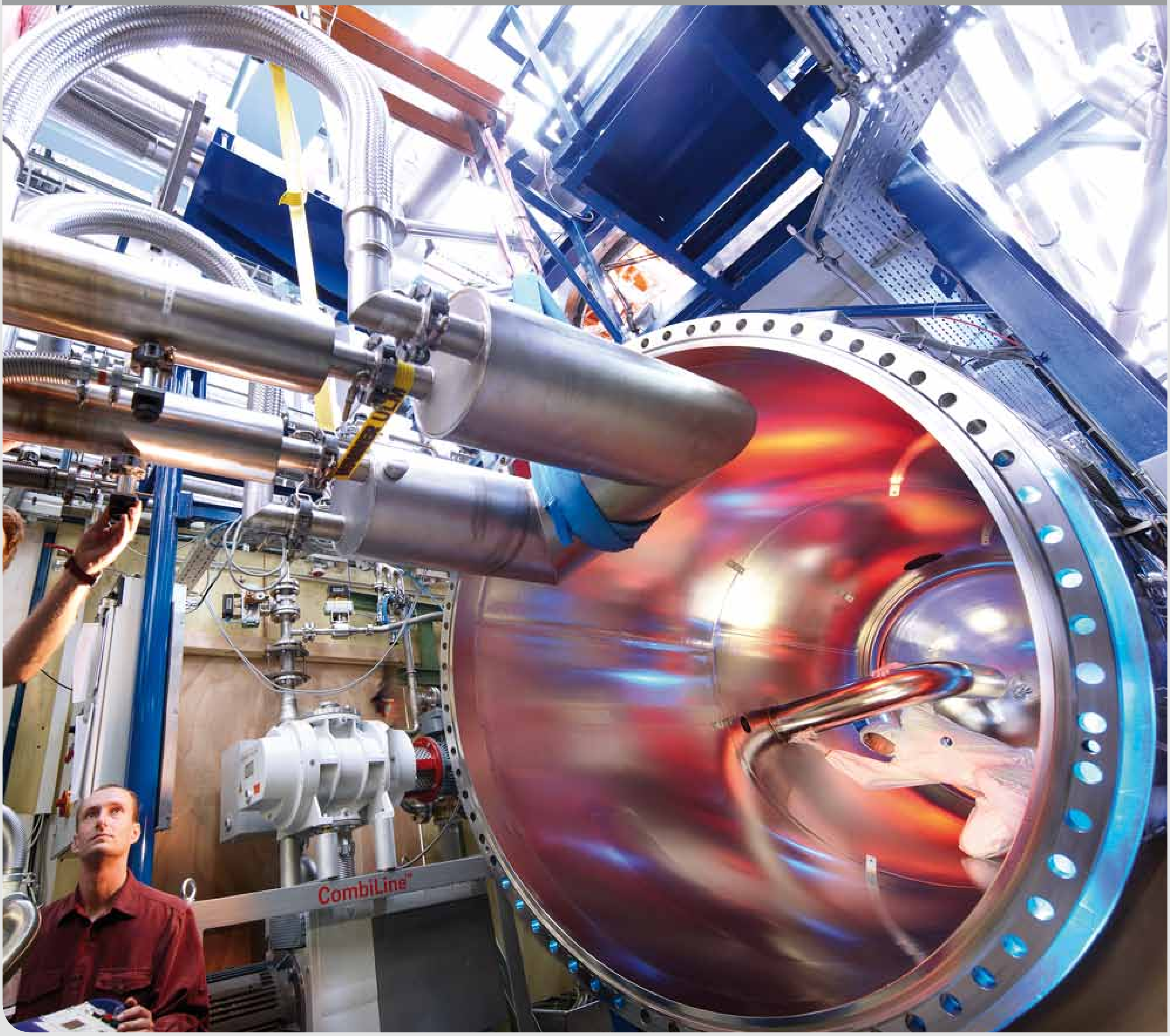
Karlsruhe Institute of Technology

ITEP – Institute for Technical Physics

Progress in Research and Development
2009 Annual Report

INSTITUTE FOR TECHNICAL PHYSICS



KIT – University of the State of Baden-Wuerttemberg and
National Laboratory of the Helmholtz Association

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Preface

The Institute for Technical Physics (ITEP) is a national and international center of competence for fusion, 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), 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, the cryogenic high-voltage laboratory, and the cryogenic materials laboratories.

2009 was characterized by important scientific results and 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 and for the Japanese JT60-SA tokamak. In this work, the institute reached an extremely important milestone in 2009: The first prototype of the current leads for Wendelstein 7-X was built and instrumented and is thus ready in time for a test in 2010. In a parallel effort, major progress was achieved in construction of the experimental facility for testing these current leads. Moreover, ITEP intensified work in its cryogenic materials laboratory, taking some first steps towards accreditation of specific laboratory sectors.

For ITER, the Karlsruhe Tritium Laboratory (TLK) will take responsibility for preparing the work packages for water detritiation and cryogenic isotope separation. In 2009, TLK, among other things, developed very precise new analytical methods for on-line and in-line measurements of tritium concentrations in water or in liquid hydrogen. Within the framework of European activities for ITER, a tritium plant consortium was established under the leadership of TLK with the purpose of making better use of synergies in Europe.

The vacuum technology department in ITEP is responsible for designing, preparing, and testing the cryo-vacuum pumps for ITER. Work in 2009 was concentrated on completing the FEM detailed design and on fundamental thermal hydraulics studies for design validation. In addition, the vacuum technology department further intensified activities in modeling vacuum flows.

Developing economically viable and powerful conductor concepts is a core duty of the ITEP. In 2009, a department on superconducting materials and power applications was extremely successful in developing Roebel-structured strip conductors with 2nd-generation superconductors by commissioning an automatic punching system for efficient fabrication. Moreover, promising multi-conductor concepts with magnesium diboride superconductors were developed. With respect to applications of superconductivity in power technology, a joint project was launched with the objective of installing a medium-voltage current limiter in the power supply grid by 2011.

In the superconducting high-field magnets area, a highlight visible worldwide was the development of the first 1000-MHz NMR spectrometer by a long-term industrial partner. Some basic technologies underlying that development originated at ITEP. In addition, preparatory work was conducted on high-field magnet use for magnetic fields of up to 25 T. In 2009, a new EU project was launched to develop the next generation of accelerator magnets, to which ITEP is contributing its know-how about superconducting high-field magnets.

Activities in the cryo-engineering area in 2009 mainly comprised the advanced development of complex and extremely large cryo-systems, such as those for TOSKA and KATRIN, the safe and reliable operation of cryo-facilities, and the supply of KIT with liquid helium and liquid nitrogen. The cryo-engineering department prepared the new laboratory area for the facility under construction for testing current leads by providing important elements of infrastructure.

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. Important steps in 2009 were the delivery and construction of the first superconducting magnet section. TLK, among other things, succeeded in implementing a newly developed laser Raman process for precise measurement of the isotopic composition of gaseous tritium.

In addition to these scientific findings, 2009 also saw some important changes in personnel. Dr. Lothar Dörr, for many years the head of the Karlsruhe Tritium Laboratory, changed to a new position in Decommissioning in June. I am most grateful to him for his excellent stewardship of the laboratory. His successors are Dr. Beate Bornschein as the scientific head, and Dr. Uwe Besserer as the head of operations. We were sad to learn of the death of Volker Leibbrand, for many years one of our very excellent staff members. He was responsible for the power supply of TOSKA.

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 diploma, a PhD thesis, and trainees.

As far as teaching responsibilities are concerned, a large number of lectures are given or supported by staff members of ITEP. On the whole, this amounts to more than ten lectures, most of them in the areas of superconductivity, fusion, and cryotechnology. Numerous national and international seminars and workshops organized by ITEP supplement the program of lectures.

Work on planning a new building to replace our old office building, building No. 410, progressed in 2009. After completion of the preparatory planning phase, the Presidential Committee of KIT released the funds. I am grateful to all parties involved, especially the presidents, the architects, and the internal and external planning staff.

A particular success was scored by ITEP researcher Dr. Francesco Grilli: In 2009, he succeeded in acquiring a Helmholtz university young scientists group to work on "Alternating-current Losses in High-temperature Superconductors." This enables him to build up a working group of his own striving for European-wide leadership in this field.

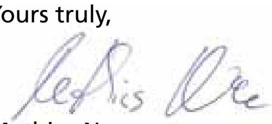
In 2009, the Science Council established a group evaluating the German faculties of electrical engineering and information technology. I was appointed member of that group. Its key duties include establishing criteria for evaluations and evaluating the results.

In 2009, Dr. Francesco Grilli acquired a Helmholtz university young-scientists group working on "Alternating-current Losses in High-temperature Superconductors."

Another major step for our Institute was the establishment of the Karlsruhe Institute of Technology in October 2009 agreed upon between the Karlsruhe Research Center and the University of Karlsruhe. In my term as chairman of the Scientific-technical Council of the Karlsruhe Research Center I was closely involved in that phase in 2009.

I should 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 2009.

Yours truly,



Mathias Noe

Two high-current supply leads under preparation for the power test.

Results from the Research Areas

Fusion Magnet Technology

Head: Dr. Walter Fietz

The fusion magnet area of ITEP is involved in the national W7-X project, the international JT-60SA and ITER projects. In addition, it performs preparatory work for the magnet system of the future DEMO demonstration reactor.

Current Leads for W7-X and JT-60SA

Work for Wendelstein 7-X

ITEP took over responsibility for developing, manufacturing, and testing 16 current leads for the Wendelstein 7-X (W7-X) plasma experiment. W7-X is under construction at Greifswald by the Max Planck Institute for Plasma Physics (IPP). The current leads (two prototypes and 14 series current leads) must be installed overhead and, therefore, are equipped with high-temperature superconductors (HTS). In this way, the cryopower required is significantly lower. The current leads are designed for a maximum current of 18.2 kA.

After the fusion magnets unit of ITEP had designed the current leads and verified the design in a number of preliminary tests in 2008, it tested and qualified all manufacturing steps in a full-scale mockup and subsequently manufactured the two prototypes in 2009.

In 2010, the two prototype current leads, together with a superconducting short circuit busbar made available by IPP, are to be combined for a test in a special test cryostat, connected to TOSKA, and subjected to detailed testing in summer. A successful test is a precondition for approval of manufacturing the 14 series-produced current leads.

Work for JT-60SA

Germany declared its willingness in 2007 to take on part of the package promised by the EU to Japan for constructing the JT-60SA satellite tokamak. Also in this project, ITEP is responsible for building and testing the current leads. In 2009, the basic data were negotiated with the EU and Japan. The contract was signed in early 2010.
ITEP elaborated the overall design in 2009. Once all connecting areas have been agreed with JT-60SA, the design is to be finalised by 2010. It is based on the current lead design for W7-X..

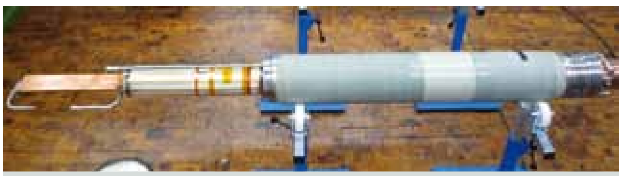


Fig. 1: Prototype current lead showing assembly of the bus bar power connection (left), HTS module (center), and heat exchanger (right, with insulated vacuum space) components.

CuLTKa Power Supply Lead Test Facility and Preparations for TOSKA

In total, 16 current leads are to be tested for W7-X, and another 26 current leads for JT-60SA. For this purpose, the new CuLTKa (Current Lead Test Facility Karlsruhe) test facility is under construction for integration into the existing cryo-infrastructure of ITEP. CuLTKa has been designed such to operate both the upside-down operation of the current leads for W7-X and "normal" operation for JT-60SA.

The main work performed for CuLTKa in 2009 comprised conversion of the stage and cryostat design for the cryo-engineering infrastructure. In addition, ITEP planned both the power connection for 30 kA to the existing power supply system, and the high-voltage electric wiring, data acquisition, and signal processing.

In order to allow the prototype test of the W7-X current leads to be performed as quickly as possible, the test will be performed in TOSKA in 2010. Preparations were largely completed in 2009, and TOSKA was ready for starting the test in February 2010.

As soon as the CuLTKa test facility will have been completed, the tests will be performed in this facility designed specifically for the purpose. Compared to TOSKA, it allows a much higher test frequency required for completion of all current leads for W7-X and JT-60SA within the given time frame. Construction of the series current leads for W7-X and the corresponding acceptance tests are to be completed by the end of 2012. Subsequently, the 26 current leads for JT-60SA are to be built and tested in CuLTKa by the end of 2015.

Studies of Transient High Voltages in ITER Coils

During fast shutdowns, large magnet coils build up high voltages which need to be managed especially under fast switching and fault conditions. The complex design of the coil system of a fusion reactor, and the associated high inductances and capacitances require a complex electrical network in which fast switching processes can give rise to brief internal local voltage overshoots. These transient voltages cannot be determined by direct measurement but must be calculated in complex simulations to obtain clear information about the insulation concepts required.

ITEP calculated the transient voltages in the poloidal field coils (PF). For this purpose, the PF3 coil and the PF6 coil were selected. First a detailed finite-element-method program was used in order to compute the frequency-dependent inductances of each winding. In the next step, the coils were simulated in a network pro-

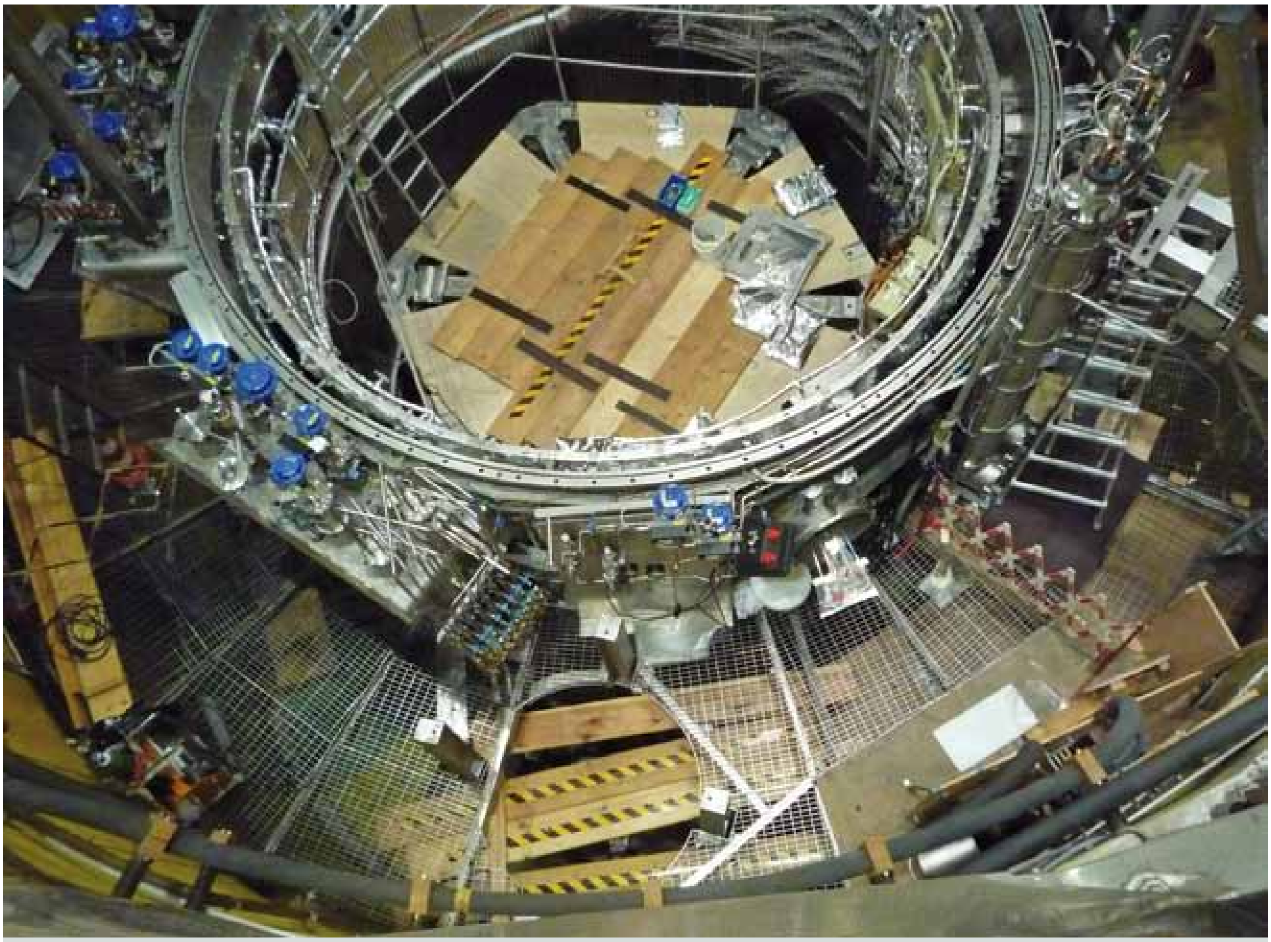


Fig. 2: TOSKA during adaptation for the prototype test of the W7-X current lead.

gram to compute both the resonance frequencies of the two coils and the voltage distribution within the coils.

The voltage to the ground, layer, and conductor insulations of the two coils were computed for four modes of operation: quick discharge, rated operation, and two fault cases with one fault to earth.

Tests of Cryogenic Materials and Mechanical Tests of Superconducting Cables

Work for ITER

In preparation of the ITER design, specific projects were launched in 2009 for the qualification of materials and production. The reference used was the database generated over the past couple of years at the CryoMaK (Cryogenic Materials Tests Karlsruhe) laboratory at ITEP.

Numerous cryogenic studies were performed until September 2009 in the CRYOGT task of EFDA (European Fusion Development Agreement). Especially the qualification of compacted TF tube material from Japan and PF jacket material from China has to be mentioned. Tensile test specimens and specimens used to determine the fracture mechanics properties were manufactured and tested at cryogenic temperatures.

In addition to the work resulting from the EFDA task, inquiries were received from industry to conduct cryogenic tests accompanying the production of ITER components. Here some examples are listed:

- He-inlet elements of the TF coil are to be subjected to fatigue tests at cryogenic temperatures.
- The insulating material is to undergo tensile, bending or shear tests to qualify for production of the TF cable packages.
- Representative elements of the cable package are to be subjected to compression and cyclic forces.

The development of electric separators for tubing of the superconducting magnets requires not only electrical tests and He pressure tests, but also mechanical tests. As these components will be subjected also to torsion loads in operation, ITEP has started the preparation of a cryogenic torsion test facility. For this purpose, a decommissioned facility will be converted and equipped with new hydraulic systems and control and measurement electronics.

Work for W7-X

Within the framework of the construction of W7-X, ITEP conducted numerous standard tensile tests of structural materials in 2009. In addition, INCONEL bolts, equipped with strain gauges, were calibrated up to 530 kN at room temperature and 4.2 K. They are used to support the magnet coils and, as a result of this calibration, can provide feedback about the distribution of forces in the magnet system during operation.

ITEP performed systematic shear tests of glass-epoxy bonds with 1.4429-type material in developing the prototype current leads for W7-X. The dominating influence of surface treatment of the steel material was clearly visible in these tests. Thus, no satisfactory bond was possible with surfaces blasted with glass beads. The best results were obtained after blasting with special fused alumina. The highest shear stress attained in this way was around 76 MPa.

Quality Management

To meet the requirements of a quality management system as increasingly demanded by industry, accreditation of the PHOENIX measurement rig for measuring standard tensile test specimens at 4.2 K was prepared according to DIN 17025. Accreditation is to be initiated formally in mid-2010.

Electromechanical Studies in a Magnetic Field – FBI

Superconducting current limiters usually are operated in liquid nitrogen at 77 K. However, the temperature in the conducting tape is increased many times (for instance to 500 K) in a limiter actuation case. The mechanical stresses resulting from thermal expansion in this case may cause the electrical properties to fail. In order to determine the thermal expansion behavior of high-temperature superconductor tapes between 290 K and approx. 900 K, a measurement setup was designed and built during a project study. Systematic studies of commercial HTS tapes gave a valuable database.

Preparatory Work for the Magnet System of the Future DEMO Demonstration Reactor

Studies and analyses of HTS materials currently available show that the RE-123 high-temperature superconductor (also referred to as "coated conductor") may be used to build magnet coils in future fusion reactors to be operated at the comparatively high temperatures of 65 K. This, in turn, permits a simpler cooling concept which saves cryogenic power, thus resulting in a simpler, more efficient fusion reactor.

ITEP developed some first concepts of high-current cables made out of a coated-conductor material. Details are described in the section on "Development of Superconductor Materials and Applications in Power Technology."

To support this development, ITEP conducted some fundamental studies of the torsion occurring in superconducting tapes for Rutherford cable concepts. The stress components were determined by means of FEM calculations and compared with available tensile experiments. A clear influence of shear stress on the current carrying capacity was found compared to the longitudinal tensile stress in torsion of a superconducting tape.

ITEP is involved in numerous discussions about harmonization, with the participation of EFDA, in order to incorporate this work in a European framework.

Solenoid coil manufactured for the helium-3 polarizer of the university of Mainz.

Results from the Research Areas

Superconducting High-Field Magnets

Head: Dr. Theo Schneider

High-Field Magnet Laboratory

Developing superconducting magnets in the high-field magnet sector and for fusion research or nuclear physics purposes requires detailed knowledge of the physical properties of the superconductors and the necessary electrical components in the magnet current circuit, such as power supply leads, protective components, superconducting switches and connections. To characterize the superconductors, the superconducting high-field magnets unit of ITEP studied various Bi2223 and YBCO high-temperature superconductors for their transport current carrying capacity as a function of temperature ($T \leq 4.2$ K), the external magnetic field up to 20 T, and the angular position between the external magnetic field and the strip conductor. The anisotropy behavior is normally determined only in the two most extreme positions, i.e. the angles of 0° and 90° between the external magnetic field and the strip conductor. Figure 1 shows the example of a test setup used to determine the characteristic E(I) curve under the influence of the external magnetic field normal to the broad side of the strip conductor. The collective measurements, as shown in Fig. 2, prove the potential of the present commercial composite high-current superconductors for high-field magnet construction.

Within the framework of other ongoing projects, the team also examined superconductors and components for the WGTS (windowless gaseous tritium source) of KATRIN (Karlsruhe Tritium Neutrino Experiment), the AC-resistivity characteristics of NbTi superconductors, and the ratio of residual resistivity of copper, for example, for the W7-X power supply leads.

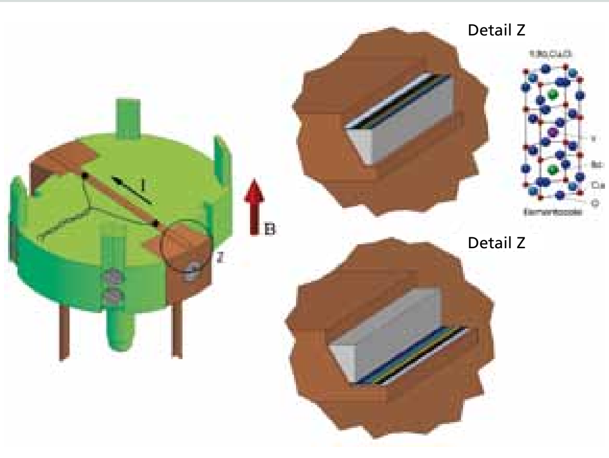


Fig. 1: Test set-up to determine the anisotropic physics properties of high-temperature superconductors with the magnet field positioned normal to the broad side of the strip conductor.

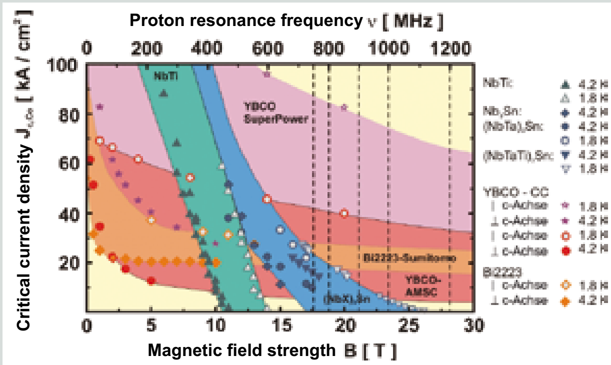


Fig. 2: The critical current density, J, plotted as a function of the external magnetic field, B, for commercial composite superconductors.

Modernizing HOMER I

The HOMER I facility is an indispensable tool for characterizing potential superconductors and for the quality assurance of superconductors in research, development, and technology transfer projects. Therefore, modernizing the plant is only possible in accordance with test operation. In 2009, the old cryo-control system in place since 1980 (partly pneumatic control operated on the spot with separate temperature logging on a multi-channel recorder) was replaced by a modern SPS control system for cryo-supply of the 300 W facility, which was then commissioned. The new control system mainly comprises these features:

- MIN selection with level control for the HOMER I external cryostat by means of a barrier.
- Optimized control of the bypass valve.
- Activation of the vacuum pumps by SPS.
- Temperature logging by SPS.
- Data exchange with the 300 W facility, and operation of the cryo-loop in HOMER I from the 300 W facility.
- Design of new plant flow sheets in the WinCC control and observation system for HOMER I and MTA I.

SPS control enables safe and stable operation and permits archiving by means of a visualization system. In view of potential tests within the framework of the EuCARD project, modernization of the MTA magnet test facility was begun at the same time (MTA I control in operation since 1988). For this purpose, a new 19" module was incorporated in the new control system for including in MTA I MIN selection with level control by means of a barrier.

Expansion of HOMER II

Depending on the experiments to be performed, future experimental operation of HOMER II requires different insert flanges to accommodate the test objects, current supply leads, and instrumentation. Currently, three insert flanges are being designed, constructed and installed, respectively. Due to increased demand and workload, in 2009 it was not possible for the workshop to complete the insert flange for the triple test coil set to characterize potential superconductors close to the operating point under a simultaneous Lorentz force. Completion and commissioning have been delayed until 2010. Another flange accommodating an $(NbX)_3Sn$ insert coil was completed in 2009. Figure 3 shows the basic design and the actual magnet flange.

In its final stage of completion, the HOMER II facility will have three main coil current circuits interconnected by strong electromagnetic coupling, and a test object cur-

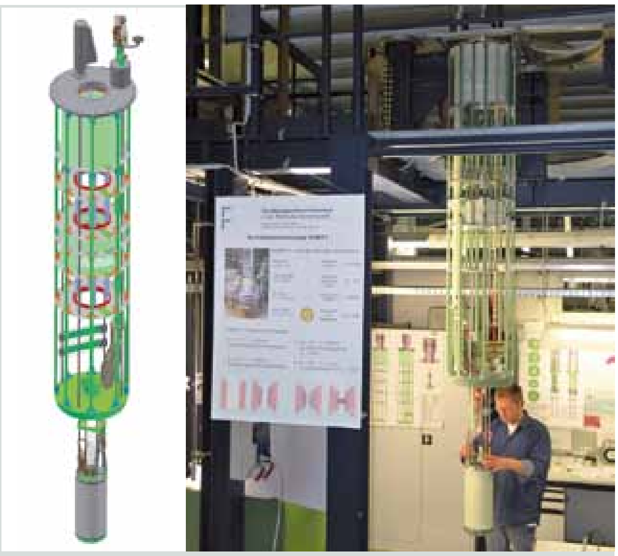


Fig. 3: Magnet flange accepting a 24-T $(NbX)_3Sn$ insert coil.

rent circuit, also with strong inductive coupling to the main coil system. Safe experimental operation of the superconducting coils of HOMER II requires a quench detection system for detecting and monitoring zones of normal conduction in the individual superconducting coils and to initiate timely safe shutdown of the entire facility. For this purpose, the quench detection unit must be stable under high voltages and shielded against spurious electromagnetic pulses.

The quench detection system in place had to be expanded for the new magnet flanges. The new design incorporates the positive experience gained from the quench detectors of the HOMER I facility installed in 2008. As in HOMER I, the quench detectors are redundant in design, flexible, and use variable shutdown criteria, such as threshold voltage and integration times. For low-risk operation of the facility, a commercial system logging the measured data was purchased to monitor the NbTi and $(NbX)_3Sn$ main coils. This freely configurable system is for continuous recording, displaying, and archiving of the electrical voltages in the magnet coils, quench detector balancing, and potential differences across superconductor connections, as well as for magnetic field control by pick-up coils and Hall probes.

EuCARD

What is the origin of mass? Why are there particles without mass? Does the Higgs boson postulated in the standard model really exist? These questions and similar ones are intriguing particle physicists all over the world. It is hoped that information will be gleaned from the results of the experiments conducted with the LHC (Large Hadron Collider) particle accelerator at CERN. The European Strategy Group for Particle Physics in July 2006 defined the priorities in particle physics for the next fifteen years. They encompass an LHC upgrade, research and development work in a TeV linear accelerator, and studies in neutrino facilities. These ambitious goals require mobilization of all European resources, as the scientific and technical challenges to be met far exceed the present state of the art facilities and the potential of individual laboratories or countries.

EuCARD combines the resources of 37 European accelerator laboratories, institutes, universities, and industrial partners involved in accelerator science and technologies. The project initiated by ESGARD (European Steering Group on Accelerator R&D) is financed in part by the European Commission within the 7th framework program for a period of four years from April 1, 2009. The main purpose is to conduct research and development for innovative concepts and technologies and, in this way, upgrade the large European research accelerators, with scientists being given the best facilities, and information to be exchanged through networks.

Upgrading the LHC to twice or three times its current level of energy means that the dipole magnets must produce a magnetic field of 20 T. This field, most probably, can no longer be achieved by means of NbTi and NbSn dipoles. Instead, coils made up of high-temperature superconductors are to be used. Plans provide for a modular design with an external background coil of Nb_3Sn (field contribution 14 T) and an internal insert coil of HTS contributing 6 T.

HTS dipole magnets are still under development, thus constituting a research and development package within the EuCARD project. Work is arranged in three phases: HTS conductor specification; HTS solenoid coil construction and testing; construction of an HTS dipole magnet. The superconducting high-field magnets group of ITEP is involved in the first and second project phases of EuCARD. The initial project phase has been mainly about the physical properties, such as critical current densities, measuring techniques, considerations of quench and stability, and the availability of the YBCO and Bi2212 commercial high-temperature superconductors.

Solenoid Coil for the University of Mainz

For several years, medicine has been using magnetic resonance tomography (MRT) with inhaled spin-polarized helium-3 as a new process of imaging the lung and its pathological changes, such as ventilation disorders. The polarized helium-3 gas atoms behave like tiny magnetic bars (dipoles). These dipoles are aligned in a preferential direction by optical pumping by means of a laser. The macroscopic magnetization of the gas produced in this way is approx. 100,000 times stronger than the alignment of the nuclear dipoles achieved by the magnetic field of an MRT for hydrogen nuclei in the tissue.

The helium-3 working group of the University of Mainz has advanced optical pumping processes such that the nuclear spins of the 3He inert gas can be polarized in quantities of litres, and has found possibilities to maintain this polarization for days. The working group is currently developing a new compact polarizer for producing spin-polarized 3He. In the new design, the required magnetic field of 10 G will no longer be generated by unwieldy Helmholtz coils (dia. = 1.6 m), but use a compact solenoid wound with insulated copper wire and shielded by a μ-metal tube to generate a homogeneous field in the whole interior of the coil. A new optical pumping section is to be developed which will use only one laser and, on the whole, will be easier to operate. The entire system is slightly longer than 2 m and has a diameter of approx. 810 mm.

Producing the solenoid with a diameter of 800 mm and a length of 2 m takes the experience and know-how of experts in high-field magnets. As a consequence, the high-field magnet unit of ITEP was responsible for the entire coil production process, from the sourcing and preparation of the precisely dimensioned coil structure of fiber glass reinforced plastic to the exact preparation of the different working steps, such as conversion of the winding device for accurate wire feeding, exact winding of the coil with a matching coil inlet and exit, up to safe assembly of the coil and the μ-metal tube. The complete solenoid installed in the μ-metal tube was delivered to the physicists of the helium-3 working group in late 2009.

Fig. 4a

Fig. 4b

Fig. 4c

Fig. 4d

Fig. 4 a-d: Manufacturing the solenoid (length 2000 mm; diameter 800 mm) for the helium-3 polarizer of the University of Mainz.

Highlight in 2009: 1000 MHz NMR Spectrometer

On June 1, 2009, Bruker BioSpin GmbH announced the commercial launch of the world's first 1000 MHz NMR spectrometer. Its successful commissioning represents another milestone in more than 25 years of cooperation between KIT and Bruker BioSpin GmbH (see Fig. 5). This very successful cooperation began with the design and construction of the world's first high-resolution 750 MHz NMR spectrometer. In that project, the breakthrough was achieved thanks to the low-loss croystats introduced by scientists at KIT, the compact new cryo-engineering system, new coil designs, new coil technologies, new magnet designs, successful persistent-mode operation with superconducting connections in high magnetic fields, and superconducting switches. In the follow-on projects, these technologies were successfully translated into NMR spectrometers up to 950 MHz. Around the middle of 2009, more than 150 high-field NMR magnet systems with resonance frequencies between 750 and 950 MHz were in place worldwide – a success never expected by the initiators in 1985.

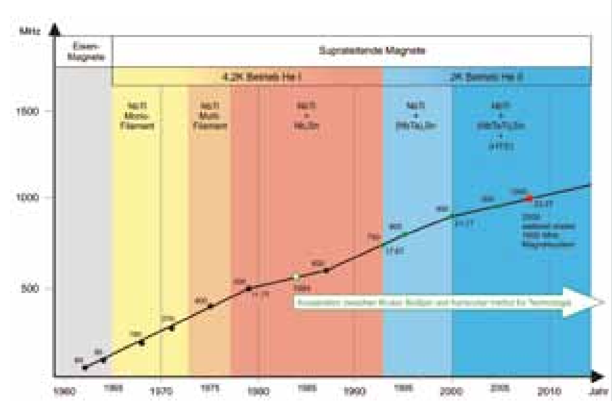


Fig. 5: Development of the NMR spectrometers.

The development of a 1000 MHz magnet system had been advanced worldwide from the mid-nineties on. In addition to the cooperation in Germany, funded by BMBF, of Bruker BioSpin GmbH, KIT, and the superconductor manufacturer, European Advanced Superconductors GmbH (EAS, formerly Vacuumschmelze), institutions like NHFLM in Tallahassee, USA, or NRIM in Tsukuba, Japan, as well as industrial companies, such as Oxford Instruments, also tried to reach this ambitious goal. The biggest difficulty in the development of a 1000 MHz magnet system, with 1000 MHz corresponding to a magnetic field of 23.5 T, is the design of the innermost magnet sections.

As Fig. 2 shows, the current carrying capacities of conventional $(NbX)_3Sn$ metal superconductors above 21.1 T are very low. Consequently, a 1000 MHz magnet system was attainable only with improved metal superconductors or with high-temperature superconductors as an alternative. The project funded by BMBF therefore sought to enhance the potential of superconductor metals and also study the usability of HTS as Bi2223 strip conductors. The introduction of high-temperature superconductivity in magnet technology also offers the possibility, in principle, to expand greatly towards higher fields the field range usable for NMR purposes.

However, the use of new superconductors entails numerous problems already solved in principle for superconductor metals, such as the development of HTS coil technology, winding technology and superconducting connections between the high-temperature superconductors. Problems also arise with superconductor metals in continuous-current operation. Major points of the project were the exact characterization, in physical terms, of the HTS strip conductors with respect to their critical currents, the n-value, the force load and thermal stability up to the definition of NMR capability.

Within the project the KIT team, performing parallel research and development (expansion of the HOMER II facility to field strengths of 25 T), showed that the HTS-Bi2223 strip conductors had not yet been fully developed. When operated in superfluid helium, the working temperature of a high-field NMR magnet, the conductors were destroyed by the penetration of helium, i.e. so-called ballooning. This problem was known to exist at a temperature of 77 K (lN2) and solutions were available. However, it had never before been observed at temperatures below 4.2 K.

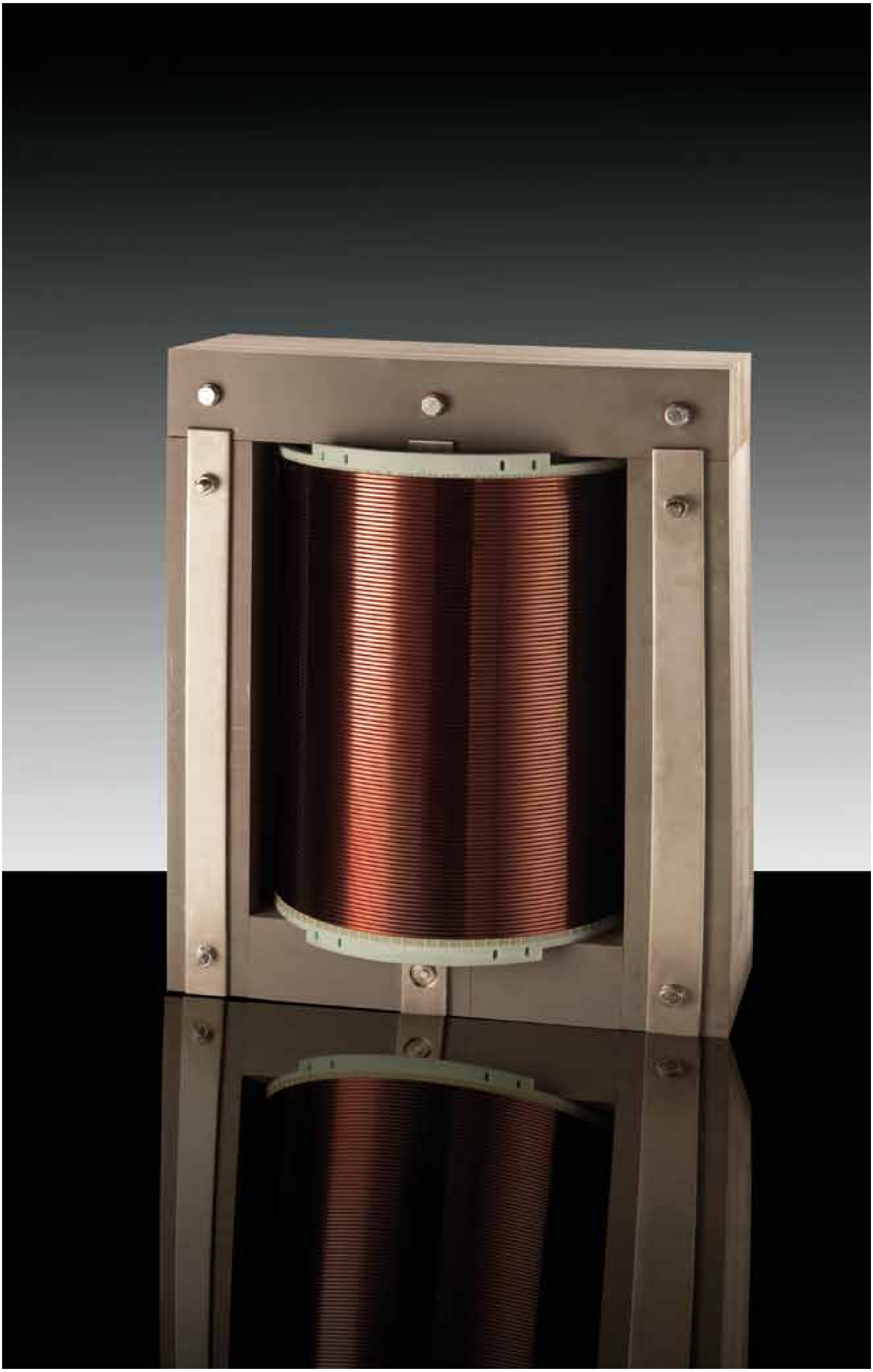
At the same time, greatly improved NbTi and (NbX)3Sn conductors were developed which showed sufficiently high critical current intensity, Ic, and also increased force loading above 200 MPa. After successful transfer of the connection technology to the improved superconductors there were no more obstacles in the way of building a 1000 MHz magnet system.

A magnet system was built which met these specifications:

- Magnet field: 23.5 T.
- Resonance frequency: 1000 MHz.
- Spatial homogeneity: $\Delta B/B_0 < 10^{-7}$ over 40 mm.
- Time stability (drift): $\Delta B(t)/B_0 < 10^{-8}$ per hour.
- Resolution: < 0.2 Hz.

The first 1000 MHz NMR spectrometer sold at a price of 11.7 million Euros and was installed at its destination (CRMN, Lyon) in early December.

Fig. 6: The world's first 1000-MHz NMR spectrometer with a field strength of 23.5 T (see www.bruker.biospin.com/pr090601.html).



Fault current limiting model transformer with a secondary winding made of high-temperature superconductors.

Results from the Research Areas

Development of Superconductor Materials and Applications in Power Technology

Head: Dr. Wilfried Goldacker

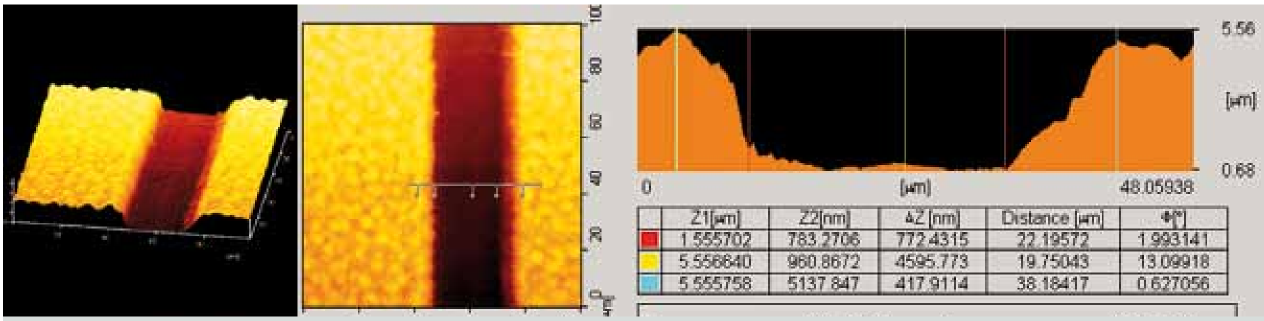


Fig. 1: AFM profilometer image of a laser-structured slit, and line scan for determining width (22.2 µm) and depth (4.6 µm).

The unit in charge of superconductor development at ITEP in 2009 focused on the production of magnesium diboride (MgB_2) cables, striated high-temperature superconducting YBCO coated conductors, and on the advanced development of Roebel cables made up of YBCO coated conductors. For both materials, work was performed in particular also on the development of superconducting connections. In addition, some tentative first concepts of high current HTS cables for fusion magnets were developed.

Development of low-AC-loss YBCO Coated Conductors

Activities were concentrated on conductors for AC-applications. Low-AC-loss YBCO coated conductors require structured layers. The most suitable manufacturing technique, among many other procedures, was found by the team to be a laser scribing technique with a picosecond YAG laser as the optimum tool. In the light of future low-AC-loss coated conductor modifications, studies were performed on the lamination of structured YBCO layers, and the properties of the superconducting connection were characterized. These activities serve to decrease hysteresis-induced losses by filamentizing the conductor and, additionally, transposing the current percolation path into a second superconducting layer. Figure 2 shows the geometry of the laser structure.

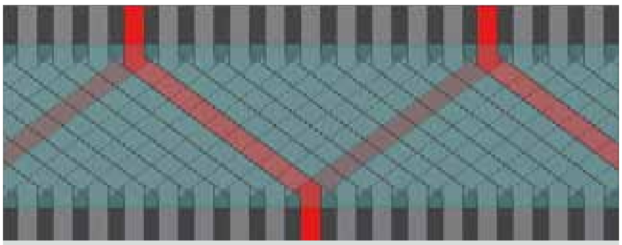


Fig. 2: CAD drawing of the superimposed laser structure of two superconducting YBCO layers and the transport current path produced.

Some first experiments were performed with face-to-face laminated laser-structured specimens. Various contacting thin films consisting of deposited metals or solution-deposited superconductor materials were applied. Some first low-resistive contacts were made. Magneto-optical imaging was employed to analyze the quality of the laser structure; this showed complete separation of the filaments at the striations.

Roebel Cable Made up of YBCO Coated Conductors

Low-AC-loss Roebel cables for high operating currents to be used in a variety of future applications in power technology are advanced continuously. The cable concept is perfectly suited for windings. Depending on the application, a few kA (motors, transformers) up to more than 20 kA (future fusion magnets) are necessary. For electrical machines, the superconductor development unit of ITEP studied the possibilities offered by cables only 4 mm wide. Different numbers of tapes, namely 14, 39, and 50, were employed; individual strands consisted of one, three, or five conductors (see Fig. 3). The current densities achieved reached approx. 1.3 kA. Measure-

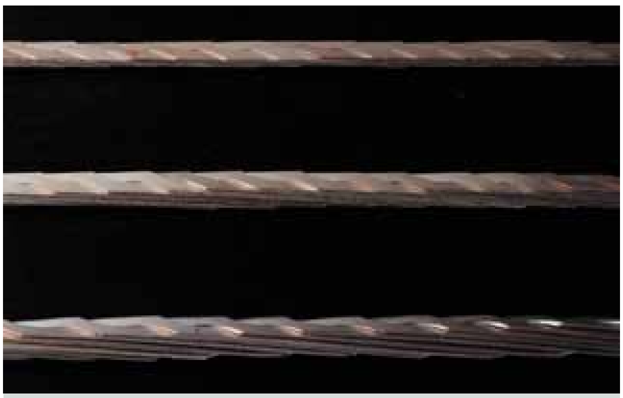


Fig. 3: Roebel cables with 14, 39, and 50 conductors (top down) and width of 4 mm.

ments of AC-losses demonstrated the expected reduction in loss and the possibility of adjusting the current by multi-stacking of strands.

Microstructure Studies

The team employed X-ray structural analysis and electron microscopy to study the microstructure of hot isostatically pressed Nb_3Sn specimens. The phase compositions as well as the grain sizes and grain structures were analyzed. Cooperation with the Berkeley National Laboratory and the University of Twente for the first time allowed tensile measurements to be performed in pure solid material. Point contact spectroscopy at the Physics Institute (PI) of KIT confirmed the existence of a second energy gap in stoichiometric Nb_3Sn. Figure 4 shows a scanning electron micrograph of Nb_3Sn grains of approx. 0.01 mm in a fracture surface of the solid material.

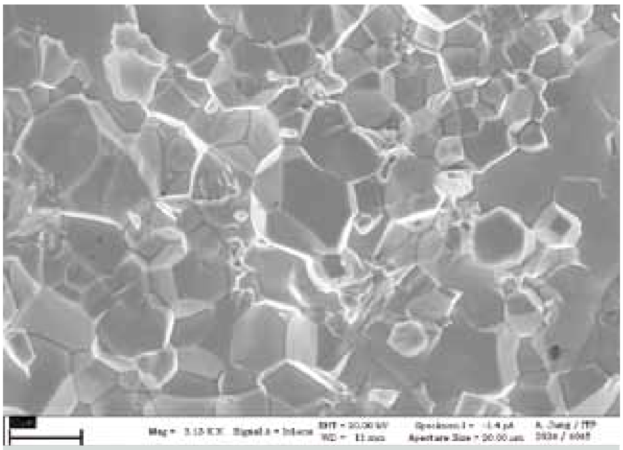


Fig. 4: Electron micrograph of the grain structure of a solid Nb_3Sn specimen. Grain sizes are around 0.01 mm in diameter.

Moreover, the team characterized the microstructure properties of the MgB_2 phase in superconducting joints, correlating it with the contacting mechanism. Electron microscopy was used to study the sintering behavior of the MgB_2 joints and the properties of the silver coating for lamination experiments and optimization of the contacting method for YBCO coated conductors.

Magnesiumdiboride Cables and Applications

Development work on magnesium diboride concentrated on the production of MgB_2 cables for AC-applications. Although MgB_2 conductors, unlike HTS tapes, can be produced quite easily in round or square cross sections, so far there have been very few efforts worldwide to reduce the AC-losses of these conductors, or develop low-AC-loss high-current cables out of this material. A cable-and-react (C&R) technique for production of MgB_2 cables with reduced ac-losses has been developed (see Fig. 5). The C&R technique allows strong deformation of the single strands during the cabling process and therefore realization of short twist pitches even below 1 cm without degradation of the critical current density. The superconductor development unit of ITEP designed an automatic cabling machine, which ensures homogeneous cabling of the wires.

Fig. 5: MgB_2 cable with thin strands.

Superconducting wire connections were developed further for the persistent-mode operation of superconducting magnets. An innovative manufacturing technique allowed wire connections to be made whose current carrying capacity is up to fifty percent that of the wires. In a magnetic field, the wire connections show a similar field dependence as the wires, which is a decisive criterion in technical application.

AC-Losses in Superconductors

The magnetic pickup coil method was used to measure AC-losses both in Roebel cables made up of coated conductors and in stranded conductors of MgB_2 wires. For the MgB_2 cables, AC-losses were measured as a function of field amplitude and frequency, and it was possible to demonstrate the AC-loss reduction on the scale forecast. For the coated-conductor Roebel cables, losses were determined in a variety of cable designs. One highly efficient way of reducing magnetization losses (hysteresis losses) turned out to be a reduction of cable width to only 4 mm.

The AC-losses of Roebel cables were modeled on the basis of numerical models (see Fig. 6) and compared with the results of other methods. Moreover, refined methods were developed to predict AC-losses in windings made up of coated conductor components, and the contributions to these losses as well as the influence of $J_c(B)$-dependence were analyzed.

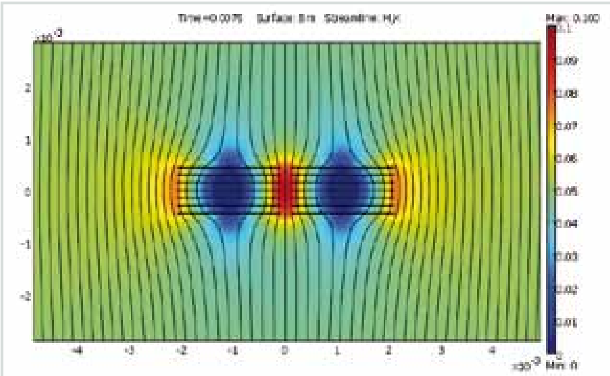


Fig. 6: Distribution of magnetic flux density in a Roebel cable with 14 conductors. The field amplitude is 50 mT, conductors are assumed to be isolated.

Superconducting Applications in Power Technology

To develop superconducting current limiters made up of YBCO coated conductors, the team elaborated the technical details, contacting methods, and cooling methods again within the framework of cooperation with industry. Additional applications were found within the framework of studies of new materials for use in power technology on the basis of YBCO coated conductors. In addition to work on modules of superconducting resistive current limiters, activities were devoted to superconducting current limiting transformers and lines for very-high-current transmission. In the field of very-high-current transmission lines, the team conducted a feasibility study taking into account both technical and economic aspects, and supported it in model experiments.

The laboratory facilities for testing conductors and superconducting materials were prepared and expanded particularly for studying HTS cables and FCL samples. One of the new items of equipment is an 8 T magnet system with a room temperature bore of 85 mm diameter for application of measurement systems at variable temperatures. Multiple holders were manufactured for studying cables which allow the strand material of flexible dimensions to be measured at reasonable expense. Magneto-optical imaging of current distributions, in addition to Hall probe scans with local resolution, allows inhomogeneous conductor properties to be analyzed.

Superconducting Current-limiting Transformer

The findings made in the studies of modules of YBCO coated conductors for superconducting resistive current limiters were transferred to the application of YBCO coated conductors in superconducting current-limiting transformers. In addition, YBCO coated conductors stabilized in different ways were studied to determine the recooling behavior of superconductors after current limitation under a current load. The maximum temperature reached by the superconductor during current limitation, and the current load in the superconductor immediately after current limitation, were varied systematically.

On the basis of the results obtained, a superconducting current-limiting transformer was designed which reduces by 50% any short-circuit current in the electrical power grid and is still able to recool after current limitation even under a rated load. The transformer has a rated capacity of 60 kVA at a primary voltage of 1000 V and a secondary voltage of 600 V. It was designed as a single-phase transformer (see Fig. 7). The primary winding was made of commercial-grade enameled copper conductor. The current-limiting secondary winding consisted of 48 m of YBCO coated conductor wound in two layers. The transformer was not designed for continuous operation and, consequently, is completely cooled in a bath of liquid nitrogen. The elements completed are available for measurements of the current-limiting properties and the recooling characteristics under current loads.

Fig. 7: Parts of an HTS transformer, HTS secondary coils, yoke, and Cu primary coil.

Fig. 1: Tritium supply from the tritium store (glove box in the background).

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 x 10^{16} Bq) of tritium, 100 kg of depleted uranium, as well as rubidium and krypton as test emitters for calibration. An experimental area in excess of 1000 m^2 holds more than ten glove boxe systems with an aggregate volume of approx. 125 m^3 as enclosures for the experimental equipment carrying tritium. The purpose of TLK when it was founded, and the most extensive 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.

TLK Operation and Infrastructure

The conventional as well as the tritium infrastructures of the Tritium Laboratory were fully available in 2009 to support the research projects for the Nuclear Fusion Program. In particular, the experimental facility for developing the plasma off-gas cleaning system for ITER (CAPER) was supplied with pure tritium from the tritium storage. After processing in CAPER, the tritium was purified, concentrated, and returned to the storage (see Fig. 1).

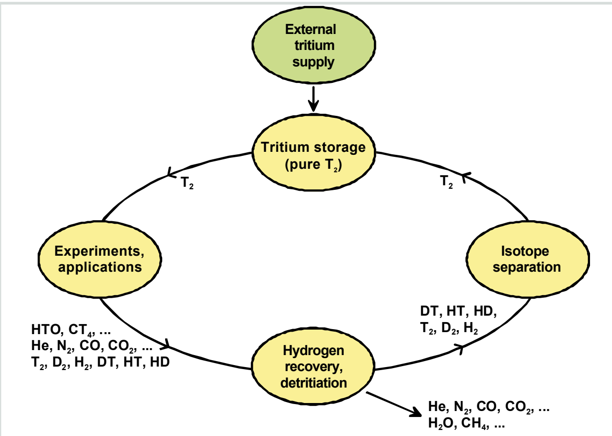


Fig. 2: Current tritium loop at TLK.

The licensing requirements listed in the new operating permit were met at all times. No complaints arose from supervisory visits by the licensing authority. No notifiable events occurred.

Most of the work on instrumentation and control focused on the development of a library of modules as a basis of PCS7 project design work on visualization and automation of the KATRIN tritium loop, the main spectrometer, the pre-spectrometer, and the monitoring spectrometer. These libraries are used to achieve uniform automation functions for the facilities designed and built, and also to provide a standardized operating interface for the operator. These activities were completed in 2009; the first part of the tritium loop was commissioned successfully (cf. "KATRIN" section).

Fig. 3: Teleperm-M cabinet.

Another important activity concerned a concept designed to replace the process I&C system of TLK. As the old Teleperm-M system is no longer maintained by the vendor, and spare components are no longer available, it absolutely needs to be replaced. Replacing the complete I&C system will take approximately three years and must not obstruct operation of TLK. Consequently, exact planning is imperative. On the basis of the concept elaborated it was possible to determine the optimum approach as well as the resources required (financial and manpower).

The isotope separation facility was recommissioned successfully. It had been shut down for more than a year in order to enable the internal tritium loop to be built up for KATRIN in the ISS glove box (cf. Section on "KATRIN").

Research and Development for ITER

Processes for water detritiation (WDS) and hydrogen isotope separation (ISS) are being developed and studied at the Tritium Laboratory within the Fusion Program. These technologies are required for the fuel cycle of future fusion reactors, and are adapted to the respective requirements.

At TLK, techniques are developed within the TRENTA experimental program, and combined. The aim of these activities is to produce important data for the WDS and ISS ITER systems and, in this way, make decisive contributions to the design of the WDS-ISS European procurement package of ITER.

In TRENTA 3, the water detritiation system (WDS), the familiar CECE (Combined Electrolysis Catalytic Exchange) process is applied to recover tritium from tritiated water. The two main systems of the CECE process are two electrolysis units with a total capacity of 2 m³/h of hydrogen gas and an LPCE (Liquid Phase Catalytic Exchange) column of 8 m length.

Hydrogen isotope separation is achieved by cryogenic distillation at temperatures in the range of 20 to 30 K. The process is based on the fact that the different species (H_2, HD, D_2, HT, DT, T_2) have different boiling temperatures. In a first step, various packing materials for the cryo-columns were tested with H_2 and D_2 at TLK in 2007 and 2008. The focus at that time was on an effective separation of the isotopes and a minimal hydrogen inventory. In later operation with tritium in ITER, the problem of the inventory is one of the most important issues because of its relevance to licensing.

The most important activity in 2009 was testing the so-called CY packing, which is a fiber packing. According to the first preliminary experiments, the packing has promising properties. Several measurement campaigns of one week each were conducted at TLK within a F4E task (Fusion for Energy, EU Agency) in the second half of the year, and the CY packing was tested in the cryo-column with different H-D mixtures. Some first evaluations seem to indicate that the hydrogen inventory in the cryo-column under normal operating conditions is higher than generally expected. The current discussion with F4E is about the way in which this important work is to be continued.

Work on combining the WDS and the cryo-column into the TRENTA4 facility was advanced alongside the measurement campaigns with the cryo-column. The focus was on the interfaces between the two subsystems. Figure 5 shows a greatly simplified schematic diagram of the facility to be completed in 2010.

TLK will be able to feed the recovered enriched tritium from the WDS straight to the cryo-column (ISS) with TRENTA4, and, in this way, test the combined system which will be used for tritium recovery also in future fusion reactors (such as ITER).

Fig. 4: Typical packing made of fabric.

Blanket and Tritium Technologies

Within the FUSION program, the recovery of tritium from the breeding blanket is a major challenge in the light of DEMO. So far, only concepts with semi-continuous processes have been studied (various traps in the adsorption or regeneration modes). However, one optimal approach would be a continuous concept without, at the same time, major temperature fluctuations (cooling, heating).

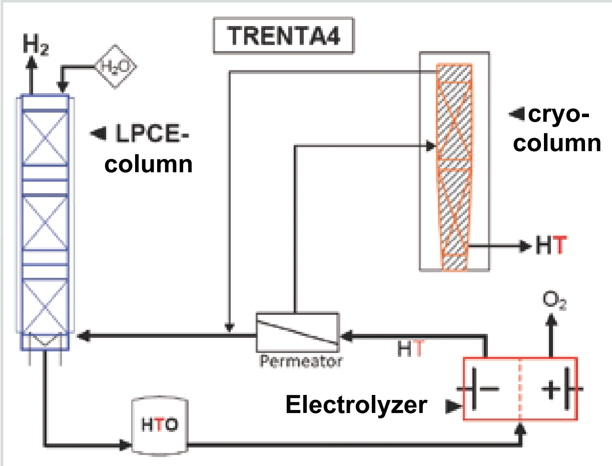


Fig. 5: TRENTA4 - WDS and cryo distillation.

The continuous concept proposed by TLK in 2008 requires a so-called PERMCAT, a combination of a catalyst and a permeator, to recover tritium from water, plus a selective permeator as a preliminary stage in order to separate most of the helium of the blanket purging gas.

While a technical solution for PERMCAT is available at TLK, the adequate materials for the selective permeator have yet to be found. For this purpose, two main activities in this area were pursued in 2009: On the one hand, preparations were begun to convert the CAPER facility for processing tritiated water by means of a PERMCAT. This work will be completed in 2010; some first test measurements next year may be a realistic assumption. On the other hand, a study of zeolite membranes was completed together with the Institute of Technical Process Engineering which provides some first indications of the further approach to be used in identifying suitable permeator membranes. Work will be continued in 2010.

In tritium technology, a major step forward has been taken in the successful commissioning of an optimized cross-shaped ionization chamber (see Fig. 6). This revitalized 20-year-old know-how which had almost been lost. TLK is now able again to produce, or have produced, ionization chambers specific to the respective process and meeting the state of the art.

Analytics at TLK

Managing qualitative and quantitative analyses of the six hydrogen isotopologues, H_2, HD, D_2, HT, DT, and T_2, and of other tritiated compounds (such as HTO) is a necessary prerequisite for handling tritium, and makes heavy demands on experimentalists and their equipment. Because of the great significance of analyses in TLK, this research and development work is coordinated and carried out in a transprogram-transgroup approach.

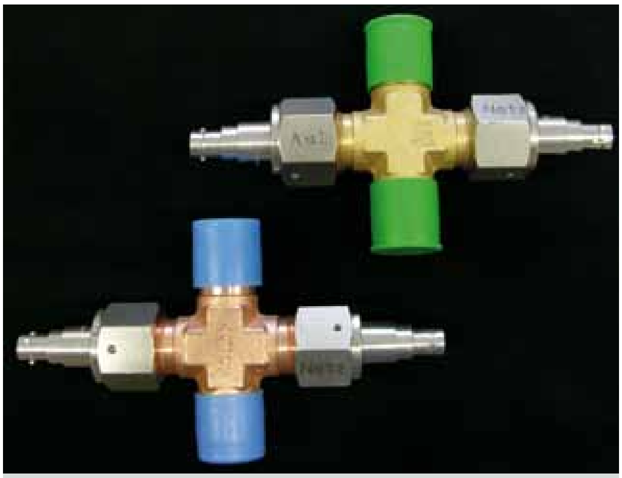


Fig. 6: Cross-shaped I-clamps electroplated with gold and aluminium, respectively.

In addition to the advanced development of the process ionization chamber used throughout the tritium facilities, which was described in the section above, research and development work in 2009 was concentrated on these areas:

- Development of an infrared spectroscopy system for liquid hydrogen within the framework of a diploma thesis (see "2009 Highlights") below.
- Laser Raman spectroscopy measurements of tritiated hydrogen isotopologues (see "Highlight" in the section on "KATRIN"). Several diploma and doctoral candidates contributed to this work, which was performed in cooperation with the University of Swansea.
- Development of a BIXS (Beta-ray Induced X-ray Spectroscopy) detector to measure tritium concentrations in water. In cooperation with the University of Toyama and in the frame of a diploma thesis, a novel detector (see Fig. 7) was commissioned, and some first measurements of tritiated water were carried out. These measurements are currently being evaluated.

Alongside pure research and development work, existing systems, such as calorimeters and gas chromatographs as well as existing calibration techniques, were further optimized. In addition to the I-chamber, these systems constitute the backbone of analytical work at TLK and are used as standard features.

Highlight in 2009: Infrared Spectroscopy of Liquid Hydrogen Isotopologs

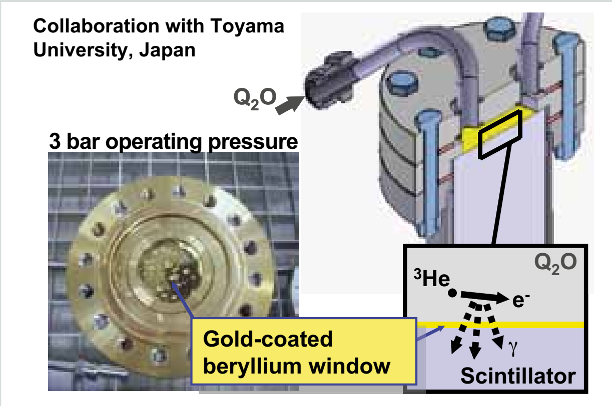


Fig. 7: BIXS detector.

As mentioned above, the TRENTA facility consists of a water detritiation system (WDS) and an isotope separation system (ISS) in which the hydrogen isotopologues H_2, HD, D_2, HT, DT, and T_2 can be separated by cryo distillation. As the boiling points of various isotopologues are spread over almost 5 K, ISS can be built as a rectification column.

For process control of TRENTA (and of ITER in the future), a non-invasive method of determining the concentration of the liquid in the bottom of the column, the point of the highest tritium concentration, is needed. For this an analytical method supplying up-to-date concentration levels reliably and quickly from the bottom of the columns without upsetting the distillation processes is needed.

A method which works without explicit sampling is preferable, as gas sampling will upset the system and produce waste. The methods so far employed in TRENTA are based on gas sampling, the products of which are analyzed by means of a quadrupole mass spectrometer. Alternatively, the gas samples extracted are first oxidized and mixed with a liquid scintillator; subsequently, the tritium concentration is determined in a scintillation counter. Both methods provide analyses only after some time delay, and they produce waste.

The methods of choice available are optical methods, such as laser Raman spectroscopy or infrared spectroscopy which, in principle, can be applied "in line," i.e. without sampling, and in "real time." In a physics diploma thesis written in 2008/09 together with the Institute for Experimental Nuclear Physics (IEKP) of KIT in the TRENTA group at TLK, the use of infrared signals to analyze liquid H_2, D_2, and HD was studied.

As no infrastructure for this kind of IR spectroscopy had been available so far, a suitable measuring setup had to be developed first, with the development of the measurement cell representing the greatest challenge. Those were the most important technical requirements:
Tritium compatibility of all materials.
Operation at temperatures between 20 and 25 K and a pressure of up to 10 bar, and free access to the optical windows of the cell.

The measurement cell successfully built and commissioned within the study is shown in Fig. 8.

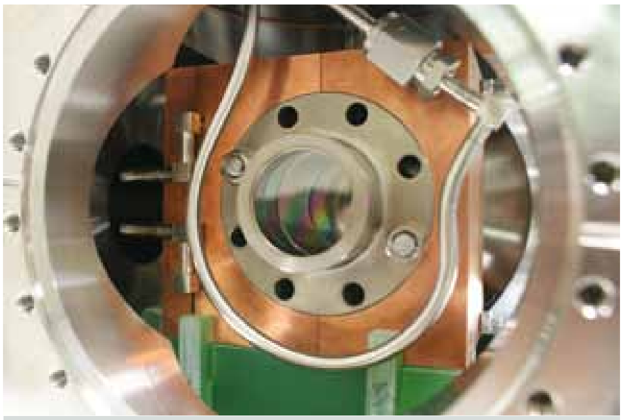


Fig. 8: IR measurement cell in the cooling structure.

The cooling structure of the measurement cell was connected to the cooling system of the TRENTA facility and operated with the associated refrigerator. The FT-IR spectrometer, Tensor 27 (Bruker), was used as the IR source. It operates in a wavelength range of 600 to 12,000 cm^{-1}, allowing the IR signal emitted by a silicon carbide tip at 1350 K to be released from the spectrometer by means of a mirror, and to be analyzed in an external detector (in this case, HgCdTe).

Figure 9 shows the transmission spectrum of a mixture of 8.3 vol.% of H_2 in D_2, measured in the liquid phase at 22 K and 2.5 bar absolute pressure. In the range between 6500 and 5700 cm^{-1}, the so-called second vibration range of D_2 can be found, while the first vibration range of H_2 is seen in the interval between 5500 and 4000 cm^{-1}.

Results made in the study:

- The feasibility of the method was demonstrated.
- All lines predicted theoretically in the transmission spectrum were identified. The detection limit of HD was determined as < 10 ppm by means of the R1 resonance band.
- More research and development work is necessary, on the one hand, to optimize the hardware (such as better heat coupling) and, on the other hand, obtain more experience in the interpretation of IR spectra.

The results are to be presented at the 2010 Tritium Conference.

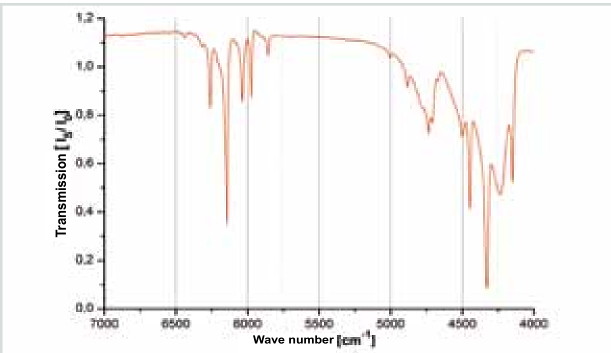


Fig. 9: Transmission spectrum of H_2 in D_2.

Work in preparation of the TIMO-2 test facility

Results from the Research Areas

Vacuum Science and Technology

Head: Dr. Christian Day

In 2009, the vacuum technology department of ITEP resumed detailed design work for ITER. It concluded contracts with the Fusion for Energy (F4E) fusion agency in various areas to ensure that the findings elaborated will be fully integrated into ITER. In this respect, the three large cryopump systems for ITER (torus, cryostat, and neutral beam injection (NBI)) will be developed to the series production level under the leadership of ITEP over the next five years. Prototype cryostat and torus pumps will be built and tested in the TIMO-2 test facility at the Institute; subsequently, the final design of the pumps for series production will be elaborated. Another prototype will be built for the NBI pumps which will be installed in the neutral beam test facility in Padova, Italy, for testing there.

Earlier in the year, the vacuum technology department unit had to accommodate the move to ITER and W7-X of several long-time staff members. However, these positions have meanwhile been refilled excellently by new staff members with key qualifications. In this way, the opportunity was used to put more emphasis in the areas of thermal hydraulics and flow simulation. In addition, a professional quality management system is currently being set up to provide the competitiveness also in future tendering procedures for ITER and F4E.

Torus and Cryostat Cryopumps for ITER

As a first step, the complete design of the prototype torus cryopump must be worked out. For this purpose, all relevant requirements were collected, initially together with ITER. This is to help the prototype to be built in such a way that it may be used later as a spare cryopump in ITER. As a consequence, all rules and design guidelines applying to nuclear components must be observed. In particular, the design process must be documented in a detailed catalog of supporting calculations (strength calculations, thermomechanical and thermal hydraulic calculations, seismic events, etc.). Figure 1 shows the present state of development.

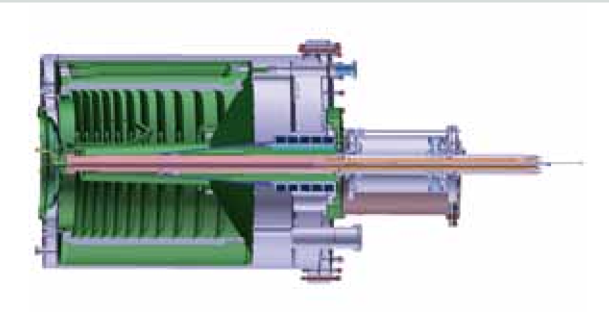


Fig. 1: 3D CAD model of the prototype torus cryopump. The inlet valve (left) has a diameter of 800 mm.

The torus cryopump contains an integral inlet valve controlling the incoming gas flow from the plasma chamber, and closing under regeneration conditions. The valve is sealed relative to the pump housing by a static metal ring whose behavior, however, is not yet known for this dynamic application. For design verification, a test facility is now being built to study quantitatively the dependence of the resultant leak rate on the closing force (up to 200 kN).

The final upgrade works in the TIMO-2 experimental facility have begun; in this way, the two recently defined additional ITER modes of operation are provided for. On the one hand, this implies supply at 4.3 K (instead of 4.5 K). As a result of this lower inlet temperature at the same temperature of 4.7 K at the pump outlet, the necessary cryogenic flows can be reduced accordingly. ITEP achieves this simply by having the liquid-helium bath in the control cryostat of the experimental facility pumped to a lower pressure. The cryo-engineering group of the Institute is able to do this at relatively little expense within the existing cryo-infrastructure. Secondly, supply at 100 K is implemented. This increase over the standard temperature level of 80 K is a consequence of the outcomes of earlier experiments, allowing a quasi-100 percent release of hydrogen during regeneration. In TIMO-2, the 100 K supply is achieved by means of liquid nitrogen, which is at a boiling pressure of 8 bar at that temperature (concept by the Messer Group, Krefeld). After completion of these extensions, the TIMO-2 experimental facility is ready for the tests with the prototype pump.

A first component required for installation of the prototype pump has already been delivered: an adapter flange ring acting as an intermediate section and sup-

Fig. 2: The adapter flange (diameter 2 m), the first component for the new tests in TIMO-2.

port between the pump and the TIMO-2 test vessel flange (see Fig. 2).

NBI Cryopumps for ITER

F4E and ITER decided in mid-2009 to build a full-scale test bed for an ITER neutral beam injector at Padova, Northern Italy. The project will run for a period of ten years. The vacuum technology department of ITEP is responsible for the cryopumps in the project which may be considered prototypes of the ITER-NBI cryopumps. These cryopumps, of which there will be eight in ITER, are outstanding because of their size (up to 8 m long, 2.5 m high). They have a record pumping speed of approx. 5000 m^3/s for hydrogen; alternatively, this would require 2000 units of the largest turbomolecular pumps available.

The cryopumps are supplied with cryogenic helium gas (at 4.5 K and 80 K). Optimum cryo-supply is essential to the operation of these extremely large pump systems. Above all, this implies small and, hence, acceptable pressure losses. As so-called hydroformed components are used, it is not possible to predict reliably the pressure loss. As a consequence, the focus in 2009 was on measurements of hydroformed components. Figure 3 shows the THEA facility employed for this purpose in the test mode in which water can be used at various temperatures to reproduce Reynolds number ranges similar to those prevailing in the cryopumps. It has been possible, in this way, to demonstrate that the pressure loss is roughly a factor of three lower than had been assumed so far on the basis of industrial software codes results. This allows the design to be simplified greatly. As the results produced in THEA are very promising, an even more extensive test program will be run in 2010 in order to identify further potential for optimization.

Fig. 3: Measuring pressure losses in complex components over a broad range of Reynolds numbers in the THEA facility.

Modeling Vacuum Flows

Work in the field of flow simulation was continued most successfully. For this purpose, measurements were carried out in various short (circular) flow channels in the TRANSFLOW facility. The short channels are typical of many vacuum applications, not only in ITER; flow processes are difficult to describe as velocity profiles are still developing, i.e. are not steady-state. For comparison with measured results, the flow conditions were simulated in a Direct Simulation Monte Carlo (DSMC) approach. Figure 4 shows an example of the mesh used for modeling. The mesh density is staged, being higher near the inlet and the outlet to ensure excellent resolution even in these critical areas with pronounced density gradients. Figure 5 shows excellent agreement between the measurement and simulation. The graph indicates the volumetric flow as a function of the inverse Knudsen number. The Knudsen number describes the flow regime: Knudsen number >> 1 means highly diluted, i.e. free molecular flow, Knudsen number << 1 means viscous flow.

Similarly convincing results were obtained in 2008 for long channels with fully developed flow profiles. The project, extending over many years, for modeling vacuum flows thus enters its final phase in which also geometrically complex systems are to be modeled (such as those with temperature-induced density gradients). Two different Monte Carlo program packages are being developed for this purpose.

Collaborations

The vacuum technology department of ITEP has accumulated extensive experience about vacuum flows over the past couple of years, which has become visible also internationally. Thus, it successfully conducted flow calculations for the Carl Zeiss company regarding a multichamber vacuum system for EUV lithography. Two researchers of the University of Thessaly, Volos spent fruitful time at the Institute. The world's leading expert in the field of modeling rarefied gas flows, Professor Dr. Felix Sharipov, decided to spend one year at ITEP for a continuous exchange between theory and practice. The first problem addressed by the vacuum technology department together with Dr. Sharipov was a key question of vacuum technology department still unsolved as yet; the fundamental understanding of leakages of pipes carrying water into the vacuum and their detection. For this problem, it must be considered that the flow on its path through a microchannel or crevice changes the

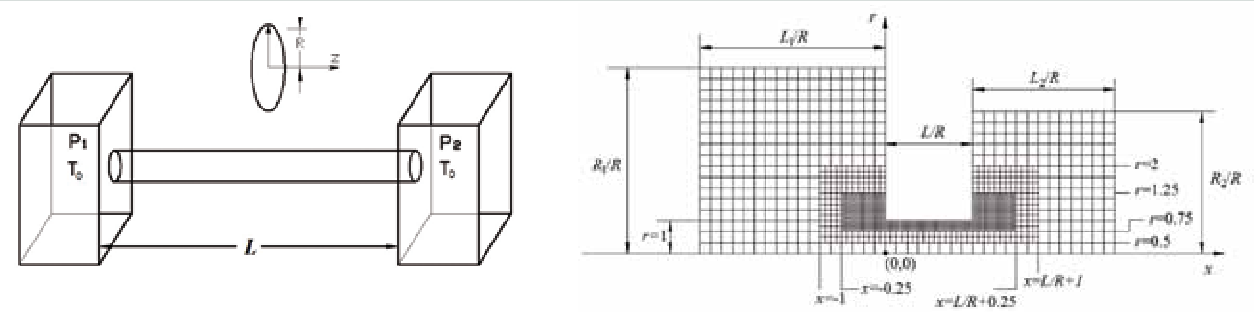


Fig. 4: Modeling and meshing for numerical simulation of the vacuum flow through short pipes in the transition range.

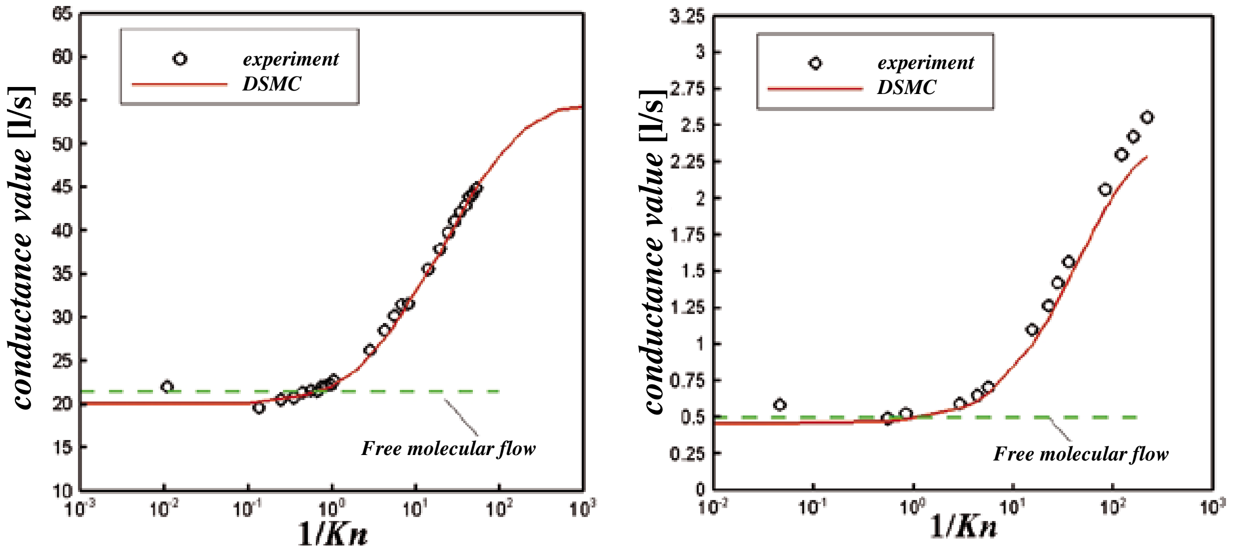


Fig. 5: Comparison between measurement (nitrogen, ambient temperature, TRANSFLOW, ITEP facility) and simulation (DSMC) of the flow regimes for two short pipes (left: length/diameter = 1; right: length/diameter = 4.28).

water phase from liquid (inside) to gaseous (at the latest at the outlet into the vacuum). This phase transition implies completely different flow regimes. Kinetic theory based on the solution of the Boltzmann equation was able to show how the location of the phase transition depends on temperature, pressure, and the size of the channel, and what concentration profile to expect at the outlet of the gap. This is the key information helping to interpret quantitatively the values measured in a helium leak test in a complex system difficult to access, such as ITER.

Highlight in 2009: Caution – An Artist Calls, or: How Cool Are Coconuts?

One special technology of the cryopumps developed at ITEP is cryosorption. This means that the gases difficult to pump are not condensed but adsorbed onto a porous material, thus changing from the gaseous phase into a bound phase. The pressure in the gas phase decreases and a vacuum is produced. Over many years of experiments, the vacuum technology department has found a specific type of activated carbon with the best vacuum pumping speed. This activated carbon, without which a fusion reactor, such as ITER, would not work, is produced by coking coconut shells. Comparative studies of various batches of the material have clearly shown the properties to depend on the quality of the coconut harvest in the respective year.

This finding was ample reason for ITER to write a KIT home story. The main players: the ITEP vacuum technology department, coconut activated carbon from prime vintage, and the artist and photographer, Peter Ginter (www.peterginter.de).

The team was busy for two days buying probably all the coconuts available at Karlsruhe supermarkets. However, it was worth the trouble. One man, one assistant, the models of the vacuum technology department, simple means – great pictures. Who would have thought that activated carbon could be so sexy?

The project had a resounding success in the media, making headlines, such as "Handle with Care, the Totally Tropical Tokamak" (New Scientist), "Vintage Coconuts Are Cool" (ITER Newsline), "Building a Second Sun: Take $10 Billion and Add Coconuts" (Technology Review). And the gist of it: A great campaign for the work of the vacuum technology department of ITEP, for KIT, and for ITER, and lots of fun on top of it.

Note: Of course, ITEP bought up all commercially available stocks of activated carbon of the best vintage, which adds up to a few tons of material sufficient for the next three or four ITERs.

The photographer on the set in the ITEP hall, and what came of it.

Machine hall of the 300 W cryoplant.

Results from the Research Areas

Cryogenics

Head: Dr. Holger Neumann

Cryogenics for Fusion

Cryo-engineering work for the "Fusion" program in 2009 was focused mainly on building superconducting power supply leads and on planning supplies to the corresponding CuLTKa (Current Lead Test Facility Karlsruhe) test rig, including integration into the existing cryo-infrastructure. In order to be able to manufacture prototypes of the power supply leads even before completion of CuLTKa, a test cryostat is to be connected to TOSKA, preparations for which were made in 2009. All these activities are earmarked for the W7X fusion experiment in Greifswald.

W7X Power Supply Leads

The cryo-engineering unit of ITEP continued work on the prototype W7X power supply leads in 2009. In addition to design work, also manufacturing activities, including preliminary tests of specific manufacturing steps, were carried out. Thus, the team started experiments on coating the HTS stacks with parylene to protect the superconductor from oxidation. The prototype HTS modules were equipped with temperature sensors.

Fig. 2: Prototype power supply leads after soft soldering of the heat exchanger, HTS module, and cold contact.

After manufacturing the two heat exchangers for the prototypes, the vacuum sleeves were welded in place and leak tested successfully. Also the TVO sensor lance and its penetration were installed. This completes work on the heat exchangers.

Another important step was the assembly of the prototype power supply leads with soft soldering of the heat exchanger, the HTS module, and a cold contact.

Preparations for Testing the W7X Prototype Power Supply Leads in TOSKA

As the test facility for the W7X power supply leads will not be ready before 2011, the prototypes are to be tested in a test cryostat to be connected to TOSKA so as to make use of the existing infrastructure and minimize expense. The test cryostat was designed and built. Fab-

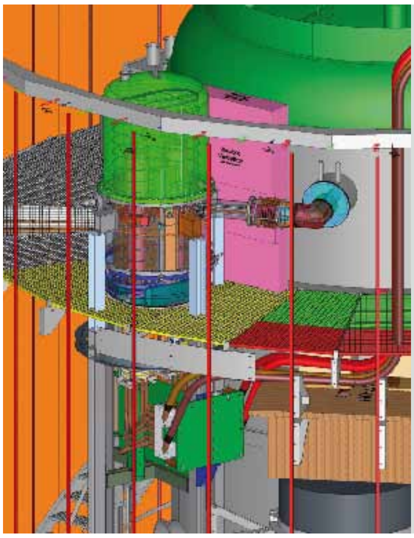


Fig. 3: Test cryostat for prototype power supply leads with a connecting line to TOSKA.

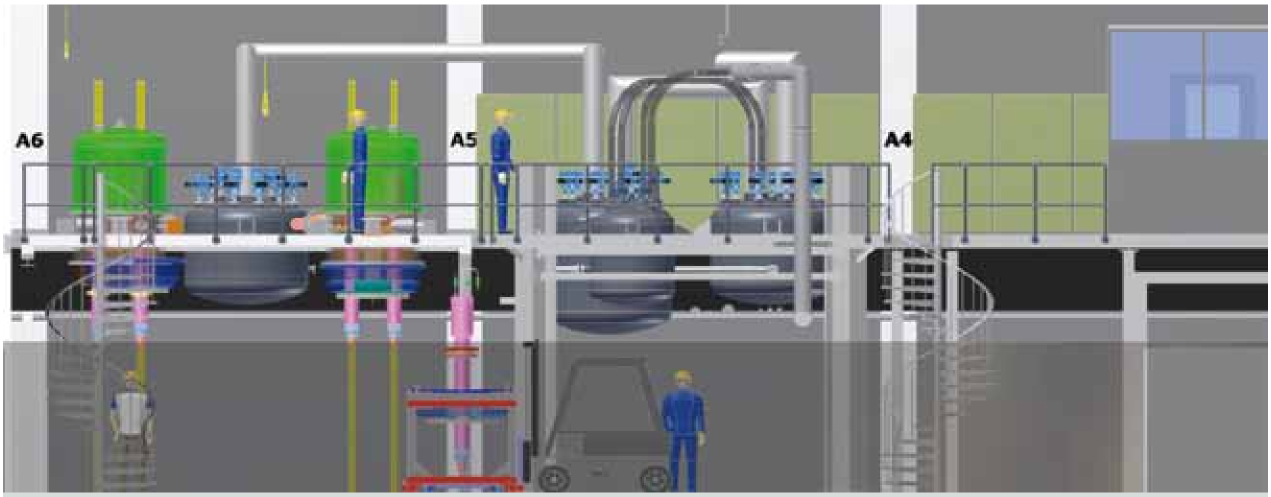


Fig. 4: CuLTKa.

rication will be completed in 2010. Also the connections in TOSKA, controls included, were modified greatly for this prototype test in 2009.

CuLTKa (Current Lead Test Facility Karlsruhe)

For the serial test of the W7X and the JT60 power supply leads, the cryo-engineering unit designed a test facility consisting mainly of a valve box for distributing the helium mass flow of the 2 kW facility to TIMO, CuLTKa, FBI, and perhaps later to the high-field magnet laboratory, a control cryostat for CuLTKa with a subcooler to produce various temperature levels, a valve box distributing the mass flows to one of two power supply lead test vessels, and the power supply lead test vessels. In 2009, the conceptual design phase including the R&I scheme were completed, the stage including the infrastructure was converted almost completely, and manufacturing the first test vessel was begun.

Cryogenics for REU

In 2009, THISTA (test rig for studies of thermal insulation in cryo-equipment) was modified so as to improve the degree of automation in operation and measured data logging, and upgrade the insulation in order to reduce zero losses. For the latter purpose, connecting lines and the cooling shield were modified. Moreover, the vacuum pump rig was replaced by a new one.

Fig. 5: THISTHA lower cooling shield with connections for test objects and sensors.

After this conversion, the facility was commissioned, and the zero losses were measured. Measurement indicted that the modifications made reduced zero losses by nearly 30%, which clearly improved the measuring accuracy of the facility. In 2009, the team again planned experiments with various kinds of superinsulations for industry. The calibration laboratory was added one room, for which the necessary infrastructure was installed in 2009, such as pipes and connections for helium, nitrogen, compressed air, and electricity as well as two laboratory tables for future work with the required equipment.

After these modifications, the calibration cryostat resumed operation. The team examined rhodium-iron sensors under a variety of boundary conditions. The results will be published at ICEC 23 in 2010. As the suitability of FBG (Fiber Bragg Getter) sensors for cryotechnology was demonstrated over the past couple of years, these sensors are now going to be used for various applications. In cooperation with the high-field magnets group, the FBG-sensors were applied to a NbTi-conductor for studies of the forces generated during loading and quenching. The first few experiments were extremely promising; studies will be continued in 2010.

Fig. 6: Laboratory table for the enlarged calibration laboratory.

For a joint project with Siemens, in which the cooling loop of an HTS generator is to be studied, rotating optical penetrations for FBG sensors were tested successfully. This means that the problematic signal transmission technique of sliding couplings could be given up.

Cryo-infrastructure

Work on cryo-infrastructure included extensive maintenance and repair, expansion, adaptation, and operation of existing experimental cryo-facilities for research purposes as well as planning, manufacturing and commissioning of new ones.

The 300-W (1.8 K) He low-temperature facility was in operation for approx. 866 hours in 2009, of which 149 hours were for liquefaction, while 79 hours were for sweeping as well as cooling and heating, which means that 638 hours of cryogeneration were used for experiments in the high-field magnet area.

Die 2-kW (4.5K) He low-temperature facility was run for approximately 998 hours in 2009. Of this, 498 hours were for liquefaction, while 192 hours were for sweeping as well as cooling and heating the facility. Consequently, 283 hours of cryogeneration were used for experiments in the fusion domain.

On the whole, the facilities liquefied approx. 116,317 liters of helium. Of this quantity, 72,148 liters were used for experiments in ITEP, while 44,169 liters were distrib-

Fig. 7: Control room with new and additional monitors.

uted to outside institutions. In addition to service work, numerous improvements were made to existing plants. Thus, the control room was equipped with new and additional monitors for controlling and supervising the different facilities and experiments.

The 5000-liter tank of the 300 W-facility was fitted a new temperature sensor which first had to be brought up to ambient temperature and then had to be cooled down again to the temperature of LHe. A number of defective high-pressure valves of the high-pressure cleaning facility were replaced. A new fan with a frequency converter control system was installed for the sound attenuation hood of the helium recompression facility; the fan was fitted a new exhaust air sound attenuator.

The MSR technology systems were prepared for incorporation of the control of CuLTKa; for this purpose, the AS5 Teleperm AS488TM system was replaced by a Simatic PCS7, including software porting. Also, the Teleperm CS275 bus system was coupled to the Simatic Industrial Ethernet (PCS7) by means of a new bridge.

The operating system was advanced from WinCC V6.1 to a PCS7 V7.0 I&C system. For this purpose, DAKO (S5 -> PCS7) and AS5 (AS488 -> PCS7) were converted, and the user software was ported or rewritten. Couplings to all participants were redesigned.

Fig. 8: Implementation of a new temperature sensor in the 5000-liter tank of the 300-W facility.

Fig. 1: Arrival of DPS2-F in July 2009. The KATRIN main spectrometer can be seen in the background.

Results from the Research Areas

KATRIN, Karlsruhe Tritium Neutrino Experiment

Head: Dr. Beate Bornschein

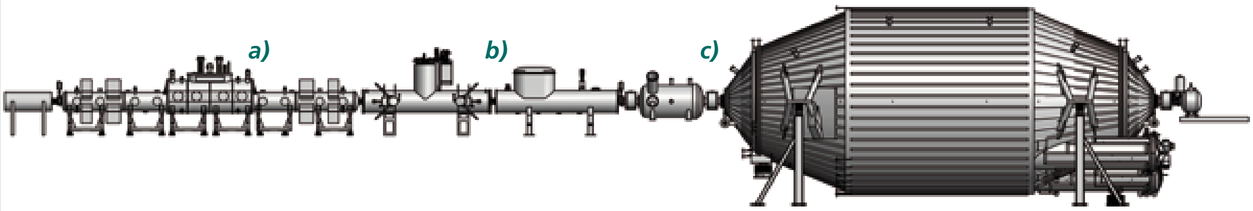


Fig. 2: Schematic diagram of the KATRIN international large-scale experiment. The electrons produced in β-decays in a high-intensity windowless molecular tritium source (WGTS, (a)) are passed through a tritium pumping section containing DPS2-F and CPS as active and passive elements (b) to a system (c) made up of two electrostatic spectrometers (pre-spectrometer and main spectrometer). The electrons analyzed are detected in a solid-state detector (d).

The aim of the Karlsruhe Tritium Neutrino Experiment KATRIN is the model independent measurement of the neutrino mass with a sensitivity of 200 meV/c^2. The motivation for building KATRIN is due to the key role of neutrinos in astroparticle physics: On one hand, massive neutrinos play a specific role as hot dark matter in the evolution of large scale structures in the universe, while, on the other hand, massive neutrinos have a key function in the unsolved problem of the origins of mass.

The experimental principle of KATRIN is based on the precise measurement of the energy spectrum of electrons the β-decay of molecular tritium close to the kinematic end point of 18.6 keV. For this purpose, electrons from a windowless gaseous tritium luminosity source with high luminosity are being guided through strong magnetic field created by superconducting magnets through the 70 m long experimental facility. A system of two electrostatic spectrometers allows the determination of the electron energy with a resolution of 0.93 eV (Fig. 2).

Fig. 3: WGTS magnet cryostat. The technical requirements to be met by the 16 m long cryostat are ambitious, and its technical structure is extremely complex. The system has twelve cryogenic loops; six different fluids (He, Ne, N_2, Ar, T_2 and Kr) are used.

An international collaboration of more than 130 scientists and engineers under the leadership of KIT is currently in the process of building up this key experiment in astroparticle physics at the Karlsruhe Tritium Laboratory (TLK). The first data are expected in 2012.

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 align 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 as the leader is responsible for the 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. 4, which is being built up completely within the TLK because of the need to handle tritium.

The main component is a 16 m long superconducting magnet system called WGTS (see Fig. 3), which contains the source of tritium gas in its 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 guiding the tritium decay electrons into the spectrometer and, at the same time, reducing by active pumping the tritium gas flow into the spectrometer system by more than twelve orders of magnitude. This is done, on one hand, by means of a differential pumping section (DPS2-F) and, on the other hand – as the last stage -, a cryogenic pumping section (CPS) operated at 3.5 to 4 K. Also shown in Fig. 4 are the tritium loops (inner loop, outer loop) ensuring controlled tritium gas

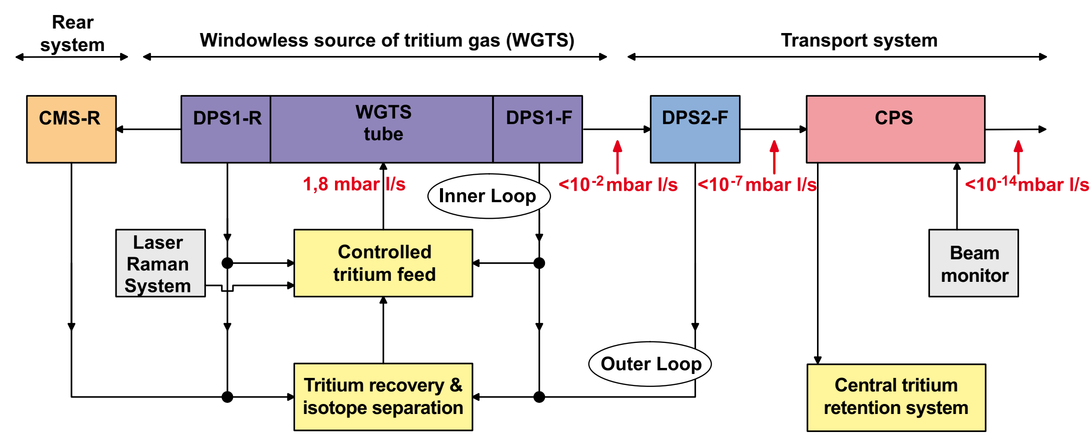


Fig. 4: Block diagram of the KATRIN tritium source and its interfaces with the TLK infrastructure.

injection, and keeping tritium purity at levels above 95%. Simultaneous injecting and removal of the tritium gas by pumping finally results in a steady-state gas column density in the beam tube of the WGTS (tritium source).

Both DPS2-F and CPS are superconducting magnet systems respectively 7 and 9 m long. Like the WGTS, they are manufactured by external companies, with ITEP supervising fabrication. The status of these activities will be outlined below.

WGTS

The WGTS is currently built by RI under contract with VARIAN. VARIAN acquired the original contract when taking over the ACCEL company. Technical supervision by ITEP of the design and fabrication by industrial partners implies a large expense. On the one hand, the WGTS is a very complex system, and the requirements to be met in the cooling system are extremely high (30 K stabilized to 0.1%) and, on the other hand, the WGTS later will have a tritium throughput of 1.5 x 10^{16} Bq per day (40 g), thus having to meet strict quality requirements as a system containing tritium.

The main activities in 2009 were checking the preliminary inspection documents and executing quality assurance tests (leak tests, surface acceptance tests, etc.) accompanying fabrication. The focus of work was on the assemblies required for the demonstrator. The demonstrator basically is a shorter version of the WGTS without the external differential pumping sections and without the magnets designed to build up the guiding field for the tritium decay electrons.

The demonstrator (see also Fig. 5) shall demonstrate the feasibility of the temperature stabilization of 30 K ± 30 mK for the beam tube. It is currently under construction with the industrial partner, and will be delivered to TLK in the spring of 2010 for operation there together with the KATRIN cryo-equipment. One of the key technological points in fabrication, i.e., correct welding of the two beam tube sections 5 m long, has already been completed successfully.

Along with the construction of the demonstrator, the industrial partner also more or less finished manufacturing the seven magnets. However, first cold tests on the manufacturer's site showed that there is still need for optimization in a few places.

Fig. 5: Temperature sensors at beam tube (vapor pressure thermometer/ Pt500).

An important research and development results in 2009 was the redesign of the WGTS beam tube condenser. The choice of lead inside the condenser allowed the thermal capacity and, consequently, the thermal inertia of the condenser to be increased. In this way, the beam tube temperature is likely to fluctuate less, which will have a important influence on the sensitivity of KATRIN. The result was published in a renowned scientific journal.

DPS2-F

After successful pre-acceptance on the premises of ASG in Genoa, the DPS2-F was delivered to KIT in July 2009 (Fig. 1). It has since then been prepared for the acceptance tests. Most of the work focused on building up the control system made up of five switching cabinets, and on installing the cabling system in the field which, however, will not be completed until 2010. Acceptance tests will begin in March 2010.

CPS

The CPS is built by ASG in Genoa (see Fig. 6) for KATRIN. A project team made up of members of several institutes oversees the manufacturing phase.

After acceptance of the technical design report in June 2009, the focus of work was shifted to supervising the manufacturing process and running quality assurance tests on the spot. In a parallel effort, the cryo group laid down the R&I scheme for the sensors and control of the CPS; supplementary research and development work in the sensor field was started. An important milestone of the project was the successful cold test of the first magnet module, which included a test quench.

Cryofacility & Cryotransfer Line

Work in 2009 was focused on the interfaces with the DPS2-F. Among other things, the flexible cryo lines required between the valve box and the DPS2-F were cleared for manufacturing, and matching the automation systems of DPS2-F and the KATRIN cryo system was advanced.

Fig. 6: CPS, manufactured by ASG.

Tritium Loops

The tritium loops of KATRIN are being developed and erected at the TLK (also within the framework of diploma and doctoral theses). Work in 2009, as in the year before, was focused on building the part of the loops for controlled tritium gas injection. Due to lack of space, this section was built up in an existing glove box (ISS box) (see Fig. 7). All piping and MSR work for this section was completed in the summer. After successful commissioning and optimization of the control parameters, first test measurements showed that the stability (0.1%) of the gas feed required by KATRIN is achieved. This marks an important physics milestone.

Physics research was concentrated on laser Raman spectroscopy (LARA) of the hydrogen isotopologs H2, HD, D_2, HT, DT, and T_2. The newly built LARA system was studied systematically in the process (see "Highlight 2009").

Fig. 7: ISS glove box with the LARA system connected. The newly erected part of the tritium loop is contained in the left section of the box.

Acknowledgment

Work associated with KATRIN was addressed and completed successfully by all ITEP groups; besides the TLK, naturally the cryo-engineering unit assumed most of the duties. All activities benefited from close, fruitful cooperation with students, technicians, engineers, and scientists of ITEP, the Institute for Nuclear Physics (IK), the Institute for Experimental Nuclear Physics (IEKP), TID-F, and SPM. The successful cooperation is gratefully acknowledged.

Highlight in 2009: Laser Raman Spectroscopy of Gaseous Hydrogen Isotopologs

KATRIN seeks to achieve a sensitivity of 0.2 eV/c² for model independent determination of the neutrino mass. This can be achieved only if both statistical and systematic errors of the observables are below 0.017 eV²/c⁴. This requires continuous monitoring of the isotopic purity of the tritium gas injected into the source. This monitoring will be done by laser Raman spectroscopy.

The Raman effect describes inelastic scattering of light by molecules. The wavelength of the scattered light is shifted because part of the photon energy is transferred into rotational and/or vibrational excitations of the molecule. The shift in wavelength thus depends on the type of molecule scattering the light. When a spectrum is recorded, the molecule is identified by means of the wavelength and by determining the quantity of molecules available via line intensities.

Characteristic for the LARA method is the possibility to perform the measurements in contactless and non-destructive way, which allows them to be incorporated in a technical process. In principle, gas samples can be obtained "in line," i.e. without sampling, and nearly in "real time." This makes laser Raman spectroscopy an excellent tool to determine the isotopic purity of the KATRIN source.

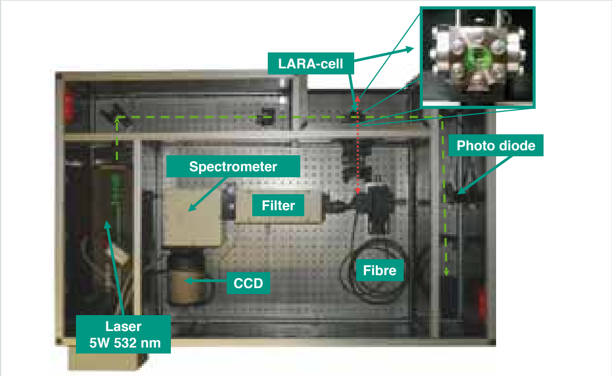


Fig. 8: LARA system for KATRIN. This system was developed over several years in a joint effort with the University of Swansea, Wales.

KATRIN imposes these requirements on LARA:

- Detection limit for hydrogen isotopologs less than 0.1 mbar at an overall pressure of approx. 100 mbar.
- Reproducibility of signals with a precision of < 0.1% (1 σ) in < 250 s at 100 mbar.
- Stability of the optical structure and the active elements, such as the laser and CCD detector, over a KATRIN measurement phase of 60 d.
- Compatibility with tritium of the LARA cells (40 g/d of tritium will be pumped through in the future).

The research and development work begun at the TLK in the autumn of 2008 was continued in 2009 in two diploma theses and one doctoral thesis. The focus was on studying the background contributions to the spectrum and the stability of the LARA system (laser beam intensity, "beam walk," aging processes of the laser windows, etc.).

An outstanding result achieved in the period under review was the first simultaneous measurement of all hydrogen isotopologs (H_2, HD, D_2, Dt, HT, T_2) at the TLK (see Fig. 9). Measurement campaigns over several weeks documented that the precision required by KATRIN within a measurement interval of 250 s can be achieved.

Work will be continued in 2010. A special tritium loop (Loopino) will imitate the KATRIN source.

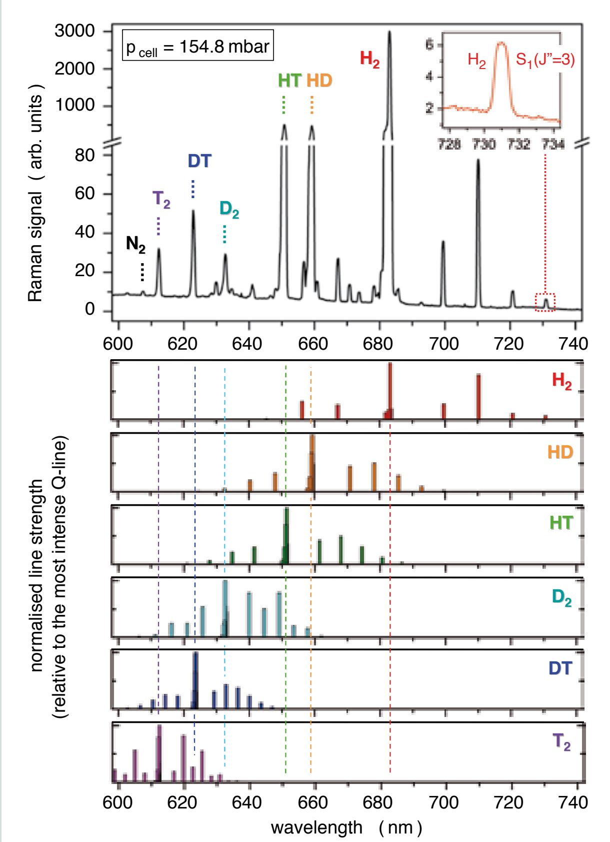


Fig. 9: Raman spectra of an equilibrated mixture of hydrogen isotopologs (measurement time 1000 s). The Q1-lines of all isotopologs are marked. Bottom: model spectra, Q1-line suppressed by a factor of 20 (Sturm et al., Laser Physics 20 (2), 2010).

Teaching and Education

Lectures, Seminars, Workshops, Summer Schools

Lectures

Universität Karlsruhe – Fakultät Elektrotechnik und Informationstechnik
WS 08/09 – Supraleitende Systeme für Ingenieure (Noe, Neumann, Siegel)
SS 09 – Supraleitertechnologie (Noe, Schlachter, Weiss)
SS 09 – Seminar Projektmanagement für Ingenieure (Noe, Day, Grohmann)

Universität Karlsruhe – Fakultät für Chemieingenieurwesen und Verfahrenstechnik
WS 08/09 – Vakuumtechnik I (Day)
WS 09/10 – Kryotechnik (Neumann)
WS 09/10 – Vakuumtechnik I (Day)

Universität Karlsruhe – Fakultät Maschinenbau
WS 08/09 – Fusionstechnologie I (Fietz, Weiss)
SS 09 – Fusionstechnologie II (Bornschein, Day)

Leibniz Universität Hannover – Fakultät Elektrotechnik und Informationstechnik
SS 09 – Neue Komponenten der elektrischen Energieversorgung (Noe, Berger)

Duale Hochschule BW – Fachbereich Maschinenbau
WS 08/09 – Konstruktionslehre I (Bauer)
SS 09 – Arbeitssicherheit und Umweltschutz (Bauer)
WS 08/09 – Thermodynamik I für Maschinenbauer (Neumann)
SS 09 – Technische Thermodynamik II für Maschinenbauer (Neumann)

Seminars/Summer Schools

Seminar „Die Kunst sich selbst zu präsentieren“
5.–6. März 2009
Karlsruhe

VDI-Seminar Kryotechnik
25.–27. März 2009
Karlsruhe

MATEFU Spring Training School
„Superconducting Magnets“
5.–9. April 2009
Cadarache, Frankreich

CIGRE Workshop on Test Techniques and Procedures for HTS Power Applications
13.–15. Mai 2009
Nagoya, Japan

Karlsruhe-Dresden
Doktorandenseminar zur Supraleitung
27.–29. Mai 2009
Colditz

NESPA Kryo Workshop
15.–16. Juni 2009
Karlsruhe

ESAS Summer School on Materials and Applications on Superconductivity
21.–26. Juni 2009
Lans en Vercors, Frankreich

International Summer School on Fusion Technologies
31. August–11. September 2009
Karlsruhe

Haus der Technik, Seminar Kryostatbau
9.–11. September 2009
Karlsruhe

Teaching and Education

Diploma Theses, Bachelor, Master Theses, Term Papers, Technician Papers, Doctoral Theses

Diploma/Bachelor/Master Theses Supervised in 2009 (*completed)

Peter Baumgartner (SEW-Eurodrive)
Applikative Anforderungen an die Sicherheitstechnik bei Geschwindigkeits- und Positionsüberwachungssystemen
Zweitgutachten

Colains Donfack
Charakterisierung von Hochtemperatur-Supraleitern für Supraleitende Strombegrenzer

Sebastian Fischer (IK)
Laser-Raman Messungen an H-Isotopen im dynamischen Bereich

Christian Friedmann*
Integration des Vorspektrometers in die KATRIN Beamline

Andreas Kosmider (IK)*
Analyse von Wasserstoffisotopomeren in der flüssigen Phase durch Infrarotspektroskopie

Haifeng Mao
Determination of Measurement Uncertainty in High Precision Cryogenic Temperature Measurement under Magnetic Fields

Frank Merkel
Messungen der thermischen Isolationsqualität von Superisolation (Vakuum-Vielschichtisolation) zwischen Raumtemperatur (» 300 K) und LN2-Temperatur (» 77 K)

Thomas Polzer*
Konstruktion einer Ausheizkammer

Florian Priester (IK)
Systematische Untersuchungen zum Stabilitätsverhalten des KATRIN Tritiumloops

Alexander Reiner*
Entwicklung eines 3D Messtisches für eine Magnetfeldmessung im Raum

Enrico Rizzo*
Determination of the heat transfer characteristics in the fin-type heat exchanger for the HTS current leads of W7-X and JT-60SA

Magnus Schlösser (IK)*
Laser-Raman Messungen an gasförmigen H-Isotopomeren für die KATRIN Tritiumquelle

Rolf Schön (IK)
Untersuchung eines BIXS-Detektors zur Messung der Tritiumkonzentration in Wasser

Sarah Stern (IBS)
Neuentwicklung und Konzeptionierung eines Schutzzaunsystems für den Maschinen- und Anlagebau
Zweitgutachten

Thomas Voigt
Rückkühlverhalten von Supraleitern in Fehlerstrombegrenzern

Elisabeth Weiß*
Vorbereitung der Akkreditierung des Labors für kryogene Werkstoffprüfungen nach DIN 17025

Term Papers Supervised in 2009 (*completed)

Stanislav Cherevatskiy*
Verlustberechnung supraleitender Transformatoren

Sebastian Stämmler (TVT Campus Süd)
Membranverfahren zur Abtrennung von Wasserstoff und Wasserdampf

Yuvens Tantra*
Untersuchung elektromechanischer und thermischer Eigenschaften technischer Hochtemperatursupraleiter und Strukturmaterialien

Technician Papers Supervised in 2009 (*completed)

Carsten Schlenker*
Auslegung und Realisierung von Mess-Sensorik im kryogenen Temperaturbereich

Exchange Program of DH Students with Industrial Partner, Babcock Noell (Kathrin Ehrhardt and Christian Pulch)

Duale Hochschule Baden-Württemberg 2009 (*completed)

Kerstin Brohl
Wirtschaftsingenieurwesen – DH-Karlsruhe

Isabelle Ehleben
Maschinenbau – DH-Karlsruhe

Beate Frank
Mechatronik – DH-Karlsruhe

Clemens Frenzel
Wirtschaftsingenieurwesen – DH-Karlsruhe

Christian Friedmann*
Technisches Management – DH-Mannheim

Nando Gramlich
Maschinenbau – DH-Mannheim

Nadja Kästle
Wirtschaftsingenieurwesen – DH-Karlsruhe

Steffen Mundt
Wirtschaftsingenieurwesen – DH-Karlsruhe

Marcus Oberle
Maschinenbau – DH-Mannheim

Christian Pulch
Wirtschaftsingenieurwesen – DH-Karlsruhe

Michael Schmidt
Maschinenbau – DH-Mannheim

Pit-André Singer
Elektrotechnik – DH-Karlsruhe

Sascha Singer
Elektrotechnik – DH-Karlsruhe

Elisabeth Weiss*
Technisches Management – DH-Mannheim

2009 Doctoral Theses (*completed); ([1] at present on parent leave)

Christian Barth
Mechanisch stabilisierte Hochtemperatur-Supraleiter-Kabel

André Berger
Entwicklung supraleitender strombegrenzender Transformatoren

Frank Eichelhardt (IK)*
Bestimmung des Tritiumrückhaltevermögens mit einer Argonfrostpumpe

Aleksandra Gotsova (IK) [1]
Investigation of the DPS2-F (Differential Pumping Section) for KATRIN

Olaf Mäder
Gleichstrom-Höchststromübertragungsleitungen mit Hochtemperatur-Supraleitern

Robert Michling (ITU)
Performances Assessment of Water Detritiation Process

Christian Schacherer*
Theoretische und experimentelle Untersuchungen zur Entwicklung supraleitender Strombegrenzer

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

Mark Stemmle (U Hannover)*
Entwicklung und Simulation von supraleitenden Hochspannungsstrombegrenzern

Michael Sturm (IK)
Aufbau und Test des Inner Tritium Loop von KATRIN

Michael Schwarz*
Wärmeleitfähigkeit supraleitender Kompositleiter im Temperaturbereich von 4 K bis 300 K

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

Alexander Winkler
Transient electrical behaviour of ITER PF coils

Teaching and Education

2009 ITEP Colloquiums

28.1.2009 Verlustberechnung supraleitender Transformatoren
S. Cherevatskiy; Studienarbeit

12.3.2009 Modelling Activities on ITER cryopumps and cryodistribution
M. Scannapiego; VAKUUM

17.3.2009 Mechanical analysis of JT-60 SA T coils
M. Nannini; FUSION

21.4.2009 Datenschutz betrifft uns alle
B. Kneifel; KIT

5.5.2009 Development of YBCO Roebel cables for high current capacity and management of AC loss (Industrial Research Ltd. Lower Hutt, New Zealand)
N. Long; SUPRA

12.5.2009 CPS Cryogenic Design
S. Putselyk; KATRIN/KRYO

20.5.2009 HTS Transformers – A Brief Sketch of Their Promise and the Progress Needed to Realize that Promise
A. Wolsky; SUPRA

26.5.2009 Fiber Bragg Grating Based Temperature Distribution Evaluation of Multilayer Insulations between 300 K–77 K
R. Ramalingam; KRYO

9.6.2009 ITEP – Arbeitsschutz mit System
K. Bauer; ADMIN

16.6.2009 Messung der thermischen Ausdehnung und ausgewählte elektromechanische Eigenschaften von supraleitenden Bandleitern
Y. Tantra, Studienarbeit

19.6.2009 Erhöhung von J_c und Birr von MgB_2 – Drähten mittels Kaltverdichtung: Beschreibung des Effekts durch ein Verteilungsmodell (Université de Genève)
R. Flükiger; SUPRA

23.6.2009 Overview of Breeder Blanket and Tritium Technology at TLK
D. Demange; T L K

30.6.2009 Services der Stabsabteilung Innovation sowie „Schutzrechte und Patente im KIT"
J. Fahrenberg, Steffi Finke; S I

7.7.2009 Theoretische und experimentelle Untersuchungen zur Entwicklung von supraleitenden Strombegrenzern
Ch. Schacherer; Doktorand

14.7.2009 KIT-Zentrum Energie
W. Breh; KIT-Büro

21.7.2009 Parametric study of the heat transfer of the fin-type heat exchanger geometry in HTS current leads for fusion applications
E. Rizzo; FUSION

8.9.2009 Superconductors for future high field use: Why not multifilamentary YBCO or something even better? (NHMFL/ USA)
D. Larbalestier; SUPRA

25.9.2009 Vorbereitung der Akkreditierung des Labors für kryogene Werkstoffprüfungen nach DIN 17025
E. Weiß; Bachelorarbeit

29.9.2009 „Integration des Vorspektrometers in die KATRIN Beamline"
Chr. Friedmann; Bachelorarbeit

10.11.2009 Die Verwendung von Monte-Carlo-Methoden zur Simulation von Vakuumsystemen
X. Luo; VAKUUM

17.11.2009 Numerical modeling of HTS
F. Grilli; SUPRA

24.11.2009 Erfahrungen mit dem DPS2-F System für das KATRIN Experiment
R. Gehring; KATRIN/SUPRA

1.12.2009 Properties of HTS Roebel cables
S. Terzieva; SUPRA

4.12.2009 Progess in High Field Magnets
M. Bird; NHFML

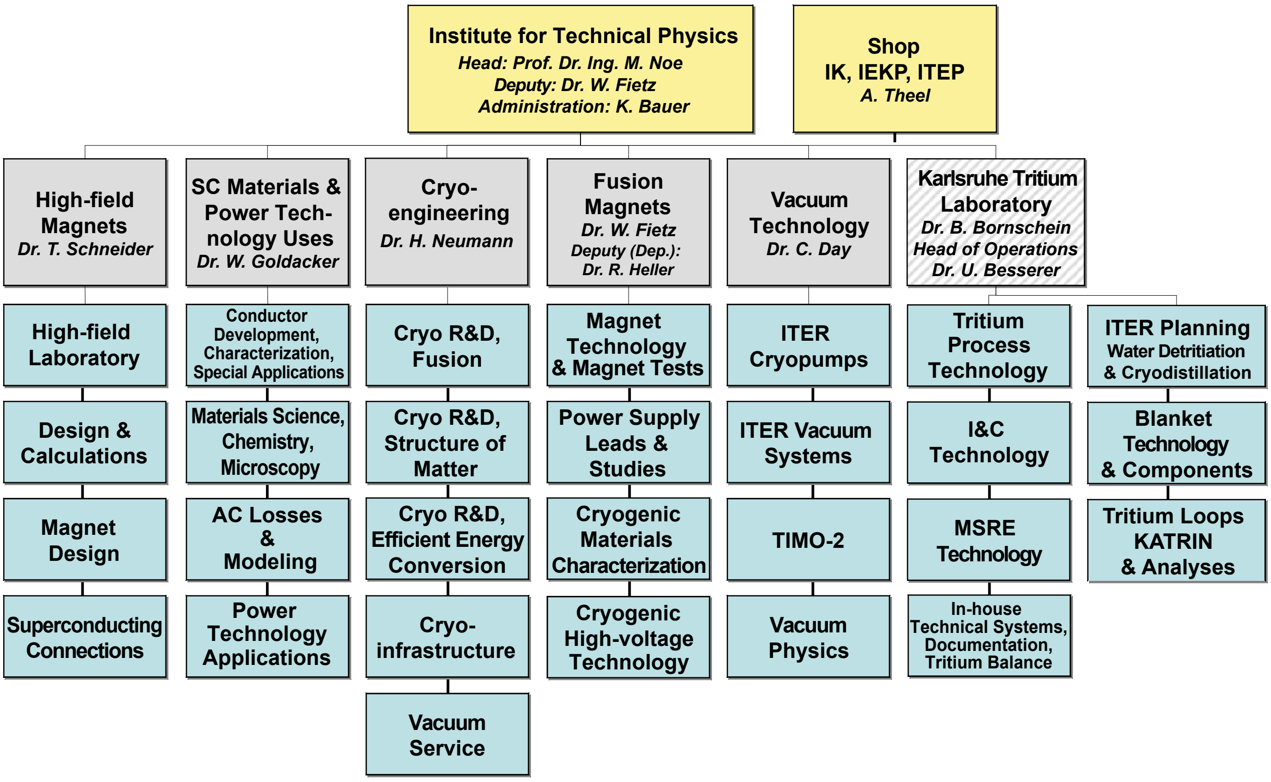
8.12.2009 Finite-Element-Berechnungen der Toruskryopumpen für ITER
H. Strobel; VAKUUM

15.12.2009 Calculation of Transient Electrical Behaviour of ITER PF Coils
A. Winkler; Doktorand

22.12.2009 Entwicklung supraleitender Transformatoren
A. Berger; Doktorand

Figures and Data

ITEP Chart of Organization (September 16, 2009)



Personnel Status (November 19, 2009)

Total	169
University graduates (of these, 2 trainees, 2 EU delegates)	51
Engineers and technicians	64
Others	25
Pre-doctoral students (of these, 6 not funded by ITEP)	9
Diploma students	8
DH students	12

In 2009	
Trainees	11
Guests	9
Student assistants	17

Figures and Data

Membership in Relevant Technical and Scientific Organizations

Christian Day

- Executive Board Member of the German Vacuum Society.
- Associated Expert of the Indian Vacuum Society.
- Chairman of the ITER Vacuum Pumping Systems Package Design Review.
- Chairman of the Coordinating Committee on Fuelling & Pumping, EFDA.
- Deputy Leader of the Topical Group Heating & Current Drive, EFDA.
- International Symposium of Fusion Nuclear Technology, Member of Technical Committee.
- Member of German Engineering Society.
- Chartered Engineer of American Vacuum Society.

Wilfried Goldacker

- Fellow of Institute of Physics (IOP), UK
- Superconducting Science and Technology (SUST-IOP), Executive Board Member
- EUCAS-2009, Dresden, Programme Committee Member
- International Cryogenic Material Conference, (ICMC) Member of Board of Directors
- Applied Superconductor Conference 2010 (ASC), Programme Committee Member, Section Materials
- International Conference on Superconductivity and Magnetism (ICSM-2010), Advisory Committee Member, Antalya
- International Cryogenic Materials Conference (ICEC-ICMC-2010), Wroclaw, Conference-Chair for ICMC
- Montecantini, 6th International Conference: Science and Engineering of new Superconductors (CIMTEC-2010), Programme Committee member
- 3rd. International conference on Ceramics (ICC-2010), Osaka, Organisation committee Co-Organizer of Symposium 9D: Ceramics for Electricity; Advanced Superconducting Materials
- DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE
  Mitglied im Fachkreis: K184 „Supraleiter"
- VAMAS, Versailles Project on Advanced Materials and Standards, Technical Working Area 16, Superconducting Materials, Commission Member
- NESPA-Workshop „Cryogenics", Veranstalter

Reinhard Heller

- Applied Superconductivity Conference, Member of International Program Committee
- Applied Superconductivity Conference, elected Board member Large Scale
- 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"

Mathias Noe

- International Council of Large Electric Systems (CIGRE) Sekretary of working group D.1.15 „Superconducting and Insulating Materials for 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
- The European Society for Applied Superconductivity, Board member
- Joint CCE-FU-F4E GB Working group on DEMO. Working group member
- International Conference on Magnet Technology, Member of International Organizing and Scientific Program Committee
- Applied Superconductivity Conference, Member of International Program Committee
- Industrieverband Supraleitung, Gastmitglied
- Helmholtz Programm Rationelle Energieumwandlung und -nutzung, Topicsprecher Supraleitung
- Vorsitzender des wissenschaftlich-technischen Rates des Forschungszentrums Karlsruhe
- KIT Zentrum Energie, Mitglied im Lenkungsausschuss und Ko-Sprecher Energiespeicherung und -verteilung

Klaus-Peter Weiss

- DKE/DIN K 184 – Supraleiter. Stellvertretender Obmann
- IEC TC90 – Superconductivity –
  Member WG 2 – „Critical current measurement of Nb-Ti composite superconductors"
  Member WG 7 – „Critical current measurement method of Nb3Sn composite superconductors"
  Member WG 11 – „Critical temperature measurement – Critical temperature of composite superconductors"

Publications

"Nuclear Fusion" (FUSION) Program (*Cited in ISI)

Aiello, A.; Bühler, L.; Ciampichetti, A.; Demange, D.; Dörr, L.; Freibergs, J.F.; Ghidersa, B.; Ilic, M.; Laffont, G.; Messemer, G.; Platnieks, I.; Rampal, G.; Tincani, A.
Mockup testing facilities and qualification strategy for EU ITER TBMs.
9th Internat.Symp.on Fusion Nuclear Technology (ISFNT-9), Dalian, China, October 11–16, 2009

* Ana, R.G.; Cristescu, I.; Dörr, L.; Michling, R.; Welte, S.; Wurster, W.
Design and experimental activities in view of water detritiation-isotopic separation system combination in TRENTA, facility.
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* Bekris, N.; Coad, J.P.; Widdowson, A.; Erbe, A.; Ehrmann, J.; Kloppe, B.
JET-EFDA Contributors
Assessment of the flash-lamp photon-cleaning detritiation method tested at JET.
Journal of Nuclear Materials, 390-391(2009) S.614–17
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Optimization of the fin-type heat exchanger geometry in HTS current leads for fusion applications.
21st Internat.Conf.on Magnet Technology (MT–21), Hefei, China, October 18–23, 2009

Cristescu, I.; Dörr, L.; Eichelhardt, F.; Liger, K.; Michling, R.; Pinna, T.; Zamfirache, M.; Welte, S.; Wurster, W.
Design and R&D activities in EU in support of ITER water detritiation and cryogenic distillation systems as in kind contribution.
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Day, C.
Kryovakuumtechnik und Kryopumpen.
VDI-Wissensforum Kryotechnik, Karlsruhe, 25.–27. März 2009

Day, C.; Hanke, St.; Luo, X.; Sonato, P.
The cryosorption pumping system for the neutral beam test facility MITICA.
19th AIV Conf.'Energy and Materials: Technologies Comparison and Perspectives', Senigallia, I, May 19–21, 2009

Day, C.
ITER, the next step to clean energy by fusion. Size matters.
Frühjahrstagung DPG, Fachverband Vakuumphysik und Vakuumtechnik, Dresden, 22.–27. März 2009
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* Day, C.; Haas, H.
Experimental assessment of the ITER cryosorption pump high temperature regeneration.
Fusion Engineering and Design, 84(2009) S.665–68
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Numerical simulations of electro-magnetic transients in ITER cryopumps with the use of TYPHOON code.
Internat.Conf.on Mathematical Modeling and Computational Physics, Dubna, Russia, July 7–11, 2009

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Recent developments in fusion vacuum flow modelling for ITER and beyond.
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3rd Internat.Symp.on Hydrogen in Matter (ISOHIM-09), Chennai, IND, December 13–16, 2009

* Dremel, M.; Day, C.; Hanke, S.; Luo, X.
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Fusion Engineering and Design, 84(2009) S.689–93
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* Dremel, M.; Day, Chr.; Hemsworth, R.; Pearce, R.; Mayaux, C.
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9th Internat.Symp.on Fusion Nuclear Technology (ISFNT-9), Dalian, China, October 11–16, 2009

* Fietz, W.H.; Heller, R.; Kienzler, A.; Lietzow, R.
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IEEE Transactions on Applied Superconductivity, 19(2009) S.2202–05
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Wissenschaftliche Berichte, FZKA-7483 (Juli 2009)

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Preparing the test facility TIMO-2 for the acceptance tests with the ITER torus cryopump.
Chang, H.M. [Hrsg.]
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Gyeongnam : The Korea Institute of Applied Superconductivity and Cryogenics, 2009 S.663–68
ISBN 978-89-957138-2-2

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Frühjahrstagung DPG, Fachverband Vakuumphysik und Vakuumtechnik, Dresden, 22.–27. März 2009
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9th Internat.Symp.on Fusion Nuclear Technology (ISFNT-9), Dalian, China, October 11–16, 2009

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Strömungsberechnung in großen Vakuumsystemen.
Frühjahrstagung DPG, Fachverband Vakuumphysik und Vakuumtechnik, Dresden, 22.–27. März 2009
Verhandlungen der Deutschen Physikalischen Gesellschaft, R.6, B.44(2009) VA 1.2

* Hauer, V.; Day, C.
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Fusion Engineering and Design, 84(2009) S.903–07
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IEEE Transactions on Applied Superconductivity, 19(2009) S.2893–96
DOI:10.1109/TASC.2009.2018503

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Abe, T. [Hrsg.]
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ProVac3D and application to the neutral beam injection system of ITER.
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Operation and characterization of a water detritiation facility at the Tritium Laboratory Karlsruhe.
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Cryogenic Engineering Conf.(CEC) and Internat.Cryogenic Materials Conf.(ICMC), Tucson, Ariz., June 28–July 2, 2009

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2nd Dresden-Karlsruhe Seminar on Materials and Applications in Superconductivity, Colditz, May 27–29, 2009

* Schwarz, M.; Weiss, K.P.; Heller, R.; Fietz, W.H.
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Tensile test results on compacted and annealed 316LN material.
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Vortr.: Korea Electrotechnology Research Institute (KERI), Changwon, Korea, 15. Juli 2009

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* Welte, S.; Ana, G.; Cristescu, I.; Dörr, L.; Kuntz, B.; Michling, R.
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Frequency behaviour of NbTi coils.
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Winkler, A.
Calculation of transient voltages of ITER PF coils.
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9th European Conf.on Applied Superconductivity (EUCAS'09), Dresden, September 13–17, 2009

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