Karlsruher Institut für Technologie

ITEP – Institute for Technical Physics

Progress in Research and Development
2011 Annual Report

INSTITUTE FOR TECHNICAL PHYSICS

Imprint

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Preface

The Institute for Technical Physics (ITEP) is a national and international center of competence for fusion technology, superconductivity and cryotechnologies with the focus on the areas of

- Technology for fusion magnets.
- Tritium process technology.
- Vacuum Science and Technology.
- Cryotechnology.
- Development of superconductor materials and applications of superconductivity in power technology.
- Superconducting high-field magnets.

The activities of ITEP are part of the "Fusion", "Efficient Energy Conversion and Use," and "Astroparticle Physics" long-term programs of the Karlsruhe Institute of Technology (KIT) and the Helmholtz Association of German Research Centers.

The complex and, in most cases, multi-disciplinary activities of ITEP are handled in very large and unique experimental facilities and laboratories, as for example the Karlsruhe Tritium Laboratory (TLK) a worldwide unique laboratory with a closed tritium cycle, the Karlsruhe Toroidal-Coil Test Facility (TOSKA) for testing large magnets for fusion purposes, the test facility for the ITER model pump (TIMO) for testing cryo-vacuum pumps, the high-field magnet laboratory for developing magnets at very high magnetic fields, the cryogenic high-voltage laboratory for investigation electrical insulation al low temperatures, and the cryogenic materials laboratories for investigating electrical and mechanical material properties at low temperatures.

100 years after the discovery of superconductivity our institute achieved in 2011 important scientific results and mastered specific challenges and events.

In the **fusion magnets** field, ITEP builds and tests the high-current leads with high-temperature superconductors for the Wendelstein 7-X fusion project. In this work, the institute reached another important milestone in 2011: The first series type current leads for Wendelstein 7-X was successfully tested and accepted in time. Moreover, the cryogenic material laboratory was extended. In this laboratory, the ITER project (www.iter.org) placed a three year contract as reference laboratory for cryogenic material characterization.

For ITER, the **Karlsruhe Tritium Laboratory (TLK)** will take responsibility for preparing the work packages for water detritiation and cryogenic isotope separation. 2011 the cold commissioning of combined water detritiation and isotope separation was achieved the first time. Another important task for ITER, the decontamination of highly tritiated water was started successfully. In addition the first results with a new membrane reactor are very promising. Besides the R&D work a focus was given in 2011 on the renewal of the tritium infrastructure. Two process control systems and the air condition control were commissioned with extremely short outage duration.

The **vacuum technology** department in ITEP is responsible for designing, preparing, and testing the cryo-vacuum pumps for ITER. In 2011 the FEM detailed design of the ITER cryopump was completely finished. To prepare the future coating of cryopanels a new and much larger facility was built. Furthermore, a new facility for the demonstration of a very attractive vacuum pumping concept of a long pulse fusion power plant was started.

Developing economically viable and low loss conductor concepts is a core duty of the department of superconducting materials at ITEP. 2011 the focus was given to making small filaments in YBCO tapes with a new laser system and the characterization of advanced Roebel cables. 2011 was the first time, that a complete simulation of AC losses of a Roebel cable was achieved. With respect to applications of superconductivity in power technology, a joint project was launched to develop a 1 km, 40 MVA superconducting cable together with industry and a utility. In addition the development of a new medium voltage type superconducting fault current limiter was successfully finished with the start of a long term field test.
The **high field magnet laboratory** of ITEP develops since more than 25 years very successfully high field NMR systems. At present an industry contract exists to develop a high field NMR system with high temperature superconductors. Many HTS samples were characterized in 2011 with focus on the anisotropy of the critical current in high fields of up to 30 T.

Activities in the cryo-engineering department in 2011 mainly comprised the advanced development of complex and extremely large cryosystems, such as those for Fusion, KATRIN and TIMO. 2011 the work for a new current lead test facility continued and important equipment for KATRIN was supplied with cryogens. In addition, this department is in charge of the safe and reliable operation of further cryo-facilities, and the supply of KIT with liquid helium and liquid nitrogen. The calibration laboratory for cryogenic sensors was further extended in 2011.

Within the **Karlsruhe Tritium Neutrino Experiment** (KATRIN), ITEP has been responsible, from the beginning of the project, for building and operating the tritium loops, for cryo-supply, and for making available the superconducting magnets. A major highlight was achieved in 2011 with the experimental proof of the highly precise and stable temperature homogeneity of the beam tube

Participants of the International Vacuum Gas Dynamics Workshop in Leinsweiler.

of the windowless gaseous tritium source. To analyze tritium, laser Raman spectroscopy was verified for all six isotopologes with very high precision. In the area of superconducting magnets for KATRIN the focus was given on the new protection system for the magnets.

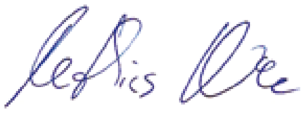
It is a pleasure again to note the continued increase in staff undergoing training, such as students of the "Duale Hochschule", students working for a bachelor thesis, a master thesis, a PhD thesis, and trainees. At present the number of persons in this field increased to far more than fourty and covers many different disciplines. We started two new lectures in 2011. In total, the number of lectures amounts to more than ten, most of them in the areas of superconductivity, fusion, and cryotechnology. In addition to the student lectures, numerous national and international seminars and workshops were organized by ITEP. Two new workshops were organized by ITEP in 2011. For the first time a new workshop on high-temperature-superconductivity in Fusion was initiated with many important international participants. The department of vacuum technology organized a higly ranked international workshop on rarified gas dynamics.

In July 2011 the inauguration of our new building 410 took place after a fast building time of 15 months only. We combined this date with our traditional summer party of ITEP. I am grateful to all supporters and participants. A very special thank is dedicated to our vice-president Dr. Peter Fritz, the architects of Behnisch, all internal and external colleagues and all companies involved.

A few particular calls were given to ITEP members in 2011. Dr. Steffen Grohmann received a call for a professorship on cooling and cryotechnology at KIT. This call is combined with leading a R&D group at ITEP's cryogenic department. Dr. Holger Neumann was elected as convenor of the cryogenic department into the board of the German Kälte- and Klimatechnischen Vereins (www.dkv.org). In September 2011 I was elected as chairman of the European Society of Applied Superconductivity (www.esas.org).

I would like to express my special thanks to all partners of ITEP in universities, research institutions, and industry for the very loyal and fruitful cooperation in 2011. I am extremely grateful for your support and cooperation.

Very cordially yours,



Mathias Noe

Current leads for W7-X, prepared for soft soldering of the cold contact.

Results from the Research Areas

Fusion Magnets

Head: Dr. Walter Fietz

In the field of fusion magnets, the ITEP is engaged in the national project W7-X and in the international projects JT-60SA and ITER. Furthermore preparatory work for the magnet system of the future demonstration reactor DEMO is performed.

Development and construction of current leads for W7-X and JT-60SA

Contribution for Wendelstein 7-X

The ITEP has undertaken the task of development, fabrication and testing of 16 current leads for the plasma experiment Wendelstein 7-X (W7-X). W7-X is under construction in Greifswald by the Max-Planck-Institut für Plasmaphysik (IPP) and is planned to be operational in 2014. The current leads (2 proto types and 14 series-current leads) have to be operated in upside down orientation and are therefore equipped with high temperature superconductors (HTS), which requires in addition much less cooling power. The current leads are designed for a maximum current of 18.2 kA.

After the extensive test of the prototype current leads has been successfully performed in 2010, the approval for the series current lead production has been given and the fabrication was started.

In 2011 the series production was continued and in total three acceptance tests of series current leads were conducted successfully.

Contribution for JT-60SA

In 2007 the German government agreed to participate in the construction of the EU-Japanese satellite tokamak JT-60SA. The ITEP has taken over the construction of the current leads. In 2009 the boundary conditions have been fixed in negotiations with EU and Japan Atomic Energy Agency JAEA. Beginning of 2010 the contracts were signed. Afterwards the conceptual design has been worked out.

Fig. 1: W7-X series current leads after assembly.

In 2011 the interfaces between the current leads and JT-60SA were fixed together within F4E and JAEA and the design has been agreed. The results of the W7-X prototype test have been used as a design base. Presently the documentation for the TÜV approval are under work. In 2012 the detailed design will be finished and the procurement of the material and components will be performed. The procurement of the HTS material has been completed in 2011.

Current lead test facility CuLTKa

In total 16 current leads for W7-X and 26 current leads for JT-60SA need to be tested. While the current leads for W7-X are being tested in a test cryostat beside TOSKA, all current leads for JT-60SA will be tested in a new facility.

For this purpose the new test facility CuLTKa (**Cu**rrent **L**ead **T**est facility **Ka**rlsruhe) and the integration of this facility in the existing infra structure of the ITEP is under construction. CuLTKa allows a higher test frequency compared to TOSKA which is necessary for the delivery of the current leads for JT-60SA in time. The construction of the different cryostats and valve boxes in KIT is in good progress. Some components are ready and are now being installed in CuLTKa. In 2012 the transfer lines necessary to connect the cryostats and valve boxes will be procured in industry.

The fabrication of the current leads for W7-X and the acceptance tests as well are expected to be ready until end of 2012. Afterwards the 26 current leads for JT-60SA will be built and tested in CuLTKa until end of 2015.

Fig. 2: Test facility CuLTKa under construction for the series test of the JT-60SA current leads.

Cryogenic material tests and mechanical investigation of superconducting cables

Work for ITER

Within 2011 the CryoMaK laboratory was installed successfully as ITER mechanical material characterization reference lab regarding conductor production for toroidal field (TF), poloidal field (PF) and the central solenoid (CS) magnets. A three year framework contract covers necessary measurements to assure the qualification of the used jacket material for the superconducting cables.

The TF, PF and CS conductor jacket material will be provided by different domestic agencies (DA) during 2010 to 2013. Recent reports reveal significant differences in testing method to measure critical mechanical properties like yield strength, ultimate tensile strength and total elongation. Additionally variations of the measured mechanical properties need to be assessed.

Due to the narrow boundary conditions within the specification, especially yield strength and total elongation, and the mentioned broad scatter of test results, it is of immanent interest to install a reference laboratory for these tests. With this reference lab it is possible to establish a standardized test method to characterize the jacket material and to eliminate variations because of different test methods.

Issues of material embrittlement after heat treatment (650°C, approx. 200h) are under investigation.

To support the production of ITER magnet components within the European DA a four years framework contract with F4E covers mechanical, thermal and optical material characterization. Fatigue tests on prototypes, like the TF He-inlet in figure 1, will lead to an optimized design.

Electromechanical investigation in applied magnetic background field– FBI

In most application areas like fusion magnets, transformers, motors or generators in which High Temperature Superconductors (HTS) are desired, low AC loss multifilament cables which are able to carry currents comparable to existing Low Temperature Superconductor technology are required. Additionally the cables must be able to withstand the high magnetic flux and the enormous Lorentz forces of fusion magnets or the centrifugal forces in the rotors of generators and motors. Such stability has to be achieved even due to angular field dependence and fragility of the HTS material.

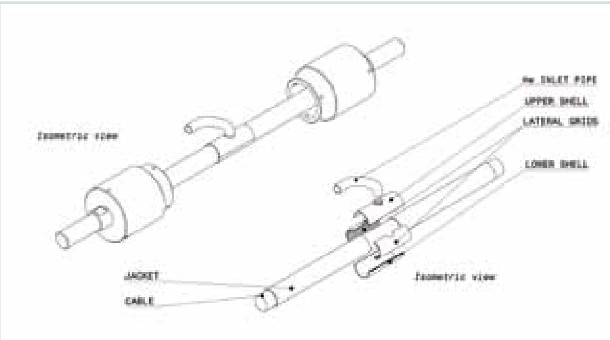


Fig. 3: TF-He-Inlet equipped with mounting fixture for fatigue test in the CryoMaK laboratory.

One concept for high current and low loss multifilament HTS cables are Roebel cables. To verify the applicability of the Roebel concept and to be able to compare its performance to other multifilament HTS concepts, measurements of the current carrying capabilities depending on tensile stress, magnetic flux and temperature are required. These measurements must be performed using an assembled Roebel cable as it is not possible, due to the complex Roebel structure, to draw conclusion for the cable solely on the basis of single tape performance.

Successful measurements were done in the FBI (force F, magnetic flux B, current I) testing facility for a 2 kA class YBCO Roebel cable consisting of 15-45 SuperPower tapes punched from originally 12 mm wide tapes. The sample length is 1.1 m and it will be tested in 2012 in its elastic regime in magnetic fluxes up to 13 T at a temperature range of 4.2 K to 77 K.

To reach these temperatures a variable temperature insert (VTI) was build covering the whole cable length. This insert is working in the liquid helium bath cryostat, necessary to cool the superconducting split coil magnet of the FBI facility. It was possible to control different temperatures, keeping the chosen temperature constant for the time to measure the critical current. Figure 2 demonstrates the stability of the different temperature levels versus time measured in the VTI. The performed measurements gave the typical critical current behavior in dependence of an increasing magnetic field. Increasing the heating power led to a systematic decrease of the superconducting properties depicted in figure 3. Because of the limited space within the first design of the VTI, it was not possible to measure the temperature directly at the same place as the critical current measurement voltage taps on the Roebel cable. Therefore only the heating power is given in figure 3 and not the temperature directly. An optimized VTI will allow to mount temperature sensors for correlating the critical current measurement to a given temperature. Measurements will start beginning of 2012.

To characterize even larger cable design a new superconducting split coil magnet will be purchased from Oxford Instruments. The gap will be enlarged from now 20 x 70 mm² to 40 x 80 mm² at a maximum field of 12 Tesla. Delivery is scheduled end of 2012.

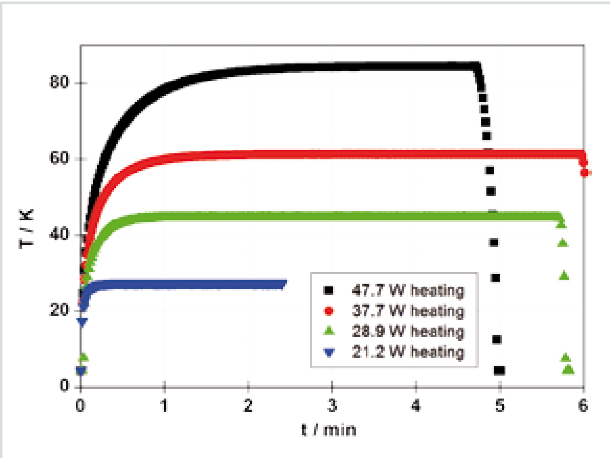


Fig. 4: Temperature versus time depending on heating power of VTI.

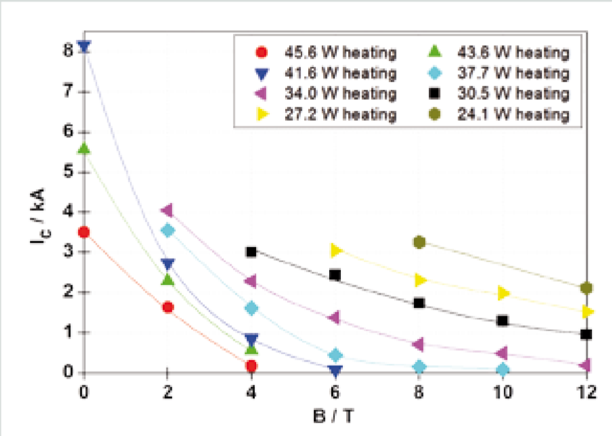


Fig. 5: Critical current depending on magnetic field and heating power.

Fig. 6: FBI facility to measure critical currents under applied mechanical load and magnetic background field.

Work for ITER

Within ITER tasks a prototype 56 kV high voltage axial break was manufactured and characterized. The manufacturing and the temperature as well as pressure cycling were performed by Bacock Noell GmbH. ITEP performed high voltage, mechanical tests and leak tests at room temperature and at low temperature. The specified performance of all low temperature breaks was met and partly even exceeded the necessary values.

Highlight 1
Tests of the HTS series current leads for Wendelstein 7-X

In 2011 three series current lead pairs for Wendelstein 7-X were successfully tested. The tests were performed in a mutually agreed test program which consist of heat load measurements without current, current tests at 14 kA and 18.2 kA, long time tests at 18.2 kA and loss of coolant flow simulation tests. All current leads fulfilled the expectation completely. The heat load at the 4.5 K level is (2.1±1) W and the helium mass flow rate at a current of 18.2 kA is 1,38 g/s.

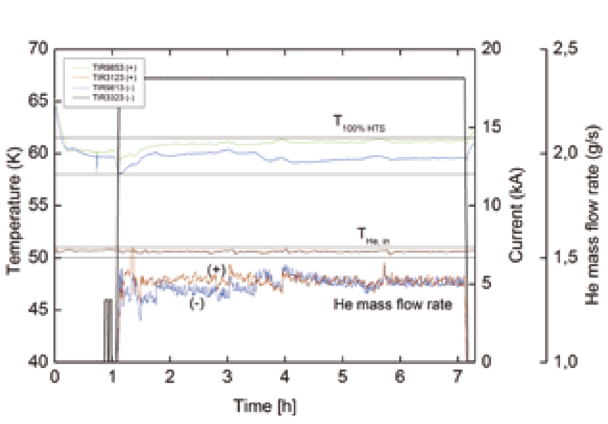


Fig. 8: Time dependence of temperature, current, and 50 K helium mass flow rate during the six hour long time test .

The temperature margin was determined and is more than 25 K, which gives enough margin in the operation in Wendelstein 7-X. In case of a loss of coolant flow at a current of 18.2 kA it lasts 18 minutes until a quench in the HTS-part of the current lead will take part.

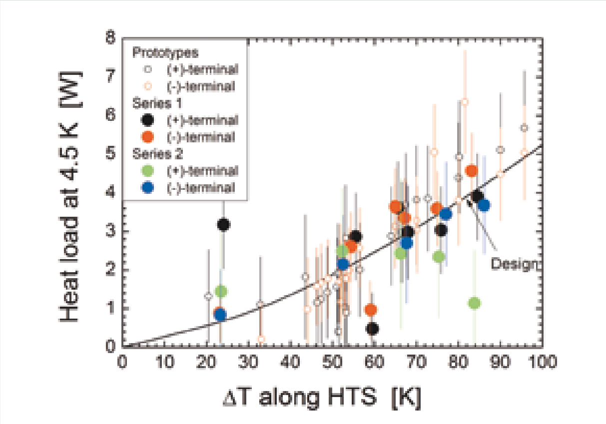


Fig. 9: Heat load at the 4.5 K level as a function of the temperature gradient along the HTS-module of the series current leads and comparison to the prototypes.

Fig. 7: Series production of the current leads for W7-X.

Highlight 2
Successful commissioning of TORSION facility

To characterize ITER components under axial as well as torsional load, a dedicated cryogenic test facility was commissioned. Axial +/– 100 kN load and +/– 1000 Nm momentum at temperatures down to 4.2 K is possible.

This facility completes the cryogenic test possibilities of the CryoMaK laboratory. All together following test devices are available:

Mechanical tests down to 4.2 K

- ATLAS	Axial	±	650 kN
- PHOENIX	Axial		100 kN
- MTS 25 & 50	Axial	±	50 kN
- TORSION	Axial	±	100 kN
	Torsion	±	1000 Nm

Electro-mechanical tests at 4.2 K

- FBI	Axial		100 kN
	Field	≤	13 T
	Current	≤	10 kA

Within the development of high voltage axial breaks for ITER working in cryogenic temperatures, this facility helped to perform mechanical quasi-static and fatigue tests at room temperature and 77 K. It was shown that the breaks met all specified mechanical requirements.

Fig. 10: View to the TORSION facility.

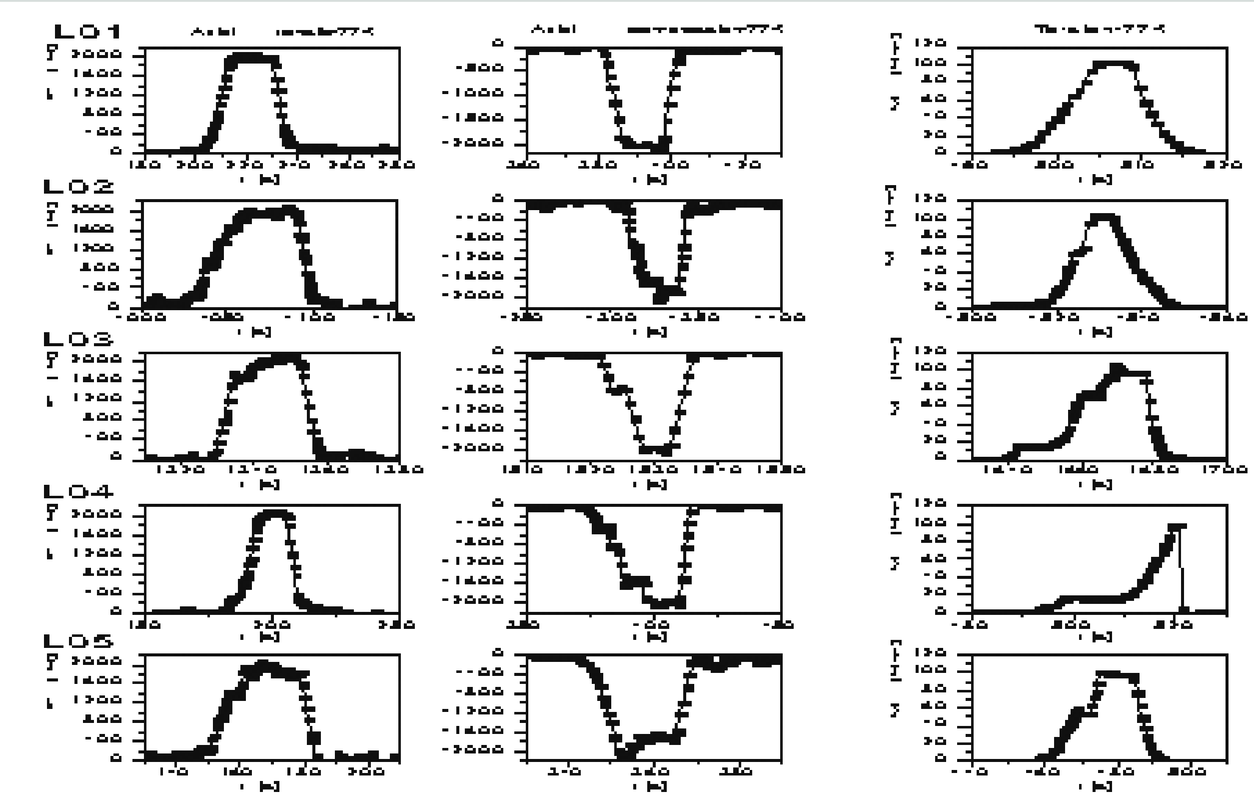
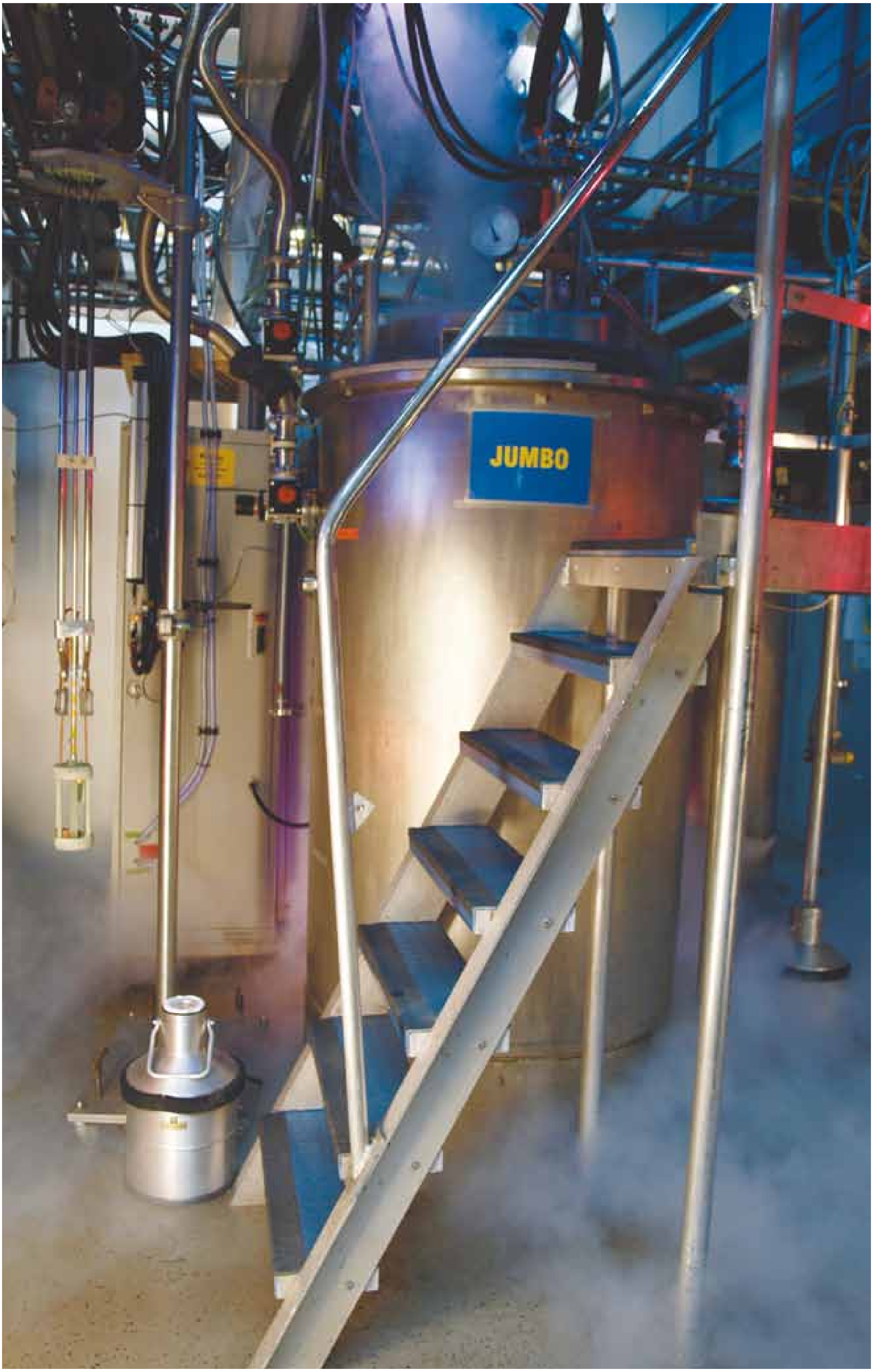


Fig. 11: Results of mechanical tests under axial tensile and compressive load as well as torsional load.



33 years in routine operation: superconducting high field magnet facility JUMBO with magnetic field strength of 10 T in a free bore of 100mm or 15 T a free bore of 44 mm.

Results from the Research Areas

Superconducting High-field Magnets

Head: Dr. Theo Schneider

The work of the Superconducting High Field Magnet (HFM) group in 2011 concentrated on the research and development needed for the expansion of HOMER II and the running of the high field laboratory, as well as the joint NMR project with the company Bruker BioSpin GmbH. Within the EU project EuCard, the group was involved in high temperature superconductor dipole magnet development. In addition, it was engaged in cooperation with the Institute of Synchrotron Radiation (ISS) and the Institute of Experimental Nuclear Physics (IEKP).

Research and Development Work

Emphasis lay on the expansion of HOMER II up to 30T as well as the development work for a 1200 MHz NMR magnet system (B=28.2T). Due to the high field strength, the innermost section of both systems must be built using high temperature superconductors (HTS). The Bi2223 high temperature superconductor of the first generation is commercially available and with this conductor the HFM team had already built an insert coil for HOMER II in 2004. This coil reached its projected field of 5.4 T at an operating temperature of 1.8 K. However, the superconductor was destroyed by penetrating superfluid liquid helium and therefore failed the deciding performance test. The Bi2223 development work of the manufacturer is virtually discontinued at the moment. In contrast to this, work is being done throughout the world on the development and optimisation of the HTS coated conductors of the second generation, the rare earth coated conductors (REBCO). These conductors are currently commercially available in lengths of over 100 m from the companies SuperPower Inc., AMSC, and Fujikura Inc.

The REBCO coated conductors are similar to the low temperature NbTi and NbSn superconductors in the way in which mostly copper is positioned alongside as a protective resistance or, as the case may be, a stabiliser. In this way the superconducting state is strengthened against electrodynamic disturbances. Furthermore, the copper serves as a bypass for the transport current in the transition of the superconductor into the resistive state and, in the case of quench, at complete transition into normal conduction. The ratio of copper to superconducting surface area determines, amongst other things, the profiles of the current-voltage curves U(I), the maximum transport current and the time taken to reach a maximum temperature (Hot-Spot temperature) in a quench situation. Reliable data on the physical parameters critical current I_c and n-value, the maximum Lorentz force load, excess current and quench behaviour in the region of the projected operating points ($T \leq 4.2$ K, $B \geq 20$T) is required.

Therefore a complete E(I) characterisation of the REBCO conductors, both experimentally in the High Field Laboratory facilities and theoretically through mathematical models, has been given priority. One way of describing the E(I) characteristic curve is by a potential function in which the curve is defined by a numerical triplet $\{E_c, I_c, n\}$. The parameters Ic and n are dependent upon temperature and surrounding magnetic field. Due to the distinct anisotropy in pinning behaviour of the REBCO, a further parameter must be taken into account, namely the angle Φ between the direction of the magnetic field vector and normal to the conductor tape. In addition, the REBCO conductor shows a variation of the critical current I_c and the n-value along the tape, so that the description must be expanded to the form I_c (T, B, Φ, x) and n(T, B, Φ, x).

In 2011 all commercially available REBCO conductors from the companies SuperPower, AMSC and Fujikura were tested. Differences exist in the construction of the conductors with regards to the substrate, buffer layers, the superconductor REBCO, as well as in thickness and material (copper, brass or steel) of the stabiliser, including physical characteristics. The I_c values of the various different conductors determined at liquid nitrogen temperature (77 K) vary between approximately 80 A up to approximately 180 A.

The HFM group examines the superconductor with the resistive four-point measurement method, in which the transport current is applied either continuously or as a current step function, depending on the aim of the test. With the high field experimental facilities JUMBO and HOMER I, experimental magnetic fields up to 20 T at temperatures from 4.2 K to 1.8 K are available. At a temperature of 4.2 K, the REBCO conductor possesses an electrical conductivity of up to twelve times that at 77 K, for example in current limiters. Therefore currents above 1500 A in self fields in 4mm wide tapes are customary today. Current feeds, test objects and power supplies in the HFM were adjusted accordingly.

The HFM group has various test objects (short probes, angle and torsion dependent) as well as one-layer test coils available for E(I) characterisation. The test coils vary in diameter and length so that conductor lengths of up to seven metres can be characterised. The behaviour of an insert coil with a long test object (ø = 90 mm) in an external magnetic field is illustrated in figure 1. In order to obtain a complete picture of the I_c and n-variation stated by the manufacturer, the scientists varied the number of voltage taps and their arrangement. A nested arrangement of the voltage taps gives an idea of the behaviour of the complete test coil in an inhomogeneous external magnetic field. In a sequential arrangement the I_c(B) distribution can be determined along the winding angle dependent due to the continually increasing radial magnetic field proportion of the background field.

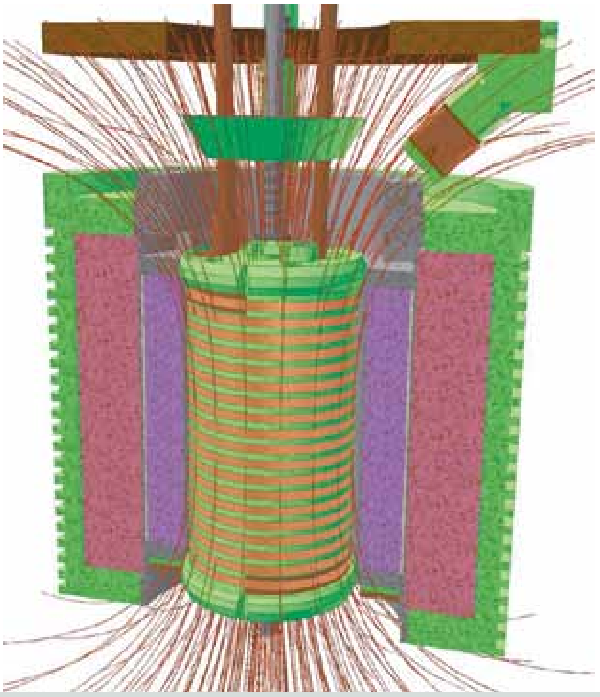


Fig. 1: Test coil with a diameter of 90 mm in the JUMBO magnet system (10 T, 100 mm).

The explicit determination of the $I_c(B,\Phi)$ distribution dependence on magnetic field B and the angle Φ was carried out by the HFM team with a newly constructed probe holder with which the angle Φ is discretely adjustable between 0 and 180 degrees. Further details are given in paragraph 'Highlights'.

For the design of the REBCO high field coil, theoretical analyses of the E(I) characteristic curves were performed. The basis for these are experiments on LTS model conductors (that are additionally stabilised with copper) which show the large variation in the shape of the E(I) curve (see fig. 2). The curve depends essentially on the applied magnetic field, the transport current, the cooling conditions in the LHe bath and the ratio of copper to superconductor..

Mathematical analyses of the curves were carried out with reference to the resistance behaviour, the current distribution and the dissipated energy. This resulted in a theoretical adjustment of resistance models of the type II superconductor in order to verify the experimental data under the specified boundary conditions. The next stage will be to transfer the results gathered for LTS conductors to the latest REBCO conductor.

An essential aspect of the quench safety of the entire HOMER II magnet system is the quench behaviour of a REBCO insert coil. Measurements in the HOMER I facility have shown that a burn-out of the REBCO conductor can occur during E(I) curve determination with transports currents of 1000 A, even with conductors with steel lamination. Therefore the temperature development over time as a function of transport current in the normal conducting state was calculated. Figure 3 shows a simulation for up to a maximum temperature of 1300 K. In this way, a tool is available in which the upper time limit for quench detection for various REBCO conductors and therefore shut down can be estimated.

Superconducting Undulators

One of the most recent research activities in the superconducting area is that of the development of superconducting wigglers and undulators in order to improve the brilliance of synchrotron radiation. In contrast with the bulky permanent magnet undulators, superconducting undulators in a compact form can reach higher magnetic fields without alteration of the distance between the poles or period length. The use of NbTi superconductor specifically optimised for the low field ($B < 5$ T) can also increase the efficiency of such superconducting undulators. Within the framework of their long-standing cooperation, in 2011 the institutes ITEP and ISS evaluated the construction of a highly effective superconducting undulator.

The focus of the research was partly on the E(I) characterisation of the low field optimised NbTi conductor. With a wire diameter of less than 1 mm, the superconductor possesses a notably high current density. As a feasibility study, the high field laboratory team produced a small racetrack coil with an iron core and using the JUMBO facility determined the maximum transport current in an external magnetic field of 0.5 to 8 T. Figure 4 shows a comparison between the race track coil data reached and the short probe values of the NbTi superconductor used, whereby the difference is attributed to the self-field of the racetrack coil with iron core.

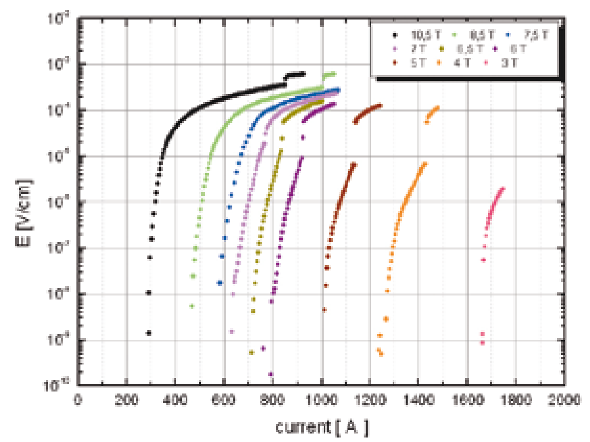


Fig. 2: Diversity of the E(I) characteristic curves of a NbSn conductor.

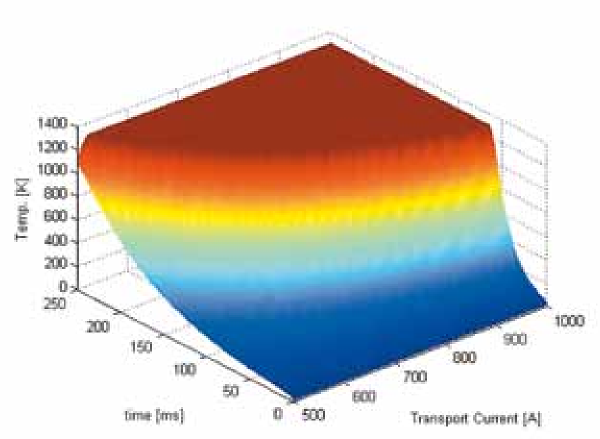


Fig. 3: Temperature progression T(I, t) of a REBCO in normal conducting state.

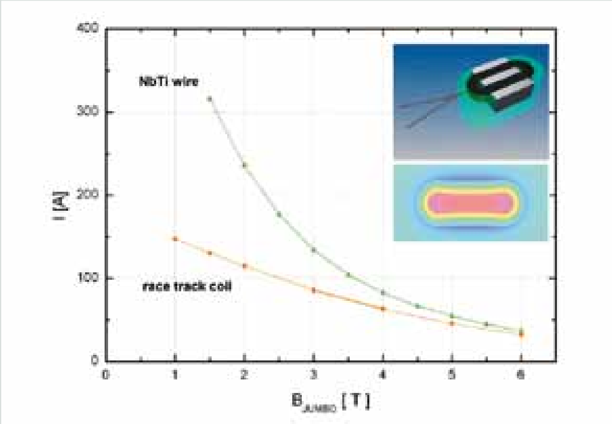


Fig. 4: Characteristics of the race track coil and of the NbTi superconductor with magnetic field distribution.

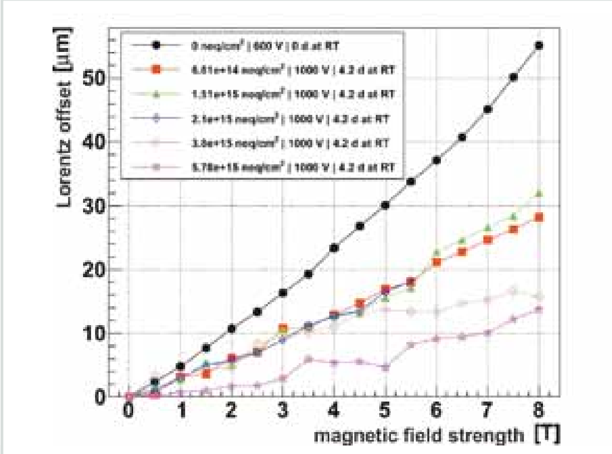


Fig. 5: Progression of the Lorentz offset dependent on the magnetic field strength under various levels of irradiation of the sensors.

Measurement of the Lorentz Angle

Within the framework of the research and development work on the planned upgrade of the central trace detectors of the CMS experiment in the LHC of CERN, silicon sensors were tested by employees of the IKEP in the JUMBO facility for their magnetic field behaviour. The CMS trace detector was placed in a magnetic field of 3.8 T that, due to the Lorentz force, bends the path of the proton-proton collision generated particles into a spiral trajectory. In passing through the detector module, these particles, through ionisation of the charge carriers, are detected in the form of an electrical signal. These charge carriers however are subject to the Lorentz force whereby the detected charge is clearly offset. This leads ultimately to deterioration in the resolution of the trace detector so long as this influence isn't corrected. The Lorentz angle is dependent on the strength of the magnetic field, the temperature, and above all the degree of damage of the sensor. In order to test this influence on the Lorentz offset, over 40 sensors were irradiated with various strengths of neutrons and protons and then placed in JUMBO with an inner cryostat at various temperatures and magnetic field strengths of up to 8 T.

Figure 5 shows measurement results at which the expected linear increase of the offset with the magnetic field strength can be clearly seen.

EuCard

One of the tasks of the EU project EuCard (European Coordination for Accelerator Research and Development) is to develop solutions for an upgrade of the LHC accelerator two to three times the energy value. The current dipole design foresees a 14-T-LTS-background magnet system and a 6-T-HTS insert magnet. Work is concentrated in the meantime on the application of REBCO conductor, which, in the first stage, was used in a solenoid winding manufactured by French partners CNRS and characterised at the ITEP. The first REBCO double pancake coil was delivered to the ITEP at the end of 2011. The constructive adaptation to experimental E(I) measurements is on-going and experimental work is planned for the start of 2012.

A further task from EuCARD is the development of superconducting undulators, in which specifically produced high current NbSn conductor, following the Restacked Rod Process (RRP), is used. In cooperation with the British Rutherford Appleton Laboratory (RAL) a RRP round conductor produced by Oxford Instruments was tested in the JUMBO facility. Summarised results of the experiments showed that the load bearing capability and above all the stability of the superconductor is unachievable in the relevant field range (3 to 5 T) for the application. As a result of this, RAL now favour another superconductor for the construction of the undulator.

Highlight 1: Extension of the NMR Magnet Technology Project

As well as in the development projects of the superconducting high field magnets for the high resolution NMR-spectroscopy (750 MHz to 1200 MHz), the ITEP has worked for 15 years with Bruker BioSpin GmbH in a NMR Magnet Technology Project. The ITEP supports the industrial partner in bringing to the world-wide market jointly developed NMR maximum field magnet technology.

The team has at its disposal a comprehensive portfolio of test and measurement programmes ranging from the optical quality analysis of high resolution E(I) measurements to the cryogenic tests of NMR magnet systems. The tests of the prototype magnets in the magnet test facility (MTA) were the main focus of the first phase of the project. The quench and drift behaviour was analysed as well as the magnetic field homogeneity of the magnet system based on its first time in operation. Thermal treatment of the $(NbX)_3Sn$ section coils was also carried out to assist in the NMR magnet production process.

The commercial success of the high field NMR spectroscopy called for further quality assurance measures. Therefore, in the course of the year, E(I) measurements verifying the high NMR requirements of the technical low temperature superconductor(LTS) and superconducting joints were of great importance. LTS superconductors of current magnet production as well as new types of conductor were tested for their NMR- suitability (I_c(T, B) and n(T, B) characteristics) in the JUMBO and HOMER I facilities. They vary in their production methods, material composition, dimensions and physical properties, and consequently require a multitude of test experiments that must be continuously improved. To this end, as part of the NMR technology project, the team constructed a probe holder that can be used at 1.8 K and at fields of up to 20 T and take transport currents of up to 2000 A.

Figure 6 gives an idea of the variety of LTS conductors available for high field magnet development. The overview shows typical NbTi and $(NbX)_3Sn$ superconductors used in the high field laboratory. Obviously the actual superconductors used in the NMR magnet system cannot be shown.

In order to reach a timed magnetic field stability of better than 10^{-8} per hour, superconducting contacts between the superconductors used must have a resistance in the pΩ range. The quality control of these superconducting joints for the on-going production is therefore a fundamental task of the NMR magnet technology project. Further problems exist in testing the integration of new types of superconductor in the contact technology as well as optimising the contacts with regard to a higher magnetic field tolerance. The number of voltage taps was increased by the researchers in order to thoroughly analyse the voltage distribution in the complex construction of a LTS-LTS joint and a re-evaluation of the measurement values was carried out accordingly. The reduction of electrical noise by means of suitable grounding and electrical shielding procedures and the use of ramp generators to control the current from the power supply completed the modernisation steps.
Following a change in organisation within the KIT, the project was handed over to the control of the EKM department. This called for a revised version of the NMR magnet technology contract.

In the first half of 2011 the partners negotiated and signed the contract thereby ensuring that the KIT/ITEP and Bruker BioSpin will continue with the NMR magnet technology project in the coming years.

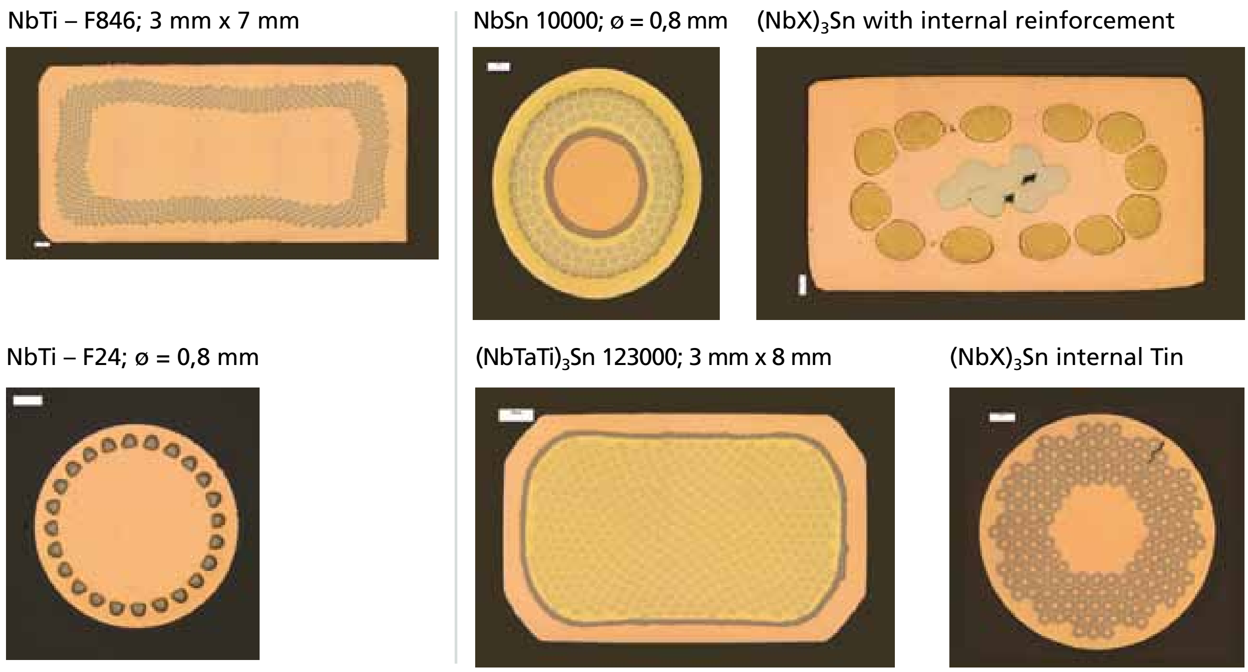


Fig. 6: Multiple varieties of composite superconductors – right NbTi superconductors, left $(NbX)_3Sn$ superconductors.

Highlight 2:
Determination of the REBCO $I_c(T, B, \Phi)$ Function

To develop the HOMER II facility further up to 30 T, work is being done on the design and construction of insert coils made out of REBCO conductor. For this the physical characteristics of the REBCO coated conductor in the region of the projected operation point ($B \geq 20$ T, $T \leq 1.8$K) must be determined.

One of the properties of the REBCO conductor is the anisotropy of the critical current $I_c(B, \Phi)$. In contrast to LTS coils, designers of an HTS coil must be aware of the fact that the limit is no longer at the point with the highest field value, but at the coil edge where the highest radial component occurs. Magnetic field calculation for a realistic HOMER II REBCO insert (see figure 1) in a background field of 20 T results in a minimum angle of 80° between the magnetic field vector and the normal to the tape.

An experimental determination of Ic under the boundary conditions ($B > 20$ T and $\Phi \geq 80°$) is not possible using the facilities of the HFM. Therefore the researchers must match available experimental data of $Ic(T, B, \Phi)$ to mathematical models and extrapolate the data up to a field strength of 30 T.

In 2011 the HFM group designed and constructed a new device for the JUMBO facility to enable angle-dependent analysis of the E(I) behaviour of the REBCO conductor. With this equipment it is possible to take measurements in external magnetic fields from 0 to 10 T along a conductor length of c. 100 mm in an angle range from 0 – 90 – 180° ($\Delta\Phi = 2.5°$) with respect to the conductor tape surface. The apparatus is equipped to handle a transport current of over 1500 A so that a complete characterisation of a 4 mm wide REBCO conductor in the total field range is possible. In doing this the researchers must be aware that the effect of such a high transport current can lead to a reversal to normal conducting, the quench, and an associated destruction of the REBCO conductor.

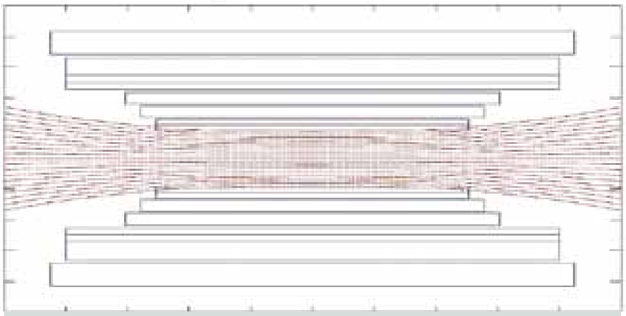


Fig. 7: Field lines of the HOMER II magnet system.

On the basis of the $I_c(B, \Phi)$ data determined experimentally in JUMBO there followed a separation of the variables. The Φ-structure function was adjusted according to the physical theory of pinning behaviour. The $I_c(B)$ distribution was approximated from the available experimental magnetic field range with a suitable form function. With the help of the subsequent extrapolation to 30 T, figure 8 shows the three dimensional $I_c(B, \Phi)$ surface normalised to the maximum critical current for a REBCO conductor from the company SuperPower.

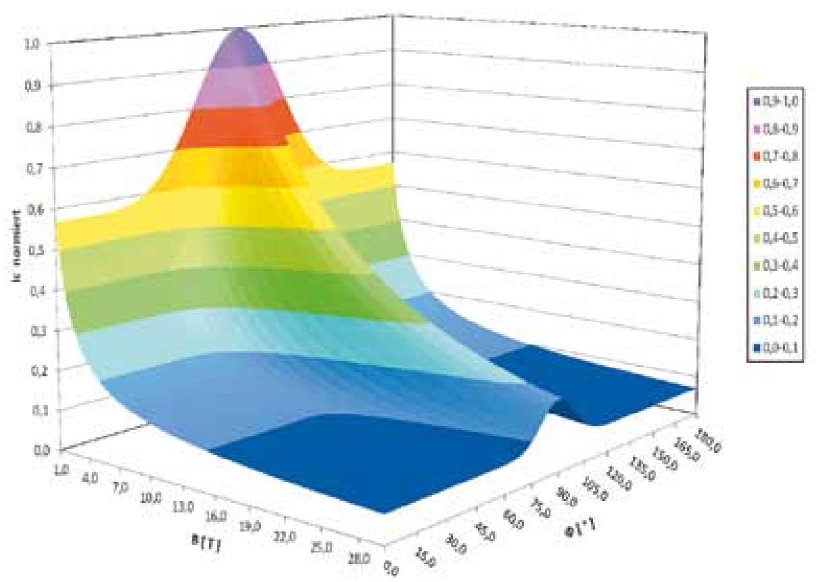


Fig. 8: Critical current I_c distribution of a REBCO coated conductor from Super Power as a function of magnet field and magnetic field orientation at 4.2 K.

Fault current limiter component of the second generation of high-temperature superconductors.

Results from the Research Areas

Superconducting Materials and Applications in Power Technology

Head: Dr. Wilfried Goldacker

Superconductor development

The development of superconductors has focused on textured YBCO-coated conductors and their lamination and on the further development of Roebel wires from YBCO tapes in 2011. Both topics are located within the BMWi-funded project "Highway".

For the development of structured YBCO-coated conductors the research area installed an innovative laser patterning device and took it into operation. The used Pico-second laser (Figure 1) allows to burn 25 µm wide lines and structures into the superconducting layer of the coated conductors, with negligible heat effects at the edges of the structures. For the qualification of the process, several patterns were structured. Above all, coated conductors with 40 parallel filaments were made (Figure 2).

More complicated structures (Figure 3) were made for lamination experiments. The aim was to laminate two structured coated conductors face-to-face to get a transposition of the superconducting percolation paths.

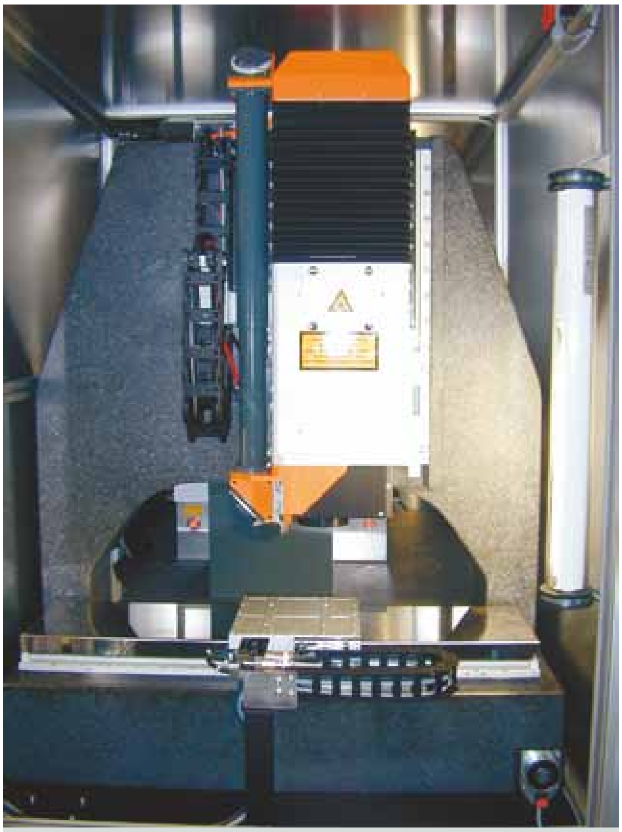


Fig. 1: Picture of the Pico-second laser system for microstructuring.

Fig. 2: Coated conductor with 40 burned filaments.

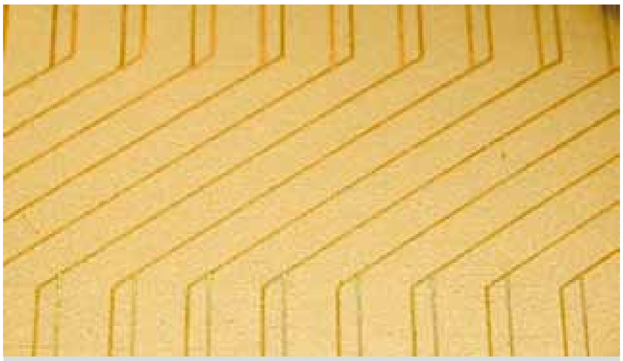


Fig. 3: Transversal structured filaments in an YBCO coated conductor.

However, the lamination is still an unsolved problem. The greatest progress was achieved by laminating conductors with non modified Ag cap layers. This process was supported by applying pressure with a screwed stainless steal jacket. During an annealing treatment a permanent connection results, with contact resistances, which are among the lowest world wide (Figure 4). A direct lamination of bare superconducting films failed. This is in accordance with the results of other groups.

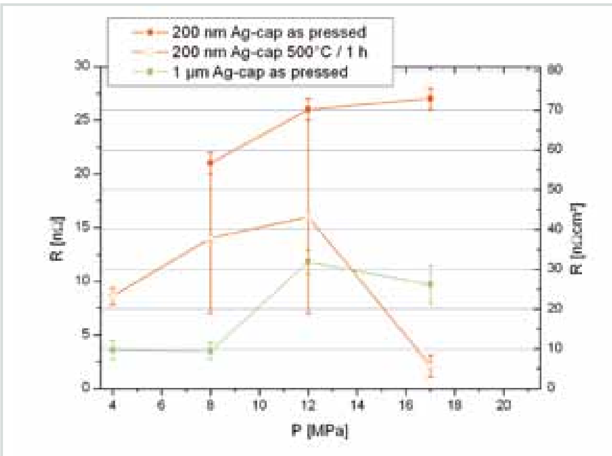


Fig. 4: Contact resistance as a function of the pressure.

A further application of the laser is to produce a periodic meandering current path in a coated conductor as shown in Figure 5. In such a structure the self-field of the superconductor creates an alternating field along the sample, which can be used as a micro-undulator. The structures are preliminary tests to develop a micro-undulator with this technology. The quality of the burned structures is shown in the electron micrograph in Figure 6. With a first upgrade of the laser system it is possible to make structures up to a length of 60 cm so that in future all kinds of short samples and cables can be prepared.

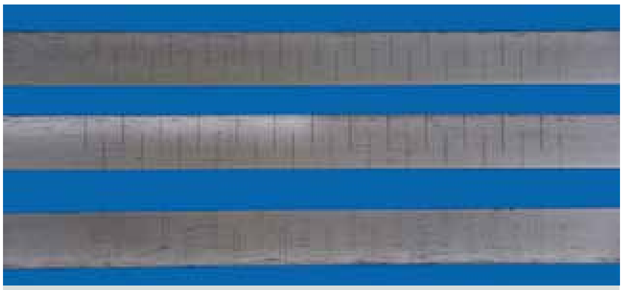


Fig. 5: Structured coated conductor for use as micro-undulator.

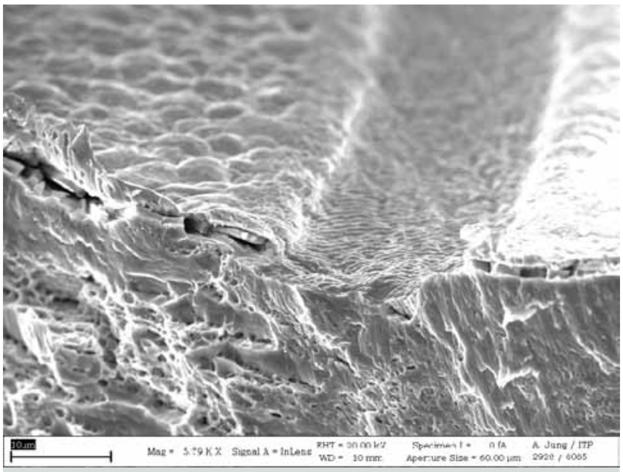


Fig. 6: Electron micrograph of a burned track in an YBCO coated conductor.

In the development of Roebel cables using YBCO coated conductors, the step for producing average sample lengths up to 5 m was realized. Two lengths of 2 m with 10 strands and 12 mm width have been produced for our partners in CERN to analyze them in a dipole background field. A second sample of 5 m length was prepared in our research group presented by the end of the year for own investigations. A cable of 4.5 m length has been cabled for the Ohio-State-University/USA for studying AC losses (Figure 7).

Using FEM simulations the research group successfully simulated the 2D field penetration into Roebel cables. The self field distribution inside the cable was also simulated using FEM codes (Figure 8); the current distribution in the individual strands of the cable was calculated. Figure 9 shows that the Roebel cable generally has an inhomogeneous self-field and consequently the

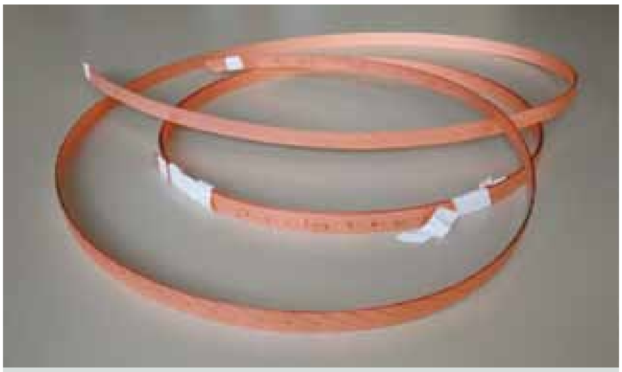


Fig. 7: Roebel cable of 4.5 m length, 9 strands and 12 mm width.

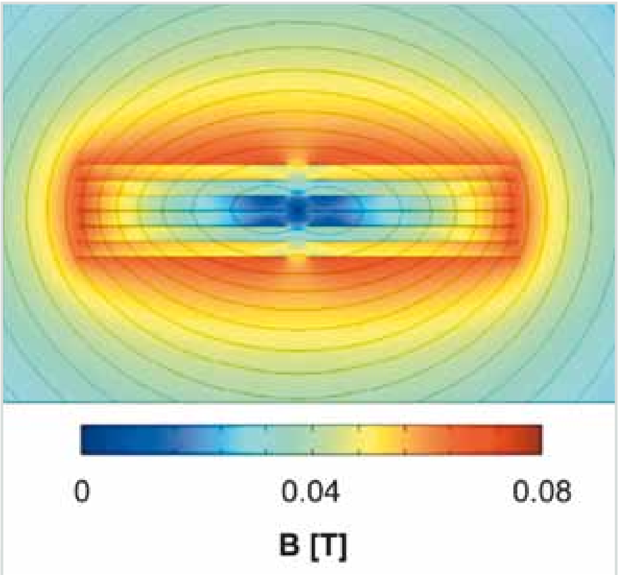


Fig. 8: Self field simulation of the cross section of a Roebel cable.

critical currents along the cable in the individual Strands vary individually. Thus, the complexity of the superconducting behaviour of the Roebel cable is shown; for a stable operation of the cable there is a technical need for a moderate coupling of the strands. For the magnetic measurement of AC losses of short cable pieces, a device was constructed and put into operation.

Further work of the materials group dealt with electron micrographs of tensile specimens, to characterize the fracture behaviour. The fracture pattern allows the decision between ductile or brittle fracture. The samples are structural material from the ITER work program (see example in Figure 10).

Applications in power engineering

The work on power engineering applications comprised the development of the current limiter within the BMWi-funded project ENSYSTROB amongst other things. Role of KIT was to design, build and test the components of the current limiter consisting of YBCO tape conductors as a preliminary stage to series production at the industrial partner NEXANS. The work on the components was completed in close cooperation with industry and the University of Mannheim. Meanwhile, the final current limiting unit has been tested high volt-

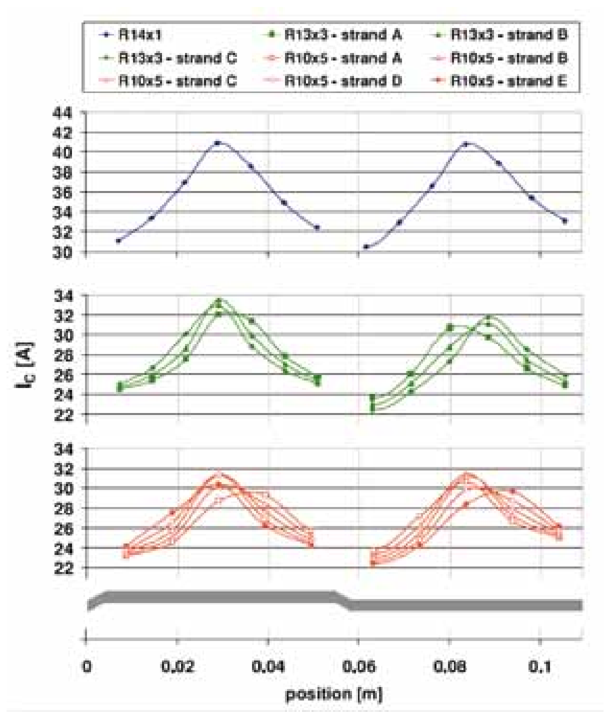


Fig. 9: Critical currents along the strands of different Robel cables with different numbers of strands.

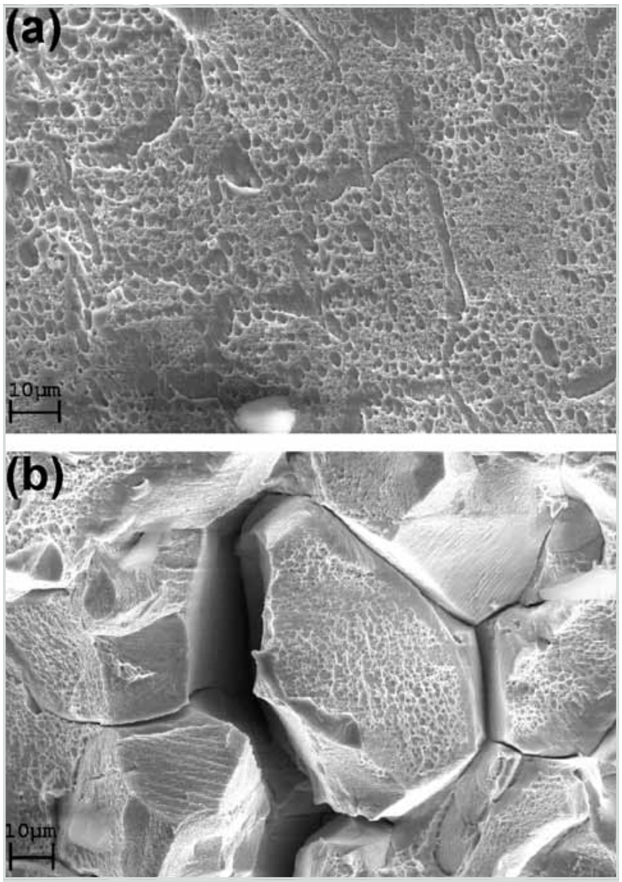


Fig. 10: Microstructure of a surface of fracture in a tensile steel sample.

age – wise and integrated into the power plant Boxberg for the practical test. Figure 11 shows the design of the components, Figure 12 the measurement of the limiting behaviour of the components. In the European successor project ECCOFLOW, the design of the components of the fault current limiter was also created. After extensive testing, conductor specifications were developed. For the technical execution an innovative method of insulation was designed and protected by a patent application. For an innovative test system VATESTA, funded by the BMWi, the department created the pre design and concluded the planning of the periphery. The facility will allow the characterization of cable samples and components up to approximately 70 cm in diameter in a background field of 5 T at variable sample temperature. Targets are mainly AC loss measurements in background field.

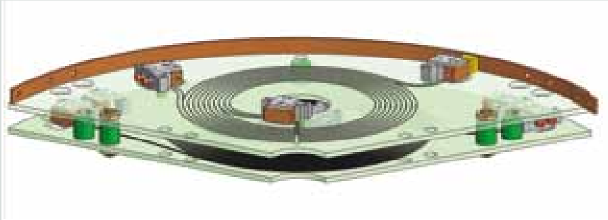


Fig. 11: CAD design of components of the fault current limiter in the project ENSYSTROB.

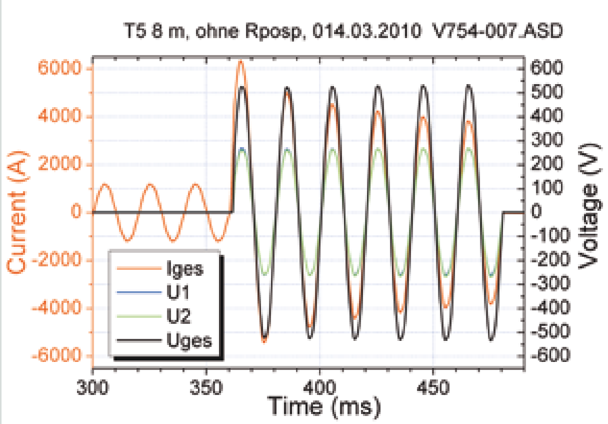


Fig. 12: Measurement of the limiting behavior of the SSB components.

Highlight

Roebel cable: The department realized Roebel cables of average lengths between 2 and 4.5 m. The figures show the prepared strands after punching and subsequent segmentation into individual pieces of length of the cable. Figure 13 shows the strands whereas Figure 14 displays the corresponding 2-m-Roebel cable produced for the test at CERN in a background field of a dipole. Roebel conductors with a mean length of 5 m and henceforth above at a width of 12 mm are only manufactured at KIT. Cables of this width can be expanded in cross-section to increase the transport currents, which can be one order of magnitude higher. Roebel cables are of interest for use in HTS rotating machines, transformers and large magnets. The implementation of complex cables into large scale industrial products is to be achieved.

Fig. 14: Stranded HTS Roebel conductor wire with ten strands, 2 m length and 12 mm width for research at CERN.

Fault current limiter: The department developed and tested the component of the fault current limiter for the BMWi project ENSYSTROB (Fig. 15). Many aspects must be considered: the arrangement, i.e. the conductor length and the number of parallel conductors, must be adapted to the desired resistance and current in the switched mode. Of utmost importance is the high voltage strength to prevent flashovers. Finally, the component must be producible in industrial series to economic costs. This aim was achieved by close cooperation with NEXANS Superconductors GmbH.

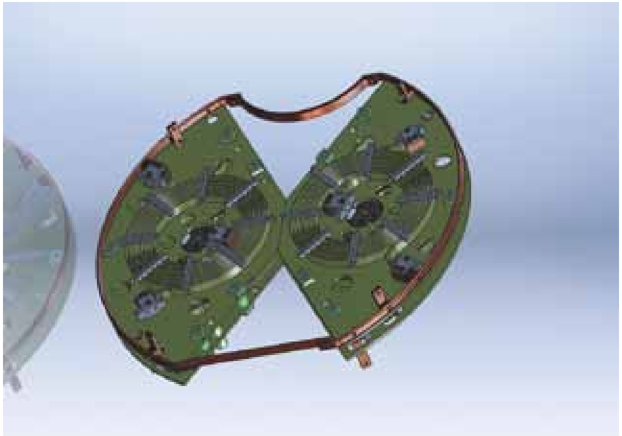


Fig. 15: Fault current limiter module of the project ENSYSTROB.

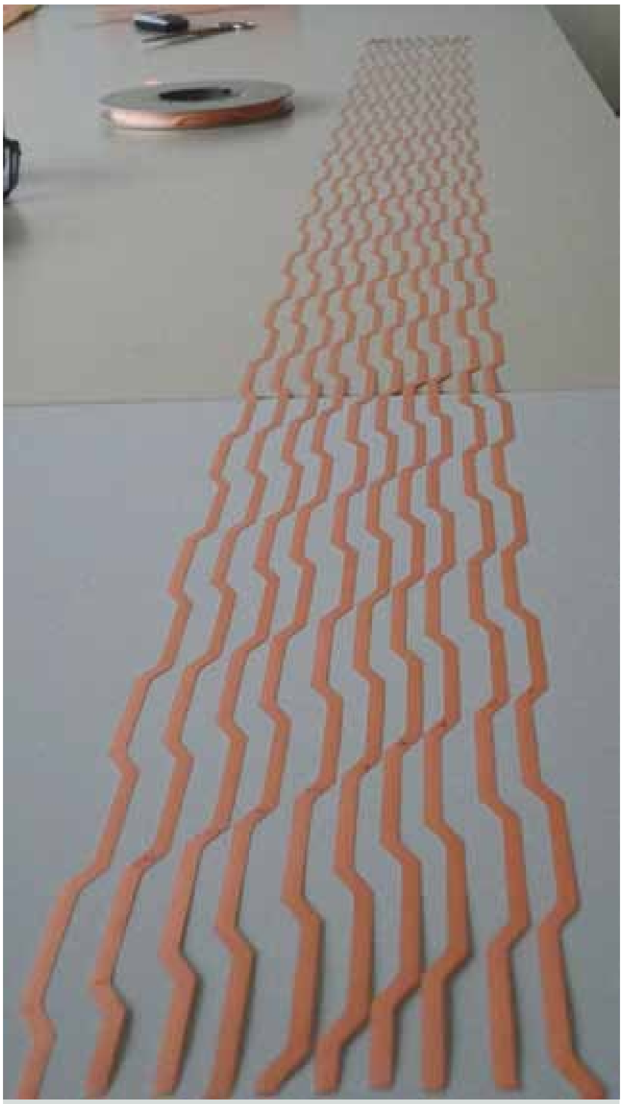


Fig. 13: Punched and elongated strands of HTS YBCO tapes before stranding.

Cooperation Agreement with IASS: The ITEP of KIT signed a cooperation agreement with the Institute for Advanced Sustainability Studies (IASS) in Potsdam. Nobel Laureate Professor Carlo Rubbia, former director of CERN, directs the department of the energy sector at IASS. Aim of the collaboration is to develop and test superconducting cables for very large distances with involvement of CERN. Accompanying studies will address the economics and functionality of the cable as well as their integration into an overall concept of the development of renewable energy sources. The best known application is the DESERTEC project that aims to bring the solar energy produced in North Africa and Middle East / Arabia over approximately 3 000 km to the industrial areas of Europe. Figure 16 shows the visiting group of IASS in front of the ITEP.

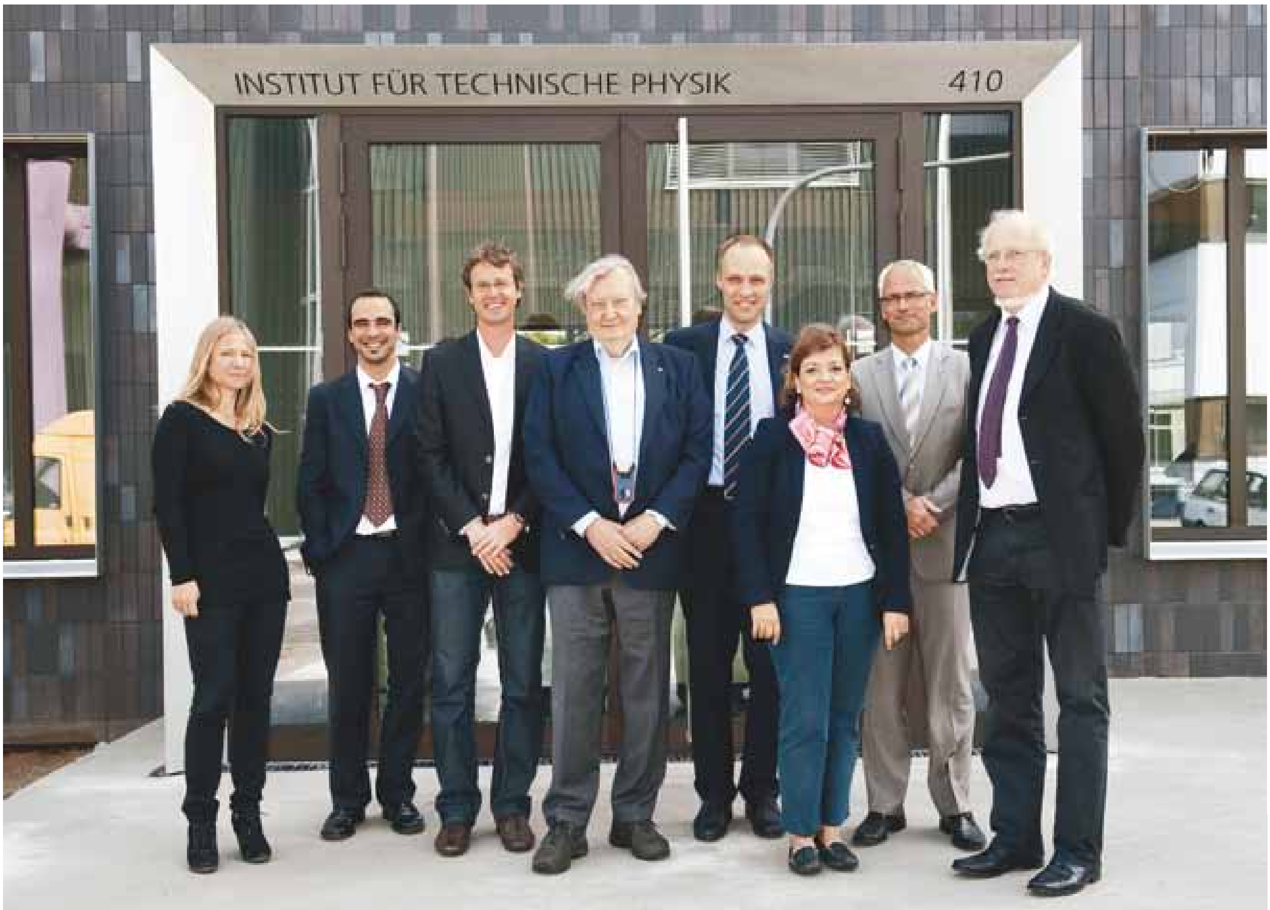


Fig. 16: Visit of the IASS in ITEP. Dr. Natalia Deniskina, Federico Bernardelli, Dr. Stefan Stückrad, Prof. Carlo Rubbia, Professor Mathias Noe, Dr. Delia Salmieri, Dr. Joachim Knebel and Dr Wilfried Goldacker.

*2*2. 5 grams of tritium were delivered in November 2011. Activity is measured with a TLK calorimeter for incoming components inspection and mass balance study. Displayed is the insertion of the second tritium container into the calorimeter.*

Results from the Research Areas

Tritium Laboratory Karlsruhe (TLK)

Head: Dr. Beate Bornschein

The Tritium Laboratory Karlsruhe is a semi-technical scale experimental facility unique in Europe and America with a permit to handle 40 g (1.5*10^{16}Bq) of tritium, 100 kg of depleted uranium, as well as rubidium and krypton as test emitters for calibration. An experimental area of about 1000 m² holds more than ten glove box systems with a overall volume of approx. 125 m^3 as enclosures for the experimental equipment carrying tritium. The purpose of TLK when it was founded, and one research item to this day, has been the development of technologies for the fuel cycle of fusion reactors. The second main area of activity is the construction of key systems for the Karlsruhe Tritium Neutrino Experiment (KATRIN) measuring the rest mass of the electron neutrino. Accordingly, work is supported in equal proportions within the "FUSION" and "ASTRO" programs.

In the past two years, TLK has attracted an increasing number of students and graduate students by placing interesting research projects (see Table). Young scientists are very important for the future of TLK, and so the laboratory is highly interested in offering them excellent, balanced training which, in addition to the technical and scientific aspects, also includes the soft skills now in demand everywhere.

	2007	2008	2009	2010	2011
Bachelor		1			
Diplom/Master	1	2	7	9	9
Ph. D.	3	3	4	8	10

Table 1: Ongoing and concluded theses at TLK.

The following sections contain brief descriptions of the activities and results in the fields of "TLK operation" and infrastructure, as well as "research and development for FUSION" research and development for fusion. A separate chapter is devoted to the KATRIN area.

TLK Operation and Infrastructure

In 2011, the conventional as well as the tritium infrastructure of the Tritium Laboratory were fully available to research project within the programs FUSION and ASTRO. The tritium storage system supplied in particular the experimental facility CAPER, which is used for both, R-&D work in the framework of fuel cycle for fusion reactors and provision of service for other experimental projects as e.g. providing tritium for the experiment LOOPINO. In addition, CAPER produced special tritium gas blends for other experiments and served as infrastructure facility for detritiation of waste gas.

The supervisory visits by the regulatory authority did not give rise to any criticism. There were no reportable events. On Nov. 22nd 2011 the TLK received a delivery of 5 g of tritium. The purchase of the tritium was necessary, to cover the loss of the radioactive decay within the last few years. The current Inventory of the TLK is about 24 g of tritium, which is enough to cover the research projects for the following two to three years.

As last year, the main focus of the Automation and I&C Group was the replacement of the TLK Process Control System. Since the manufacturer of the old systems does no longer support them and many replacement components are no longer available, the exchange was inevitable. After a successful setting in operation at the designated test environment over the years turn 2010/2011 the first two new automation systems AS3 and AS4 (PCS7-AS417) were degraded as planned and after the dismantling of the old systems, the new were arranged and connected at the place of the old. Due to experiences made in the preliminary phase it was decided to abandon the rollback strategy for the automation systems of the second stage (AS5 and AS8, PCS7-AS417) and the new systems were set up at their final position (see Fig. 1).

The affected automation systems AS5/8 have to assure the retention of tritium of all experiments and the connection of important status – and fault signals to the

Fig. 1: Setup of the new automation systems.

"Alarmzentrale" of KIT-CN. These were the reasons why the replacement was intensively prepared within a period of 9 months where the software was developed and tested. As a result of this intensive work, the new systems were able to fully adopt all functions of the old ones after 3.5 days already. Three of the dismantled systems Teleperm M AS488 were given to the Cryo-Group of ITEP, where they will replace systems of an older generation (Teleperm M AS235).

Concerning building services a further major measure of maintenance was accomplished. The facilities for ventilation, air conditioning, cooling and pressurized air are obligatory for licensing and for safe handling of tritium as well as for tritium accountancy regarding to licensing requests. The process measuring and control technology, partially older than 30 years, ran out of service of the manufacturers. So a reliable operation could not be guaranteed further on. During the last year, the control technology of the ventilation system was replaced in collaboration with an external company. Meanwhile the laboratory work went on with support of a temporary control system with reduced possibilities in air conditioning. Actually the new control system is in initial operation. The laboratory work has to be stopped a few times only for single hours to do the necessary switching procedures. In 2012 work goes on with the substitution of the control systems for cooling water and pressurized air. The measures stand for a capital asset of 800 000 Euro and were planned, coordinated and technically supported by the operational office of the TLK.

Analytical Work at TLK

Managing qualitative and quantitative analyses of the six hydrogen isotopologs, H_2, HD, D_2, HT, DT, and T_2, as well as other tritiated compounds (such as HTO) constitutes a major precondition for handling tritium, imposing strict requirements on experimentalists and their equipment. Because of the great importance of analytical work for TLK, the research and development activities are coordinated comprehensively across programs and groups. This year the work concentrated on the following areas:

- Laser Raman spectroscopy on gaseous tritiated hydrogen isotopologs (see KATRIN chapter).
- Beta-induced X-ray spectroscopy (BIXS) on tritiated water and gaseous hydrogen isotopologs (see KATRIN chapter)
- Infrared spectroscopy on hydrogen isotopologs (see below)
- Application of liquid scintillation as inline-method to define the tritium contents of water.

Alongside pure research and development activities, TLK optimized calorimeters, ionization chambers, and gas chromatographs as well as existing calibration processes. The instruments referred to above are used regularly, Forming the backbone of analytical work at TLK.

F&E for ITER

Current work on the tritium loop of ITER is concentrated on the European contribution, "Water Detritiation and Isotope Separation (WDS-ISS)". For this purpose TLK, within the framework of the Fusion programme, studies processes of water detritiation and hydrogen isotope separation by means of the TRENTA facility. These activities serve to generate important data for the WDS and ISS ITER systems and, in this way, contribute decisively to the ITER design.

Like the future ITER system, the TRENTA facility at TLK is made up of two subsystems, WDS and ISS. WDS uses the familiar Combined Electrolysis Catalytic Exchange (CECE) process for recovering tritium from tritiated water. The two main systems of the CECE process are two electrolyser units with a total capacity of 2 m^3/h of hydrogen gas and an 8 m long Liquid Phase Catalytic Exchange (LPCE) column. Besides the recovery of tritium from water, another main task of the WDS is the tritium decontamination of the generated hydrogen stream prior to be released to the environment. Fro this purpose TLK has to guarantee a decontamination factor in the order of 10^4 to 10^5. Regarding the higher activity streams at ITER a decontamination of about 10^7 needs to be guaranteed with the final technical ITER WDS. Hydrogen isotope separation is achieved by cryogenic distillation at temperatures between 20 – 30K. It makes use of the fact that the different species (H_2, HD, HT, D_2, DT, T_2) have different boiling temperatures.

This year's main focus was given to the WDS test campaigns in the framework of a task with the European agency "Fusion for Energy" (F4E). The experiments should reveal the influences on the decontamination performance caused by operational parameter like pressure, temperature, flow rates and tritium concentrations. In addition, the influence of increased deuterium content in the tritiated process water was of crucial interest. Therefore, experimental runs with deuterium concentration up to 50% and activities in the range of 10^{10} Bq/kg have been performed. As assumed, the decontamination factor of the WDS was decreased by 1 to 2 orders of magnitude with increasing deuterium content. Those experimental data will find a use in the conceptual design studies of the ITER WDS and they are required for benchmark test of a developed process simulation software.

Based on the availability of the WDS at TLK, it was possible to arrange a cooperation with JET (Joint European Torus), to successfully demonstrate the operational capability of TLK's WDS to process tritiated water in large amount and activity level, as it is available at JET as triti-

Fig. 2: A view on a part oft he Trenta System. The glove box is a connection between WDS and ISS.

ated waste water. Therefore, 180 kg of tritiated water from JET was processed at TLK. During the experimental demonstration a volume reduction factor of 30 could be achieved. Thus, the tritium of the initial 180 kg was transferred into 6 kg of enriched tritiated water, and finally shipped back to JET, England.

In parallel with the experiments of WDS, the final preparation of TRENTA4 for the operational combination of the two test facilities WDS and ISS was further expedited (see figure 2). The focus was given to the procedural, electro technical, controlling and safety installations and working. After the commissioning of TRENAT4 important campaigns will be performed next year. The targets of these test runs are related to different ITER operational scenarios and their influence on the final system design of WDS and ISS. In addition, the TRENTA4 facility will be implemented into the TLK infrastructure to process the arising tritiated water of the TLK. This will finally improve the tritium cycle at TLK.

A continuous work within the TRENTA project is the identification, development and enhancement of analytical methods for the determination of hydrogen isotopes (H, D, T = Q) in the water and gas phase. Existing methods, like the quadrupole mass spectrometer for the online determination of Q_2 in the gas phase or the Infrared spectroscopy for measurements of deuterium in water were further improved and adjusted to the respective requirements and conditions. Furthermore, the application of infrared signals for the analysis of liquid hydrogen isotopologues (H_2, HD, HT, D_2, DT, T_2) at about 25K is under investigation. For this purpose a new experimental setup is planned, applying the cryogenic helium system of the ISS.

Blanket and Tritium Technologies

Within the FUSION program and with regard to DEMO – the future demonstration fusion reactor – the tritium recovery from the breeding blanket constitutes a major technical challenge. To accumulate practical experience, various concepts are to be tested in a first step in the ITER experimental fusion reactor under construction. In the last two years, TLK has contributed greatly to a thorough process review of the systems involved. The main concern was to simplify the process in a whole, so as to make it more reliable, more robust, and to facilitate the crucial tritium accountancy procedure. The state of this R&D work is detailed in the TLK highlights chapter.

In parallel to this work, some experiments were focused on the handling and processing of highly tritiated water (HTW). Indeed, the preliminary safety analysis for the ITER machine emphasized an important missing package regarding HTW. It has been recognized the necessity to install an additional system that is able to detritiate HTW at specific activities up to 1.4 MCi/kg (stoichiometric DTO). TLK proposes to use a catalytic membrane reactor (PERMCAT). The HTW detritiation is achieved by feeding the reactor with HTW, where the catalyst promotes isotope exchange with fresh protium fed in counter current. The Pd-Ag membrane ensures that tritium from the water is finally recovered in the pure molecular form (Q_2).

The overall experimental plan with tritium consists in 3 main steps (Fig. 3) carried out in the CAPER facility. The major issue for this work is the necessity to produce HTW. Afterwards, the PERMCAT detritiation efficiency can be assessed for different experimental conditions (flow rates, concentrations). The first step (fig. 3a) put into operation in 2009 used a metal oxide reactor (MOR) to generate HTW. Since a MOR is consumed, it has to be disposed of as radioactive waste. Alternatively, as a viable – waste free – solution for a long term experimental program, the use of a micro-channel catalytic reactor (µCCR) is the next objective (fig. 3c). The molecular sieve bed (MSB) shown downstream of PERMCAT is used for the (interim) storage of the water after detritiation. It can be reinstalled upstream (fig. 3b) for a further detritiation pass, by heating thus desorbing the water previously stored.

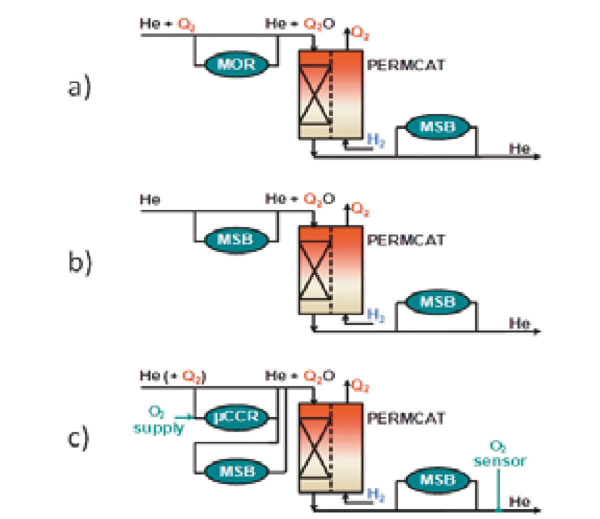


Fig. 3: 3 Staged approach for HTW processing with PERMCAT in CAPER (MOR: metal oxide reactor; MSB: molecular sieve bed; µCCR: micro-channel catalytic reactor).

In this context, R&D work in 2011 focused on the characterization of the molecular sieves (adsorption / regeneration) and the inactive commissioning of the micro reactor produced by the Institute of micro-process Engineering (IMVT) campus north. Fig. 4 shows an example of a MSB regeneration in CAPER. The tritium recovery with PERMCAT (green line) shows that release rate can be controlled with the temperature.

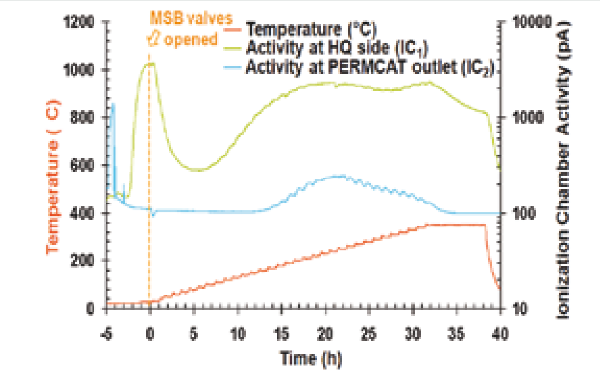


Fig. 4: Desorption over 2 days of a MSB in CAPER with online monitoring of tritium levels.

Highlight in 2011: membrane and catalytic membrane reactor for tritium processes in the breeder blanket

Beyond ITER, the future fusion reactors using a mixture of deuterium (D) and tritium (T) as fuel will have to generate their own tritium inside the machine. This tritium self-sufficiency will be managed within the so called breeder blanket. The reaction of the neutrons arising from the D-T fusion and lithium-based materials placed in the walls surrounding the plasma shall produce the required amount of tritium. The tritium produced in the blanket will have to be then extracted and recovered as fast and as completely as possible to be afterwards injected in the plasma to maintain the fusion process. The tritium will be flushed out of the blanket with a purge gas (e.g. helium).

In DEMO, the next machine after ITER, the processes used to recover the tritium from the breeder blanket will already have to be very efficient, i.e. fast, reliable, economic and minimizing tritium inventory. In this sense, the concepts retained so far for the ITER Test Blanket Modules (TBM) do not appear really satisfactory. Indeed, the tritium management in TBM foresees the use of different "traps" to extract the tritium from the purge gas, using Molecular Sieve Bed (MSB) and metal Getter Bed (GB) for tritiated water and molecular tritium, respectively. This implies unnecessary tritium inventory immobilization, the need to operate the components discontinuously with adsorption/regeneration cycles (temperature change). Moreover, the need of purge gas during the beds regeneration will unavoidably dilute the tritium, which makes more difficult its further use. Last but not least, the huge gap in term of tritium amounts and purge gas throughputs in ITER and DEMO – more than 3 orders of magnitude higher in DEMO – has motivated the R&D on alternative concepts using more advanced technology.

A combination of membranes and catalytic membrane reactor "PERMCAT" (see Fig. 5) is the concept that is currently investigated at TLK: Such combination would exhibit many important advantages, mainly constant temperatures and pressures, fully continuous processing and minimal tritium inventory. The PERMCAT process, successfully used for more than 15 years at TLK can extract in a single step tritium from different chemical forms as it is the case in the blanket. The tritium is efficiently recovered because it is directly in its pure molecular form (such as T_2, DT or HT) that is easily reusable in the inner fuel cycle of the reactor. However, since the tritium concentration of in the purge gas is typically very low (some parts per million, ppm), it appears mandatory to engage a two stage process to relax the PERMCAT requirements and optimise the whole process. Thus, a pre-separation and pre-concentration step using membranes is being intensively studied in collaboration with Professor Kind, head of the Institute for Thermal Process Engineering at KIT campus south.

First of all, about two years ago, potential membrane material candidates have been evaluated. As outcome, it has been acknowledged that zeolite membranes, even at an earlier stage of development, appear very promising. Indeed, such materials are intrinsically tritium compatible (not the case for polymeric membranes), and zeolite membranes could pre-concentrate in a single step both the molecular and oxide form of tritium (not the case for metallic membranes). Moreover, many different zeolite membrane exist and can be in principle customised (pore size, chemical affinity) so that particularly adapted membranes could

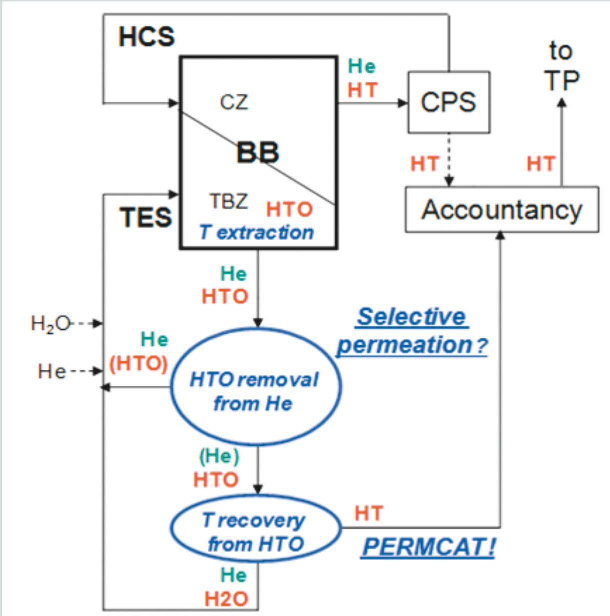


Fig. 5: A combination of membrane and catalytic membrane reactor for tritium extraction from solid breeder blanket (BB: breeder blanket, TES: tritium extraction system, HCS: Helium cooling system, CPS: coolant purification system, TP: tritium plant).

be developed for this application. Afterwards, an experimental rig has been built to investigate the properties (permeability, selectivity) of different membranes candidates. This work is being carried out in the framework of one PhD and several master studies.

The ongoing R&D work to develop the PERMCAT process and consolidate the new approach with zeolite membranes is presented in the following paragraphs.

Research and Development with PERMCAT

Two parallel experimental programs are being pursued on PERMCAT. On the one hand, at a rather small scale but with tritium, experiments are ongoing in the CAPER facility that comprises a PERMCAT reactor as the 3rd (last) tritium recovery stage. These experiments are presently closely related with the experimental programme on highly tritiated water (see main text). The objective here is to gather experience in handling and processing highly tritiated water with PERMCAT, so as to transpose it later to the tritium extraction system in the blanket. On the other end hand, the latest PERMCAT reactors totally produced in collaboration with the KIT campus north main workshop are semi-technical units, i.e. significantly bigger size and processing capability. Recent inactive experiments (preliminary experiments without tritium) have highlighted an optimal geometry of the reactor that has been retained and implemented in the latest PERMCAT made of a cascade of 2 units (see Fig. 6). This reactor, the biggest produced so far, can process higher throughputs with well improved performances in terms of detritiation factor. It has been successfully commissioned and will be thoroughly characterized in a large range parametric study.

The experimental investigation and PERMCAT reactors design are supported by model and numerical calculations performed by Professor Munakata from the Akita University in Japan. The main recent improvement consisted in upgrading the original 1D model by implementing the

Fig. 6: Latest PERMCAT reactor with 2 units each comprising 13 Pd/Ag membranes enclosed in a common catalyst bed.

radial phenomena and end up with a 2D simulation code. Such evolution is necessary in order to optimise and adapt the design of future Permcat reactors to particular applications, i.e. depending on the tritiated stream to be processed.

F&E with zeolite membranes

Permeability and selectivity data are essential to design a pre-concentration stage for tritium extraction in the blanket with zeolite membrane. However, such data very scarce for the gas mixture encountered in the blanket, i.e. helium with traces of molecular and oxidised tritium. A dedicated facility has been constructed to carry out a vast experimental program where fundamental properties of different zeolite membrane will be measured.

The first zeolite membrane tested at TLK is a nanocomposite MFI membrane provided by Ircelyon, (Lyon University) France (see Fig. 7). It has been produced via a rather advanced method called "pore-plugging". This consists in filling the pores of a hollow fibre asymmetric support. (α-alumina, length 150 mm, o.d.: 1.65 mm, i.d.: 1.44 mm) with a zeolite solution that is afterwards crystallised. This

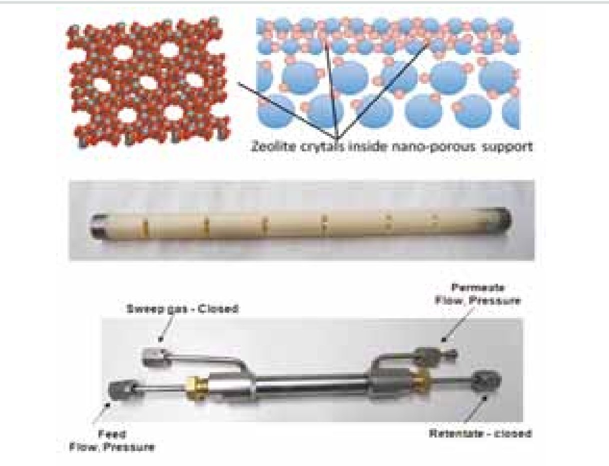


Fig. 7: MFI zeolite crystal incorporated inside a porous substrate (top), hollow fibre membrane inside the membrane holder (middle), and membrane module configuration to perform permeation tests in "dead-end mode" (bottom).

technique allows obtaining a very thin (<1 μm), defect free, and mechanically stable selective layer that should exhibit both high permeability and selectivity.

The first experimental campaign has been performed with single gases, i.e. helium or hydrogen. A simple, reliable, and accurate method called "dead-end mode" has been used to measure the membrane permeability for each gas under different experimental conditions, varying temperature and pressures. The results on Fig. 8 show that the permeation rate decreases when increasing the temperature. Around room temperature, the permeability of hydrogen is about twice the one measured with helium. Such transport has been calculated using a model based on "activated gas translation diffusion". A rather good agreement can be found between experiments and calculations.

These first results are encouraging and allow pursuing this new R&D activity. The next measurements will be performed using hydrogen-helium mixtures, i.e. under relevant conditions for the blanket. Other membrane types will also have to be characterised to find out the most promising zeolite membrane to be used for the blanket.

In parallel to the experimental program a numerical tool has been developed to simulate a multi-stage permeation process. This should help to design and optimise the multi stage process, in particular to define the number of stages, operating pressures and temperatures, membrane surfaces, with regards to the tritium management, i.e. separation and enrichment factors. Such tool shall enable the design of the technical equipment to be operated in the tritium extraction system of DEMO.

Tritium accountancy for ITER test blanket modules

The validation of neutronics predictions for the amount of tritium produced in the TBMs is a high level objective for the ITER experimental programme. A robust and accurate procedure to account for this bred tritium needs to be implemented on the top of the tritium processes.
A first brainstorming exercise has been done, comparing and evaluating the different analytical methods and accountancy strategies (static, dynamic, chemical conversion,…) with regards to the ITER requirements. Finally, a dynamic tritium accountancy method using ionization chambers for real-time tritium measurements should be adopted. Such approach should enable an absolute accuracy of 5% which is satisfactory for ITER. The experimental demonstration of this approach is however still pending.

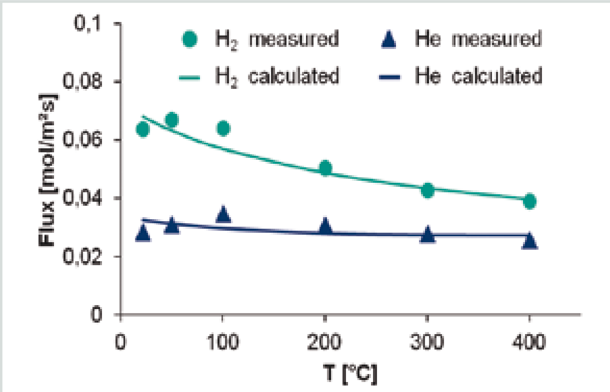


Fig. 8: Single gas experiments on MFI membrane and calculated flows (from geometry, experimental conditions, and literature data).

"Installation of the heating oven for the new coating facility".

Results from the Research Areas

Vacuum Technology

Head: Dr. Christian Day

The development of vacuum systems for nuclear fusion is still the clear focus within the activities of the vacuum technology research area.

The concept of cryogenic pumping based on cryosorption at activated charcoal has been successfully demonstrated at KIT as feasible technology for nuclear fusion, and is now the common technology used for all primary vacuum pumping systems at ITER. As these cryopumps are part of the European procurement package for ITER, KIT has been charged with the elaboration of the complete build-to-print package of the torus and cryostat cryopumps and the neutral beam (NB) cryopumps. These pump designs are unique and will have to be validated by a 1:1 scale prototype. After manufacturing in the European industry, the prototype of the torus and cryostat cryopump (the so-called pre-production cryopump) will be tested in the TIMO-2 facility at KIT, whereas the NB prototype pump will be manufactured and tested in the neutral beam test facility MITICA which is under construction at Consorzio RFX, Padova, Italy.

In 2011, the majority of the work was spent to elaborate the detailed design of the cryopumps for the ITER torus exhaust and neutral beam injection system. This work is being done for Fusion for Energy (F4E), the European Union´s Joint Undertaking for ITER and the Development of Fusion Energy.

In parallel to that, first actions could be started under the new European Power Plant Physics and Technology Programme, aiming to set up a conceptual design for a demonstration power plant (DEMO) until 2020.

In mid-term perspective of the vacuum technology research area, the DEMO related activities will take over from the ITER activities. This will not only comprise the DEMO vacuum system design but also an in-depth modelling of the complete fusion fuel cycle of DEMO.

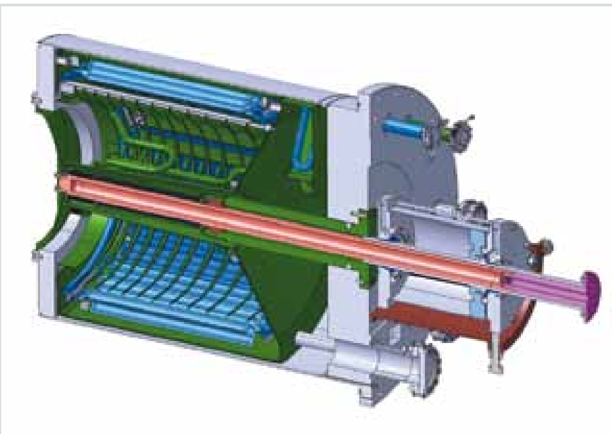


Fig. 1: Finalised detailed design of the ITER torus cryopump prototype.

ITER Torus Cryopumps

In the development programme of the ITER torus cryopump system, a prototype cryopump is to be built and tested thoroughly in the TIMO-2 facility at the Institute. The prototype is to be built in such a way that it can be used later as a replacement cryopump in ITER. As a consequence, all regulations and design criteria for nuclear components must be met. In particular, the design process must be documented in a detailed catalog of accompanying calculations: strength calculations; thermomechanical and hydraulic calculations; seismic events, etc.

In 2011, lots of extra simulations had to be run in order to help ITER to demonstrate to the French regulator compliance with all design guidelines (especially EN13445). Moreover, accident scenarios and safety events were investigated (loss-of-vacuum) and the corresponding heat loads to the cryogenic circuits were estimated. Thus, safety devices could be properly sized and located. The team also had to integrate all changes made to the ITER requirements during the ongoing design progress.

Figure 1 presents the final design of the pump. The picture shows the main assemblies: the inlet valve, the thermal shields (green), and the cryopanels (light blue). The pump has a cylindrical shape, is 2054 mm long and has a diameter of 1776 mm. The thermal shield system is cooled by cold helium at 80 K; the cryopanel system coated with activated carbon is cooled in operation to

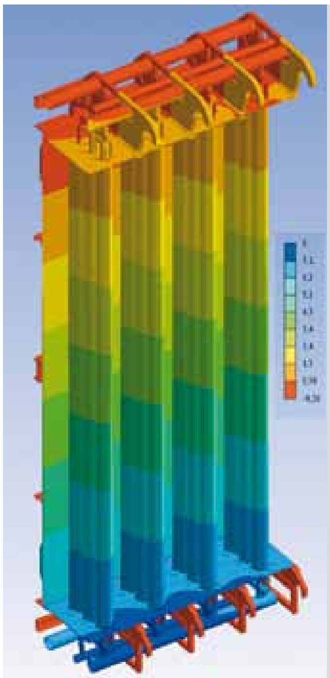


Fig. 2: One module of the NBI cryopump. Shown are thermal expansions in the vertical direction during the nominal 4K/80K operation.

4.5 K by means of supercritical helium. The cryopanel system constitutes a pumping surface of more than 11 m², which allows pumping speeds of the order of 75 m³/s to be achieved. Besides the central 3D CATIA product, the final package contained a number of 230 2D manufacturing drawings and about 1400 weld descriptions.

The design was approved from F4E and ITER and will be given to the manufacturer. Once the prototype pump is manufactured, it will be installed and tested in the TIMO-2 test facility in order to demonstrate the validity of the pump design before issuing the order to build the series pumps (6 for the torus vessel, 2 for the cryostat vessel). F4E is currently preparing the call for tender to manufacture the pump and delivery to KIT is expected for end 2013.

ITER NBI Cryopumps

The vacuum technology area is also charged to develop the detailed design of the cryopumps for the neutral beam injection (NBI) systems of ITER and for the MITICA test bed.

The detailed design development of the NBI/MITICA prototype cryopump made excellent progress in 2011. The design could be further elaborated to the level of great detail already in many areas. The focus of the work in 2011 was given to an impressive catalogue of FEM analyses, see Figure 2. The cryopump is an extremely large component (2.5 m high, 8 m long, subdivided into 8 similar modules), which means large thermal effects during cold operation.

In 2011, a re-design of the cryopanels of the 4.5 K circuit had to be accomplished. To ensure that the temperatures along the cryopanel fins stay acceptably low also in areas that are exposed to the very high electron heat loads originating from the ion source, the fins will now be copper plated which ensures improved thermal con-

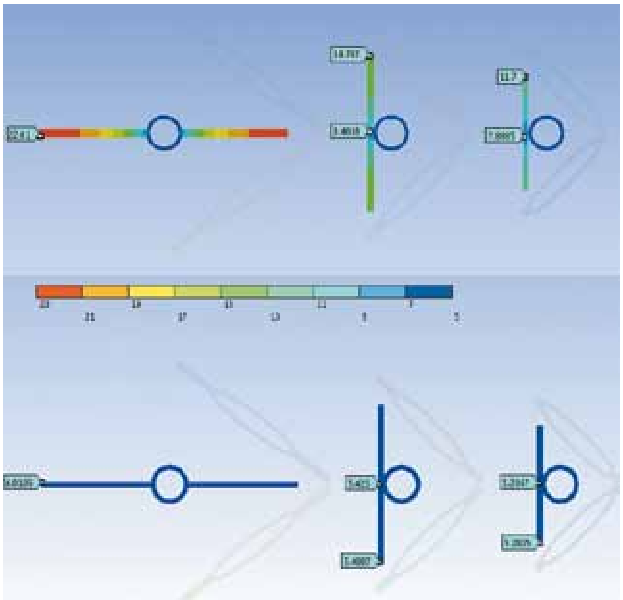


Fig. 3: Simulations of the temperature profiles (in K) at the fins of the NBI cryopanels. The top figure shows the case with stainless steel, the bottom figure the case with an additional copper coating (0.5 mm thick).

Fig. 4: The new coating facility is getting shape.

ductivity. Figure 3 illustrates the improvements of the new design: The maximum temperatures could be reduced from 20 K down to below 7 K.

The detailed design of the NBI cryopumps will be finalized next year and the call for tender to manufacture the first pump as prototype is expected to be launched early 2013.

In a parallel activity, KIT was supporting the Consorzio RFX team with specific know-how on the cryoplant concept design, based on the many years of experimental cryopump characterisation and TIMO operation. Until the end of 2011, a first draft of a Technical Specification for the cryoplant to operate the HNB cryopump could be elaborated.

Charcoal Coating

The various cryopanels of the torus and NBI cryopumps (first the prototypes, then the serial ones) will be coated with activated charcoal according to a validated procedure which has been developed at the Institute over the last decade. The charcoal acts as a cryogenic sorbent so that also light gases (hydrogen, helium), which do not condense at the available 4.5 K, can be pumped at high speeds.

In preparation of this large work package (more than 1000 surfaces to be coated altogether), a new coating facility was constructed and set up to a large extent in 2011, see Figure 4. It is a semi-automatic facility which ensures a good repeatability of the coating process. The general concept behind was previously demonstrated on the level of a smaller facility.

Vacuum systems for DEMO

2011 was also characterised by the start of the new European Fusion programme (EFDA) Power Plant Physics and Technology activity, which aims to develop a concept for a 2 GW(el) fusion power plant based on long pulse (several hours) operation. In a first step, all technology systems of ITER were assessed in terms of their maturity and technology readiness in view of DEMO, in order to identify the areas which can extrapolate from ITER and the others for which there is a technology gap.

The vacuum technology area was charged to conduct a study of potential improvements and simplifications of the ITER inner fuel cycle in view of different power

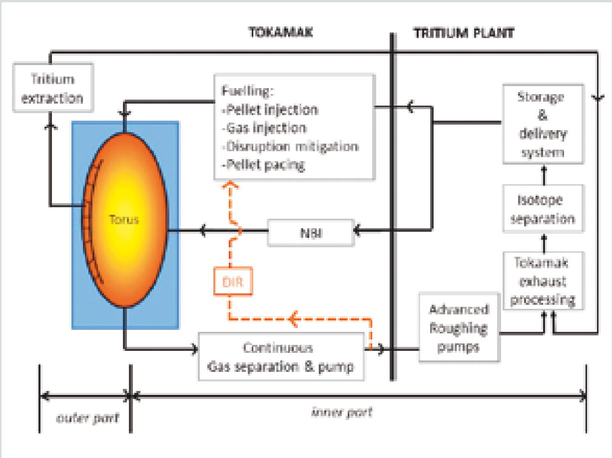


Fig. 5: The concept of Direct Internal Recycling to simplify the DEMO fuel cycle.

Fig. 7: Kick-off meeting of the VACU-TEC Training Programme.

plant concepts with different requirements. As main outcome, the concept of Direct Internal Recycling (DIR) was developed, see Figure 5, which introduces a short-cut for the torus exhaust gas around the tritium plant in order to reduce the tritium inventories, to improve the balance of plant, and to allow for shortest processing times. Within the new EFDA framework, a detailed assessment of potential vacuum system solutions for a fusion power plant was launched. It was clearly found that the ITER solutions are very specific and a simple extrapolation to the larger scale of a fusion power plant is not considered to be attractive. The main result of this study was a clear definition of the characteristics a vacuum system for a power plant must have, namely being continuous, non-cryogenic, and providing a separation between hydrogenic species and helium close to the divertor. KIT has developed a concept design of a candidate pumping system that fulfils these requirements and first proof-of-principle tests are planned for 2012.

Fig. 6: The THESEUS facility testing a mercury diffusion pump.

Based on these considerations, a first theoretical concept for the DEMO vacuum systems was developed in 2011. It comprises three stages. Separation will be provided by metal foils, which are permeable for hydrogen but not for helium, and, thus, can also provide a certain gas compression. For high vacuum pumping a diffusion pump is foreseen with liquid metal as operating fluid, to make it tritium-compatible. Finally, rough pumping is provided by a liquid ring pump, which is also operated with a liquid metal. It is intended to validate this concept in the nextg years by proof of principle testing of the various pump types. For this purpose, a dedicated facility is being set up, the THESEUS facility, see Fig. 6. Initial funding for starting hardware work was given from the Helmholtz KIT start-up initiative.

Networks

The European Goal Oriented Training Programme VACU-TEC for educating young researchers in the area of vacuum technology in nuclear fusion was kicked-off in late 2011 at KIT, see Fig. 7. The network includes 5 trainees and five Associations (KIT, CEA France, UTH Greece, IPP Germany, CRPP Switzerland). Kit is co-ordinating the network and providing the work packages in the area of vacuum pump design and instrumentation.

Triggered by VACU-TEC, a new research activity in characterisation of vacuum outgassing of materials was started. For this purpose, a new facility will be set up to measure outgassing rates at high resolution and to characterise highly sensitive instruments for total and partial vacuum pressure measurement. These activities are performed under the umbrella of the European Metrology Research Programme.

Fig. 8: IUVSTA, the International Union of the national vacuum societies, was financially supporting the workshop.

Highlight:
Workshop of the vacuum gas dynamics

The scientific and social highlight in 2011 was the successful organisation of an international workshop in the area of vacuum gas dynamics, held in May in Leinsweiler, with 60 participants from 19 countries from all over the world. This indicates the leading and visible role of the Institute in this field.

This workshop was organised in view of the impressive progress that was made in the last years in the area of flow modelling in a wide range of Kn number. This topic plays a key role in current vacuum science and technology and also has broad implications for industry applications. For the first time, representatives of academia, engineering science and industry were brought together in an environment which allowed for perfect interaction and exchange. Among them were the world-leading scientists in their area. Many new contacts have been made which will definitely be helpful to initiate new collaborations in the next future.

The event was structured in 9 sessions, covering hot topics from large R&D projects (accelerators, fusion devices, fundamental research), experimental and numerical investigations and industrial vacuum process optimisation. All contributions and related documentation is available under: http://www.itep.kit.edu/VGD-2011

One of the immediate outcomes was the initiative to set up a school on the subject of vacuum gas dynamics. Moreover, as common goal for the coming years, it was agreed to work on a flow simulation toolbox, usable by non-expert engineers in support of everyday design work. The importance to simulate transient flow phenomena was clearly highlighted, as a result of which first activities have been launched in this direction. This will be integrated in the upcoming EFDA ITER Physics Programme.

High pressure He purifier.

Results from the Research Areas

Cryogenics

Head: Dr. Holger Neumann

Cryogenics for FUSION

The cryogenic topics in 2011within the program FUSION are concentrated on the manufactoring and testing of the HTSL-current leads for the fusion experiment Wendelstein 7-X (W7-X) in Greifswald and the construction of components for the current lead test facility Karlsruhe (CuLTKa) (see fig. 1-3). During the test of the test facility a leackage could be detected only one time. Below 20 K this leackage couldn't be detected once more. Also a hydraulic pressure test with 18 bar at 300 K couldn't detect a leackage.

Test of the W7-X HTSL-current leads

The tests of the HTSL-current leads for W7-X within the TOSKA facility were performed on schedule. By the end of 2011 the current leads number 5 and 6 of 14 were tested. By the end of 2013 the last current leads should be tested in TOSKA.

CuLTKa

The designed components for CuLTKa (valve boxes, control cryostat, transfer lines, etc.) were implemented in the layout-plan (fig. 1) which is now finalized as far as possible. Furthermore some essential components could be manufactured and installed this year:

- control cabinets with pressure transducers are mounted and installed on the CuLTKa-platform
- a new water bath heat exchanger was designed, procured and installed
- the valve box with radiation shield and valves was manufactured and installed
- the infrastructure for vacuum and He-exhaust are installed
- the support structure for the cryogenic transfer lines are installed
- the cryogenic transfer lines are designed and can be announced in 2012
- the manufacturing of the LN_2 radiation shield by an American company has started

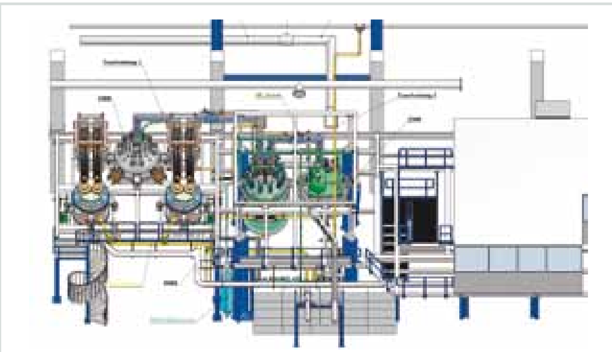


Fig. 1: CuLTKa-layout-plan.

So also the works on CuLTKa are on schedule and the current leads for JT60 can be tested in this facility according to the planning.

Cryogenics for REUN

Within the "Efficient Energy Conversion and Use (REUN)" program the following topics were covered:

LIQHYSMES

The increasing contributions of variable renewable energy sources like wind and solar energy require additional measures for the balance of supply and load fluctuations. The storage of liquid hydrogen as energy carrier could be one forward-looking method. But the combination of electrolysis and fuel cell or gas turbines is only suitable for long-term buffering of fluctuations. Because of the inertia of these components high short-

Fig. 2: top view of the valve box.

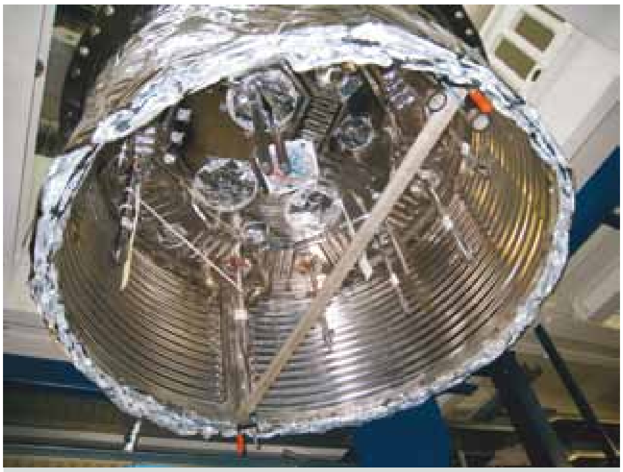


Fig. 3: valve box with LN_2 radiation shield.

Fig. 4: LIQHYSMES-concept.

term fluctuations cannot be buffered. A new concept was proposed which adds superconductive magnetic energy storage (SMES) as a short term storage system to this long-term storage system with liquid hydrogen, electrolysis and fuel cell. One advantage consists in the fact that the superconductive magnet is working at 20 K, the temperature of liquid hydrogen at nearly 1 bar. The SMES is characterized by low losses during load and discharge cycles.

In 2011 calculation methods were developed to calculate the losses during load and discharge cycles for the estimation of the dynamic behavior of such a SMES.

Design and construction of such a LIQHYSMES should be realized with a funded project. For this an EU-proposal with eight partners are provided. Furthermore an BMBF-proposal was provided for basic experiments and studies. Finally this project is implemented within the approved hydrogen initiative EWI of the KIT.

Basics HTS-generator
In February 2011 the BMWi-funded cooperation project (Siemens/KIT) "Basics for a HTS-generator" has started. The project aim is to set essential stages for the use of HTS-technology for electrical generators. For this a rotating test rig with a HTS-coil should be constructed which will be cooled with a Neon driven thermo-syphon at 30 K.

A first insulation concept was developed. For the measurement of the local Neon temperature and the mass flow, FGB glass fiber sensors seem to be suitable. A rotating feed through was tested successfully.

A spin-bunker is foreseen for the protection of the environment.

Cryogenic flow channel
For the calibration of a new developed FBG-mass flow sensor a cryogenic flow channel was designed, constructed (Fig. 5) and commissioned. The cryogenic supply can be performed with LHe- and LN_2-vessels. At room temperature compressed gas cylinders can be used. The temperature can be regulated with an implemented electrical heater. So nearly each temperature between 300 K and 4.2 K can be adjusted. Flow elements take care for a hydrodynamic and thermal fully developed flow for the calibration of the new mass flow sensor.

Installed laminar flow meters can be used as references which are also used at the thermal insulation test facility THISTA. So the cryogenic flow channel is directly connected to THISTA.

Thermal investigations of bulk goods at non developable surfaces
An optimal thermal performance of multi-layer insulation (MLI) can be achieved at developable surfaces like a cylinder surface. But such surfaces are not representative because the thermal performance of MLI is often degraded e.g. by cut-off points at tee-piece connectors or by spherical surfaces. Such cut-off points or spherical surfaces require a tailored MLI.

So cut-off points cannot be avoided. One alternative is the use of bulk goods like microspheres. The heat conductivity of the material is not influenced by the geometry.

Experiments are performed at a cylinder with tee-piece connectors. These experiments were compared with experiments at a smooth cylinder which has the same surface area. Numerical simulations using ANSYS were performed for evaluation and to get a better understanding of the measurement results (Fig. 6).

Upgrade of the calibration laboratory for temperature sensors
Because of the increasing breakdown of out of date equipment in the calibration laboratory which was strongly needed, some components (measuring, control and automation technique) were replaced by state of the art equipment. After a detailed layout planning phase the first components are ordered this year. In 2012 the remaining components should be ordered. Also programming and documentation should be finalized in 2012. A detailed documentation is needed for the incorporation of new staffs and as a fundament for accreditation.

Cryo-infrastructure
Works to be done in the cryo-infrastructure are extensive maintenance, repair and service works. Furthermore the infrastructure was expanded and adapted

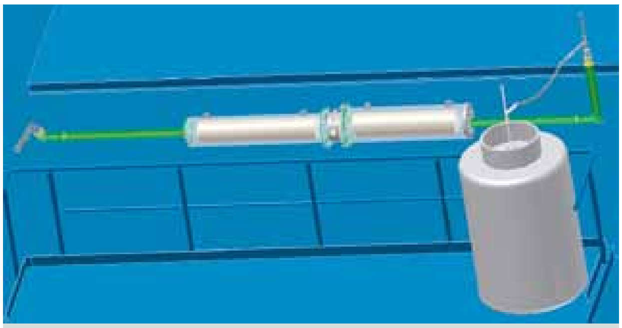


Fig. 5: cryogenic flow channel.

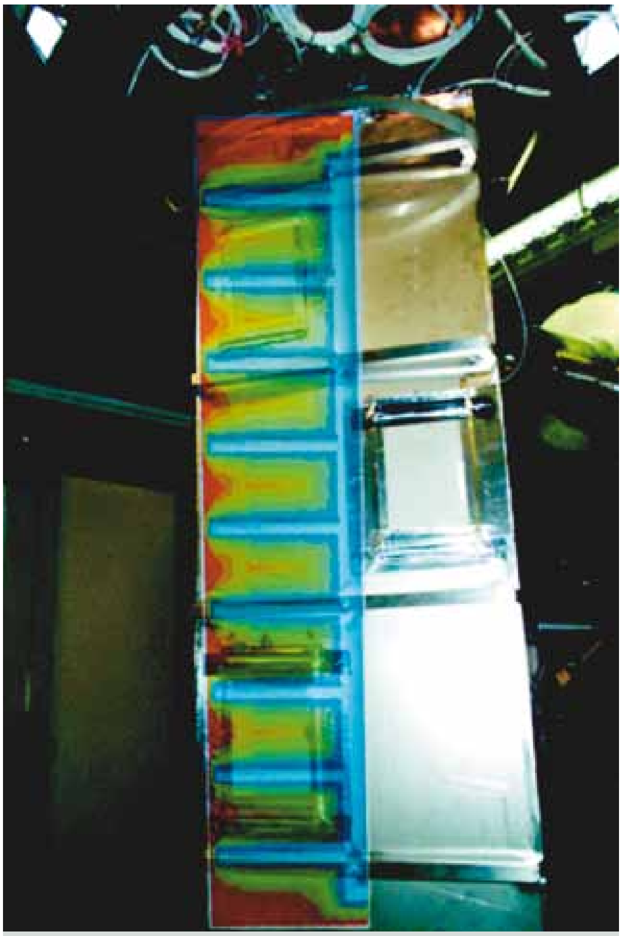


Fig.6: Vessel with insulating bulk goods around a LN_2 filled cylinder with tee-piece connectors; numerical simulation results for the temperature distribution are also shown.

Fig.7: change of the oil filter at the oil-sealed screw compressor of the 2 kW-refrigerator.

for new experiments. Also new devices are commissioned. So this works includes e.g.:

- modification of the AS1, AS2 and AS3 of Siemens teleperm AS235 to AS488
- Change and implementation of new vacuum gauges
- amplification of the control system to enable a fully automatically cool-down and warm-up mode for TOSKA and the test of the HTS-current leads
- implementation of new modules for the control of valves and motors
- modification or modernization respectively of the local lubrication unit of the turbines of the 300 W refrigerator
- reconstruction of the voltage supply of the process control for the network infrastructure
- change of anti-vibration devices of the He-compressors of the He-recovery system
- reconstruction and change of the piping for safety valves

At the time of writing, the 300 W (1.8K) refrigerator had been in operation for 912 hours. Of that time, 263 hours were spent on liquefaction, 55 hours on purging as well as cool-down and warm-up of the refrigerator, which leaves 594 hours of pure refrigeration time for experiments in the high-field magnet laboratory.

The 2 kW (4.5K) refrigerator had been in operation for approx. 1855 hours. Of that time, 422 hours were for liquefaction, 210 hours for purging and cool-down and warm-up of the refrigerator. In this way, 1223 hours were devoted to pure refrigeration time for FUSION. On the whole, the facilities liquefied some 169,833 liters of helium, with 109,005 liters for experiments in ITEP, and 60,828 liters for other institutes.

The 500 W (4.5K) refrigerator had been in operation for the KATRIN experiment for 6459 hours. Of that time, 41 hours were spent on purging, cool-down and warm-up of the refrigerator. In this way, 2479 hours were devoted to the operation of the DPS2-F and 3973 hours to the operation of the “demonstrator”. No noteworthy failures could be observed. This results in the conclusion that this refrigerator is suitable for long-term use.

Demonstrator Tests at TLK.

Results from the Research Areas

KATRIN, Karlsruhe Tritium Neutrino Experiment

Head: Dr. Beate Bornschein

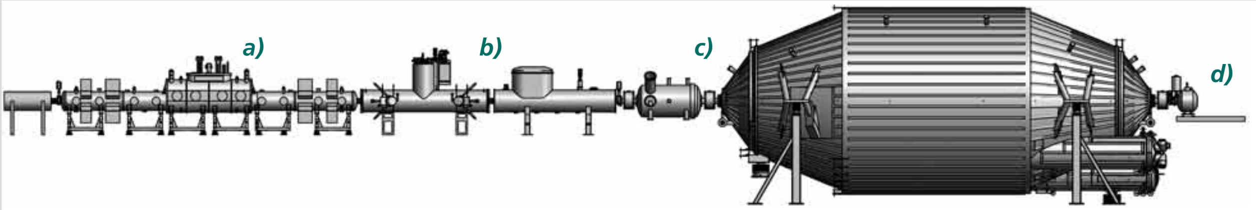


Fig. 1: Schematic diagram showing the KATRIN international large scale experiment. The electrons produced in β-decays in a high-intensity windowless molecular tritium source (WGTS, (a)) are passed through a tritium pumping section with the active and passive elements of DPS2-F and CPS (b) to a system (c) consisting of two electrostatic spectrometers (roughing and main spectrometers). All electrons which have passed the spectrometer are counted in a solid-state detector (d).

KATRIN, the Karlsruhe Tritium Neutrino Experiment, is to be used for a model-independent measurement of the neutrino mass with a sensitivity of 200 meV/c^2. The reason for building KATRIN is evident from the key role of neutrinos in astro particle physics: On one hand, neutrinos with a mass play a specific role as hot dark matter in the evolution of large structures in the universe. On the other hand, neutrino mass has a key function in the unsolved problem of the origins of mass.

The experimental principle of KATRIN is based on precise measurement of the spectrum of electrons from the ß-decay of molecular tritium close to the kinematic end point of 18.6 keV. For this purpose, electrons from a windowless high-intensity source of tritium gas are led adiabatically through strong magnetic fields of superconducting magnets through the 70 m long experimental facility. A system of two electrostatic retarding spectrometers allows the electron energies to be determined with a resolution of 0.93 eV (Fig. 1).

A worldwide collaboration of more than 150 scientists, engineers, and technicians under the leadership of KIT is currently in the process of building up this key experiment in astro particle physics at and in the Karlsruhe Tritium Laboratory (TLK). The first data are expected to come forth in 2014. The design, construction, and successful execution of the KATRIN experiment impose very strict requirements in terms of process technology, especially tritium process technology, ultrahigh vacuum and cryo technologies, and high-voltage stabilization technology. Additional requirements are a functioning project management in order to harmonize the allocation of resources (financial and manpower) with the objectives of KATRIN in terms of time and content.

Within the framework of the KATRIN experiment, ITEP is responsible for tritium process technology and for magnet and cryo technologies. More than 95% of ITEP's scope of work in the KATRIN project lies in the so-called source and transport system shown as a block diagram in Fig. 2, which is being built up completely within TLK because of the need to handle tritium.

The main component is a 16 m long superconducting magnet system called WGTS (see Fig. 2), which contains the tritium source in its cold beam tube at 30 K. In addition, the so-called calibration and monitoring system (CMS-R) is situated in the rear part, the transport system in the front part of the beam axis (in the direction of the spectrometer). The transport system has the function of conducting the tritium decay electrons into the spectrometer and, at the same time, reducing by pumps the tritium gas flow into the spectrometer system by more than 12 orders of magnitude. This is done, on the one hand, by means of the differential pumping section (DPS2-F) and, on the other hand – as the last stage – by a cryo pumping section (CPS) operated at 3.5 to 4 K. Both DPS2-F and CPS are superconducting magnet systems with a length of 7 and 9 m, respectively. Like WGTS, they are, or were, manufactured by external companies, with ITEP supervising fabrication.

Also shown in Fig. 2 are the tritium loops (inner loop, outer loop) ensuring controlled tritium gas feeding and keeping tritium purity at levels above 95%. Simultaneous feeding and removal of the tritium gas by pumps finally produces a steady-state gas column density in the beam tube of WGTS (= tritium source).

The following paragraphs will outline the status of these activities.

WGTS and Demonstrator

The contractual situation at WGTS has changed again in fall 2011. Until summer WGTS was built by RI, while the magnets were made by BASC, both activities on behalf of VARIAN. VARIAN acquired the original contract when taking over the ACCEL Company and then commissioned the RI and BASC companies, parts of former ACCEL, to do the construction work. In fall the contract was terminated mutually. Questions concerning intel-

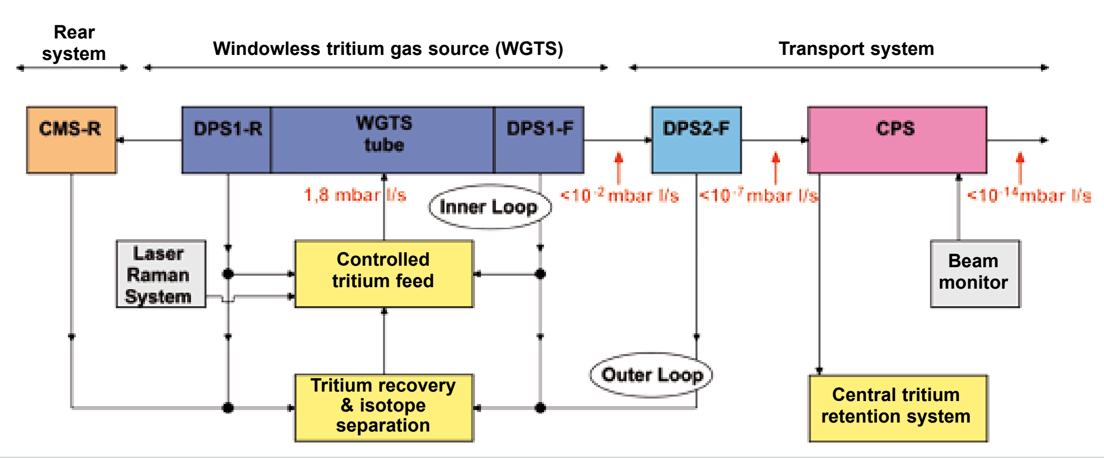


Fig. 2: Diagram of the KATRIN tritium source and its interfaces with the infrastructure of the TLK.

lectual property rights have been solved. The further assembly of WGTS is now being carried out under responsibility of KIT.

Technical supervision of the design and manufacturing phases with the industrial partners implies great expense on the part of ITEP: On the one hand, the WGTS design is very complex, and cooling requirements are extremely high (30 K stabilized to 0.1 %). On the other hand, WGTS later will have a tritium throughput of 1.5 x 10^{16} Bq per day (40 g) and, as a system carrying tritium, will have to meet high quality standards. Because of the extremely sophisticated cooling concept for the source tube, a preliminary version of WGTS was built first, a so-called demonstrator, which does not yet contain the magnets and the central helium tank. The demonstrator has been tested intensively this year (see highlight). The manufacturing as well as manufacturing control of the other WGTS subsystems (seven superconducting magnet modules, the helium tank, subassemblies for DPS1-F) continued in parallel. For next year magnet tests of the individual modules are foreseen in Saclay, France. Depending on the success of these tests the assembly of the actual WGTS will start.

DPS2-F

After extensive tests, DPS2-F was finally accepted in March 2011. In collaboration with the Institute for Nuclear Physics and the Institute of Experimental Nuclear Physics (IEKP) the scientific program was launched, whose first mission were the gas-flow reduction factor measurements. The aim of these measurements was to prove, whether the calculated gas flow reduction factor can actually be reached. After manufacturing and setting up the piping and vacuum system (see fig. 3) as well as the gas-injection and detection system the first measurements were performed at room temperature by April. Afterwards DPS2-F was cooled down (ca. 3-4 weeks), so in June the actual gas flow reduction measurements at a beam tube temperature of about 80 K were performed. The measurement results showed good agreement with the results from simulations for the beam tube geometry and the turbo molecular pumping units (see fig. 4).

The second part of the scientific program, the measurement of the electromagnetic properties of DPS2-F could not be performed this year, since DPS2-F quenched during ramping up the magnetic fields. At this instance one of the magnet coils protection diodes was destroyed. At the moment a repair concept is in preparation which includes the exchange of all protection diodes by a different type as well as the implementation of an access possibility from the outside to the diodes. The repair is foreseen for next year.

CPS

CPS is being built by ASG, Genova. The fabrication is accompanied by an inter-institute project team representing KATRIN. In 2011, the focus of quality assurance work was the inspection of the gold coating of the seven beam tube sections. The gold coating of the beam tube's inner surface is required to minimize the number of neutral tritium molecules sitting on the beam tube wall after regeneration (= purging with warm helium gas). The quality of the gold coating of the individual

Fig. 3: DPS2-F. View of the Pumping chambers 2 and 3.

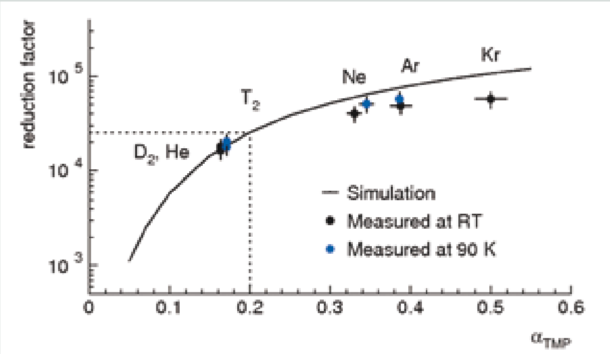


Fig. 4: gas flow reduction factor of DPS2-F for various gases. (α_{TMP} capture probability of the turbo molecular pump for the gas being considered).

Fig. 5: Gold coating of beam tube section #3. The three capillaries for argon injection are mounted inside the beam tube.

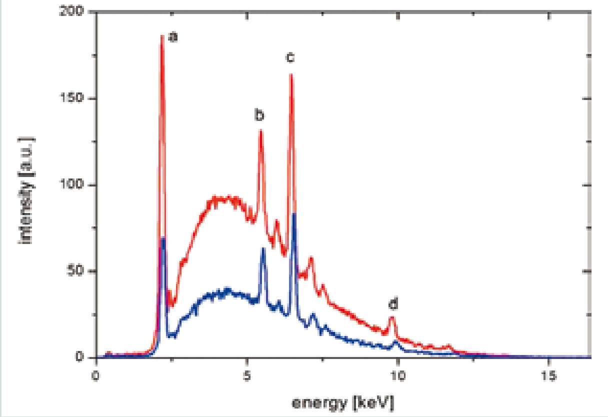


Fig. 6:. Bremsstrahlungsspektrum recorded at TriReX (100 s). The tritium activity in the recipient matched the KATRIN source activity (10^{11} Bq). Red with magnetic field, blue without magnetic field. Characteristic peaks: a) Zr, b) Cr, c) Fe, d) Au.

sections was checked properly according to a KIT approved test procedure with a heating test up to 250°C, respectively 350°C.

The seven control cabinets needed for cryo operation of CPS, viz. to control the more than 420 sensors and valves were specified and called for tender. The ordering for manufacturing will be done until end of the year. The superconducting filling level probes have been designed and manufactured. After failure of one of the protection diodes of one magnet module in DPS2-F in summer 2011 a revision of the magnet protection concept is in discussion.

Cryo facility & Cryo transfer Line

Work in 2011 was focused on operating the demonstrator (see highlight) and the DPS2-F. Cooling down these very complex systems necessitated precise planning and preparation of the work by the cryo group of ITEP, and was handled very successfully. Another major activity in 2011 was planning, tendering, and supervising fabrication of the third part of the cryo transfer line and the third valve box required for cryogenic connection of CPS. Fabrication of the last section to the CPS valve box is close to finish. The factory acceptance test will take place in January 2012. The cryogenic connection lines for CPS have been ordered.

Tritium Loops

The tritium loops of KATRIN are being developed and built in TLK (inter alia within diploma and doctoral theses). In 2011, hardware activities were concentrated on construction of the tritium test experiments, TriTOP and TriIREX. At TriTOP (Tritium Test of Pump) a MAG2800 turbo molecular pump with magnetic bearings is being tested in long term operation with tritium. This is done in operation conditions which correspond to those of the eight turbo molecular pumping units at the first two pumping chambers on WGTS. After operation with tritium for up to now five months no clear signs for damage in tritium operation under KATRIN conditions were observed. The long term test continues. TriREX (Tritium Rear System Experiment) is used to study the possibility of determining the tritium concentration in WGTS by means of the bremsstrahlung generated by the decay electrons in the rear wall of WGTS. The experiment is a first prototype of the KATRIN rear wall. With the first measurements the general feasibility has been demonstrated in addition the influence of magnetic fields on the spectrum has been examined (see Fig. 6).

In the field of Laser Raman Spectroscopy (LARA) several works were pending. One important task is to calibrate LARA for quantitative analysis. For this calibration measurements with mixtures of protium and deuterium were conducted. On the other hand depolarization measurements on the hydrogen isotopologues H_2, HD, D_2, HT, HD and T_2 were performed to determine the polarization properties whose knowledge is indispensable for the quantitative analysis of the LARA spectra. When performing the measurements with the LOOPINO test setup the last year, it was observed that the anti reflective coatings being used until now for Laser windows of LARA are being damaged during long term operation with tritium. In order to find a coating resistive to tritium, the COATEX (Coating test experiment) was built up and commissioned. Various types of optical coatings are being exposed to tritium atmosphere and removed regularly for examination of the surface for changes. The first results approve, that the coatings being used until now are not suitable for application in tritium atmosphere. The measurements will continue until mid of next year to find a suitable type of coating.

Acknowledgements

ITEP scientists addressed activities for KATRIN in an interdisciplinary fashion and conducted them successfully. Besides TLK, naturally the cryo engineering area assumed a major share of the duties. All areas benefitted of a close and fruitful cooperation with students, technicians, engineers, and scientists of ITEP, the Institute of Nuclear Physics (IK), the Institute of Experimental Nuclear Physics (IEKP), the Central Shop (TID-F), and the KIT Project Management group (PMQ). Thanks are due to all of them.

Highlight in 2011: Successful test of WGTS beam tube cooling

The tritium source (Windowless Gaseous Tritium Source, WGTS) at the KATRIN experiment will be operated at a temperature of 30 K. It consists of a 10 m long beam tube of 90 mm inner diameter. In the middle gaseous tritium will be injected and then diffuses to both ends of the tube where it will be pumped of at pumping chambers - each with 4 large turbo molecular pumping units - and then returned in a closed tritium loop to the pressure controlled injection vessel.

One of the most challenging tasks at KATRIN is to provide the cooling of the tritium source with a temperature stability of $\Delta T \leq 30$ mK/h and a temperature homogeneity of $\Delta T \leq 30$ mK (except for the two 25 cm beam tube ends). The beam tube temperature directly influences the conductance and by this immediately the tritium density profile: fluctuations in temperature lead to fluctuations of the source strength. This influence considerably affects the experiments systematic for measuring the neutrino mass with a sensitivity of 0.2 eV/c^2.

To fulfill these extraordinary requirements a novel cooling system was developed at ITEP which is shown in Fig. 7. Two evaporator tubes are brazed over the whole length on both sides of the beam tube, which are filled half with boiling neon. The evaporating neon absorbs the latent heat along the beam tube, without changing the temperature. The neon vapor diffuses (atop of the phase boundary) from the feed to the opposite ends of the evaporator tubes and is then guided back via a common return line to a condenser. The neon is then liquefied in the condenser with the help of gaseous helium. Gravitation forces the neon to stream back to the feed of the evaporator tubes. This principle is also referred to as natural circulation or thermo siphon.

Due to the cooling system's uniqueness an experimental proof was essential before the final assembly of the WGTS. Original parts of the WGTS were used to build a test cryostat, the so called "Demonstrator", including the the 10 m long beam tube, the pumping chambers, the thermal shields and the vacuum vessel. Instead of the superconducting magnets an aluminum cold mass which is cooled by 2 GM-refrigerators was installed for supporting the beam tube. Setting up the demonstrator inside TLK, connection to the KATRIN transfer line and gas supply, installation of the vacuum system and commissioning of the I&C electrical system had already been done in summer and fall 2010.

First cool-down of the Demonstrator

By end of November 2010 the demonstrator was operated for the first time. At first the LN2 shield together with the aluminum cold mass and afterwards the pumping chambers were cooled down for about 3 weeks. By mid of December the beam tube was cooled down with neon to about 28 K, the temperature trend is shown in Fig. 9. This first test was the evidence that the beam tube cooling of WGTS is working properly. By raising the pressure to refill the neon circuit it was proven that stable 2-phase cooling conditions were established over the whole beam tube length inside the evaporator tubes. (See right side in Fig. 9). After several days of stationary operation, the demonstrator measurements were stopped due to the turn of the year 2010/11.

Measurement of the temperature stability

After cooling down the demonstrator again, the first measurements for temperature stabilization were performed in February 2011. Fig. 10 shows the maximal temperature fluctuations over a period of 4 hours. With a standard deviation of only 1.6 mK a temperature stability was reached which exceeds the requested value by a factor of 20. This value corresponds to a relative temperature stability of about 5×10^{-5} related to an operating temperature of 30 K. The KATRIN tritium source is for this reason most probably the most stable cryo technical large scale apparatus ever built. The grey temperature band in Fig. 10 of ±30 mK was not even exceeded in stability measurements over a whole week. The overspending stability of the KATRIN tritium source was reached by using a specially designed condenser which dampens the fluctuations of the helium cryo supply by more than 2 orders of magnitude.

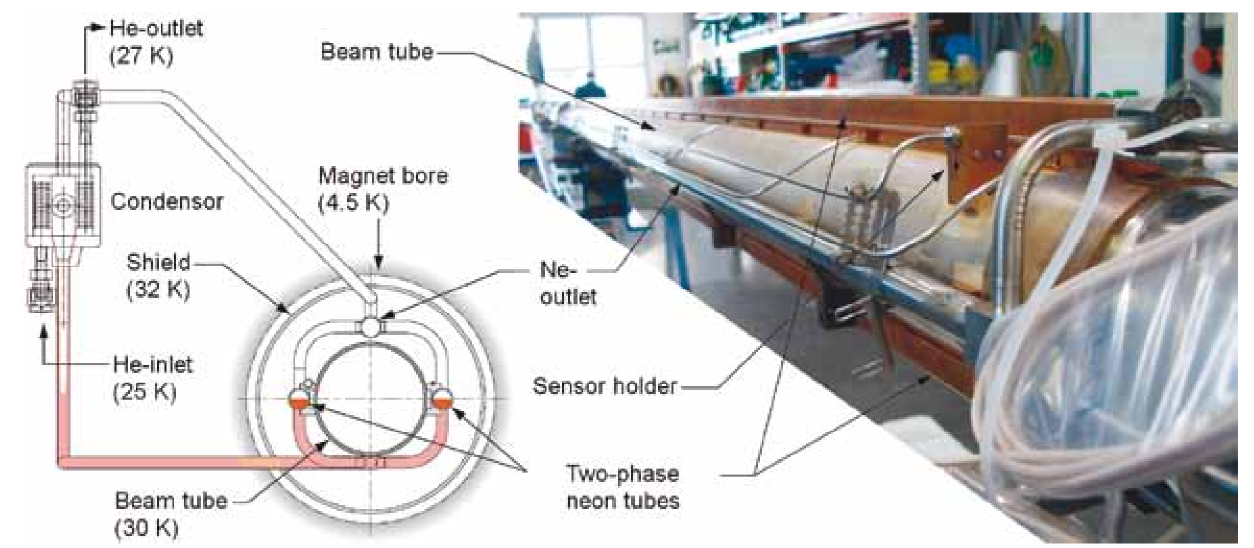


Fig. 7: Principle of the thermo siphon cooling of the KATRIN tritium source with liquid neon at 30 K (left). On the right side the 10 m long beam tube of the KATRIN tritium source is (resting on the side).

Fig. 8: Shown is the Demonstrator inside TLK for testing the WGTS beam tube cooling.

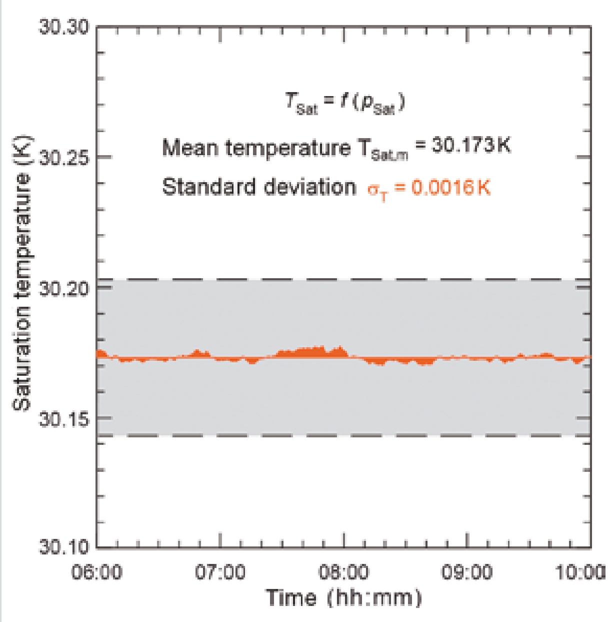


Fig. 10: Measured temperature stability of the KATRIN tritium source. The grey band marks the requested temperature stability of ±30 mK/h.

Measurement of the temperature homogeneity

On order to measure the temperature homogeneity a new measurement principle had to be developed due to the high bake-out temperatures of the beam tube of 550 K. It consists of a combination of PT500 sensors and vapor pressure sensors which are installed in 24 pairs along the beam tube. The vapor pressure sensors are being used for in-situ calibration of the Pt500 sensors. An uncertainty in measurement of 4 mK is reached, the resolution of the Pt500 measurement is 1 mK.

During the measurement phase in 2011 the 24 vapor pressure thermometers could not be filled uniformly with neon due to communication problems between hard- and software. In summer these problems were fixed. The demonstrator was again put in operation in fall 2011 for further cold tests. It is planned to finish the measurements for the temperature homogeneity of the tritium source until end of 2011.

Outlook 2012

In early 2012 out baking tests will be performed at 550 K. Afterwards the system will be dismantled and prepared for the final assembly of the WGTS.

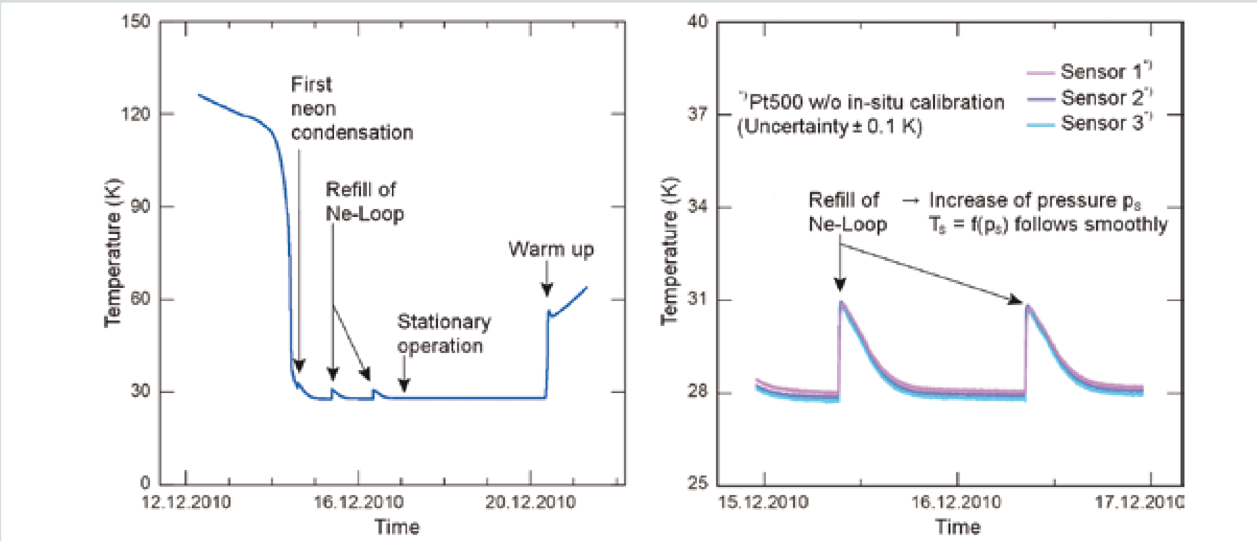


Fig. 9: First cool-down of the KATRIN tritium source in December 2010 with stationary operation at about 28 K (left). On the right side the effect of the two phase cooling can be seen. Even though the sensors are arranged, the change in saturation temperature in distances of about 4 m along the 10 m long beam tube when changing the pressure (refilling) is everywhere the same.

Teaching and Education

Lectures, Seminars, Workshops, Summer Schools

Lectures

KIT – Fakultät Elektrotechnik und Informationstechnik
Supraleitende Systeme für Ingenieure (Noe, Neumann, Siegel) WS 10/11-11/12
Supraleitertechnologie (Noe, Schlachter, Weiss) SS 11
Superconductivity in smart grid power applications (Grilli, Noe) SS 11
Seminar Projektmanagement für Ingenieure (Noe, Day, Grohmann) SS 11

KIT – Fakultät für Chemieingenieurwesen und Verfahrenstechnik
Vakuumtechnik I (Day, Varoutis) WS 10/11-11/12
Kryotechnik (Neumann) WS 10/11-11/12
Kältetechnik I (Grohmann) WS 11/12

KIT – Fakultät Maschinenbau
Fusionstechnologie A* (Fietz, Weiss) WS 10/11-11/12
Fusionstechnologie B* (Bornschein, Day) SS 11

KIT – Fakultät Physik
Messmethoden und Techniken in der Experimentalphysik (Bornschein) SS 11

Leibniz Universität Hannover – Fakultät Elektrotechnik und Informationstechnik
Neue Komponenten der elektrischen Energieversorgung* (Noe) SS 11

Dresden International University – Masterstudiengang Wasserstofftechnologie
Kernfusion (Bornschein) SS 11

Duale Hochschule BW – Fachbereich Maschinenbau
Arbeitssicherheit und Umweltschutz (Bauer) SS 11
Technische Thermodynamik I für Maschinenbauer (Neumann) WS 10/11-11/12
Technische Thermodynamik II für Maschinenbauer (Neumann) SS 11

Seminars / Summer Schools

2nd ITEP Young Scientists Seminar
17.–20. Januar 2011, Kristberg, Österreich

VDI-Seminar Kryotechnik
21.–25. März 2011, Karlsruhe

5. Karlsruhe-Dresden Doktorandenseminar zur Supraleitung
8.–10. Juni 2011, Krippen

5th ESAS Summer School on Materials and Applications on Superconductivity
13.–17. Juni 2011, Harjatulla Mansion, Turku, Finnland

1. Doktorandenseminar Fusion
27.–28. Juli 2011, Bad Herrenalb

5th International Summer School on Fusion Technologies
19.–30. September 2011, Karlsruhe

JT60-SA Technical Coordination Meeting
6.–7. December 2011, Karlsruhe

Rarefied Gas Dynamics
15.–19. August 2011, Karlsruhe

Workshops

Vacuum Gas Dynamics Workshop
16.–19. Mai 2011, Leinsweiler

HTS4Fusion Conductor Workshop
26.–27. Mai 2011, Karlsruhe

* with participation of ITEP

Teaching and Education

Docoral Theses – Master- and Diploma Theses – Bachelor Theses – Term Papers – DHBW Project theses

2011 Doctoral Theses (*completed)

Martin Babutzka (TLK)
Entwicklung, Aufbau und Integration des Calibration und Monitoring Systems (CMS) am KATRIN-Experiment

Christian Barth (FUSION)
Mechanisch stabilisierte Hochtemperatur-Supraleiter-Kabel

André Berger (SUPRA)*
Entwicklung supraleitender strombegrenzender Transformatoren

Olga Borisevich (TLK)
Simulation and experimental study of a multi-stage permeation process for tritium recovery in breeder blanket

Florian Erb (SUPRA)
Entwurf supraleitender Windkraftgenerator

Sebastian Fischer (TLK)
Laser Raman Spectroscopy For The KATRIN Experiment

Thomas Giegerich (VAKUUM)
Entwicklung eines Vakuumpumpkonzepts für zukünftige Fusionsreaktoren

Robin Größle (TLK)
IR-Spektroskopie an flüssigen Wasserstoffisotopen und Entwicklung einer Methode zur Bestimmung der Tritiumkonzentration im Brennstoffkreislauf von ITER

Zoltan Köllö (TLK)
Further Development of Tritium analytic devices

Philipp Krüger (SUPRA)
AC Loss characterization of HTS devices for power applications

Olaf Mäder (SUPRA)
Stabilität von Hochtemperatur-Supraleitern

Robert Michling (TLK)
Performances Assessment of Water Detritiation Process

Oliver Näckel (SUPRA)
Untersuchungen strombegrenzender Spulen

Florian Priester (TLK)
Optimierung der KATRIN Tritium-Loops

Enrico Rizzo (FUSION)
Thermal-fluid dynamic and electrical optimization of high temperature superconductor current leads for fusion magnet systems

Marco Röllig (TLK)
Tritiumanalytik bei KATRIN

Magnus Schlösser (TLK)
High-precision Laser Spectroscopy on Hydrogen Isotopologues

Kerstin Schönung (TLK)
Charakterisierung und Aufbau eines Calibration and Monitoring Systems (CMS) für das KATRIN-Experiment und Durchführung erster Messungen

Stanimira Terzieva (SUPRA)
Preparation and investigation of Roebel-Cables from Coated Conductors

Mater- and Diploma Theses 2011 (*completed)

Christoph Bayer
Bestimmung des Pinningverhaltens technischer Hochtemperatursupraleiter

Tobias Bode*
Untersuchungen zum thermischen Verhalten der Tritiumquelle im KATRIN-Experiment

Philipp Herwig*
Aufbau des endgültigen Laser Raman Systems für KATRIN

Patrick Lenz
Genauigkeitsanalyse für ein kalorimetrisches Messprinzip zur Messung der thermischen Isolationsqualität im Tieftemperaturbereich

Jicheng Li*
Investigation of FBG based displacement sensors for low temperature applications

Harald Moosmann*
CFD simulation of adsorption columns for tritium processing

Teresa Parracho*
Measurement of permeability and selectivity of zeolite membranes for blanket application

Marco Röllig*
Rear Wall Tritium Experiment

Kerstin Schönung*
Test von Anti-Reflexionsbeschichtungen unter Tritiumatmosphäre für KATRIN

Severin Strauss*
Wirtschaftlicher und technischer Vergleich von Energieübertragungssystemen

Thomas Strobel*
Simulation des strombegrenzenden Verhaltens supraleitender Kabel

Tobias Werner* (LuK GmbH & Co. KG)
Standortanalytische Planung einer Großserienfertigung

Stefan Zimmermann*
Analyse und Konzeption der betrieblichen Regelbetreuung im Rahmen der DGUV Vorschrift 2 für die Helmholtz-Gemeinschaft der Forschungszentren

Bachelor Theses 2011 (*completed)

Rami Chahrouri
Konzeptionierung von Kryosystemen mit Kälteversorgung für supraleitende Energiespeicher verschiedenster Baugröße unter Berücksichtigung der Investitions- und Betriebskosten

Sebastian Della Bona
E-Modulbestimmung über die Resonanzfrequen

Maurizio Festa*
Experimentelle Untersuchung der thermischen Isolationsqualität von Microsphere-Hohlglaskugeln und Perlit an einem Körper mit nicht abwickelbarer Oberfläche

Jennifer Gsell* (Bystronic Lenhardt GmbH)
Funktionskostenanalyse und Potentialermittlung zur Reduzierung der Herstellkosten im Bereich Materialzuführung und Fasspumpen

Timo Fabian Henninger* (IK)
Konstruktion der letzten beiden Elektrodenmodule für das KATRIN Experiment

Jürgen Hieringer
Charakterisierung von YBKO-Bandleitern für einen supraleitenden Strombegrenzer

Katharina Höveler
Messung tritiuminduzierter Bremsstrahlung an TRIREX für KATRIN

Simon Kudella*
Suche nach Gravitationswellen mittels Laserinterferometrie und Untersuchungen zur Laserstabilität im Rahmen des KATRIN-Raman-Systems

Dominik Leiser* (BLANCO CS GmbH + Co KG)
Anpassung der Einkaufsstrategie auf die Belange der Geschäftseinheit Medical Care am Beispiel der BLANCO CS GmbH + Co KG

Sebastian Mirz*
Aufbau und Inbetriebnahme des finalen Laser Raman Systems für KATRIN

Franz Möltgen
Weiterentwicklung eines Messsystems zur Messung der kritischen Stromdichte in Supraleitern bei Veränderung der Winkel des wirkenden Magnetfeldes sowie deren Feldstärke

Manuel Pitsch
Potentialanalyse regenerativer Energien zur Eigenversorgung von Versorgungsgebieten

Stanislav Plohotski
Materialcharakterisierung für den Kryostatbau

Toni Quach
Demonstrationsstand kryogener Zugversuch

Alexander Rein
Inbetriebnahme und Charakterisierung eines Silicon-Drift-Detectors für BIX-Messungen an tritiiertem Wasser

Roland Richter*
Erstellung eines Programms zur Auslegung und Validierung von Vakuumsystemen beliebiger Komplexität auf Server – Client Basis

Florian Schleißinger
Winkelabhängige E(I)-Messungen an technischen HTS-Bandleitern

Sebastian Schüler
Charakterisierung von Festkörper-Szintillatoren für den Einsatz zur Messung von Tritium in Wasser

Hendrik Seitz*
Kalibration des LARA-Systems mit katalytisch hergestellten, inaktiven Wasserstoffisotopologmischungen

Rozita Soleimani*
Time response and stability investigation of copper Embedded FBG sensur ar cryogenic Temperature

Severin Strauss*
Untersuchung der Machbarkeit von supraleitenden Windkraftgeneratoren

Sophie Sulzmann
Untersuchung der Sorption an Aktivkohle bei kryogenen Temperaturen

Baden-Wuerttemberg Cooperative State University (DHBW) 2011 (*completed)

Kerstin Brohl*
Implementierung eines Exceltools zur Personalkostenkalkulation

Isabelle Ehleben*
Konstruktion einer Kalibriervorrichtung für Extensometer

Nando Gramlich
Entwicklung, Aufbau und Inbetriebnahme einer Apparatur zur Messung von Wasser unterschiedlicher Isotopenzusammensetzung in einem feuchten Gasstrom mittels Laser-Raman-Spektroskopie

Nadja Kästle
Market Potential Analysis of Superconducting Fault Current Limiters

Steffen Mundt
Konzept zur Betriebskostenberechnung des Heliumversorgungssystems

Marcus Oberle*
Aufbau eines kryogenen Strömungskanals zur Kalibrierung von Massenstromsensoren

Michael Schmidt
Auslegung, Design und Konstruktion eines Potentialtrenner-Teststandes

Michael Schmidt
Bilanzierung eines kryogenen Teststandes im Hinblick auf den Kryogenverbrauch bei unterschiedlichen Abkühlszenarien

Pit André Singer*
Messung relativer Luftfeuchtigkeit und Temperatur mit dem digitalen Sensorelement SHT21

Sascha Singer
Automatisierung und Visualisierung eines Langzeitexperiments zur Überprüfung der Tritiumverträglichkeit von Turbomolekularpumpen über NI LabVIEW Real-Time

Sascha Singer
Feldgeräte- und Signalsimulation mittels Simulationsbaugruppe und NI LabVIEW

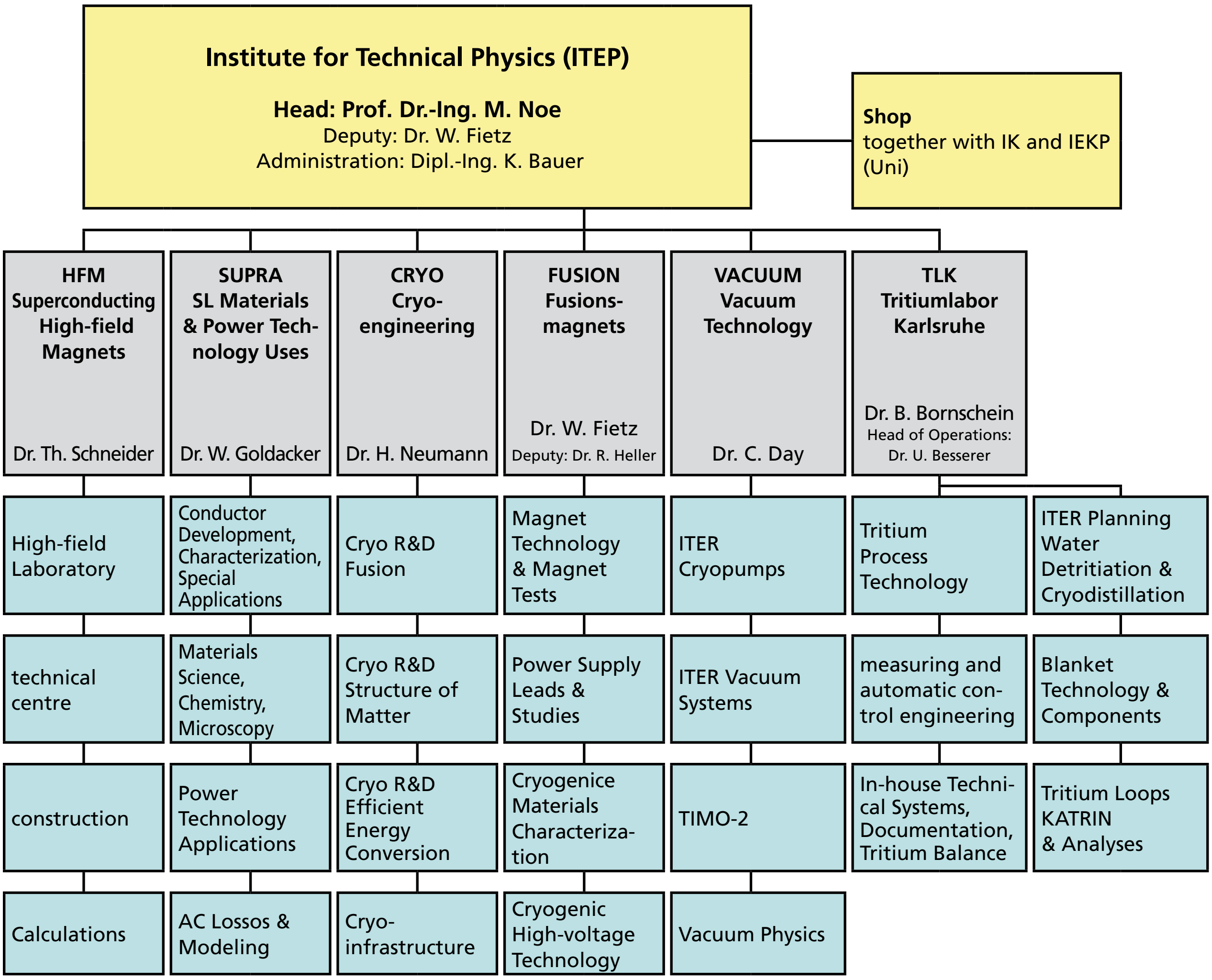
Teaching and Education

2011 ITEP Colloquies

11.1.2011	Entwicklung supraleitender strombegrenzender Transformatoren André Berger; SUPRA
26.1.2011	Modelling Superconductors – Electromagnetics, AC-losses, Engineering and Science Antti Stenvall; SUPRA
1.2.2011	Genauigkeitsanalyse für ein kalorimetrisches Messprinzip zur Messung der thermischen Isolationsqualität im Tieftemperaturbereich Patrick Lenz; KRYO
8.2.2011	Konzeptionelles Design von supraleitenden Windkraftgeneratoren Severin Strauss; SUPRA
17.2.2011	Status der Montage von W7-X Steffen Jung; MPI Greifswald
22.2.2011	Entwicklung eines Programms zur Berechnung komplexer Vakuumsysteme auf Server-Client-Basis Roland Richter und Pascal Kraft; VAKUUM
29.3.2011	Coated Conductors quench characterization for FCL purpose Bertrand Dutoit; Ecole Polytechnique Lausanne
19.4.2011	TIMO-2 – Testeinrichtung für Kryosorptionspumpen Horst Haas; VAKUUM
25.5.2011	Overview of Superconducting Activities at MIT's Plasma Science and Fusion Center Dr. Leslie Bromberg; Fusion
5.7.2011	Superconductor AC-losses in cables – new results and development of experimental techniques for device characterization Antti Stenvall; Gastwissenschaftler im ITEP
12.7.2011	Investigation of copper embedded Fiber Bragg Grating sensors for temperature measurement at cryogenic environment Tejas Naphade; Gast ITEP
28.7.2011	Cryocooler Technology development at Indian Institute of Technology Bombay (IITB), India Milind Atrey; Indian Institute of Technology Bombay
20.9.2011	Entwicklung eines erdfreien Sensormesssystems Pit Andre Singer; Bachelorarbeit
27.9.2011	Aufbau eines Instandhaltungsmanagements für das Großprojekt KATRIN Konzept zur Betriebskostenberechnung des Heliumversorgungssystems Clemens Frenzel; Bachelorarbeit Steffen Mundt; Projektarbeit
27.10.2011	Update on the ITER Conductor Production Arnaud Devred; Section ITER France
3.11.2011	Research on applied superconductivity in GREEN Lab Bruno Douine; Univ. of Nancy
15.11.2011	Wirtschaftlicher und technischer Vergleich von Energieübertragungssystemen Severin Strauss; Diplomarbeit
22.11.2011	Process & analytical issues for tritium management in breeder blankets of ITER & DEMO David Demange; TRITIUM
23.11.2011	Simulation des strombegrenzenden Verhaltens supraleitender Kabel Thomas Strobel; Diplomarbeit

Figures and Data

ITEP Chart of Organization (January, 2011)



Personnel Status (01.12.2011)

Total	**195**	**additionally, during 2011**	
University graduates	58	Guests	15
Engineers and technicians	62	Trainees	18
Others	33	Student assistants	16
Pre-doctoral students	16	Term Papers, bachelor theses	22
Diploma students	10		
DH students	16		

Figures and Data

Personnel Changes in 2011

Leaving (Excluding Trainees, Guests, and Student Assistants)

Dr. André Berger

Kerstin Brohl

Erhan Cilbir

Clemens Frenzel

Dr. Sergiy Putselyk

Pit André Singer

Stanimira Terzierva

Dr. Alexander Winkler

Werner Wurster

Newly Recruited (Excluding Trainees, Guests, and Student Assistants)

Katharina Battes

Christoph Bayer

Adalbert Braun

Rami Chahrouri

Sebastian Della Bona

Isabelle Ehleben

Florian Erb

Manuel Grasina

Robin Größle

Marcus Hollik

Dr. Anna Kario

Xavier Lefebvre

Lisa Marie Maurer

Franz Möltgen

Marcus Oberle

Florian Priester

Manuel Pitsch

Bianca Purr

Toni Quach

Pascal Reutter

Marcus Röllig

Florian Schleißinger

Michael Schrank

Michael Schwarz

Severin Strauß

Sophie Sulzmann

Valentin Tschan

Irina Völker

Sonja Wendel

Figures and Data

Trainee / Student assistants

Trainee 2011 (* completed)

Katharina Battes
GOT VACUTEC

Andras Bükki-Deme
GOT-TRI-TOFFY

Thomas Giegerich
GOT VACUTEC

Benedikt Kuffner
GOT GIRO

Xavier Lefebvre
GOT-TRI-TOFFY

Santiago Ochoa Guamán
GOT NIPEE

Ana Parracho*
GOT-TRI-TOFFY

Christoph Plusczyk
GOT-TRI-TOFFY

Alessia Santucci*
GOT-TRI-TOFFY

Michael Schrank
GOT GIRO

Ionut Spiridon
GOT-TRI-TOFFY

Student assistants 2011

Daniel Barth

Christoph Bayer

Sebastian Della Bona

Bijay Devkota

Sebastian Hellmann

Till Holzhäuser

Florian Kassel

Pascal Kraft

Patrick Lenz

Jicheng Li

Franz Möltgen

Klaus Müller

Simon Niemes

Teresa Parracho

Toni Quach

Severin Strauß

Figures and Data

Guest Researcher

Guest Researcher

Julien Andre
19.09.–07.10.11 Trainee EFDA Vakuumnetzwerk VACU-TEC - CEA, Grenoble, Frankreich

Prof. Milind Atrey
04.07.–30.07.11 Institute of Technology Bombay, Mumbai, Indien

Aurelien Durocher
03.10.–07.10.11 Trainee EFDA Vakuumnetzwerk VACU-TEC - CEA, Cadarache, Frankreich

Timothy James
09.03.–12.03.11 Universität Swansea
14.07.–22.07.11 Universität Swansea
10.10.–21.12.11 Universität Swansea

Tejas Naphade
10.05.–10.07.11 IIT Bombay / Indien

Alina Niculescu
09.05.–29.07.11 National Institute of R&D for Cryogenic and Isotopic, Technologies, Institut ICIT, RM Vilcea, Rumanien
26.09.–08.12.11 National Institute of R&D for Cryogenic and Isotopic, Technologies, Institut ICIT, RM Vilcea, Rumanien

George Okoth
15.08.–19.08.11 Universität Bremen

Serafeim Misdanitis
03.09.–08.10.11 University of Thessaly / Volos – Greece

Dr. Antti Stenvall
01.01.–31.07.11 Tampere University of Technology / Finnland

Christos Tantos
03.10.–07.10.11 University of Thessaly / Volos – Greece

Prof. Dr. Helmut Telle
08.03.–11.03.11 Universität Swansea
05.12.–09.12.11 Universität Swansea

Lucie Tvrznikova
25.07.–10.09.11 Universität St. Andrews / Schottland

Prof. Dimitris Valougeorgis
03.10.–07.10.11 University of Thessaly / Volos – Greece

Figures and Data

Membership in Relevant Technical and Scientific Organizations

Kai Bauer

- Member of the Helmholtz Management Academy
- Member of the „Arbeitssicherheit und Umweltschutz" working group
- Member of the committee of culture of study at the Baden-Württemberg Cooperative State University Karlsruhe
- Member of the examination board of the Baden-Württemberg Cooperative State University Karlsruhe in the programs Mechanical Engineering and Business & Engineering

Beate Bornschein

- Member of the „International Steering Committee" of the „International conference on Tritium Science and Technology"
- Member of the „Executive Committee of IEA Nuclear Technology for Fusion Reactors Network Co-ordinator for EU network trainee programme 'TRI-TOFY'
- Member of the KATRIN Executive Committee
- Member of the KATRIN Collaboration Board
- Coordinator Source and Transport Section of KATRIN
- Member of the Scientific Technical Assembly of KCETA

Ion Cristescu

- Manager of cooperation TriPla-CA Consortium

David Demange

- Member of the Expert Panel for the Preliminary Design Review of the IFMIF/EVEDA Liquid Breeder Validation and the Tritium Release Modules

Christian Day

- Member of the council of the German Vacuum Society (DVG)
- Vice-President of the „FachverbandesVakuumphysik und -technik der Dt. Physikalischen Gesellschaft (DPG)"
- Invited expert for Vacuum Technologies, „Innovationsdialog der Bundeskanzlerin mit Wirtschaft und Wissenschaft"
- Associated Expert of the Indian Vacuum Society (IVS).
- Chartered Engineer of American Vacuum Society (AVS)
- Co-ordinator of the VACU-TEC Goal oriented Training Programme, EFDA (GOT).
- International Symposium of Fusion Nuclear Technology, Member of the International Programme Committee (ISFNT)
- Spokesperson Topic „Vakuum und Tritium", Deutsche DEMO Initiative

Wilfried Goldacker

- Vice-President of Board of Directors ICMC International Cryogenics Material Conf. (ICMC)
- Program Board Member ICSM-Conf. Antalya, Turkey
- Member of Advisory Board of Turkisch Centre for Superconductivity – Ankara
- Member of the commission „Elektrotechnik Elektronik Informationstechnik" at DIN und VDE Referat K 184 „Supraleiter"

Steffen Grohmann

- Appointment on the W3 Professorship „Kälte- und Kryotechnik" at the „Institut für Technische Thermodynamik und Kältetechnik" of KIT
- Vice-chairman of „Normenausschuss NA 016-00-07 AA „Flüssighelium-Druckbehälter – Sicherheitseinrichtungen gegen Drucküberschreitung"
- Member of the „Verein zur Förderung der Luft- und Kältetechnik e. V."
- Member of the KATRIN Executive Board and KATRIN Publications Committee
- Member of the Institute of Refrigeration (IIF/IIR), Commission A1: Cryophysics, cryoengineering

Reinhard Heller

- Applied Superconductivity Conference, Member of International Program Committee
- Applied Superconductivity Conference, elected Board member Large Scale
- Applied Superconductivity Conference, Technical Editor
- Magnet Technology Conference, Member of International Program Committee
- Magnet Technology Conference, Technical Editor
- Computation of Thermo-Hydraulic Transients in Superconductors (CHATS-AS), Board member
- DKE/DIN K 184 – Supraleiter
- International Electrotechnical Commission (IEC TC90) – Superconductivity – Member WG 12 – „Superconducting Power Devices-General Requirements for Characteristic Tests of Current Leads designed for Powering Superconducting Devices"

Holger Neumann

- Board member of the „Deutscher Kälte- und Klimatechnischer Verein e.V. – DKV" – Head of the „Arbeitsabteilung I: Kryotechnik"

Mathias Noe

- President of the European Society for Applied Superconductivity (ESAS)
- International Council of Large Electric Systems (CIGRE) Convenor of working group D.1.38 „Emerging Test Techniques Common to High Temperature Superconducting (HTS) Power Applications"
- International Council of Large Electric Systems (CIGRE) Member of working group D.3.23 „Application and feasibility of fault current limiters in power systems"
- International Energy Agency, Implementing Agreement for a co-operative programme for assessing the impacts of high-temperature superconductivity on the electric power sector, German representative
- Fusion for Energy (F4E) – Member of Technical Advisory Panel
- Fusion for Energy (F4E) – Member of the Assessment Group on the procurement of the ITER PF coils
- Member of the Association Steering Committee Euratom-KIT
- International Conference on Magnet Technology, Member of International Organizing and Scientific Program Committee
- Applied Superconductivity Conference, Member of International Program Committee
- European Conference on Applied Superconductivity, Member of International Program Committee
- Industrieverband Supraleitung, Guest member
- Helmholtz Program Efficient Energy Conversion and Use Program, Spokesperson Topic Superconducting Components
- Member of Administrative Board of the„Heinrich-Hertz-Gesellschaft"
- KIT Energy Center, Member of the steering committee and Vice Spokesperson Energy Storage and Energy Distribution
- Member oft he Evaluation board of the „Bewertungsgruppe des Wissenschaftsrates zur Evaluierung der Fakultäten für Elektrotechnik und Informationstechnik"
- IEEE Transactions on Applied Superconductivity, Editor for Large Scale Applications
- Coordination of the sub-program Superconducting Magnetic Energy Storage in the Joint Programme on Energy Storage of the European Energy Research Alliance (EERA)

Sonja Schlachter

- Member of the „Executive Board of Superconductor Science and Technology (SUST) in the Institute of Physics (IOP) UK"

Manfred Süßer

- Chairman of „Normenausschuss NA 016-00-07 AA „Flüssighelium-Druckbehälter – Sicherheitseinrichtungen gegen Drucküberschreitung"

Anne-Kathrin Weber

- Member of the 'Delegiertenversammlung' of the 'Karlsruhe Institute of Technology'
- Member of the examination board of the 'Baden-Württemberg Cooperative State University Karlsruhe' in the program Business & Engineering
- Member of the Review board for professorship applicants at the 'Baden-Württemberg Cooperative State University Karlsruhe' in the program 'Business Engineering'

Klaus-Peter Weiss

- DKE Deutsche Kommission Elektrotechnik Elektronik
- Vice-chairman Informationstechnik im DIN und VDE Referat K 184. „Supraleiter"
- Member of the IEC International Electrotech nical Commission/Technical. Comittee 90 „Superconductivity"
- Member of the Executive Committee of the "internationalen Forschung und Industrie Workshops MEM" „Mechanical-Electromagnetic Properties of Superconducting Materials"
- Spokesperson of the task force „Magnet Design" within the German coordination of Fusion-research for DEMO

Jürgen Wendel

- Founding member and longtime member of the executive board of the "Deutschen Gesellschaft für Flüssigszintillationschromatographie e.V. (DGfS)", tresurer
- Course instructor at the Fortbildungszentrum für Technik und Umwelt (FTU) for the Programmes radiation protection and radiochemistry

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Invited Papers

Beate Bornschein

- B. Bornschein „Between fusion and cosmology – the future of the Tritium Laboratory Karlsruhe (TLK)." Progress in Cryogenics and isotope Separation Konferenz Valcea Rumänien

David Demange

- D. Demange „Process and Analytical Issues for Tritium management in Breeder Blanket of ITER and DEMO." ISFNT 2011

Christian Day

- Chr. Day, „Vacuum technology in DT fusion devices", Current research topics in Nuclear Fusion Engineering Lecture Series, Politecnico Torino, Italien, 25. Januar 2011.
- Chr. Day, D. Demange, Th. Giegerich, V. Hauer, R. Wolf, V. Kotov, D. Reiter, „An integrated view on high density operation and fuel cycle", MFE Roadmapping Workshop, Princeton, NJ, USA, September 2011.
- Chr. Day, Th. Giegerich, St. Hanke, V. Hauer, M. Scannapiego, St. Papastergiou, R. Lässer, „Design development of cryopumping systems of ITER in view of future DT fusion devices", Int. Symp. On Fusion Nuclear technology (ISFNT), Portland, OR, USA, September 2011.
- Chr. Day, Th. Giegerich, H. Haas, V. Hauer, St. Hanke, X. Luo, St. Varoutis, „Modelling and simulations of the ITER cryopumping systems", Annual Symposium of the American Vacuum Society, Nashville, TN, USA, Oktober 2011.

Wilfried Goldacker

- Workshop: Roadmap for Superconductivity in Turkey: HTS4Fusion KIT Beitrag Goldacker.

Francesco Grilli

- F. Grilli, AC Losses in Roebel Cables. HTS4Fusion Conductor Workshop, Karlsruhe, Germany, May 26–27, 2011.

Stefan Hanke

- St. Hanke, Chr. Day, X. Luo, P. Sonato, „Status of the cryosorption pumping system for the Neutral beam test facility MITICA", 20. Jahrestagung der Italienischen Vakuumgesellschaft, Padua, Italien, Mai 2011.

Xueli Luo

- X. Luo, „Monte Carlo calculation of the ITER pre-production cryopump", Institutsseminar ASIPP, Hefei, China, 7. Dezember 2011.

Mathias Noe

- M. Noe, E. Marzahn „Hochtemperatur-Supraleiter Kabel", 77. Kabelseminar, 22.–23. Februar 2011, Leibniz Universität Hannover
- M. Noe „Superconducting power applications and their potential to increase energy efficiency", Symposium on Superconducting Devices for Wind Energy, February 25th 2011, Barcelona, Spain (Plenary talk)
- M. Noe „Status of Development of Superconducting Fault Current Limiters (SCFCL) and Superconducting Cables", European Summer School on Superconductivity 2011, June 12–17, 2011, Turku, Finland
- M. Noe „History, state-of-the-art and prospects of superconducting power equipment" Superconductivity Centennial Conference, EUCAS-ISEC-ICMC 2011, September 19–23, The Hague, Netherlands (Special plenary session)
- M. Noe „Supraleitende Transformatoren: Mit hoher Effizienz und mehr Sicherheit in die Zukunft", 6. Fachtagung Energie, 5.–6. Oktober 2011, Köln
- M. Noe „Superconductivity for Future Energy Technology", International Symposium of Superconductivity, October 24–26 2011, Tokyo, Japan (Plenarvortrag)
- M. Noe, M. Stemmle, F. Merschel, L. Hofmann, J. Bock, F. Schmidt „Neue Mittel- statt konventioneller Hochspannungsnetze durch Hochtemperatur-Supraleitung", Internationaler ETG Kongress, 8.–9. November 2011, Würzburg
- M. Noe, P. Komarek „History and prospects of applied superconductivity technology for fusion magnets", 21st International Toki Conference (ITC-21) on Integration of Fusion Science and Technology for Steady State Operation, November 28 – December 1, 2011, Toki, Gifu, Japan (Plenarvortrag)

Sonja Schlachter

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- St. Varoutis, „Numerical and experimental investigation of rarefied gas flows over the whole range of the Knudsen number", PORE-NET Graduiertenkolleg, Bremen, 12. Dezember 2011

Publications

Patents Held

* New patent applications in 2011
** Patents granted for Germany in 2011

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Verfahren zur Steuerung der Netzgeräte zum Laden der Energiespeicher eines Leistungsmodulators und Leistungsmodulator zur Durchführung des Verfahrens
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