the standard rabbit irradiation system. The positions are vertically staggered in the moderator tank, allowing for the selection of a thermal neutron flux density adapted to the sample. The neutron flux densities range from $5 \cdot 10^{12}$ to $7 \cdot 10^{13}$ $cm^{-2}s^{-1}$. Sample sizes should be less than 8 cm^3. The samples are packed in polyethylene capsules and conveyed pneumatically by CO_2 into the irradiation position. The available thermal neutron fluence varies between $2 \cdot 10^{14}$ cm^{-2} and $3 \cdot 10^{17}$ cm^{-2}. For the various irradiation channels the ratio of thermal/ fast neutron flux density is as high as 15000 – 60000.

These favourable irradiation conditions avoid the production of undesired radioisotopes due to threshold reactions by fast neutrons and make the pneumatic rabbit system a valuable tool to be used

Figure 3: The standard rabbit irradiation system has six independent irradiation channels and is operated by carbon-dioxide.

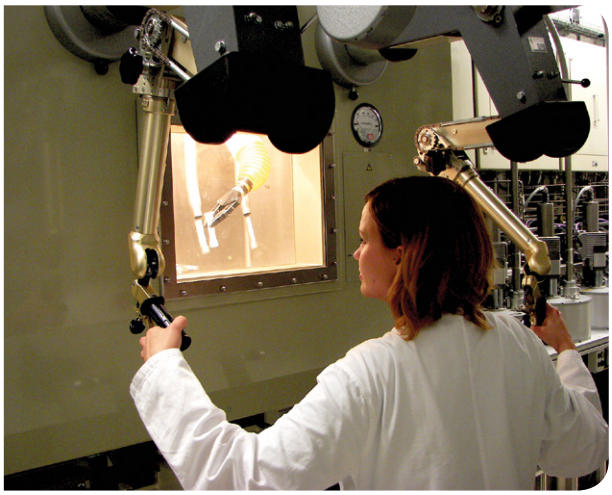


Figure 4: After irradiation in the rabbit system, the samples are prepared via manipulators to be sent to the customers.

in the framework of neutron activation analysis or for the production of particular radioisotopes with well defined low activity values, as required for instance in material sciences. In order to facilitate the cooperation with the neighbouring Institute for Radiochemistry (RCM) the pneumatic rabbit system is connected directly to their laboratories by an additional pneumatic dispatch.

Capsule irradiation facility (KBA)

High dose irradiation spanning periods from several hours to weeks, is carried out in the capsule irradiation facility. It is a pool water-driven hydraulic rabbit system with two mainly identical irradiation channels exhibiting thermal neutron flux densities of up to $1.3 \cdot 10^{14}$ $cm^{-2}s^{-1}$. The samples are packed in aluminium capsules with a volume of up to 20 cm^3. If required, the samples are additionally packed water tight in an inner capsule made from high purity aluminium or quartz in order to avoid their direct contact to pool water. At maximum three capsules may be irradiated simultaneously in each channel. The ratio of thermal/ fast neutron flux density ranges between 330 and 770. The main application of KBA is the production of high activity radioisotopes to be used in radiopharmaceuticals or for industrial purposes such as density or level sensors. Further activities deal with the study of the deterioration of moving parts in motors.

Mechanical irradiation system

Samples sized up to 120 cm^3 can be irradiated in a facility in the moderator tank. In spite of the available sample size of 2.5 l, the facility is typically used for short term irradiations of smaller samples. The thermal neutron flux density is $1.1 \cdot 10^{13}$ cm^{-2} s^{-1}. The maximum licensed irradiation time is 2 h corresponding to a thermal neutron fluence of $8 \cdot 10^{16}$ cm^{-2}. Due to the low radioactivity resulting from short term irradiations at moderate neutron flux density the facility is particular useful for scientists who are less interested in radioactivity but in other irradiation induced effects on sample properties. The mechanical irradiation system turned out to be perfectly suitable for geochronological studies using the fission track technique.

Irradiation position in control rod

The highest possible fluence of $1.1 \cdot 10^{21}$ cm^{-2} can be reached at the irradiation position within the control rod. It is only possible, however, to load and unload it when the reactor is shut down, after the completion of its 60-day cycle.

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Irradiation facilities

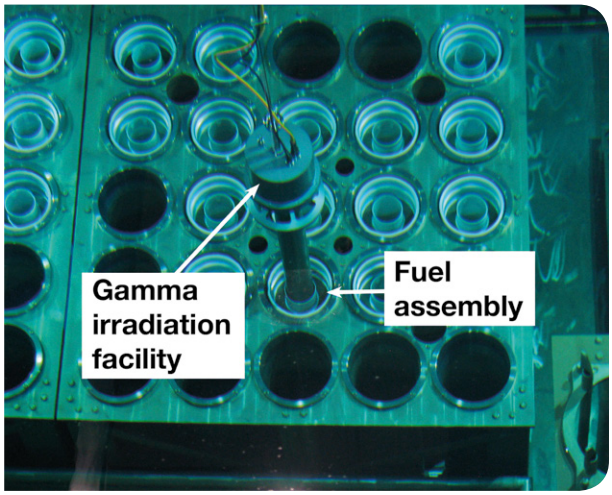

Figure 5: Gamma irradiation facility in spent fuel assembly.

Gamma-ray irradiation facility

The newest facility in operation at the FRM II is gamma irradiation. It uses the intense gamma-radiation emitted by spent fuel assemblies (fig. 5). Its installation was supported by the German Research Association (Deutsche Forschungsgemeinschaft, DFG). It is located in the storage rack of spent fuel elements. The typical gamma dose rate ranges from 1 kGy/h up to 100 kGy/h. The sample container has a diameter of 76 mm and a height of approximately 1 m. Additionally, the sample position can be heated up to 140°C, if required. The irradiation time can vary between several minutes to several weeks. Up to now the application is restricted to inorganic solids. If required the application range could be extended to organic compounds, e.g. cable insulation or organic sealing materials.

Figure 6: ^{177}Lu produced by the company ITG at the FRM II at the capsule irradiation facility. The radioisotope is filled in little vials with a volume of 2 ml and then packed in cans with a diameter of 45 mm and a height of 70 mm.

Figure 7: Loading of the capsule irradiation facility.

Typical applications

Neutron Activation Analysis

Neutron **a**ctivation **a**nalysis (NAA) is used to analyse element composition in a material. Up to 30 or 40 elements can be determined simultaneously down to the ppt and sub-ppt range.

Industrial applications:

- Trace elements in pure silicon
- Environmental monitoring, e.g. retained substrates in the filters of an exhaust of a chemical production

Archeological and geological applications:

- Fingerprint of materials gives clues about the origin of the findings
- Determination of the age and composition of rock by methods requiring reactor irradiation

Radioisotopes for medical and technical applications

Production of radioisotopes in the different facilities (e.g. KBA, RPA)

- ^{60}Co for industrial purposes (e.g. non-destructive material testing)
- ^{177}Lu, which is used for the therapy of neuroendocrine tumours (see fig. 6)
- ^{161}Terbium, ^{166}Holmium for medical purposes (primarily for tumour therapy)
- The production of ^{99}Mo at the FRM II is planned to start in 2018. Its daughter isotope ^{99m}Tc is used in more than 80% of all nuclear medical diagnoses.

outside moderator tank

Figure 8: The tumour irradiation facility (MEDAPP) with a face mask for the accurate positioning of the patient. The Klinikum rechts der Isar (MRI), Department of Radiotherapy and Oncology, is responsible for conducting the therapy.

Irradiation possibilities at beam tube SR-10 using fission neutrons

The beam tube SR-10 can deliver very different beam qualities: A pair of uranium converter plates generates an unmoderated fission spectrum with mean energy of 1.9 MeV, accompanied by prompt and delayed photons. A large, homogeneous, horizontal beam of either fission neutrons (flux up to $7 \cdot 10^8$ cm^{-2} s^{-1}) or thermal neutrons (flux up to $3.9 \cdot 10^9$ cm^{-2} s^{-1}) is available for scientific, medical, and commercial testing, available with an adjustable exposure area of up to 40 x 30 cm^2. More details about the irradiation possibilities at SR-10 can be found in the instrument section about the instruments MEDAPP and NECTAR.

Technical Data (all facilities)

Silicon doping facility (SDA)

- $1.7 \cdot 10^{13}$ thermal neutrons cm^{-2} s^{-1}
- Si dimensions: height ≦ 500 mm, ∅ = 200, 150, 125 mm
- ρ_{target}: 25 Ω cm – 1200 Ω cm

Standard rabbit irradiation system (RPA)

- $5 \cdot 10^{12}$ to $7 \cdot 10^{13}$ thermal neutrons cm^{-2} s^{-1}
- ϕ_{th} / ϕ_f: 15000 – 60000

Capsule irradiation facility (KBA)

- Up to $1.3 \cdot 10^{14}$ thermal neutrons cm^{-2} s^{-1}
- ϕ_{th} / ϕ_f: 330 – 770

Mechanical irradiation system

- $1.1 \cdot 10^{13}$ thermal neutrons cm^{-2}s^{-1}
- ϕ_{th} / ϕ_f: ~770

Irradiation position in the control rod

- $2 \cdot 10^{14}$ thermal neutrons cm^{-2} s^{-1}
- $2 \cdot 10^{14}$ fast neutrons cm^{-2} s^{-1}

Gamma ray irradiation facility

- 1 kGy/h up to 100 kGy/h

Neutron activation analysis

- Irradiation time: seconds – hours
- Sample weight: mg – g
- Rel. efficiency at 1.3 MeV: > 40%
- Energy resolution: < 0.9 keV at 122 keV, < 1.8 keV at 1.3 MeV

Irradiation with fast neutrons at SR10

- up to $7 \cdot 10^8$ fast neutrons cm^{-2} s^{-1}

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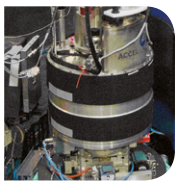
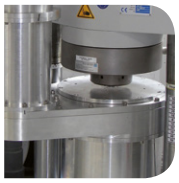
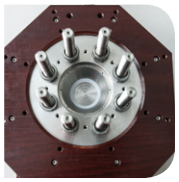


SE
magnetific field



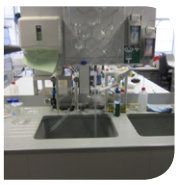
SE
high pressure



SE
specialised equipment

SE
low temperatures

SE
high temperatures



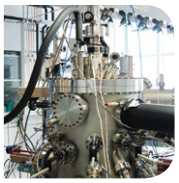
LAB
Bio Laboratory

LAB
Chemistry Laboratory

LAB
Materials Science Laboratory

LAB
Sample Preparation Laboratory

UF
TEM



UF
MBE

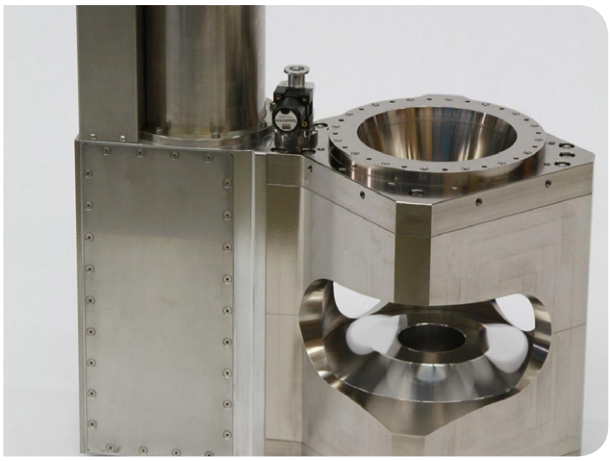
UF
X-ray Tomography

Sample Environment (SE), Laboratories (LAB), and User Facilities (UF)

SE

magnetic field

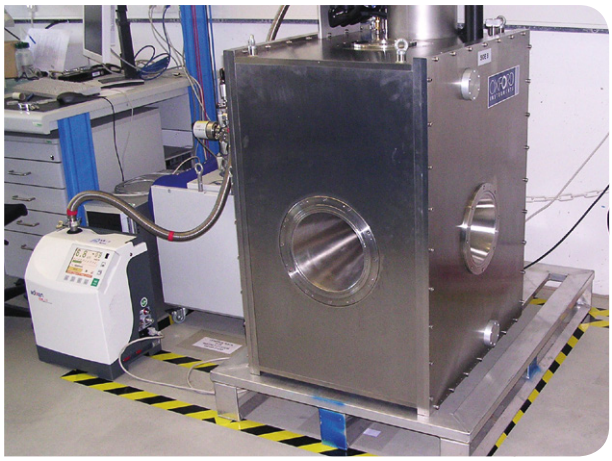
MAG-2.2T-HTS



Specifications

- Maximum magnetic field:
- ± 2.2 T, orientation arbitrary
- Homogenity of the magnetic field (15mm DSV): 1.45%
- Three room-temperature bores: minimum Ø 80 mm
- Beam window dimensions: 4 conical windows, opening angle ± 20°, 1 window opening angle 150 °
- Cooling system: dry
- Cool down: 22 hours
- Additional sample environment available (CC, CCR)

MAG-H-5.0T



Specifications

- Maximum magnetic field: ± 5.0 T (symm.), ± 2.5 T (asymm.)
- Homogenity of the magnetic field (25 mm x 25 mm cylinder): 2.0%
- Three room-temperature bores: Ø 80 mm
- Beam window dimensions: horizontal and vertical angle: 30°
- Cooling system: dry
- Cool down: 10 days
- Additional sample environment available (CCR)

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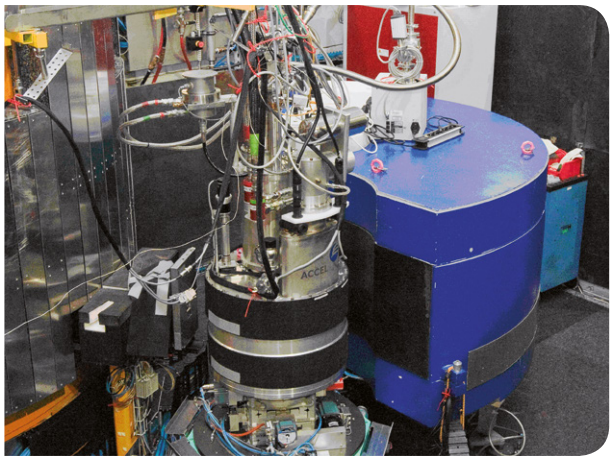
SE

magnetic field

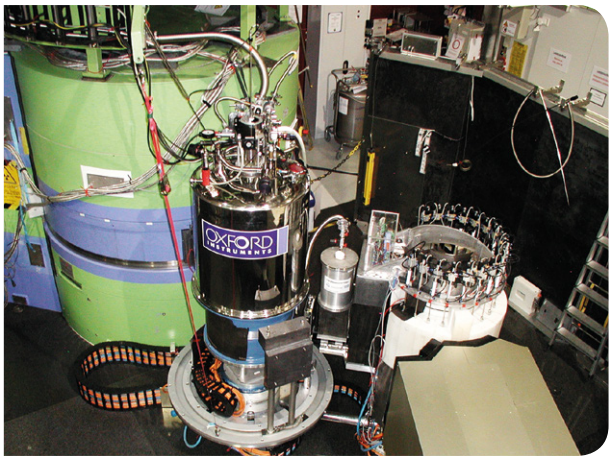
MAG-V-7.5T



Specifications

- Maximum magnetic field: ± 7.5 T
- Homogenity of the magnetic field (Ø 15 mm sphere): 0.2%
- Room-temperature bore: Ø 100 mm
- Beam window dimensions:
  vertical gap: 30 mm
  vertical open angle: 3°
  in plane open angle: 320°
- Cooling system: dry
- Cool down: 3 days
- Total thickness of Al in the beam: 30 mm
- Additional sample environment available (CC, CCR, HTF)

MAG-V-15T



Specifications

- Maximum magnetic field: ± 13.2 (14.5) T
- Homogenity of the magnetic field (20 mm x 12 mm cylinder): 0.85%
- Low-temperature bore: Ø 20 mm
- Beam window dimensions: 20 x 20 mm^2
- Scattering angle: 320° horizontal
- Cooling system: LHE
- Additional sample environment available: dilution insert
- MAG-V-15T is available at instrument PANDA; for the use at other instruments ask the local contact

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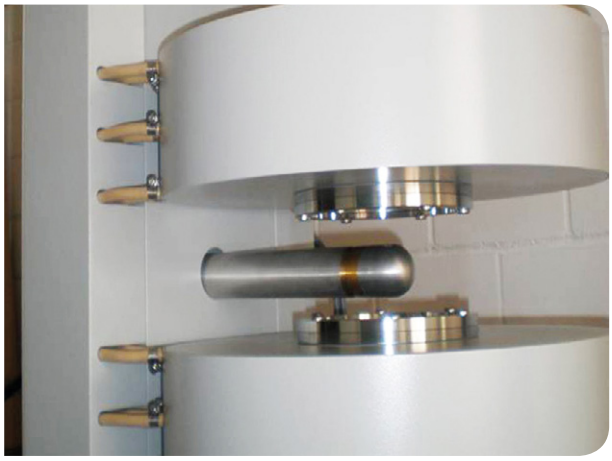
SE

magnetic field

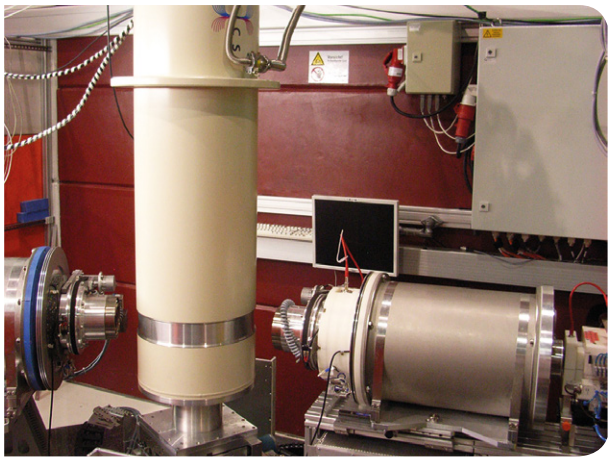
Electromagnet with CCR



Specifications

- Two pieces available
- Maximum magnetic field: up to 1.4 T
- Temperature: 3 – 320 K
- used for small angle scattering and reflectometry

JVM1-5.0T active shielded



Specifications

- Maximum vertical magnetic field: ± 5.0 T (asymm.)
- Homogenity of the magnetic field (Ø 15 mm, 30 mm in height, cylinder): 1.8%
- Beam window dimensions: horizontal and vertical angle: 30°
- Sample space: Ø 30 mm, height 50 mm
- Split: 30 mm
- Access angle: ± 5° vertical
- Scattering angle: 330° horizontal
- VTI: 1.8 – 300 K
- Strayfield < 1 G at 1 m
- Cooling system: LHE
- Cool down: 4 hours
- Additional sample environment available: Kelvinox insert, base temperature 25 mK

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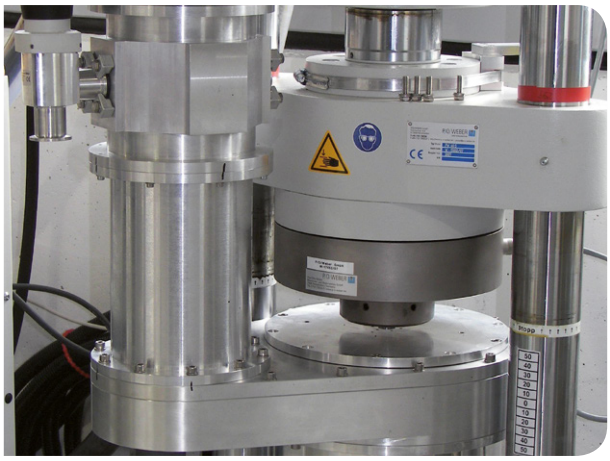
SE

high pressure

HP 400 kN press



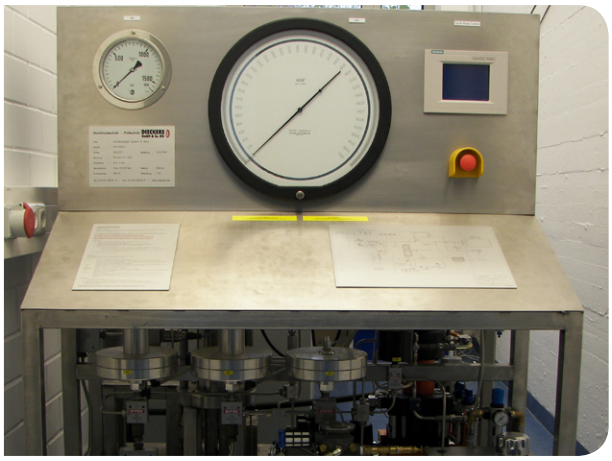
Specifications

HP 400 kN press:
- compressive force: 450 kN
- repulsive force: 220 kN
- dynamic pressure up to 10 Hz possible

Closed cycle cryostat CC-11-P adapted to be used with the HP 400 kN press.
- Temperature range: 20 K – 600 K
- Cooling power 2. stage: 1.5 W
- number of radiation shields: 1
- Heater cartridge 25 Ω / 100W
- Cool-down time RT – 20 K: 4 h
- Sample space: max Ø 16 mm, height 10 mm
- Pressure range: 200 MPa for Ø 16 mm anvil

A special challenge is to go to low temperatures at high pressures. The newly constructed high-pressure cryostat allows one to apply and vary the force in situ, even at low temperature. The sample cell is operated externally by the hydraulic HP 400 kN press. It can be mounted in a dewar and cooled down to below 10 K within four hours. With a piston-in-cylinder cell and a piston diameter of 16 mm a maximum pressure of 2.0 GPa (20 kbar) can be achieved at a sample size up to 30 mm length and 16 mm diameter. Reducing the piston diameter and the sample volume the pressure can be increased up to 100 kbar. Using anvil cells the pressure range extends to 30 GPa (300 kbar) and above. In addition, a dynamic pressure can be superimposed on the static pressure with a frequency of up to 10 Hz.

HPG-10 kbar



Specifications

- Pressure range 10^5 Pa ≤ p ≤ 10^9 Pa

Pressure measurement:
- 10^5 Pa ≤ p ≤ $7 \cdot 10^8$ Pa Heise high-precision manometer; resolution 0.1% ME
- $7 \cdot 10^8$ Pa ≤ p ≤ 10^9 Pa transmitter; resolution $9 \cdot 10^6$ Pa

To load gas pressure cells, the MLZ provides a gas compression unit for inert gas pressure up to 10 kbar. The unit can be oprerated either manually or remote controlled. The remote controlled operation allows for individually programmable pressure time profiles. The measurement system includes a high-precision manometer and a pressure transmitter that cover the range up to 10 kbar.

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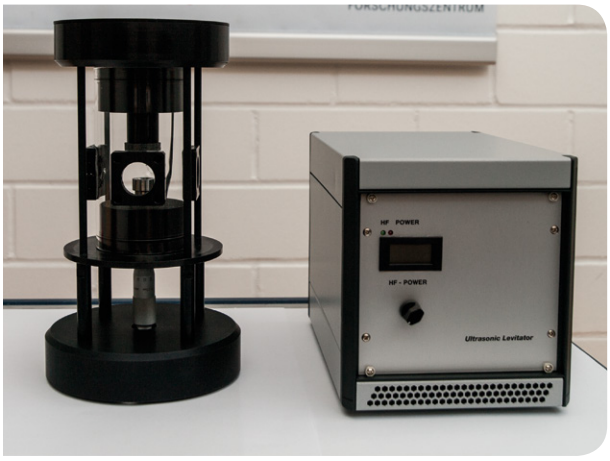
specialised equipment

Ultrasonic levitator (tec5 AG)



Specifications

- Frequency: 58 Hz
- Wavelength: 5.9 mm
- Optimal diameter (without drop deformation): 2.5 mm

Multiposition sample holders

Specifications

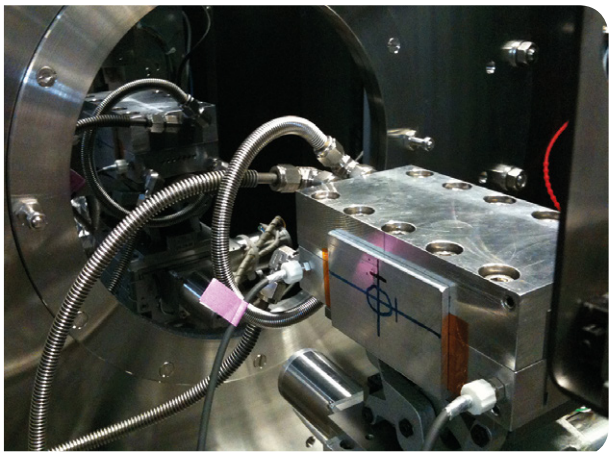
- 8 – 32 positions
- Thermalising devices: Temperature -10°C – 120°C (220°C with silicon oil)

Peltier furnace

Specifications

- 8 positions
- Temperature -20°C – 120°C

GISANS liquid flow cell



Specifications

- 15 x 5 x 2 cm^3 silicon block
- Liquid volume of 7 ml
- Heatable by circulation bath

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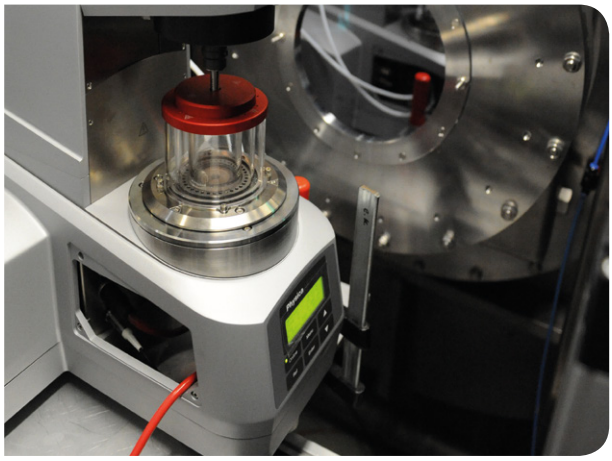
SE

specialised equipment

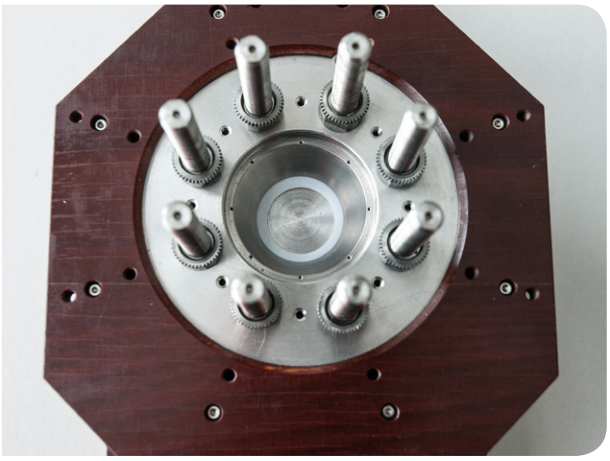
Rheometer RSA II



Specifications

- Couette geometry for liquids
- Shear rate: 0.001 to 5000 s^{-1}
- Temperature: 20 to 200°C

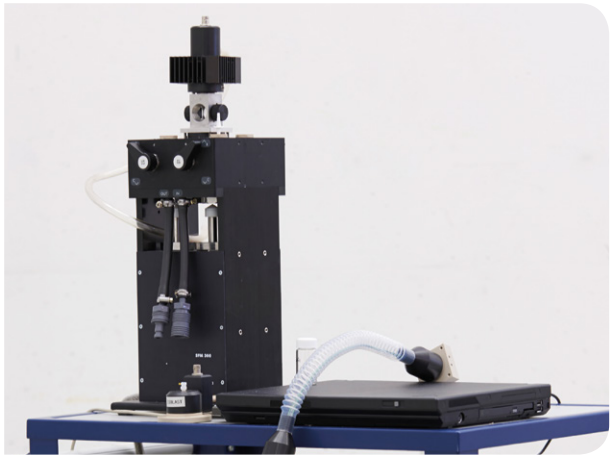
Pressure cell



Specifications

- Temperature: -40°C – 80°C
- Pressure: 5000 bar

Stopped-flow (Bio-Logic® SFM-300)



Specifications

- 3 independently controlled syringes and two mixers
- Mixing ration from 1:1 to 1:100
- Exact control of flow rate
- Dead-time of mixing: < 20 msec
- Neutron-cell volume: 0.4 ml
- Recommended mixing volume: 1 ml

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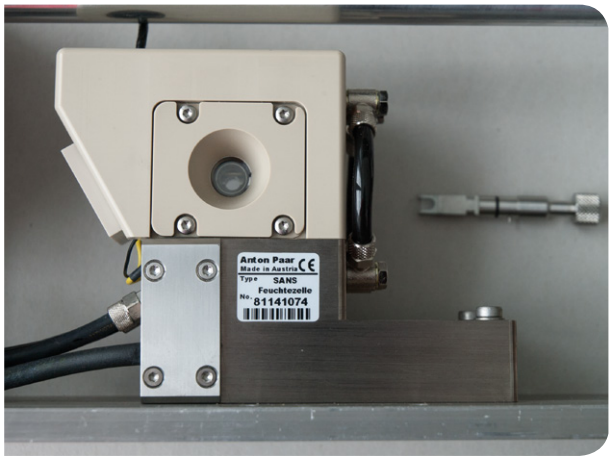
specialised equipment

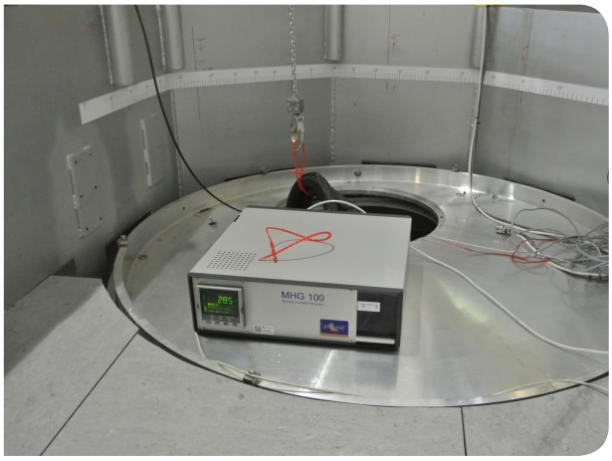
Humidity cell



Specifications

- Temperature: 10°C – 90°C
- Humidity range: 5% – 95%
- Sample size: Ø 8 mm, thickness: 1 mm

Humidity generator



Specifications

- Massflow 0…15 l/min, saturated flow up to 10 l/ min
- Rel. humidity 5% … 95%
- Temperature +5°C ….75 (95)°C , depends on humidity
- 2 tempered pipes (1.5 m)

Measurement with customer cell at SPHERES on fuel-element parts.

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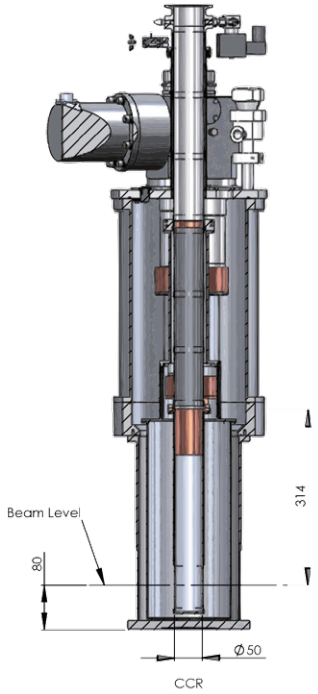
low temperatures

The MLZ sample environment groups supply a variety of liquid refigerant free cryostats adapted for the different needs on the instruments. Besides standard closed cycle cryostats, either of toploading type or sample directly mounted to coldhead, adapted versions for the use inside the vertical field 7.5 T magnet system, the 40 kN press or equipped with a thermoswitch for temperatures above RT are available. For special requirements please contact the Sample Environment Group or your local contact to discuss details.

CCR - closed-cycle cryostat with sample tube



Cut through CCR cryostat.

The liquid refrigerant free closed cycle cryostats of the CCR-type are designed for a fast change of samples. They are based on pulse-tube technique refrigerators with a 6 kW water cooled compressor unit. The sample tube is connected to the pulse tube cold plate with a copper heat exchanger.

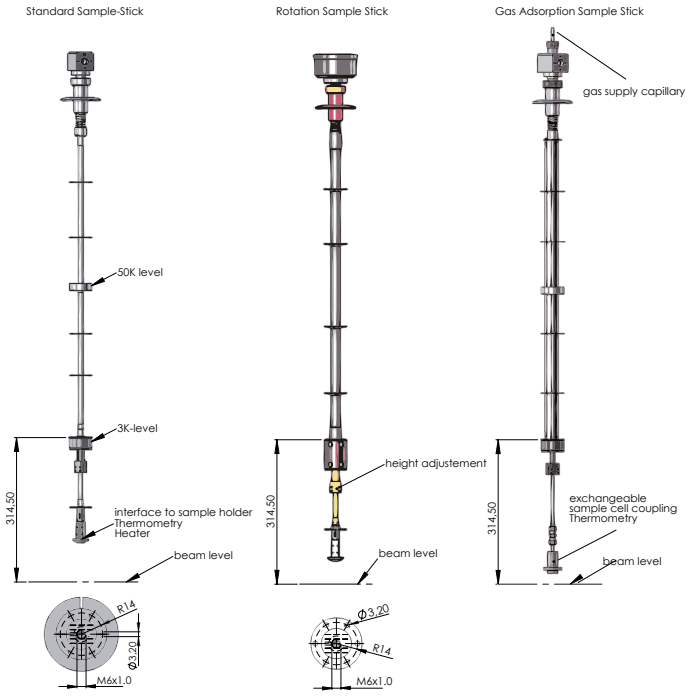
The sample tube is filled with exchange-gas. Temperature regulation is achieved by a sensor and a heater attached to the sample tube. The sample-holder is in general mounted to a sample stick (see fig. 2). Temperatures ranging from 3.5 K to RT can be regulated. To reach for temperatures above RT to 700 K the sample space has to be evacuated and a special high-temperature sample-stick has to be used. For this case temperature control is provided by a heater and sensor mounted on the sample stick.

Common features

- Based on pulse-tube refrigerator
  cooling power 2nd stage:
  1000 mW
- 1 radiation shield connected to 1st stage
- Temperature sensor Cernox® 1.4 K – 325 K
- Heater 25 Ω / 100 W
- Temperature range:
  with exchange gas in sample space
  2,8 K – 300 K
- Extended temperature range:
  evacuated sample space and HT sample stick
  T < 700 K
- Typical cool down times of the cryostat
  RT to base temperature
  min. 2,5 h
- Cool down time for sample change with cryostat at base temperature < 1.5 h

Dimensions

- Diameter sample space:
  < 50 mm and < 80 mm
- height of sample space (beam window):
  approx. 75 mm



Available sample sticks provided for CCR cryostats.

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low temperatures

CCI - low temperature inserts

To reach temperatures below 3 K ^{3}He and ^{3}He/ ^{4}He insert cryostats for the CCR systems are available. Please note an additional preparative time of up to 4h is needed before first cool-down.

CCI specifications

	CCI - ^{3}He	CCI ^{3}He/^{4}He
Temp. range	450 mK – 10 K	50 mK – 1 K
Cooling power	1 mW (500 mK)	15 µW (100 mK)
Heater	10 Ω	10 Ω
Cool-down time	5 h	7 h
Sample Ø	30 mm	30 mm
Sample space-height	145 mm	70 mm
Distance cold plate to beam level	106.5 mm	27 mm

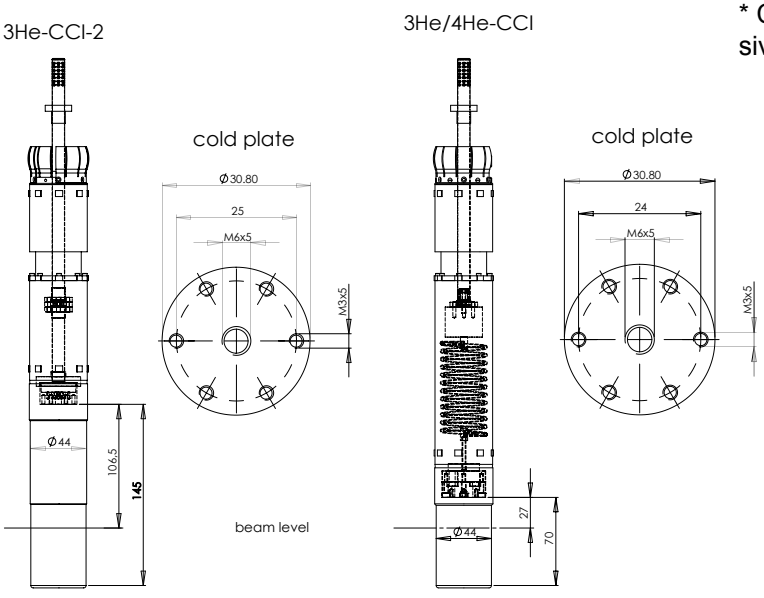
CC- closed-cycle cryostats

The closed cycle cryostats of the CC-type are based on SHI-RDK-2025D and SHI-RDK-101D cold-heads mounted with differing isolation vaccum tails. The sample space of these liquid-cryogen free closed-cycle cryostats is inside the isolation vaccum. The thermalisation of the sample is achieved by the thermal conductivity of the sample holder and the cold-plate. The temperature sensor for temperature control is mounted on the cold-plate. To avoid temperature gradients a sample mounting with adequat thermal conductivity is needed. In case of sample with poor thermal conductivity, the usage of an exchange-gas (He) containing sample can or the use of a CCR-type cryostat should be considered.

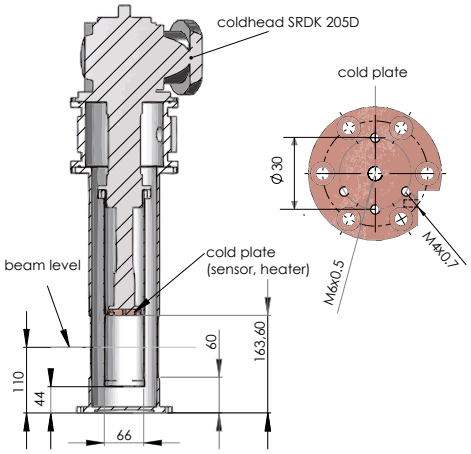
CC-1*, CC-2-PUMA, CC-3, CC-4-PANDA

- Temperature range: 2.8 K – 300 K
- Cooling power 2. stage: 250 mW
- Radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1.4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 2.5 h
- Total height of sample space: 110 mm
- Diameter of sample space: 60 mm

* CC-1 prepared for the condensation of non-corrosive gases up to P = 100 bar



Cut through the CCI inserts.



Cut through CC-3.

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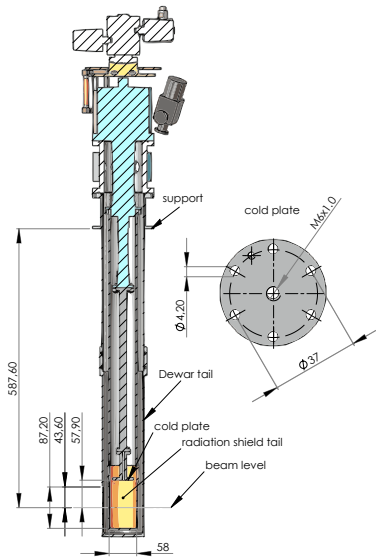
CC-5, CC-6

- Temperature range: 2.2 K – 300 K
- Cooling power 2. stage: 110 mW
- Radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1.4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 2 h
- Sample space: Ø 10 mm, height 10 mm



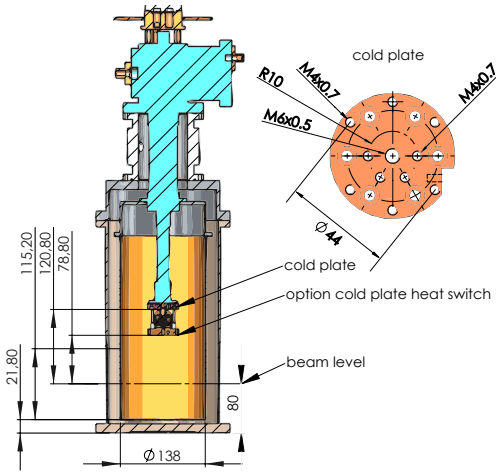
Cut through CC-5/ CC-6.

CC-7-CCM

- Temperature range: 2.2 K – 300 K
- Cooling power 2. stage: 110 mW
- Radiation shields attached to 1st stage: 1
- Thermometry: Si-diode; Cernox® 1.4 K – 325 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 4 h
- Sample space: Ø 55 mm, height 85 mm

CC-8, CC-9-RESEDA,CC-10-PUMA

- Temperature range: 2.8 K – 600 K
- Cooling power 2. stage: 110 mW
- Radiation shields attached to 1st stage: 1
- Thermometry: Pt1000 IST 10 K – 600 K
- Heater cartridge 25 Ω / 100 W
- Cool-down time RT – 2.8 K: 3 h
- Cool-down time 600 K – 2.8 K: 5 h
- Total height of sample space: < 136 mm (< 85 mm CC-9 / CC-10)
- Diameter of sample space: < 138 mm (< 55 mm CC-9 / CC-10)



Cut through CC-8.

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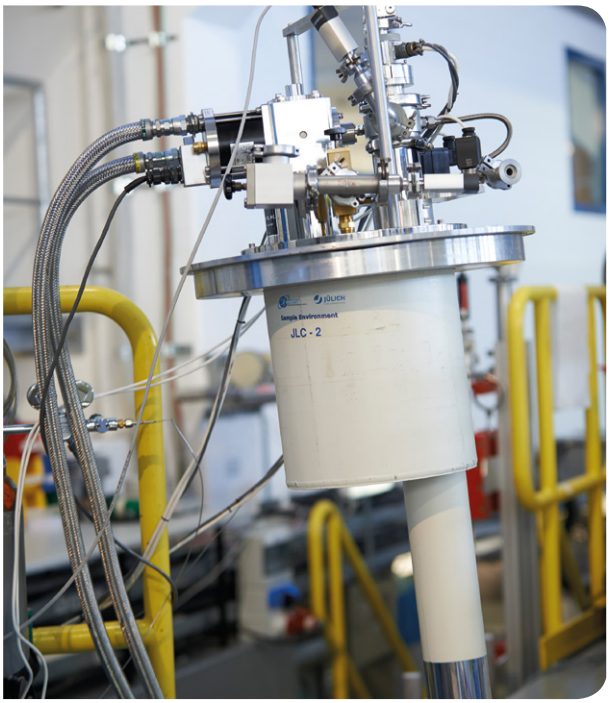
low temperatures

JTC 1-4



Standard cryostat.

Common features

- Heater 25 Ω / 100 W
- Temperature range:
  with exchange gas in sample space
  3 K – 300 K
- Extended temperature range:
  evacuated sample space and HT sample stick
  T < 700 K
- Typical cool down times of the cryostat
  RT to base temperature
  min. 2.5 h
- Cool down time for sample change with cryostat
  at base temperature < 1.5 h

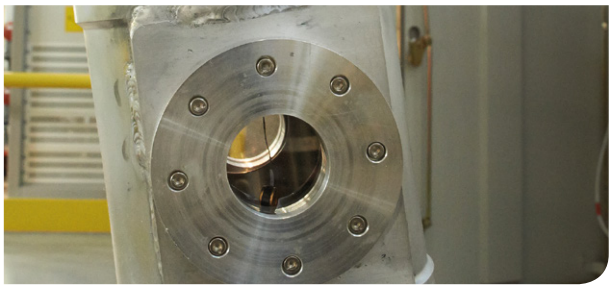
Dimensions

- Diameter sample space:
  < 60 mm
- Height of sample space (beam window):
  approx. 100 mm

Available sample sticks

- Standard stick (T 3 – 700 K)

The sample position and orientation in the beam can be adjusted by a simple height adjustement and rotation at the top part of the sample stick during the experiment.



Cryostat with sapphire window.

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HTF – high temperature furnace

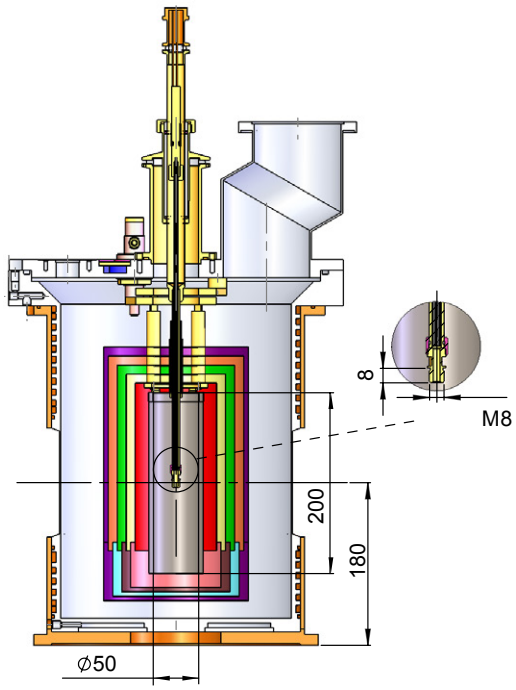
The heater of the HTF consist of a resistive Nb double cylinder element. Radiation shields made of Nb reduce the thermal loss. The sample is mounted on a sample rod top down, using a M8 screw. Maximum reachable temperature is 1900°C. For temperatures up to 300 °C the furnace can be filled with Ar or He exchange gas to improve regulation stability. Temperature sensors are type C thermocouples.

Further a special version of the furnace with a reduced diameter for usage inside the CCM-7.5T vertical magnet is available.

Specifications

Designation: HTF 1, 2, 3, 4 - SPODI

- Temperature range (vacuum): RT – 1900 °C
- Temperature range (exchange gas): RT – 900°C
- Thermometry: type C thermocouple
- Total height of sample space: 100 mm
- Diameter of sample space: 45 mm
- Sample rod tail: M8 (male)



Cut through a standard HTF.

IRF – Infrared light furnace

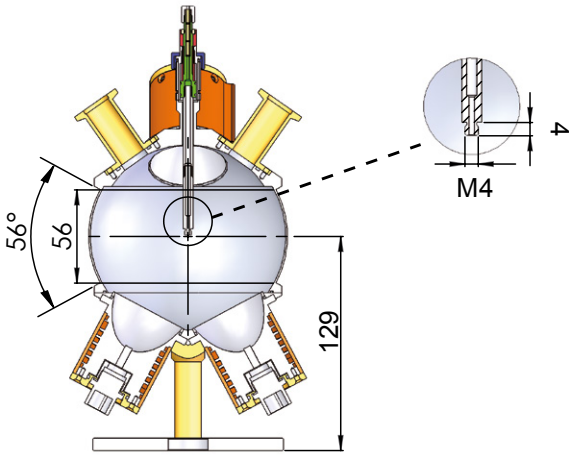
Compact dimensions are the key feature of the light furnace. The sample is placed at the focus of four halide lamps, therefore restricting the sample volume to a few mm³. The sample can be heated in vacuum or any convenient atmosphere up to ambient pressure respectively. Of course the maximum temperature depends on pressure.

A dedicated version of this furnace for use together with a load frame is availbale. Twelve halogen bulb lamps heat the sample up to 900 °C with an almost homogeneous temperature distribution. The sample volume has 6-8 mm diameter and 30 mm length. By means of an additional heat shield temperatures beyond 950 °C are expected.

Specifications

Designation: IRF 1, 2

- Temperature range (vacuum): RT – 1200 °C
- Temperature range (Ar 100mbar): RT – 300 °C
- Thermometry: type K, R, S thermocouple
- Height of sample space: 15 mm
- Diameter of sample space: 10 mm
- Sample rod tail: M4 (male)



Cut through IRF light furnace.

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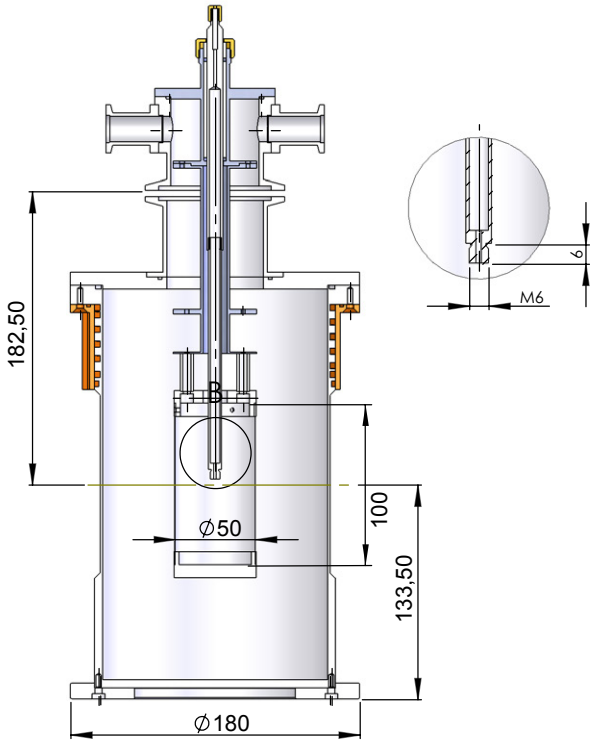
high temperatures

PF – Polarised neutron furnace

For experiments using a polarised neutron beam a furnace with special bifilar heater cartridges is available for the temperature range up to 700 °C.

Specifications

Designation: PF 1
- Temperature range (vacuum): RT – 700 °C
- Thermometry: Pt100
- Height of sample space: 80 mm
- Diameter of sample space: 45 mm
- Sample rod tail: M6 (male)



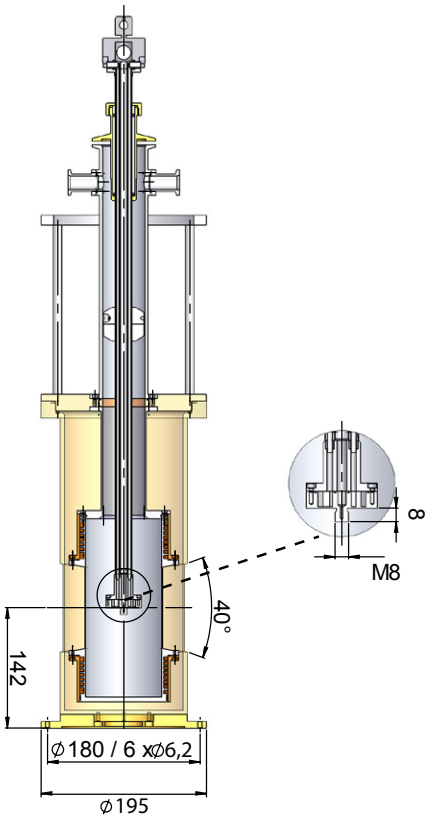
Cut through PF 1 furnace for polarised neutron experiments.

CTF1 – Circulation thermostat furnace

For the temperature range -20 °C to 200 °C a furnace using a thermalised cirulating medium allows for a precise regulation of the particularly homogenous sample temperature.

Specifications

Designation: CTF 1
- Temperature range (vacuum): -30 °C – 200 °C
- Thermometry: Pt100
- Height of sample space: 80 mm
- Diameter of sample space: 48 mm
- Sample rod tail: M8 (male)



Cut through the CTF circulation thermostat furnace.

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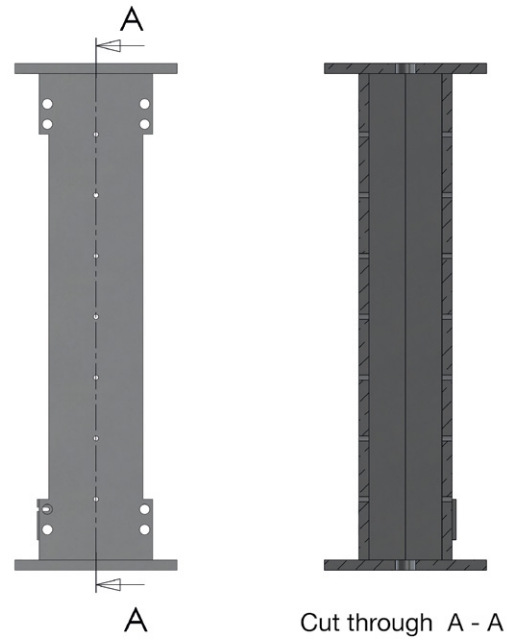
Special application furnace: battery furnace

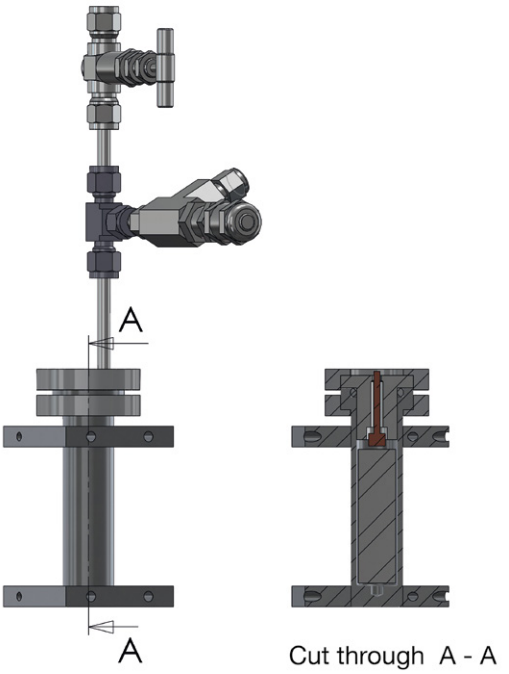
Battery furnace set-up.

For research, e.g. on rechargeable energy storage systems such as lithium-ion batteries, dedicated heater elements are available. Depending on battery size and temperature specification the furnaces have to be designed and manufactured (for details, please get in contact with the Sample Environment Group). Heating is accomplished by an appropriate set of high performance cartridge heaters allowing for temperatures up to 700°C. A remote controlled power supply provides the heater current. Optional temperatures below **r**oom **t**emperature (RT) are possible.

Specifications

- Temperature : RT – 700 °C (optional < RT)
- Thermometry : PT 1000
- Dimension: adapted to battery size





Examples for battery furnaces available at MLZ.

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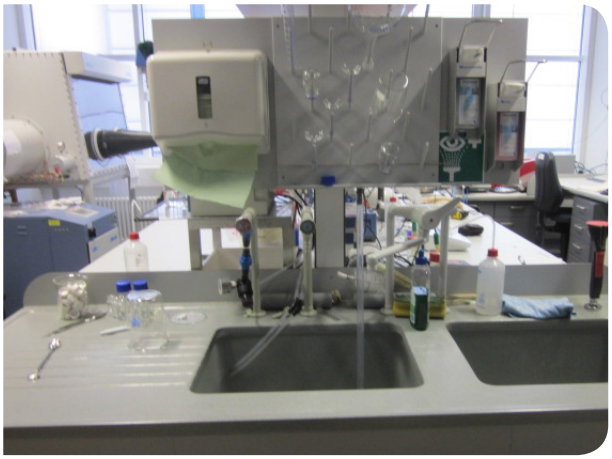
LAB

laboratories

Biology Laboratory



The biology laboratory is a 40 m² facility which serves to prepare biological and soft matter samples for measurements at the neutron scattering instruments. It is equipped to handle samples in inert gas atmosphere within a glovebox and pre-characterise samples by UV-VIS spectroscopy and dynamic light scattering. A low-temperature freezer can be used to store samples at temperatures down to -80°C.

Equipment

- Fine balance
  max. weight 405 g, resolution 1 mg
- Elga Labpure water system (18 MOhm)
- Glovebox H_2O and O_2 < 1ppm, Ar atmosphere
- pH-meter with a 3 mm diameter probe
- Freezer -80°C
- Refrigerator +4°C and freezer -18°C
- UV-VIS spectrometer NanoDrop
- Malvern Zetasizer Nano S
- Optical microscope
- Thermostated centrifuge up to 60 000 G
- Rheometer
- ÄKTA FPLC for protein purification

Chemistry Laboratory

The chemistry and sample preparation laboratory is a 45 m² facility equipped with double hood to prepare samples for subsequent measurements on the neutron scattering instruments. It offers a basic tool set to handle samples from users, prepare solutions or even perform chemical reactions resulting in specific modifications. Samples can be handled under inert gas atmosphere like N_2 or Ar.

Equipment

- Fine balance
  max. weight 405 g, resolution 1 mg
- Balance
  max. weight 4.2 kg, resolution 0.1 g
- Refrigerator with freeze box -18°C
- Vacuum heating cabinet
  max. temperature 300°C, min. pressure 25 mbar, inertgas: N_2, Ar
- Thermostatic bath, 20 – 80°C
- Ultra-sonic bath
- Rotary evaporator
- Rheometer Rheometrics Solid Analyzer RSA II, temperature from liquid N_2 to 500°C

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Materials Science Laboratory

In collaboration with HZG and TUM, the Materials Science Lab serves as laboratory to prepare samples (polishing, cutting, etching, and annealing) for subsequent neutron scattering measurements. It is equipped with several analytic instruments for instance X-ray Diffractometer (XRD) mainly for battery research and high-performance materials, Differential Scanning Calorimeter (DSC), Micro-Hardness and Optical Microscopes to perform complementary analytics.

Equipment

Analytic instruments:
- PANalytical Empyrean XRD (Cu, Mo, XRR, Tramsm. Reflection)
- Differential Scanning Calorimetry (-80°C – 600°C)
- Struers Micro Hardness DuraScan (HV 0.1 – 10)
- BioLogic – Bi-Potentiostat
- Digital Microscope & Stereomicroscope

Preparation instruments:
- GERO – Programmable High Temperature Tube furnace
- ATM BRILLANT 200 – corundum wheel saw
- ATM OPAL 410 – resin sample hot embedding
- ATM SAPHIR 520 – polishing machine
- Binder – vacuum heating cabinet (200°C)
- Well Diamond Wire Saw

Sample Preparation Laboratory

For the preparation or post-treatment of samples, the MLZ offers a sample preparation laboratory in the Neutron Guide Hall West. In addition to the equipment listed below, the sample preparation lab provides a supply of argon, helium, compressed air, and ultrapure water. Usually, small amounts of commonly used solvents and laboratory dishes are available. Additionally, you can use the official proposal form to point out your special requirements, so that your local contact and the Sample Environment Group can prepare appropriate conditions for your experiment in time.

Mobile glove boxes are installed in both, Neutron Guide and Experimental Hall, to be used close to the instruments.

Equipment

- Fume hood
- Glove box
- Refrigerator
- Freezer
- Scales
- Stirrers
- Heating oven
- Ultrasonic bath

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UF

user facilities

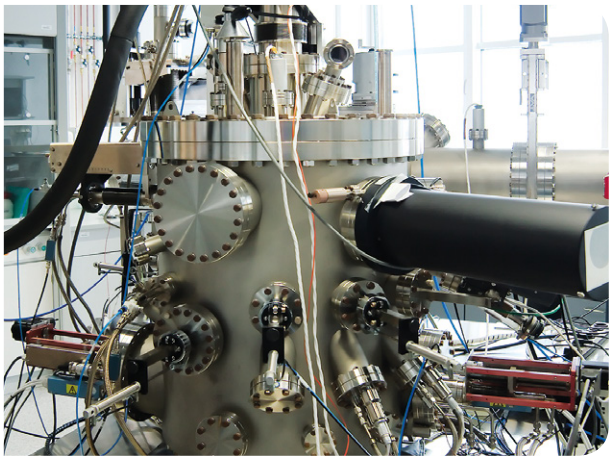
TEM: JEOL 200 kV JEM-FS2200

Transmission **e**lectron **m**icroscopy is a complementary technique with neutron scattering in the frame of soft matter studies. With the TEM, real space investigations are performed to access information about shape, size, and size distribution of particles, self-assembly and aggregation. Users will be supported by JCNS staff (M.S. Appavou) to conduct the suitable preparation and TEM investigation.

Specifications

- JEOL 200 kV JEM-FS2200 with a field emission gun (FEG) and energy filter
- Magnification from 50x to 1 000 000x
- Image resolution of 0.2 nm in point and 0.1 nm in lattice
- Tietz CCD camera with 2048 × 2048 pixels
- Grid preparation by carbon sputtering on bare grids
- Glow discharge process to make the coated grids hydrophilic
- Plunge freezer to prepare cryo-specimen for direct imaging (Cryo-DI), for freeze fracture and direct imaging (FFDI) or freeze fracture before shadowing with Pt/C or Ta/W, so-called freeze fracture and electron microscopy (FFEM)
- Cryo-specimen investigation at low temperature around -180°C under vacuum.
- Ultramicrotome for room temperature and cryo sectioning

Thin film laboratory: MBE system



The Jülich Centre for Neutron Science operates a state-of-the-art oxide **M**olecular **B**eam **E**pitaxy (MBE) system (DCA Instruments Oy, Finland) to prepare tailored samples for the investigation with the neutron reflectometer MARIA, other neutron scattering instruments or methods.

The system is equipped with six effusion cells and two e-guns (each with four crucibles) for co-deposition. An RF plasma atom source enables atomic oxygen introduction into the chamber to grow oxides. Thin film growth analysis is performed by **r**eflection **h**igh **e**nergy **e**lectron **d**iffraction (RHEED). Additionally **l**ow **e**nergy **e**lectron **d**iffraction (LEED) and **A**uger **e**lectron **s**pectroscopy (AES) are offered for thin film characterisation.

Sample growth will be performed in strong collaboration with the instrument scientist.

Please ask for the feasibility of your desired sample!

Equipment and services

- Thin film growth using MBE technique
- Atomic Force Microscopy (AFM)
- Magneto-Optical Kerr Effect (MOKE) set-up, magnetic field up to 0.7 T, temperature range 4.5 – 420 K

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X-ray Tomography: v|tome|x

In order to offer an X-ray facility complementary to the neutron tomography station ANTARES, the FRM II and the Chair of Biomedical Physics at the TUM have started to operate a high resolution computer tomography facility. The “micro CT VtomeX” is also available to users of the MLZ. Samples, that can be examined, include geo and composite materials, semiconductors and biomedical specimens.

The X-ray tomography station is featured by its high flexibility: Due to two different exchangeable X-ray tubes, both, pictures with high resolution and pictures with lower resolution but higher contrast, can be taken. The detector allows for fast and highly contrasted pictures. The reconstruction of the data is accomplished within a few minutes due to a cluster of four computers using graphic cards to calculate the images.

Possible scanning parameters

- Max. sample diameter 230 mm
- Max. sample height 420 mm
- Min. resolution < 1 micron (isotropic)
- Max. voxel size of reconstruction 2048^3
- Max. X-ray energy 240 keV
- Max. sample weight 10 kg
- Typical scanning time 1–120 min

Location

Institute for Medical Engineering (IMETUM)
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General information for users

Access to the MLZ

User Office

From idea to publication

General information for users

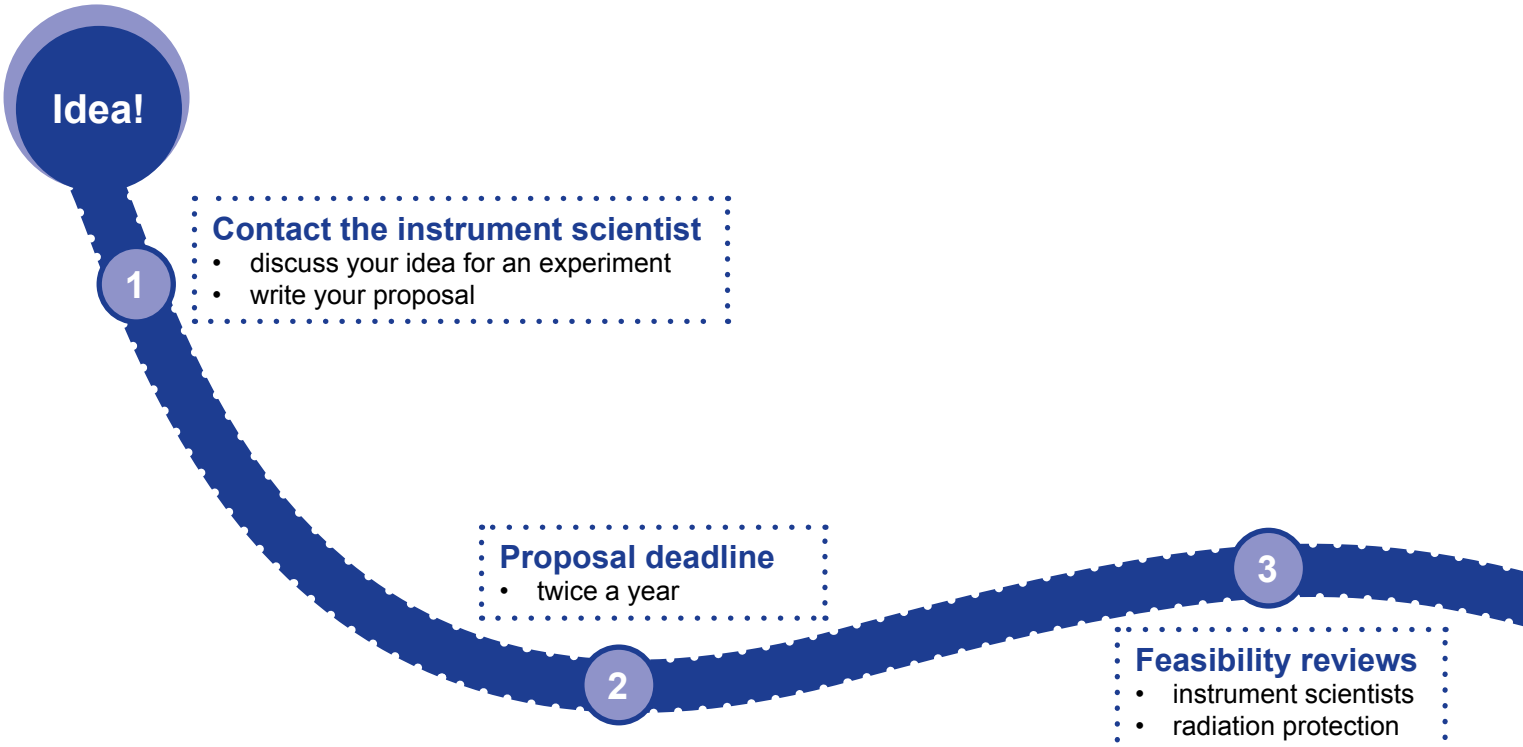
The User Office organises the scientific experiments at the MLZ, handles the proposal rounds and takes care of everything scientists visiting the neutron source in the scope of their work have to deal with.

You can call us, drop in when visiting the MLZ, or find all available information at

www.mlz-garching.de/user-office

There you learn about

- our Terms of References, for example regarding publications,
- reactor cycles and upcoming proposal deadlines,
- the online User Office System,
- workflows,
- requirements for the access to the site,
- radiation protection regulations,
- accommodations at Garching,
- the public transport system,
- possibilities regarding financial support,
- forms and templates for proposals and reports ready for download,
- and much more...

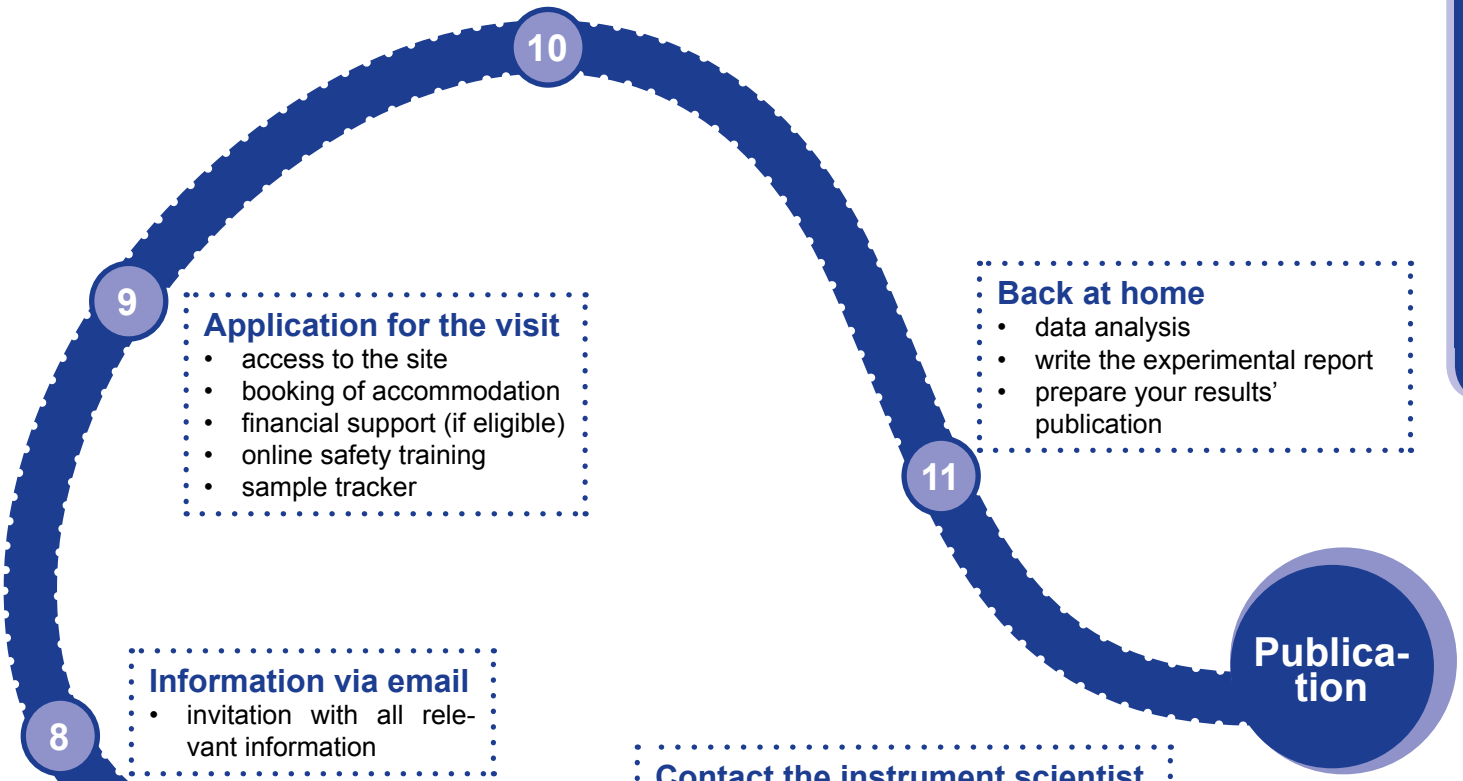


Additionally

Rapid Access Programme

- feasibility measurements before submitting a proposal/ completing an already performed investigation
- to be allocated:
  - at selected instruments
  - up to three days/ cycle per instrument
  - up to 12h per proposal
- deadline before each cycle

Heinz Maier-Leibnitz Zentrum



Visit at the MLZ
- conduct your experiment!

10

Back at home
- data analysis
- write the experimental report
- prepare your results' publication

11

Publica-tion

9

Application for the visit
- access to the site
- booking of accommodation
- financial support (if eligible)
- online safety training
- sample tracker

8

Information via email
- invitation with all relevant information

Contact the instrument scientist
- schedule the experiment at the instrument

7

Information via email
- proposal accepted
- proposal not accepted

6

MLZ Directorate
- approves the beam time's distribution

5

4

Scientific review
- 7 panels (in 2015)
- referees from universities and research institutes from all over Europe
- meet after online period
- rank proposals
- suggest distribution of beam time

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www.mlz-garching.de/user-office

Access to the MLZ

Access to the site

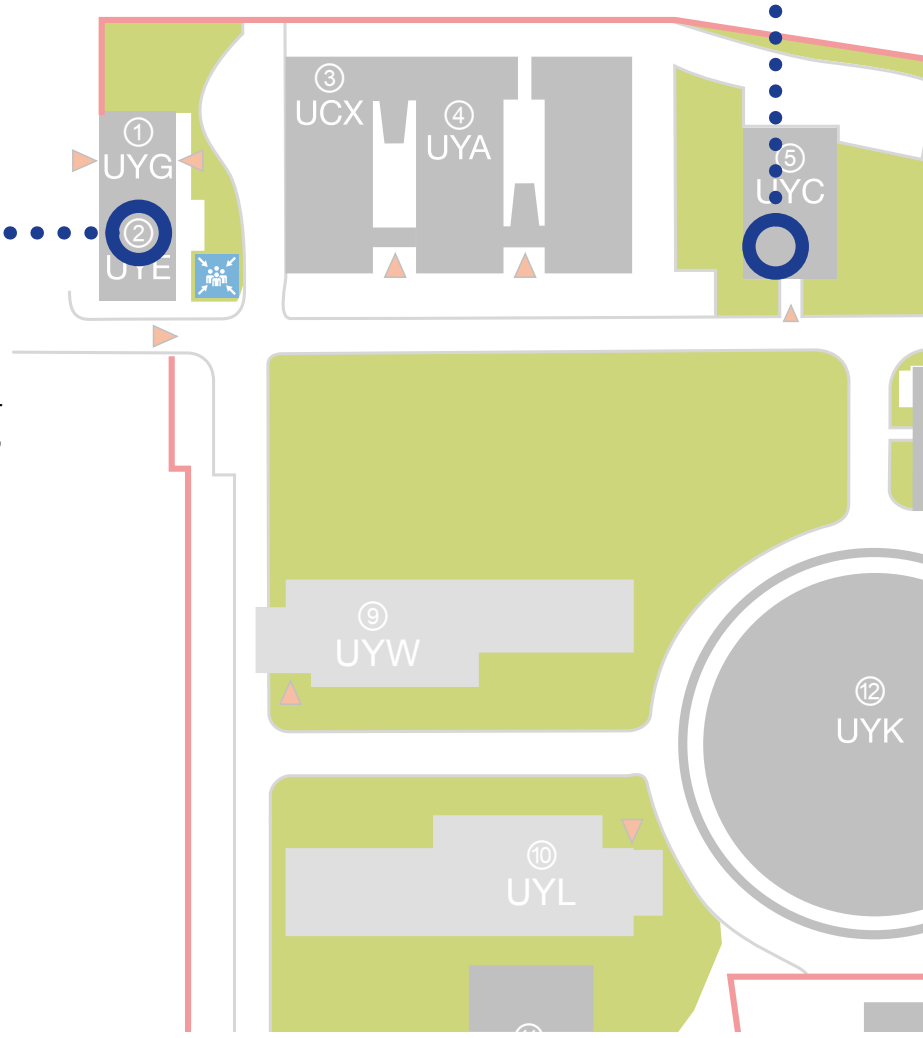
- You had to apply online for the visit well in advance before your experiment starts.
- A valid passport or ID-card is required. Driving licenses or other personal documents are not sufficient!

Radiation protection requests from Users working in Germany:

- ‘Strahlenpass’, dose record not older that 3 months
- dosimeter (capable of detecting neutron and gamma radiation)
- the home institution needs a valid license according to §15 StrlSchV as well as an ‘Abgrenzungsvertrag’

- access to the internet
- control experiments remotely
- access data

Terminal room



Reception

ON ARRIVAL
- getting a badge
- blue folder with process slip, experimental safety sheet, samply tracker print-out, further information
- your local contact will be informed

ON DEPARTURE
- return your badge
- return the completed process slip

Radiation protection requests from Users working outside Germany:

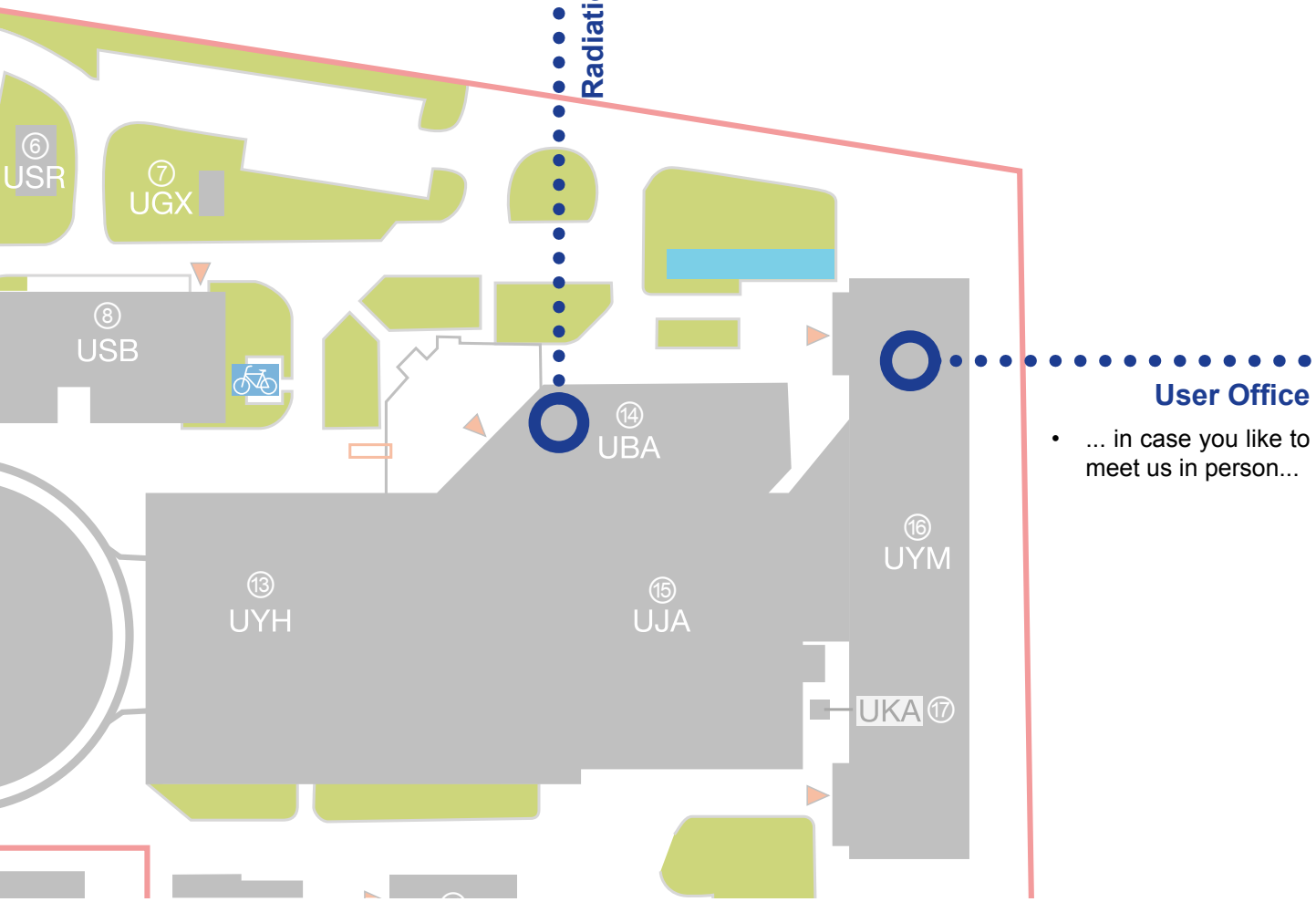
- subdivided in “radiological workers” and persons, who have never worked in a controlled area
- download the appropriate form from the User Office Webpage
- complete it, sign it, and present it upon arrival

ON ARRIVAL

- register for dosimetry
- register your samples

ON DEPARTURE

- check-out of dosimetry
- discuss your sample’s clearance



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www.mlz-garching.de/user-office

Partner institutions

Bayerisches Geoinstitut
Universität Bayreuth
www.bgi.uni-bayreuth.de

Georg-August-Universität Göttingen

- Institut für Physikalische Chemie
  www.uni-pc.gwdg.de/eckold
- Geowissenschaftliches Zentrum
  www.uni-goettingen.de/de/125309.html

German Engineering Materials Science Centre GEMS
Helmholtz-Zentrum Geesthacht GmbH
www.hzg.de/institutes_platforms/gems/

Jülich Centre for Neutron Science JCNS
Forschungszentrum Jülich GmbH
www.jcns.info

Karlsruher Institut für Technologie

- Institut für Angewandte Materialien – Energiespeicher-systeme (IAM-ESS)
  www.iam.kit.edu

Ludwig-Maximilians-Universität München

- Sektion Kristallographie
  www.lmu.de/kristallographie
- Sektion Physik
  www.softmatter.physik.uni-muenchen.de

Max-Planck-Institut für Festkörperforschung, Stuttgart
www.fkf.mpg.de

RWTH Aachen

- Institut für Kristallographie
  www.xtal.rwth-aachen.de
- Institut für Anorganische Chemie
  www.ac.rwth-aachen.de

TU Clausthal

Technische Universität Clausthal

- Institut für Werkstoffkunde und Werkstofftechnik
  www.iww.tu-clausthal.de

TECHNISCHE UNIVERSITÄT DRESDEN

Technische Universität Dresden

- Institut für Festkörperphysik
  www.physik.tu-dresden.de/ifp

Technische Universität München

- E13 – Lehrstuhl für Funktionelle Materialien
  www.e13.physik.tu-muenchen.de

Technische Universität München

- E18 – Lehrstuhl für Experimentalphysik I
  www.e18.ph.tum.de

E21
Arbeitsgebiet stark
korrelierte Elektronensysteme

Technische Universität München

- E21 – Lehrstuhl für Neutronenstreuung
  www.e21.ph.tum.de

Excellence Cluster Universe

Technische Universität München

- Exzellenzcluster „Origin and Structure of the Universe“
  www.universe-cluster.de

Klinikum rechts der Isar

Technische Universität München

- MRI - Klinikum Rechts der Isar
  www.med.tum.de

RCM
Radiochemie München

Technische Universität München

- RCM - Radiochemie München
  www.rcm.tum.de

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Technische Universität Wien

- Neutronen- & Quantenphysik
  Forschungsbereich am Atominstitut Wien
  Arbeitsgruppe Abele
  ati.tuwien.ac.at/research_areas/neutron_quantum_physics/

der Bundeswehr Universität München

Universität der Bundeswehr München

- Institut für Angewandte Physik und Messtechnik
  www.unibw.de/lrt2

Universität zu Köln

Universität zu Köln

- Institut für Kernphysik
  www.ikp.uni-koeln.de
- II. Physikalisches Institut
  www.ph2.uni-koeln.de

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Wenzel Schürmann, TUM:
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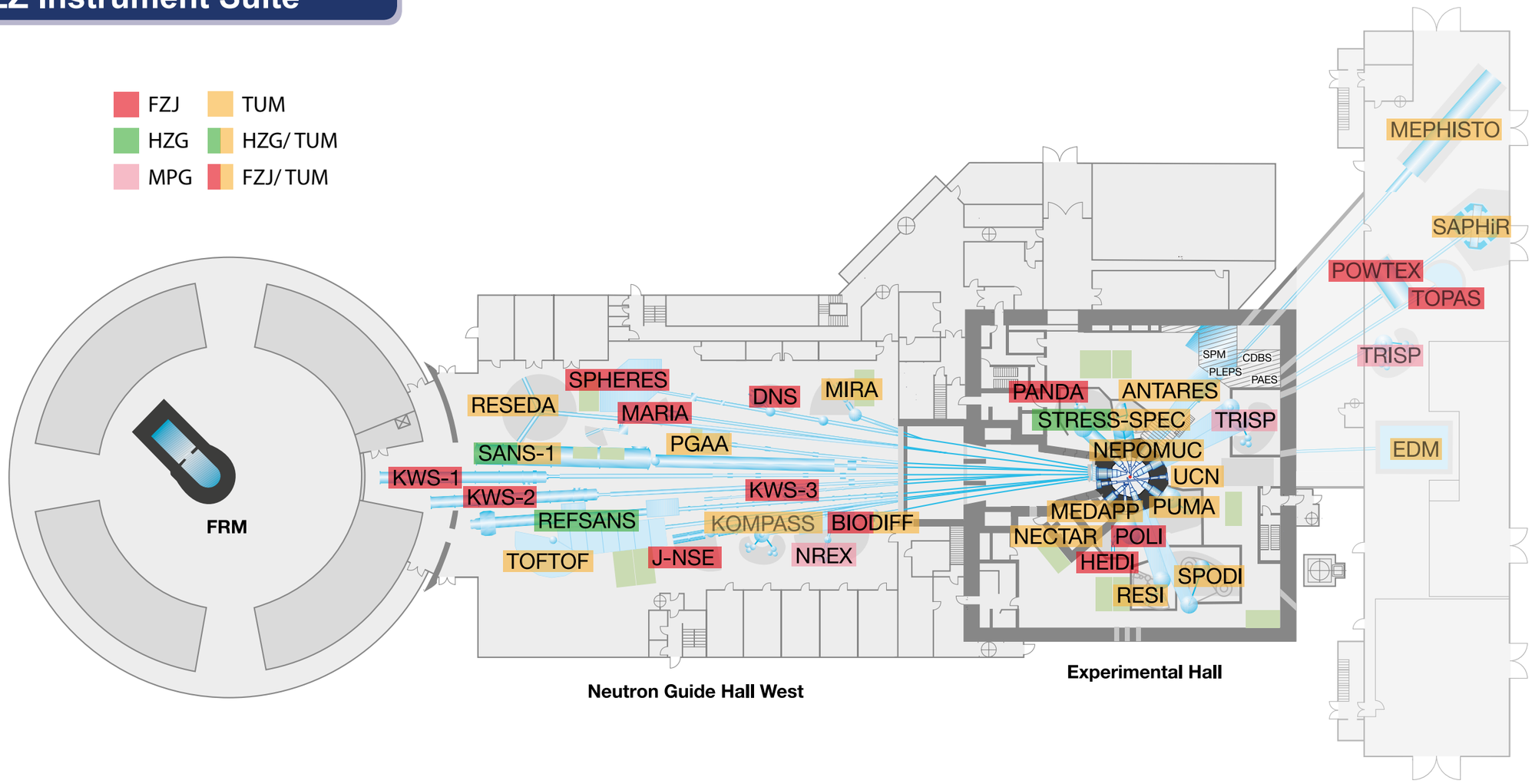
MLZ Instrument Suite



Instrument	Description	Neutrons	Status	Operated by	Funding
ANTARES	Radiography and tomography	cold	operation	TUM	TUM
BIODIFF	Diffractometer for large unit cells	cold	operation	TUM, JCNS	TUM, FZJ
DNS	Diffuse scattering spectrometer	cold	operation	JCNS	FZJ
HEIDI	Single crystal diffractometer	hot	operation	RWTH Aachen	FZJ
J-NSE	Spin-echo spectrometer	cold	operation	JCNS	FZJ
KOMPASS	Three axes spectrometer	cold	construction	Uni Köln, TUM	BMBF
KWS-1	Small angle scattering	cold	operation	JCNS	FZJ
KWS-2	Small angle scattering	cold	operation	JCNS	FZJ
KWS-3	Very small angle scattering	cold	operation	JCNS	FZJ
MARIA	Magnetic reflectometer	cold	operation	JCNS	FZJ
MEPHISTO	Facility for particle physics, PERC	cold	reconstruction	TUM	TUM, DFG
MIRA	Multipurpose instrument	cold	operation	TUM	TUM
MEDAPP	Medical irradiation treatment	fast	operation	TUM	TUM
NECTAR	Radiography and tomography	fast	operation	TUM	TUM
NEPOMUC	Positron source, CDBS, PAES, PLEPS, SPM	-	operation	TUM, UniBw München	TUM, BMBF
NREX	Reflectometer with X-ray option	cold	operation	MPI Stuttgart	MPG
PANDA	Three axes spectrometer	cold	operation	JCNS	FZJ

Instrument	Description	Neutrons	Status	Operated by	Funding
PGAA	Prompt gamma activation analysis	cold	operation	Uni Köln	TUM
PUMA	Three axes spectrometer	thermal	operation	Uni Göttingen, TUM	TUM
POLI	Single-crystal diffractometer polarized neutrons	hot	operation	RWTH Aachen	BMBF, FZJ
POWTEX	Time-of-flight diffractometer	thermal	construction	RWTH Aachen, Uni Göttingen, JCNS	BMBF, FZJ
REFSANS	Reflectometer	cold	operation	GEMS	HZG
RESEDA	Resonance spin-echo spectrometer	cold	operation	TUM	TUM
RESI	Single crystal diffractometer	thermal	operation	LMU	TUM
SANS-1	Small angle scattering	cold	operation	TUM, GEMS	TUM, HZG
SAPHIR	Six anvil press for radiography and diffraction	thermal	construction	BGI	BMBF
SPHERES	Backscattering spectrometer	cold	operation	JCNS	FZJ
SPODI	Powder diffractometer	thermal	operation	KIT	TUM
STRESS-SPEC	Materials science diffractometer	thermal	operation	TUM, TU Clausthal, GEMS	TUM, HZG
TOFTOF	Time-of-flight spectrometer	cold	operation	TUM	TUM
TOPAS	Time-of-flight spectrometer	thermal	construction	JCNS	FZJ
TRISP	Three axes spin-echo spectrometer	thermal	operation	MPI Stuttgart	MPG
UCN	Ultra cold neutron source, EDM	ultra-cold	construction	TUM	TUM, DFG