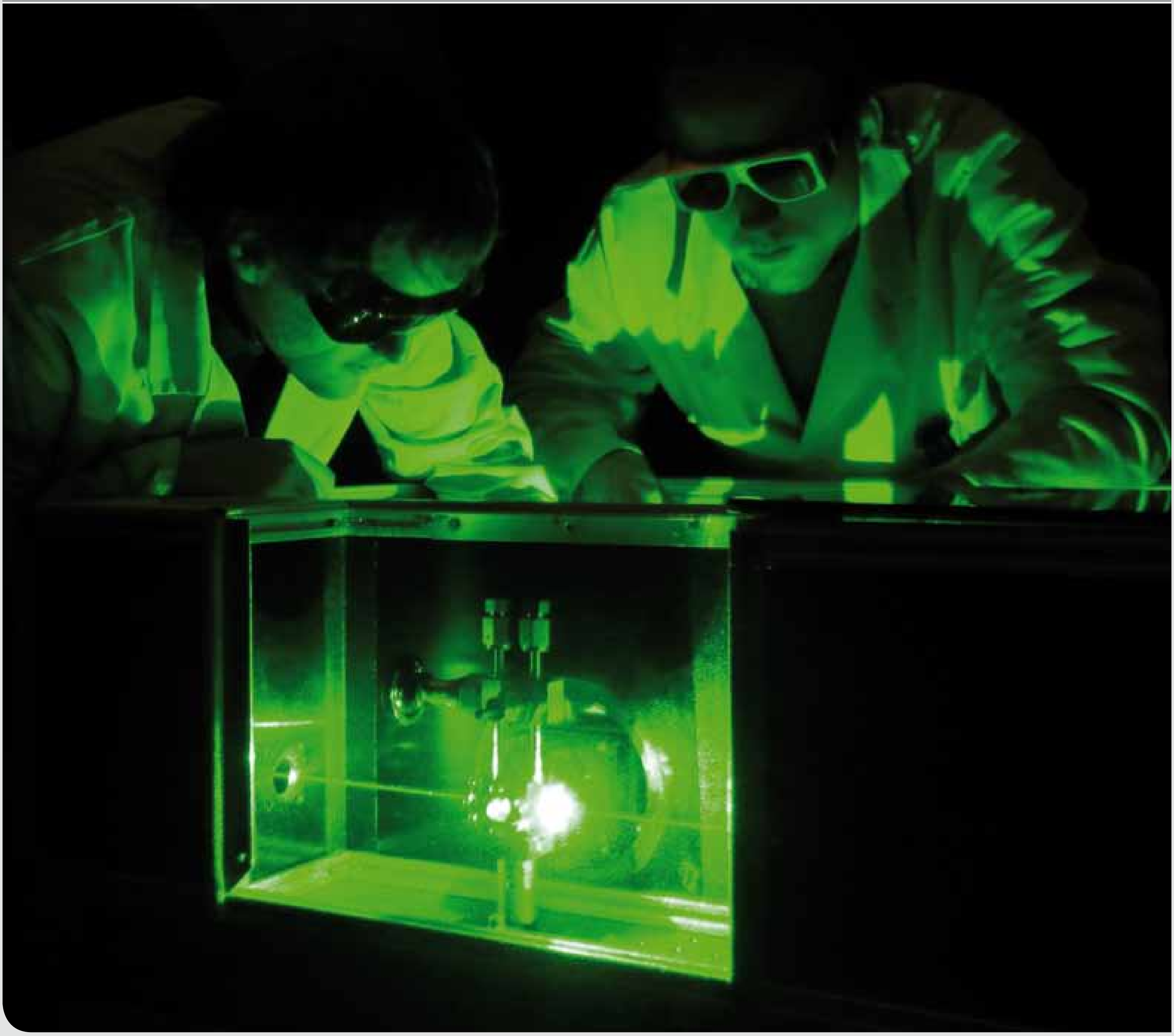
Karlsruhe Institute of Technology

ITEP – Institute for Technical Physics

Results of Research and Development
2013 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 competence centre for fusion, superconductivity, and cryogenic technologies. Activities focus on the following areas:

- Technology for fusion magnets.
- Tritium process technology.
- Vacuum technology.
- Cryo-engineering.
- Development of superconductor materials and applications of superconductivity in power technology.
- Superconducting High Field magnets.

The work of ITEP is part of the "Fusion", "Efficient Energy Conversion and Use", and "Astroparticle Physics" long-term programmes of the Karlsruhe Institute of Technology (KIT) and Helmholtz Association of National Research Centres.

The complex and, in most cases, multi-disciplinary tasks are accomplished by ITEP in large, unique experimental installations, laboratories, and technical infrastructure facilities. These are among others:

- The Karlsruhe Tritium Laboratory (TLK), a worldwide unique laboratory with a closed tritium cycle for civil purposes.
- The Karlsruhe Toroidal Coil Test Facility (TOSKA) for testing large magnets for fusion and for developing components for future fusion reactors.
- The test facility for the ITER Model Pump (TIMO) for the development of cryo-vacuum pumps.
- The High Field Magnet Laboratory for developing superconducting High Field magnets.
- The Cryogenic High-voltage Laboratory for investigating high-voltage stability of cryogenic insulation materials.
- The Cyrogenic Material Laboratories for studying electric and mechanical properties at very low temperatures.

The most important scientific results, successes in development projects, challenges, and events of and at ITEP in 2013 will be summarised briefly below.

We are highly pleased about the appointment of Professor Bernhard Holzapfel from IWF Dresden as a member of the Board of Directors of ITEP on 01 October 2013. With the support of the Helmholtz Association, Professor Holzapfel is establishing a working group on "Superconducting Materials". This new working group ideally complements the application-oriented activities in the field of superconductivity that have been carried out so far. Thanks to its inter-disciplinary expertise, ITEP is now in a position to tackle research and development problems in the complete range from materials to application. Bernhard Holzapfel also holds the professorship for Superconducting Materials at the Department of Electrical Engineering and Information Technology of KIT.

Professor Bernhard Holzapfel from IFW Dresden was appointed member of the Board of Directors of ITEP and Professor for Superconducting Materials at KIT on 01 October 2013.

In the **Fusion Magnets** field, ITEP develops, builds, and tests high-current leads with high-temperature superconductors for the Wendelstein 7-X and JT60-SA fusion projects. In 2013, the last current leads for Wendelstein 7-X were accepted by IPP to the complete extent and according to schedule. Moreover, manufacture and assembly of high-current leads for the JT60-SA project were continued successfully. ITEP was pleased to note a constantly increasing demand for cryogenic materials tests, in particular for the ITER fusion experiment (www.iter.org).

Within the framework of the ITER international fusion experiment, the **Karlsruhe Tritium Laboratory (TLK)** is to supply the work packages for water detritiation (WDS) and cryogenic isotope separation (ISS). In 2013, the TLK for the first time processed highly tritiated water on the ITER-relevant scale of several kilograms. The process developed by the TLK is based on platinum-coated zeolite beds. It reached the required exchange factor of more than 100. This means that the concentration of isotopologues was reduced by a factor higher than 100 after processing. In addition, an in-line measurement system was built for liquid hydrogen isotopologues and subjected to extensive testing.

The **Vacuum Technology Division** of ITEP focuses on the development of vacuum systems of extremely high pumping capacity as well as on the development of numerical codes, in particular for vacuum flow in the transition range. In 2013, a new divertor neutral particle code was presented. Using this code, it was demonstrated for the first time how the plasma behaviour in the divertor can be influenced by the pump design. On this basis, it will be possible in the future to considerably improve the design of divertors. In addition, the new process developed by ITEP to ensure high flow rates and a minimised inventory of the fuel cycle was established as the reference concept for future fusion power plants. Dr. Christian Day was appointed Project Leader of the Work Package Tritium, Fuelling and Vacuum, one of 25 Work Packages that constitute the European Fusion Programme.

In the area of **Development of Superconductor Materials**, development of economically viable low-loss conductor concepts suited for high currents represents a major task. Roebel cables from coated conductors are under development for insert coils of dipole magnets as possible upgrade of the LHC at CERN and as strands applied in Rutherford Cables for future fusion magnets (DEMO). Within the framework of the AmpaCity joint project, ITEP produced a model cable. AC properties of this cable were characterised in detail. In this way, ITEP provided the project partner with a new modelling tool for the design of future power cables. As regards **applications of superconductivity in power technology**, a superconducting current limiter for 20 kV was installed at the place of commissioning within the framework of a European joint project (www.eccoflow.fp7-eu). Prior to the set-up, it had been tested successfully. Moreover, ITEP successfully tested a first demonstrator for a novel type of current limitation by conventional chokes for a superconducting application.

Work of the **High Field Magnet Laboratory** focuses on the development of high-field NMR systems with high-temperature superconductors. In 2013, ITEP produced several high-temperature superconducting coils under a cooperation project with industry and tested them successfully in the high-field facilities at more than 20 tesla. Dependence of the critical power density on the magnetic field direction was studied using several superconducting specimens. Within the framework of the development of a demonstrator for a superconducting magnetic energy store, two superconducting coils were wound and successfully tested for their ampacity.

The **Cryo-engineering Division** develops, extends, and operates complex and large-scale cyrosystems, among others for the KATRIN neutrino experiment or the CuLTKa current lead test facility. The CuLTKa facility was completed in 2013 and is now available for tests of current leads for the JT60-SA project that are planned to start in 2014. In addition, the Cryo-engineering Division is in charge of repair and maintenance of cryogenic facilities and of supply of KIT with liquid helium and liquid nitrogen. Under the Suprapower (www.suprapower-fp7-eu) European joint project, ITEP submitted the cryostat design report according to schedule and proposed further improvements.

Within the **Karlsruhe Tritium Neutrino Experiment KATRIN** (www.katrin.kit.edu), ITEP makes major contributions to the tritium loops, cryogenic supply, and superconducting magnets. For the rear section of KATRIN, ITEP researchers, together with international colleagues, submitted a new concept and accepted the collaboration's design report. Florian Priester of the TLK was appointed task head for this area. Moreover, major work was performed in the area of the cryogenic pumping section technology.

As regards **changes of staff**, the number of staff members undergoing training and advanced education, such as students of cooperative state universities, diploma students, doctoral students, and trainees, continued to further increase. In total, more than 70 persons are presently undergoing training in various disciplines at ITEP. A terrible loss for the Institute was the decease of its long-term staff member Gunther Dittrich. At ITEP, he worked as an operator and was responsible for the operation of the TOSKA facility.

In the field of **teaching**, more lectures were newly conceived and introduced. In 2013, ITEP staff offered lectures in the amount of more than 30 hours per week per semester for KIT students. Numerous national and international seminars, summer schools, and workshops organized by ITEP complement the education programme. In 2013, the European Summer School for Materials and Applications of Superconductivity was prepared and organised at KIT for the seventh time already.

In July 2013, the celebration of the 20th anniversary of the Karlsruhe Tritium Laboratory was combined with the traditional summer party of ITEP. We would like to cordially thank all helpers and participants.

Our sincere thanks go to all partners of ITEP from universities, research institutions, and industry for the very loyal, fruitful, and successful cooperation in 2013.

Sincerely yours,

Mathias Noe Bernhard Holzapfel

Board of Directors

New twelve-tesla magnet of the FBI facility to measure superconducting cables under realistic operation conditions.

Results from the Research Areas

Fusion Magnets

Head: Dr. Walter Fietz

In 2013, the Fusion Magnets Division of ITEP carried out work for the national W7-X project and the international projects JT-60SA and ITER. In addition, the scientists studied the use of high-temperature superconductors for future fusion reactors.

Development and Construction of Current Leads for W7-X and JT-60SA

Work for Wendelstein 7-X

ITEP has developed, constructed, and tested 16 current leads for a maximum current of 18.2 kA for the Wendelstein 7-X stellarator (W7-X). Thanks to the use of the high-temperature superconductor (HTS) BiSCCO, losses in the range below 60 K were reduced significantly, as the HTS material does not possess any resistance in this temperature range. After the successful test of two prototypes, ITEP manufactured 14 series current leads for W7-X and tested them successfully. Meanwhile, all current leads have been delivered to W7-X and are presently integrated into the machine.

Work for JT-60SA

Based on the experience of ITEP in the area of HTS current leads, the BMBF promised in 2007 to deliver current leads for the satellite tokamak JT-60SA. In the first project stage from 2008 to 2012, the design was made and the interfaces were agreed upon with F4E and Japan. Then, the layout was completed and the materials needed for construction were purchased.

In the second project phase funded until February 2017, fabrication of the current leads started in 2013. In total, six current leads with an operation current of 26 kA will be required for the TF coils. 20 current leads with a maximum current of 20 kA will be needed for the CS and PF coils of JT-60SA. Based on the experience gained from the manufacture of current leads for W7-X, all current leads will be produced at KIT in close cooperation with

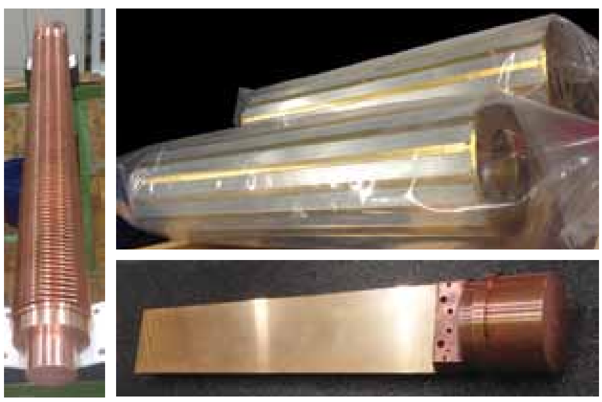


Figure 1: Components for the 26 kA current lead.

Figure 2: Heat exchangers with insulated cladding tubes.

the Technology House on KIT Campus North. In the meantime, nearly all semi-finished products have been fabricated for the 26 kA current leads (see Figures 1 and 2). All heat exchangers are available. Assembly of the first pair of current leads has started. It will presumably be completed in early 2014.

Current Lead Test Facility CuLTKa

Construction of the new test facility CuLTKa (Current Lead Test Facility Karlsruhe) needed for the tests of the 26 current leads for JT-60SA, see Figure 3, was largely completed in 2013. The facility is planned to start operation in 2014. Hence, it will be available for testing as soon as the first pair of current leads will have been manufactured.

Figure 3: Valve box (right), control cryostat (centre), and second valve box (rear left) in the CuLTKa test facility.

Development of Cables Made of High-temperature Superconductors

When impregnating high-temperature superconductors (HTS) with an epoxy resin, the problem of a significantly different thermal expansion of the HTS tape (see Figure 4) is encountered. This problem leads to the degradation of critical current. To adapt thermal expansion of the epoxy to that of the HTS tape, a filler material can be used, such as quartz sand. The Stycast epoxy cannot be applied for impregnation, as the superconducting material is attacked chemically in case of direct contact. HTS tapes impregnated with araldite and quartz sand (1:1) do not exhibit any degradation even after several temperature cycles.

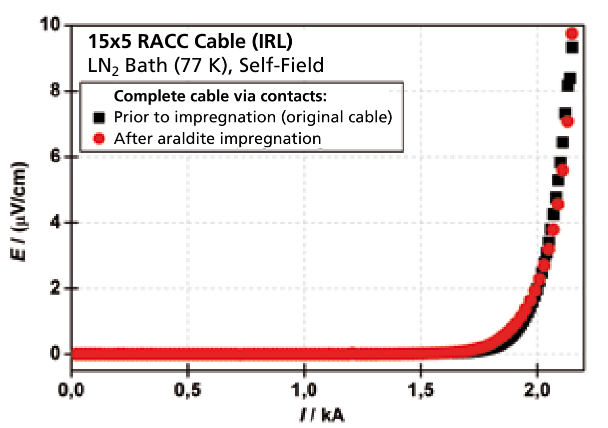


Figure 4: Critical current of an HTS tape prior to and after impregnation with araldite / quartz sand (1:1).

While upgrading the FBI facility to measure superconducting cables up to 10 kA, ITEP accomplished the next step in 2013: A superconducting 12-tesla split coil magnet of enhanced specimen volume was installed successfully. As a result, the available cross-section for the specimen has been doubled (40 mm x 80 mm), such that it is possible to test HTS sub-size specimens.

Together with CRPP (Switzerland), ITEP tested a stacked tape cable (see Figure 5). A Roebel cable of enhanced mechanical stabilisation is being prepared.

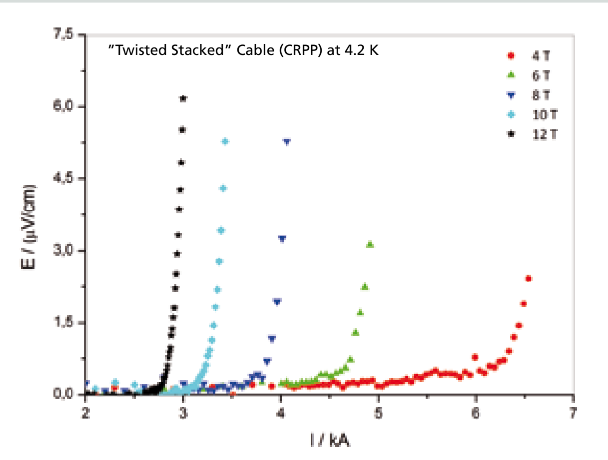


Figure 5: Measurement of critical current at variable magnetic fields and 4.2 K. The cable was supplied by CRPP (Switzerland).

Concept of the Design of a TF Coil for DEMO

Within the framework of a doctoral thesis, the concept of a TF coil with REBCO tape conductors is being studied for the DEMO fusion reactor. Based on existing conductor concepts (CORC, TSC, Roebel-Rutherford), a helium-cooled and steel-cladded conductor was selected for the design of the winding package of the TF coil (see Figure 6). The basis is the current DEMO design that can be derived from the PROCESS system code. The selected operation temperature is 4.5 K in order to optimally exploit the potential of HTS materials.

Based on current REBCO conductor data (see Figure 7), the temperature margin and the adiabatic hotspot temperature in case of a quench with subsequent safety discharge were determined. Compared to ITER, it is possible to work with a much higher discharge time constant. This results in an acceptable discharge voltage in spite of the higher number of turns in the winding. The temperature margin is about 11 K and, hence, much larger than for the LTS design with Nb_3Sn.

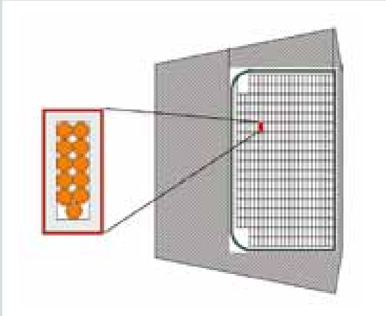


Figure 6: REBCO conductor design (left) and winding package (right) of the TF coil for the DEMO fusion reactor.

The next steps envisaged are a structural analysis as well as a hydraulic and a thermohydraulic analysis of the REBCO conductor.

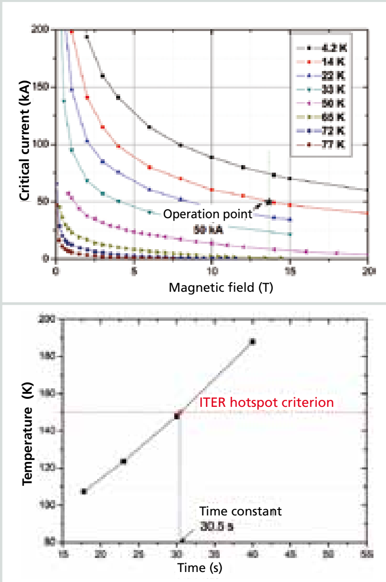


Figure 7: Critical current as a function of the magnetic field and operation point (left) as well as hotspot temperature as a function of the discharge time constant (right) of the REBCO conductor of the TF coil for the DEMO fusion reactor.

CryoMaK – Cryogenic Materials Testing Laboratory

Work for ITER

As a result of the increasing worldwide production for ITER, an increasing number of cryogenic components and structural materials are studied for qualification purposes at the CryoMaK Laboratory. Meanwhile, specimens of cable jackets for the toroidal and poloidal coils, the central solenoid, and the correction coils as well as base material of radial plate segments and neutron shield materials with boron alloys of the cryostat have been subjected to testing. Present studies are concentrating on metallic materials. Tensile tests, fracture mechanics tests, thermal expansion and conductivity tests are being performed. Since October 2013, characterisation of the specific heat from 4.2 K to room temperature has been possible in a magnetic field of up to 9 T.

Figure 8: HTS wire prepared for a tensile test at room temperature and extensometer.

Standardisation Work for the IEC

The IEC 61788 standards define various terms relating to superconductors and specify various characterisation methods. Among others, these documents contain basic standards for classical superconductors, such as Nb_3Sn or NbTi. As the use of high-temperature superconductors is gaining relevance, there also is an increasing need for standardisation. In 2013, a series of international experiments started by determining mechanical properties at room temperature (see Figure 8). Among the participating laboratories were Daido University, RIAS, and Furukawa (Japan), Andong University (Korea), University of Twente (the Netherlands), NHMFL (USA), the CEME company (Germany), and KIT's CryoMaK Laboratory. Commercial HTS tapes of about 4 mm in width were supplied for examination by AMSC, SuperPower, SuNAM, and Fujikura. Based on the results obtained, the text of the standard can now be drafted and measurement uncertainties can be assessed. At the 2014 "Applied Superconductivity Conference" in Charlotte (USA), a compilation and evaluation of the results of our project partners will be presented.

Afterwards, it is planned to extend the HTS tape measurement methods to also cover typical characterisation methods at cryogenic temperatures, such as strain dependence of critical currents both in axial direction as well as under bending conditions.

GSI – Nuclotron Cable

When producing the nuclotron cable for the FAIR project (see Figure 9), the superconducting strands have to be fixed externally on a central cooling pipe. So far, a NiCr wire has been used for this purpose. However, it may damage the surface of the superconducting wire. Consequently, a carbon or Kevlar thread shall be applied instead. In cooperation with GSI and BNG, ITEP studied two different thread types (samples 1 and 2: Para-aramide thread; sample 3: Para-aramide twaron thread). For this purpose, the researchers adapted the testing method existing for threads at room temperature to cryogenic temperatures. In general, a tensile strength of about 100 N was reached at room temperature (see Figure 10). However, to increase statistics to a sufficient level, further tests are required at room temperature and cryogenic temperatures.

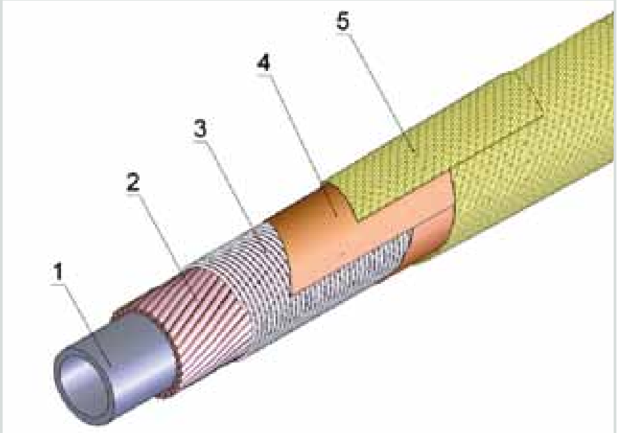
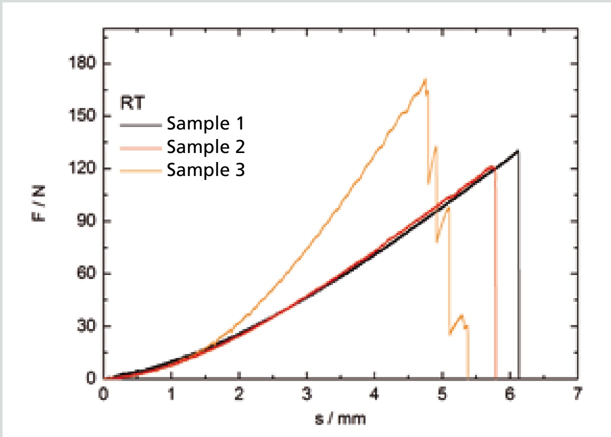


Figure 9: Nuclotron cable: 1 CuNi pipe, 2 SC wire, 3 NiCr wire (possibly carbon / Kevlar thread), 4 Kapton, 5 glass fibres.



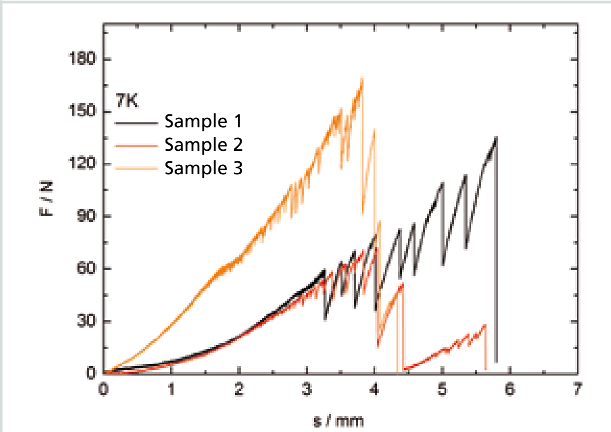


Figure 10: Mechanical behaviour under tensile loading at room temperature and 7 K (samples 1 and 2: Para-aramide thread and sample 3: Para-aramide twaron thread).

Highlight: Successful Test of He Inlet Prototypes for the ITER TF Coils

After the successful fabrication of the first cable lengths for the TF coils, the next production phase starts: The cables are wound in the typical D-shape and equipped with so-called helium inlets. Then, the cable winding can be subjected to the temperature treatment.

Qualification of the helium inlets is a critical issue. The original design of 2005 did not survive the required mechanical loads. A fatigue test aimed at reaching 600,000 cycles under alternating loading from 0.08 to 0.14% strain had to be stopped after about 480,000 cycles due to the failure of a weld seam.

Meanwhile, the design has been revised largely. For this purpose, real load in operation was considered. For the ITER-relevant loading test at 4.2 K, six prototypes manufactured in Europe and two Japanese prototypes were supplied (see Figure 11). Of these eight components, ITEP tested six for up to 261,000 cycles at strains ranging from 0.079 to 0.125%. One prototype was subjected to the same strain for 600,000 cycles. Moreover, a helium inlet was tested under extreme loading from 0.094 to 0.14% strain for 600,000 cycles. All helium inlets passed the test successfully without any failure during the loading cycles envisaged. Hence, the design of the helium inlet was confirmed in terms of structural integrity. Production of the TF coils can now proceed to the next phase. As the tests were successful, it is planned to test further Japanese helium inlet prototypes in 2014.

The rather ambitious test campaign in terms of time and contents could only be executed thanks to the high motivation and commitment of the CryoMaK team that conducted these tests parallel to their routine tasks.

Figure 11: Four European prototypes of helium inlets for the ITER TF coils with a length of about 1.2 m each. On both sides, the clamps to mount the components in the test facility are visible. In the centre (see arrow), the welded pipe section for the helium inlet is located.

Highlight: Work on the Current Leads for Wendelstein 7-X Completed

For the Wendelstein 7-X stellarator (W7-X), ITEP has developed, built, and tested a total of 16 current leads. Two prototypes and 14 series current leads were equipped with BiSCCO superconductors (HTS) that considerably reduce the cooling power required. The current leads were designed for 18.2 kA (see Figure 12).

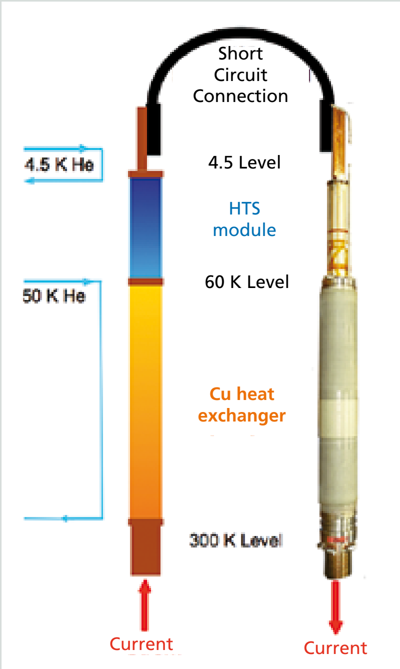


Figure 12: Basic principle of the current lead test, with two current leads being coupled by a shorting link.

Upon the successful detailed testing of both prototype current leads in 2010 and the approval of manufacture of the 14 series current leads, series manufacture by KIT took until October 2012 (see Figure 13).

Figure 13: Three W7-X current leads.

Until March 2013, all series current leads were subjected to acceptance tests. All tests produced reproducibly good results.

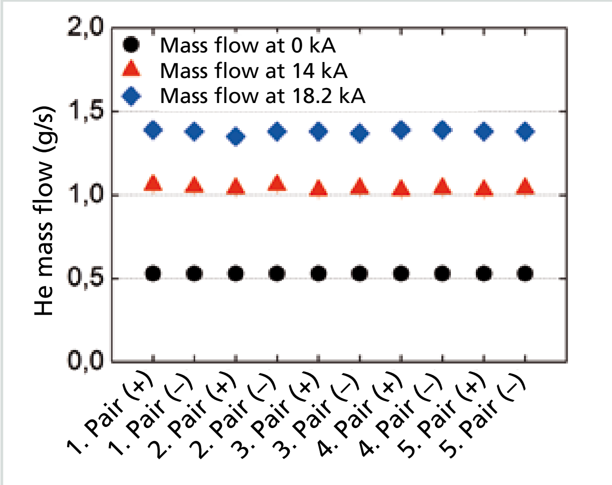


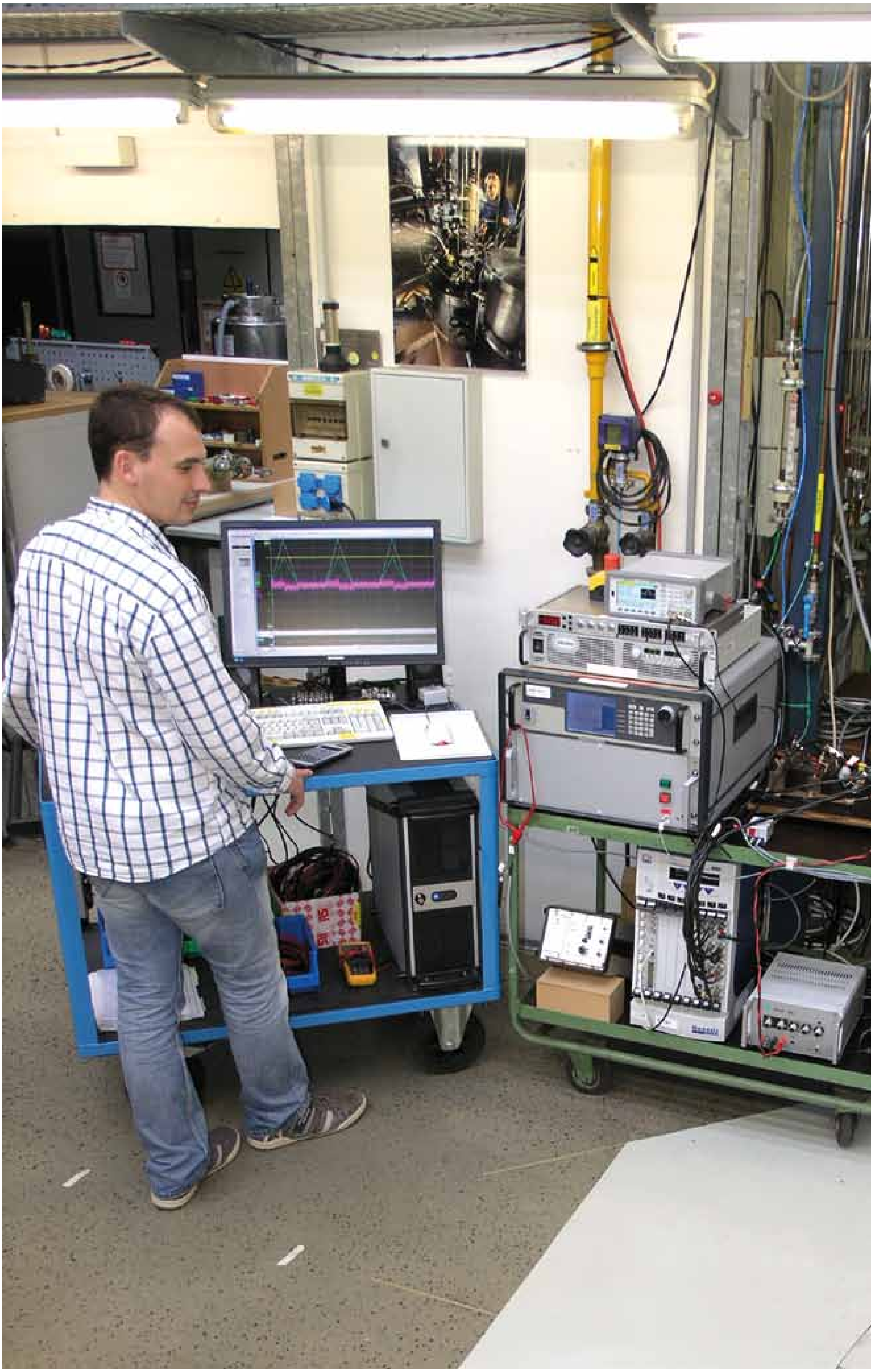
Figure 14: 50 K helium mass flows measured at 0.14 and 18.2 kA for five series current leads.

From 2011 to 2013, all 14 series current leads for W7-X were tested successfully (see Figure 14). Successfully executed tests:

- SFZ 1-ABF61 + 62 (04/2011)
- SFZ 1-ABF63 + 64 (09/2011)
- SFZ 1-ABF65 + 66 (11/2011)
- SFZ 1-ABF67 + 68 (03/2012)
- SFZ 1-ABF69 + 70 (07/2012)
- SFZ 1-ABF71 + 72 (10/2012)
- SFZ 1-ABF73 + 74 (12/2012)
- SFZ 1-ABF61 + 63 (02/2013)

Upon the delivery of the current leads to IPP, Greifswald, work of ITEP for Wendelstein 7-X was completed successfully.

Figure 15: Hand-over of the acceptance records of the last current lead delivered by IPP during the final colloquium at KIT.



Set-up and commissioning of the magnetic current supply unit with integrated quench protection for a superconducting energy storage system under the EWI-LIQHYSMES project.

Results from the Research Areas

Superconducting High Field Magnets

Head: Dr. Theo Schneider

Work of the Superconducting High Field Magnets (HFM) Group of ITEP in 2013 mainly covered the development of insert coils with commercial REBCO tape conductors for High Field magnet systems with central field strengths of 25 – 30 T. The results serve as a basis for the extension of HOMER II and the development of a high-resolution 1200 MHz NMR spectrometer in cooperation with Bruker BioSpin GmbH. Under another project with Bruker BioSpin, work relating to the quality assurance of NMR spectrometers with frequencies from 800 to 1000 MHz was continued. Moreover, ITEP continued to extend and modernize the High Field laboratory. The LIQHYSMES project was continued, the European EuCARD project was completed.

LIQHYSMES

The LIQHYSMES (LIQuid HYdrogen & SMES) project focuses on an approach to balancing supply and load variations due to fluctuating renewable sources used for energy supply. LIQHYSMES is a hybrid storage concept combining long-term storage of energy in liquid hydrogen with short-term storage in a superconducting energy storage system (SMES). The liquid hydrogen is also used as SMES coolant. The storage system is made of the MgB_2 superconductor. The project funded by the EWI hydrogen initiative is aimed at proving the functioning principle by a demonstrator. The ITEP Cryogenics Division carries out work relating to the heat exchanger and cryostat. The IKET Hydrogen Division is responsible for studying all aspects relating to the handling of liquid hydrogen. The HFM Division of ITEP is in charge of magnetic coil development and magnetic current control.

The SMES coils are made of the commercially available MgB_2 conductor purchased from the company of Columbus Superconductors. In this connection, the High Field laboratory performed extensive characterisation work as a function of the magnetic field, temperature, and winding diameter. Design studies for the large-volume demonstrator coil were completed. Detailed construction work will be finished in spring 2014.

The magnetic current control system of the SMES coil was set up and commissioned within the framework of a bachelor's thesis. Figure 1 shows the block diagram of magnetic current control. To simulate later operation of partial SMES discharge, two mains units were used for power supply: one for a constant background current and a four-quadrant mains unit for charge and discharge simulation. The functioning principle of the set-up was tested first using a single-layered REBCO coil (Ø = 150 mm, l = 300 mm) at 77 K. Project-relevant measurements were made using a single-layered MgB_2 coil of the same size at 4.2 K in the HOMER I facility. The MgB_2 coil was operated stably along various characteristics up to 95% of the I_c value with frequency-depending charge and discharge cycles. Figure 2 shows the behaviour of the MgB_2 coil in case of triangular current changes with an amplitude of 50 A and frequencies of 0.3 Hz and 3 Hz, respectively. The quench detection system and upstream protection circuit were also tested successfully. To improve the switching behaviour of the protection system, power thyristors can be applied as an option.

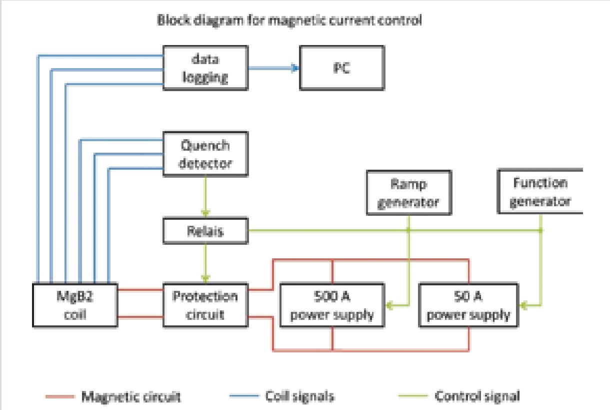


Figure 1: Block diagram of the magnetic current control system of the EWI MgB_2 demonstrator coil.

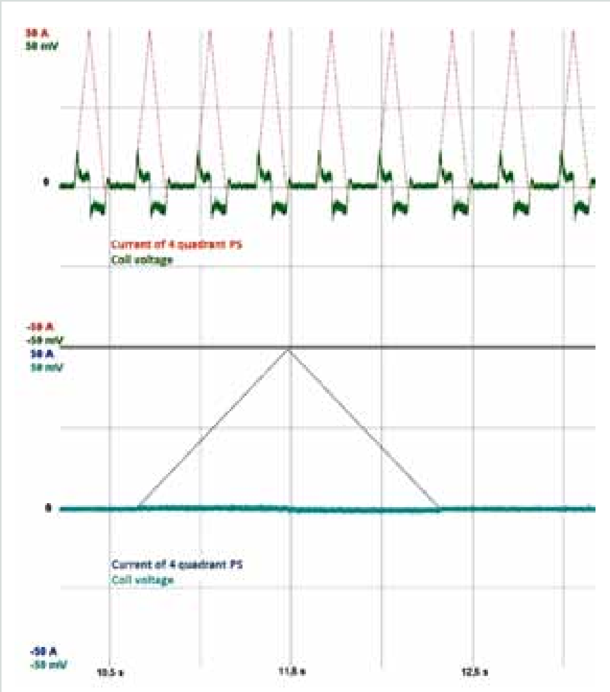


Figure 2: Behaviour of the MgB_2 test coil during a triangular charge and discharge cycle at frequencies of 0.3 Hz (top) and 3 Hz (bottom), respectively.

Infrastructure – Extension and Modernization of Facilities

Activities of HFM mainly focus on the maintenance and modernization of the experimental facilities JUMBO and HOMER I as well as on the continued integration of components into the process control system. In HOMER I, for instance, a temperature-controlled automatic system to heat the 20 T insert coil up to a defined limit with overheating protection and an automatic unit to cool down the insert coils from RT to 4.2 K at controlled cooling rates were commissioned successfully. The preparation for changing over the HOMER I heating system to a continuous process-controlled regulator has been carried out. Work will be completed in 2014.

For the JUMBO facility, a student of the DHBW (Baden-Württemberg Cooperative State University), within the framework of his bachelor's thesis, designed and tested a new temperature control system for residual resistance determination of technical superconductors. The residual resistance ratio (RRR) is an important physical parameter. Its value among others reflects the suitability of a copper type for use as heat exchanger material in ITEP current leads. When constructing superconducting magnets, the RRR value influences cryogenic stability and the quench behaviour of magnetic coils. Hence, the RRR value is an important quality parameter in acceptance tests of superconductors for large magnet systems. The control unit is designed such that both the I_c(B) curve and the RRR value can be determined for standard test objects with 10 cm long superconductor samples. Currently, the system is being extended for measuring the transition curve of superconductors.

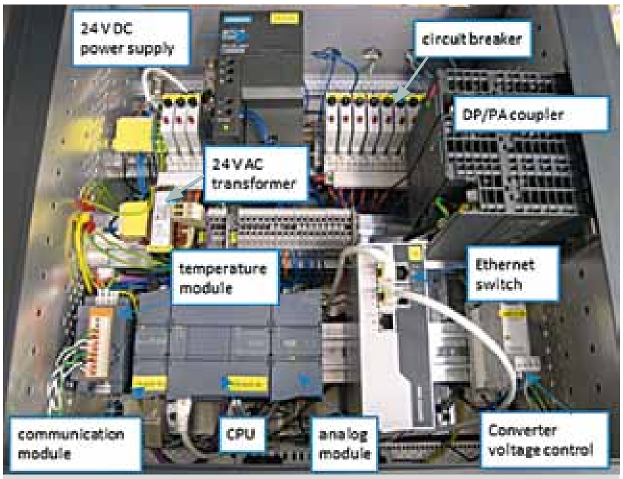


Figure 3: Hardware of the temperature control unit.

EuCARD

With the discovery of the Higgs boson named after the British physicist Peter Higgs in 2012, the Large Hadron Collider (LHC) of the CERN accelerator centre fulfilled its most important task. For the theoretical prediction of the Higgs particle and Higgs mechanism, Higgs and Francois Engler were granted the Nobel Prize in physics in 2013.

To extend knowledge, the LHC accelerator is planned to be upgraded to higher particle energies in the long term. In the past, these and other accelerator development activities were coordinated under the EuCARD project funded by the European Union. After four years, this project ended in 2013. The LHC upgrade requires novel superconducting dipole magnets of the 20 T class. According to the current design, these magnets consist of a 14 T background magnet of NbSn and a 6 T HTS insert. A 3D FEM study relating to such a dipole of so-called block design is shown in Figure 4.

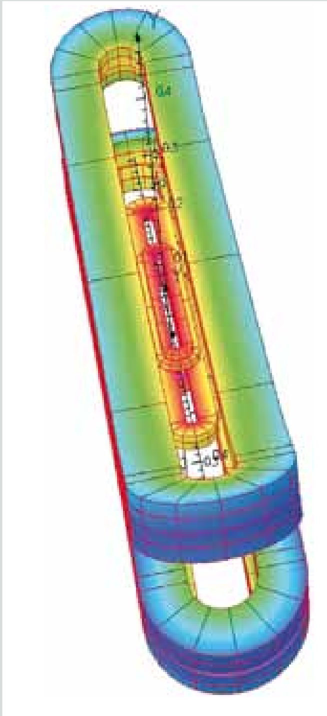


Figure 4: 3D-FEM study of a 20 T dipole magnet of so-called block design for LHC upgrade (taken from a presentation of the project partner P. Tixador, CNRS, Grenoble).

Work of the ITEP Superconducting High Field Magnets Division concentrated on the test of HTS solenoid coils made of a REBCO tape conductor. These coils had been manufactured by the French project partner CNRS, Grenoble, as precursors of a dipole winding. Moreover, activities focused on the characterisation of NbSn wires for the construction of superconducting undulators at the Rutherford Appleton Laboratory (UK).

According to the conductor characterisations, envisaged use of NbSn as undulator material in the operation range of 3 – 5 T is possible for selected conductors only due to mechanical and superconductivity-related instabilities. The test of the HTS solenoid double pancake coil was completed successfully. The winding of the 4 mm wide HTS tape carried about 700 A at 4.2 K in a background field of 10 T. The Lorentz forces of about 730 MPa encountered, however, caused the conductor to break. Hence, the test shows that a larger HTS winding can be operated safely only, if the margin to critical parameters of the winding (critical current, tensile strength of the HTS, etc.) is sufficient.

Work in the area of accelerator technology will be continued under the follow-up project EuCARD2.

Superconducting Undulators

Theoretical and experimental studies for an optimized design of a superconducting undulator with a switchable period length are performed by KIT in cooperation with the ISS and LAS. For the winding, low field-optimized NbTi superconductors are applied. On the basis of the first prototype, weaknesses can be recognised and design adjustment carried out. For the routine calibration of the Hall probes, manufacture of a Helmholtz coil pair was started.

Cooperation with Industry – NMR Projects

NMR-Magnet Technology

ITEP´s HFM Division and Bruker BioSpin have been developing superconducting High Field magnets for high resolution NMR technology with proton resonance frequencies from 750-1000 MHz in a continuous long term cooperation since 1985.

In complementary projects for NMR magnet technology, the HFM team has supported its industrial partner for more than 15 years in additional measures for quality assurance and worldwide commercial launch. Emphasis lies on the characterisation and qualification of commercial technical superconductors by means of high resolution E(I) measurements in the JUMBO and HOMER I facilities. The superconductors tested differ in their principle construction, material composition, production process, dimensions and physical properties that require a multitude of test configurations. Alongside the superconductors, the scientists also characterise the superconducting joints made from the conductor and optimise their residual resistivity in the pΩ-range with dependence on external magnetic field and transport current. The results of the experiments and their evaluation are cooperation know-how and strictly confidential.

1200 MHz NMR-Project

Bruker BioSpin and the HFM Division of ITEP have set the target of developing together a high resolution 1200 MHz NMR-spectrometer. The proton resonance frequency of 1200 MHz corresponds to a central magnetic field strength of 28.2 T. This field strength can only be realised with HTS insert coils. The work in 2013 was carried out according to the project schedule. Focus was upon the physical characteristics of the best commercially available REBCO tape conductor with lengths of more than 100 m. In particular, the High Field properties as well as the Lorentz force limit at field strengths of up to 20 T were investigated.

In addition experiments determining the degradation due to the effects of superfluid helium, temperature and force cycles were carried out as well as analysis of the anisotropy in specific angle ranges.

R&D Work for HTS Characterisation

For the design of HTS magnetic coils under the 1200-MHz project, extension of HOMER II towards 30 T, and applications at 77 K, such as transformers or current limiters, anisotropy $I_c(B, T, \Phi)$ of the REBCO tape conductor has to be known.

By means of the angular set-ups existing and further developed at the HFL, the $I_c(B, T, \Phi)$ curve of the REBCO tape conductor was determined in the JUMBO facility at magnetic fields of 0 – 10 T for both 77 K and 4.2 K. The set-ups are designed such that transport currents of up to 300 K at 77 K and of more than 1500 A at 4.2 K can be reached. Measurements are made using original tape conductors of about 4 – 5 mm width. Most of the results presented in literature, by contrast, were obtained using specially prepared "microbridges" of reduced width.

Commercially available REBCO tape conductors were characterised. Work focused on two types produced by the Korean manufacturer SuNAM (without and with brass lamination). Angular dependence was determined at 4.2 K and 77 K in the range of 0 – 180°. As the variations of the $I_c(B, T, \Phi)$ characteristic are largest at an angle of about $\Phi = 90°$, i.e. at a magnetic field perpendicular to the tape normal, measurements in this range were performed at small angular intervals of $\Delta\Phi = 2°$. For High Field applications, measurements at 4.2 K in a magnetic field range of 2 - 10 T were prioritised. For 77 K applications, the magnetic field range between 0 and 1 T is of particular interest due to the strong decrease of critical current. Consequently, the $I_c(B)$ dependence was studied in detail in this range at intervals of 0.1 T.

The I_c values were determined by fitting a power function to the $U(I, B, T, \Phi)$ characteristics. For the mathematical fitting of all $I_c(B, T, \Phi)$ data, four fitting models were selected and evaluated. Figure 5 presents normalised 3D plots to reveal the best fit functions for the laminated SuNAM conductor and the variations of the I_c values as a result of partial derivations to the angle Φ and magnetic field B.

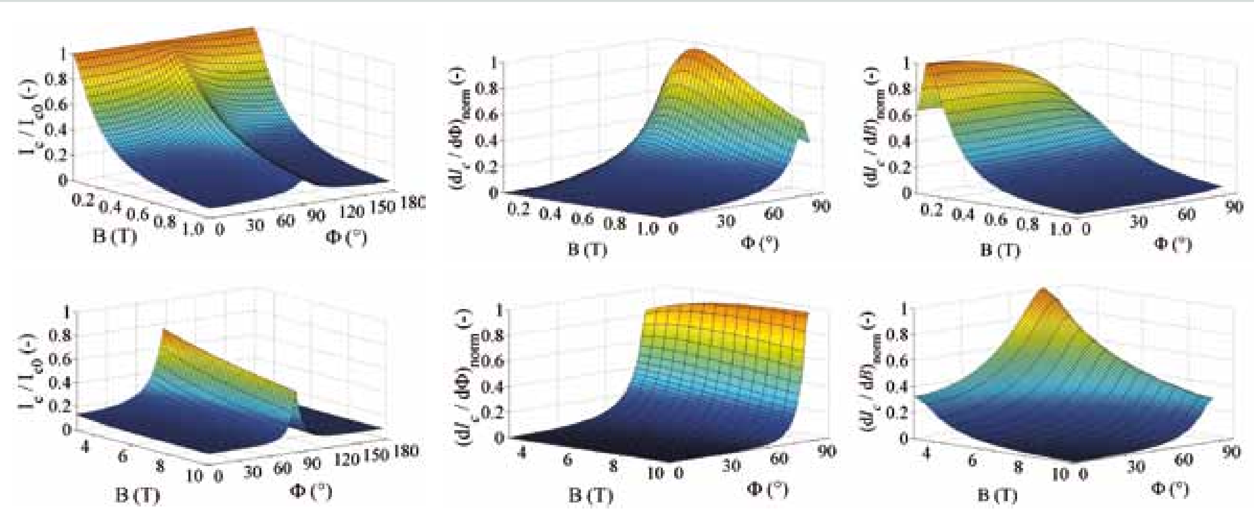


Figure 5: 3D fit (normalised) of the $I_c(B, T, \Phi)$ data determined and partial derivation of the fit functions to the angle Φ and magnetic field B for T = 77 K (top) and T = 4.2 K (bottom).

Highlight:
HTS Coil Development – Lorentz Force Studies

Superconductors in a magnetic coil are exposed to axial and radial forces. The radial force is proportional to the axial field component, coil diameter, and magnetic current applied. Axial forces are proportional to the radial component of the magnetic field in the winding. To determine the maximum force load, researchers carried out experiments in the JUMBO facility and in the 15 T configuration of the HOMER I test facility. Figure 6 shows single-layered REBCO test solenoids of variable coil length, winding number, and coil diameter. In addition, loading tests were carried out using various commercially available REBCO tape conductors in a triple coil set. The maximum Hoop stress was determined under a simultaneous Lorentz force for coil diameters of 40, 80, and 150 mm, respectively.

Figure 6: Single-layered REBCO solenoid coils of variable length and diameter for the experimental facilities JUMBO and HOMER I.

Axial force tolerance was studied using single- and multilayered solenoid coils with maximum diameters of 150 mm and coil lengths of up to 300 mm. Measurements were carried out successfully at background fields of 14 T in superfluid helium with coil currents ranging up to the conductor-specific I_c value. No degradation occurred. Functioning of the coil (Ø = 150 mm, L = 300 mm) was demonstrated in a subsequent experiment in liquid nitrogen (see chapter on LIQHYSMES). The coil was charged and discharged in a frequency-dependent manner with transport currents of variable characteristics and, hence, subjected to cyclic loading. Figure 7 shows the behaviour of the coil at a triangular transport current with a frequency of 3 Hz. In the experiment, the scientists increased the current from 50 A to 120 A. The range from 110 A to 120 A is shown in the figure.

The resistive increase of coil voltage (green peaks) from 110 A is clearly visible. The critical current I_c of the REBCO conductor is about 111 A according to the manufacturer's data and HFM measurements. This good agreement shows that the coil withstood the Lorentz force loads of the HOMER I measurements without any damage.

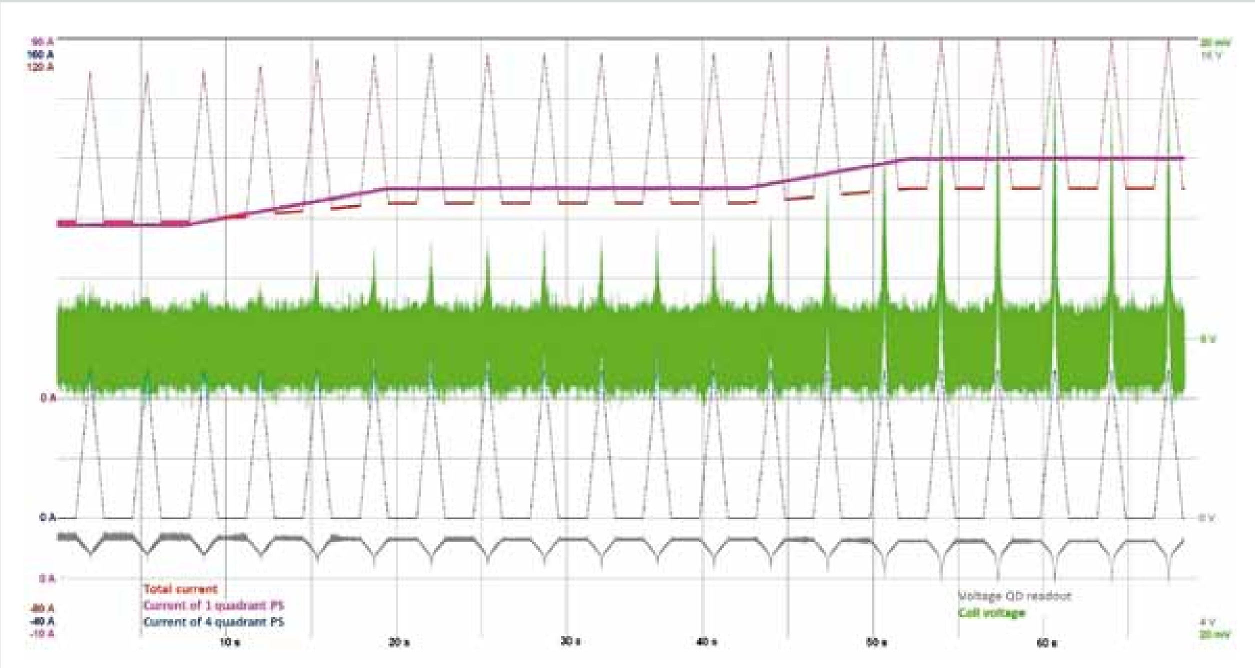


Figure 7: Behaviour of the REBCO solenoid coil at 77 K under triangular current loading in the range from 110 A to 120 A.

Highlight: HTS Coil Development – High Field Properties/High Field Behaviour

For the extension of the HOMER II experimental facility up to 30 T and for the cooperation project to develop an insert coil for a high-resolution 1200 MHz NMR magnet system, scientists require information about High Field properties, force tolerance, and cryogenic stability of the commercially available REBCO tape conductors in order to be able to develop and build insert coils meeting the requirements specified.

In later application, the insert coils have to be able to carry a magnetic current of more than 300 A at background fields larger than 20 T and cryogenic temperatures below 4 K. To determine the I_c (B, T, Φ) characteristic, the HFM team performed measurements on the best REBCO conductors at background fields of up to 20 T and temperatures of up to 1.8 K. With the help of mathematical models, extrapolations were made up to 30 T. According to the results, the higher performance of the commercial tape conductors in terms of both I_c(B) characteristic and cryogenic stability enables the construction of multi-layered insert coils for HOMER II and the 1200 MHz project.

This was confirmed experimentally by multi-layered mini solenoids with a maximum outer diameter of 48 mm, which were manufactured at the HFM workshop. Figure 8 shows such a mini solenoid consisting of 92 windings of a REBCO tape conductor. Together with the background field of HOMER I at 1.8 K and a magnetic current of 525 A, the solenoid coil reached its calculated design field and increased the central field of HOMER I to 21 T.

Figure 8: 1 T REBCO mini solenoid for the HOMER I-20 T configuration.

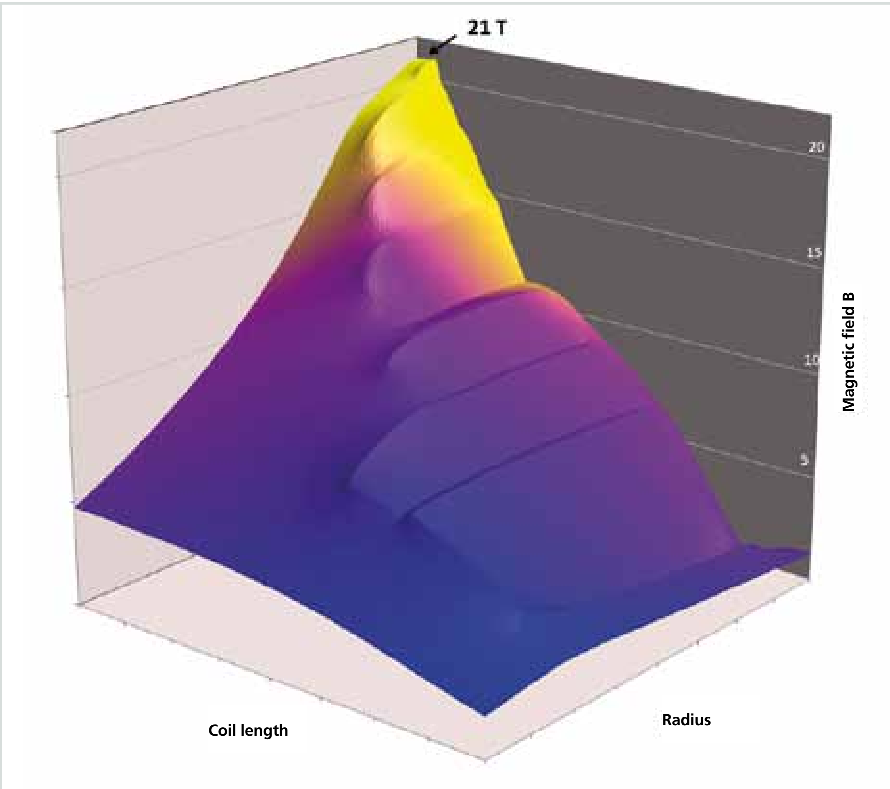


Figure 9: Magnetic field distribution of the complete magnet system with $B_{0,\,max}$ = 21 T, consisting of 3 NbTi and 3 $(NbX)_3Sn$ coils of the HOMER I facility (B_0 = 20 T) plus one REBCO mini solenoid coil (B_0 = 1 T).

Model of the power cable in the liquid nitrogen bath.

Results from the Research Areas

Superconducting Materials and Applications in Power Technology

Head: Dr. Wildfried Goldacker

Superconductor Development and Applications in Power Technology

In 2013, superconductor development at ITEP concentrated on the following topics:

- Development of low-AC-loss REBCO tape conductors with laser-structured filaments;
- Development of various low-loss high-current cables based on high-temperature superconductors (HTS) of the second generation (CORC, Roebel, and Rutherford cables);
- Development of stranded AC conductors based on the magnesium diboride superconductor.

ITEP researchers optimised conductors and cables, measured their current-carrying capacities and AC losses, calculated their properties with the help of numerical methods, and correlated them with experimental results. They produced HTS Roebel cables of moderate length in various winding arrangements, studied them, and characterised the properties. In 2013, modelling of both superconductors and superconducting components using self-developed methods played an important role. The results obtained are of pioneer character. As regards applications of high-temperature superconductivity, research focused on a model of the HTS power cable for the AmpaCity project in Essen. In the area of HTS current limiters, ITEP scientists technically supported the transfer to and conditioning of the ECCOFLOW current limiter in the RSE test field at Milan and at the place of installation on the island of Mallorca. Work on an inductively coupled current limiter was completed largely by measurements using a functional model within the framework of a doctoral thesis. A conductively cooled HTS magnet based on YBCO tape conductors of the five-tesla class was designed and produced.

HTS AC Conductors and Cables for Windings/Magnets

The filament structure of REBCO conductors is of decisive importance for a major reduction of AC losses. For some time now, ITEP has been applying a structuring method based on a pico-second YAG laser. This method has been optimised to achieve complete electrical decoupling of the filaments in the material by subsequent heat treatment. Up to 120 filaments of about 80 µm in width were burnt. The associated reduction of AC losses and, hence, the effect of the post-treatment were confirmed. Transport currents are subject to a moderate degradation caused by the loss of superconductor material and the effects of inhomogeneous superconducting layers (see Figure 1).

In addition, tapes of stranded conductor-on-round-core (CORC) cables were provided with five filaments. The

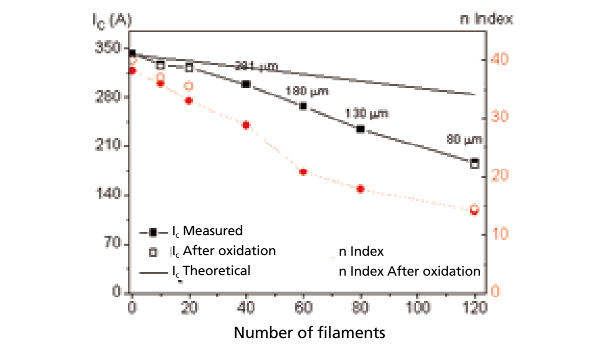


Figure 1: Transport currents and n values of conductors with various numbers of filaments. The conductor remains indifferent in case of subsequent annealing in oxygen.

AC losses were measured by the Institute of Electrical Engineering of the Slovak Academy of Science in Bratislava. Highly efficient loss reduction in the CORC geometry was confirmed.

Of the few technical HTS concepts, Roebel cables made of REBCO conductors are the most promising candidate for use as low-loss high-current cables in windings. These cables are of particular interest for applications at temperatures ranging between 4 and 77 K and partly high background fields of up to 20 T (dipole magnets of the LHC of CERN, transformers, and rotating machines). ITEP scientists manufactured 2 to 5 m long Roebel cables and measured their behaviour at low temperatures in a background field (FRESCA facility at CERN, 4.2 K, 0 to 10 T). Moreover, they systematically studied the cable properties in terms of current-carrying capacity and AC losses of the windings (pancake and layer windings). Degradation of currents in a layer winding and dependence of AC losses on winding density are small, as vertically oriented components of the self-field hardly play any role. At 4.2 K, transport current of Roebel cables exceeded that of 77 K by a factor of 11 to 12 (measurements on ITEP cables at CERN). A standard cable of ITEP with 10 strands of 5.5 mm in width carried 14,000 A. In the presence of a background field, a high anisotropy of transport current by up to a factor of 3 was observed, similar to the behaviour of an individual strand or outlet tape. Furthermore, permissible mechanical loading of the cable under transverse stress caused by the Lorentz force was studied. It was found to be about 160 MPa and, hence, to meet the application requirements. Depending on the requirements, transport current of the cable can be increased by several factors through multiple strands and extended transposition.

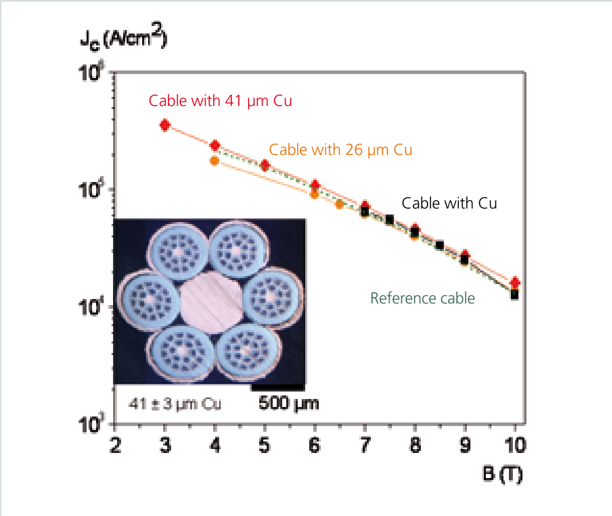


Figure 2: Stranded magnesium diboride AC cable cross-section with central Cu stabilisation and Cu plating for improved coupling and behaviour of the transport currents.

Figure 4: ECCOFLOW current limiter at the ENDESA transformer station, Palma de Mallorca.

Magnesium diboride cables presently are of high interest for AC and DC applications, as this superconducting wire is comparably inexpensive. ITEP purchased commercially available multiple-core wires from Hypertech, produced stranded cables of various designs with copper wires for external stabilisation, and measured their transport currents and AC losses. An innovation of the scientists was additional coupling of the strands using electroplated copper (see Figure 2). In this area, ITEP cooperated closely with IEE-SAS Bratislava and the University of Wollongong (Australia). The cable concepts are envisaged for use as bus bars to connect magnets (CERN), AC windings in transformers/engines, generators for wind power plants, and superconducting HVDC power cables in the EU-funded Best Paths project, for instance.

HTS Cables for Fusion Magnets

Based on measurement results obtained for a model cable, the progressive concept of a Rutherford cable with HTS Roebel strands, a candidate for future fusion magnets, had to be revised to pevent a degradation of the superconducting material under bending. The measurement data allowed for a safe revised design of the cable with a round central tube and a transposition of the Roebel strands of about 2/3 m. The researchers produced a cable of about 1.4 m in length for measurements. The model cable concept is shown in Figure 3.

Superconducting Fault Current Limiters

Work on fault current limiters was concentrated in the EU-funded ECCOFLOW project. In addition, an inductively coupled superconducting current limiter was developed. Within the framework of ECCOFLOW, ITEP supported the Nexans company in the final conditioning of the superconducting fault current limiter for the field test on the island of Mallorca after the test at ERS in Milan. Stability of the superconductor insulation specially developed by ITEP was rather positive. It remained defect-free over all test cycles. 3.5 km of superconducting tape were encapsulated with polyamide foils at the Nexans company using a facility developed and delivered by ITEP. Figure 4 shows the current limiter at the ENDESA transformer station on the island of Mallorca.

Numerical Modelling of HTS Cables and Components

ITEP developed the first time-dependent electromagnetic 3D model of Roebel cables. It was applied for the calculation of a 14-strand cable. Use of periodical framework conditions with a reduction of the modelling domain to 1/n of the transposition length is important. Figure 5 shows the calculated field distribution in a Roebel cable.

Moreover, ITEP generated a 2D-3D hybrid model for pancake windings based on Roebel cables. The scientists combined a 2D simulation of the anisotropic current behaviour in the magnetic field with 3D modelling of the contacts.

As a contribution to the power cable to be developed under the BMWi-funded project AmpaCity, ITEP scientists conceived a 2.5-D code to model the current behav-

Figure 3: Rutherford cable concept with six Roebel strands in hexagonal geometry and a cladding tube for mechanical stabilisation.

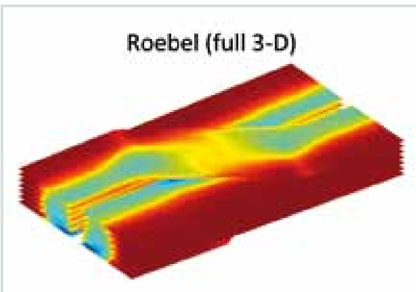


Figure 5: Modelled field distribution in a Roebel cable.

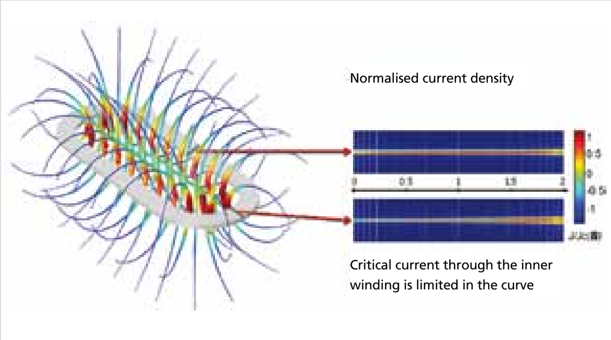


Figure 6: Calculated field distribution in a racetrack coil.

iour and resulting AC losses and verified it successfully by measurements on the ITEP model cable. 2.5-dimensionality results from a periodic disc structure along the cable axis. It allows the transposition of the conductors to be considered. The model is no real 3D model, as it does not take into account axial field components. However, these are negligibly small. The calculation code was made available to the industry partners involved in the project. It allows for an optimisation of AC losses and superconductor quantity in the design phase of a power cable already.

As far as the components are concerned, a 3D model of stacked superconductor tapes was developed. It can be used to simulate coils of non-axisymmetric geometry, such as racetrack coils (see Figure 6). The model assumes the winding to be a larger conductor. It is the only model existing to calculate such coils in three dimensions. However, the model is not limited to coils. It can also be used for cables with transposition and conductor stacks.

Superconductors in Space Research

For an experiment in the DLR plasma channel, ITEP designed and constructed an HTS magnet under the COMBIT HGF project. This magnet is to be used for studying whether the dreaded radio blackout occurring when space shuttles re-enter the atmosphere of the Earth can be mitigated by reducing the plasma density with the help of crossed electric and magnetic fields. The magnet system developed by ITEP consists of five double pancake coils connected in series with a special low-ohmic contact (see Figure 7). For verification of the magnet technology, a single double pancake was produced in the same way, impregnated with bees wax, and measured at 4.2 K. The field of 1.32 T reached is in agreement with the OPERA calculation.

Superconducting Transformer to Limit Short-circuit Currents

ITEP developed a special computer programme for the design of superconducting current-limiting transformers. With the help of this programme and a few given basic transformer design parameters, a superconducting transformer can be designed and its fundamental parameters can be estimated and adapted. Moreover, the computer programme allows statements to be made with respect to the material costs arising, electric losses during operation, dimensions, and the resulting transformer weight. In this way, the transformer design can be optimised for the application desired and an application-specific optimal transformer concept results.

Based on the calculated transformer parameters, the computer programme developed by ITEP can also be used for the transient simulation of the behaviour of a transformer designed as a superconducting short-circuit current limiter. This option is highly useful, as the properties of a current-limiting transformer are not trivial to predict in case of a short circuit. These properties are determined by numerous parameters and design-related factors.

After the development of the above computer programme, this tool was applied by ITEP for the design of a superconducting transformer of 577 kVA nominal power. The transformer developed is a single-phase representation of a 1 MVA three-phase transformer. It has a 20 kV primary winding made of a conventional copper conductor, a superconducting secondary winding of 1 kV nominal voltage, and an iron core operated at room temperature. The secondary winding based on YBCO tape conductor material is supposed to limit short-circuit currents. During normal operation, the secondary winding is kept at an operation temperature of 77 K using liquid nitrogen. A sketch of the transformer is presented in Figure 8. In the next working step, this superconducting transformer is planned to be built as a laboratory demonstrator by ITEP and to be subjected to testing.

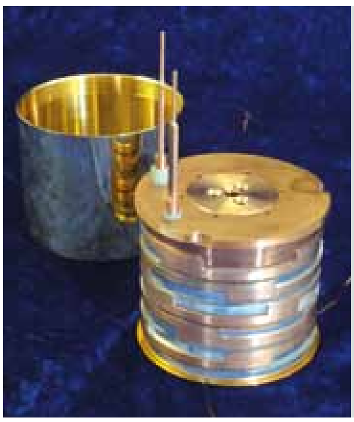


Figure 7: Magnet based on HTS tape conductors in five double pancake windings prior to the application of solder contacts with a central field of 5 T.

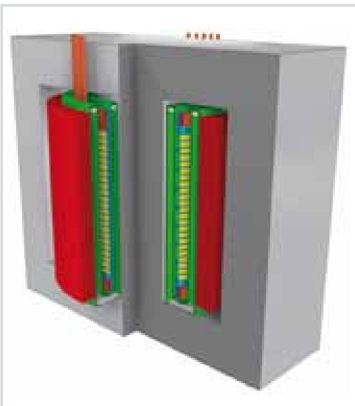


Figure 8: Sectional view of a superconducting transformer. The current-limiting superconducting winding is coloured yellow.

Highlight: Inductively Coupled Current Limiter

The system based on a reactance coil used so far for short-circuit current limitation was further developed to using high-temperature superconductors in a current limiter concept with inductive resistance coupling. During normal operation, impedance of the reactance coil is to be compensated to minimise grid feedbacks and to enhance the stability of the electric power grid. For this purpose, a superconducting insert made of YBCO tape conductors is installed in the reactance coil. During stationary operation, this secondary, superconducting winding shields the magnetic field of the reactance coil and reduces impedance. In case of a short circuit, the current induced exceeds the critical current of the superconductor, the shield loses its effect, and impedance increases.

Abb. 8: Am ITEP entworfener und gebauter Strombegrenzer mit induktiver Widerstands-einkopplung.

For the verification of the concept and analysis of the limitation behaviour, a demonstrator of 60 kVA, 400 V, and z = 6 % was developed, built, and tested (Figure 9). YBCO tape conductors of 12 mm width with copper stabilisation were used as secondary, superconducting winding. In total, 33 m of superconductors were incorporated in 22 tapes connected in parallel. Measurement results obtained at various short-circuit currents for a period of four half-waves are shown in Figure 10. The superconducting current limiter reaches the same limitation effect as the reactance coil. In the best case, current is limited by 30 %.

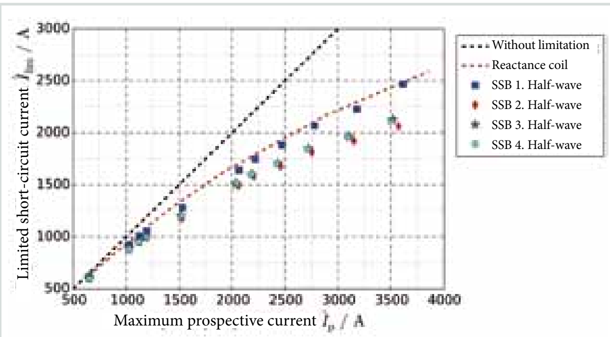


Figure 9: Current limiter with inductive resistance coupling designed and built by ITEP.

Highlight: HTS Roebel Conductor Layer Coil

For the first time, ITEP produced a layer coil with a variable winding distance from a 5-m HTS Roebel conductor. Currents and AC losses were measured and calculated using a numerical model. Compared to a pancake winding, current degradation in the self-field of the winding is much smaller. Only at the ends of the winding can a higher influence of vertical field components be noticed.

The figures show the coil (Figure 11), the calculated field distribution (Figure 12), and the analysed AC current losses (Figure 13). From the measurements obtained for various geometries, an optimum combination of low AC losses and the required winding distance for a given magnetic field results.

Figure 10: Short-circuit current limitation of the demonstrator measured for various short-circuit currents and a short-circuit duration of 4 half-waves.

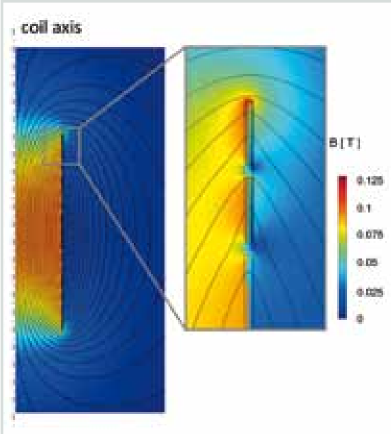


Figure 11: Layer winding made of a 5-m HTS Roebel conductor.

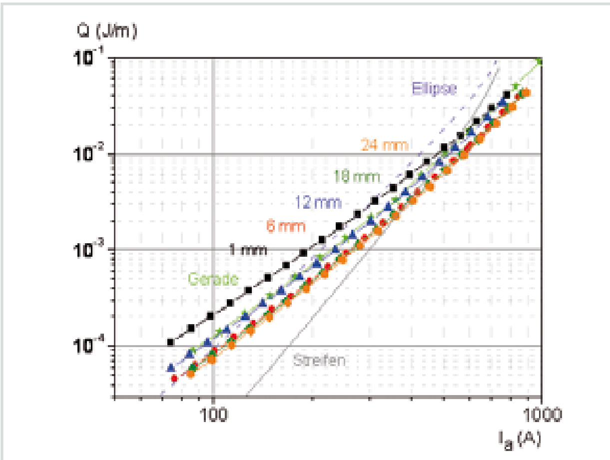


Figure 12: Numerical calculation of the field distribution of the Roebel winding.

Highlight: AmpaCity Power Cable – Studies of the Model Cable and Numerical Modelling

ITEP scientists characterised the KIT model cable having a geometry equivalent to that of the power cable with two phases as well as mutual interactions of the phases. Using a completely newly developed code for numerical modelling, the measured properties were reproduced quantitatively in 2.5 dimensions. The 2.5 D model describes the properties quantitatively and allows to calculate optimised cable designs. Figure 14 shows the functioning principle of the model. Figure 15 represents potential optimised cable concepts. Figure 16 presents a photo of a model cable with partial equipment.

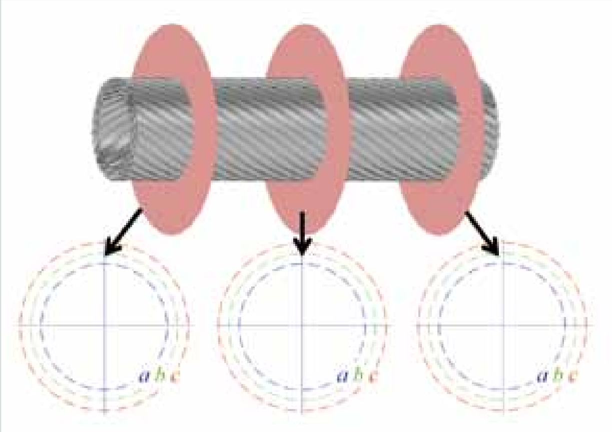


Figure 13: AC losses of various modifications of the Roebel layer winding.

Figure 14: Principle functioning of the numerical model with axial periodic segmentation of computation domains and phase relationships.

Figure 15: Two cable designs with current-carrying capacities of the individual phases of 50 % (left) and 90 % (right) and a current-carrying capacity adjusted to phase 1 (left) or phase 2 (right) of the real cable.

The photo shows the interior of the cryogenic measurement cell used for the TApIR experiment. It is completely filled with liquid deuterium that is invisible. However, the separation layer between both substances, which reflects the frozen neon, can be seen.

Results from the Research Areas

Karlsruhe Tritium Laboratory (TLK)

Head: Dr. Beate Bornschein

The Karlsruhe Tritium Laboratory (TLK) is a semi-technical experimental facility, unique in Europe and America. It has the permission to handle 40 g (1.5 * 10^{16} Bq) tritium, 100 kg depleted uranium and rubidium and krypton as test emitters for calibration purposes. An experimental area of more than 1000 m^2 accommodates more than 15 glove box systems with a total volume of about 125 m^3 serving as enclosures of the tritium-containing experimental set-ups. The foundation mission and paramount activity of the TLK is the development of technologies for the fuel cycle of fusion reactors. A second focus lies on the construction of key systems for the Karlsruhe Tritium Neutrino Experiment KATRIN to measure the rest mass of the electron anti neutrino. Accordingly, work is embedded in the "Fusion" and "Astroparticle Physics" programmes at equal shares.

Figure 1: The beginnings of the TLK.

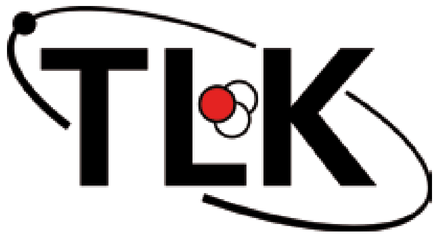


Figure 2: The new TLK logo.

Young scientists are very important for the future of the TLK. In the past years, TLK attracted an increasing number of students and doctoral researchers by offering interesting research projects (see Table 1). The TLK is highly interested in providing young people with excellent and balanced training that does not only cover technical and scientific aspects, but also various soft skills required today.

	2009	2010	2011	2012	2013
Bachelor			6	12	9
Diploma/Master	7	9	9	6	7
Doctorate	4	8	10	10	11

Table 1: Completed and ongoing theses at TLK.

The activities and results obtained in the areas of TLK operation and infrastructure as well as in fusion research and development will be outlined briefly below. The KATRIN activities will be covered by a separate chapter.

20th Anniversary of TLK

TLK started operation in 1993 with the delivery of 3.5 g tritium. To celebrate its 20th anniversary, a colloquium with a subsequent summer party was organised on July 23, 2013. Presentations provided an interesting overview of 20 years of TLK history, from the planning and implementation of the project to the current operation of the facility. Present and former staff members of the TLK spoke about operational aspects and research-relevant topics. A highlight of the event was the presentation of the new TLK logo (see Figure 2) and the handover of the associated prize to the authors. The anniversary event was completed by a summer party.

TLK Operation and Infrastructure

In 2013, the conventional infrastructure facilities as well as the tritium infrastructure systems of the Tritium Laboratory were fully available to the research projects conducted under the programmes of "Fusion" and "Astroparticle Physics". The tritium storage system mainly provided the CAPER experimental facility, used for operational tasks, such as the detritiation of waste gases, and for research and development, as well as the experiments TriToP and TriReX (see chapter on KATRIN) with tritium of high isotope purity (> 95%). The CAPER group additionally produced special tritium gas mixtures for other experiments. The legal sicensing requirements, needed for the operational approval, were always fulfilled. No reportable events occurred.

Work of the Operations Office, the Automation and I&C Group, and the Tritium Process Technology Group in 2013 again focused on maintaining safe operation of the TLK and keeping the infrastructure facilities available for research and development activities under the programmes of "Fusion" and "Astro". One ongoing important task is the knowledge transfer to students, working on their student research projects, who have normally no experience on tritium handling at the beginning of their studies. For this reason, the operations staff provides major support in planning the experiments and checking safety-relevant documents in detail (safety-related description, etc.) in accordance with the operations instructions.

Apart from its usual major activities, such as operation, maintenance, recurrent inspections of the infrastructure facilities (second enclosures, tritium storage system, tritium transfer systems, etc.), and waste management, the Tritium Process Technology Group had to ensure smooth operation of the main systems of the TRENTA facility in 2013. An important task was the repair of the two highly expensive electrolysers after extensive fault diagnosis. Repair covered the exchange of control units, mains systems, and filters, diagnosis and exchange of the electrolysis cells. Another time-consuming task was the preparation and execution of the internal inspection of the Linde He refrigerator.

As in the previous year, work of the Automation and I&C Group focused on the replacement of the TLK process control system. This replacement was necessary, because the old Teleperm M system is no longer supported by the supplier and spare parts are no longer available. In the fourth reconstruction phase, software development for the reconstruction of the last old automation system AS6 was completed as planned.

For various reasons, this software development was a big challenge. The automation system, which has to be exchaned, controls the central tritium retention system (ZTS) of the Tritium Laboratory. Apart from numerous monitoring and safety functions, 32 complex, extensive, and interlinked automatic flow control systems had to be implemented. Upon their implementation, the MAT Group developed special Labview programmes to model the I/O periphery and the behaviour of the tritium retention system by simulation assemblies. This had to be done, as the central tritium retention system was not available for these tests. Final tests of the flow controls will take place in the second quarter of 2014 upon reconstruction. Then, the old system will have been dismantled completely, and the new PCS7 system will start operation.

Set-up of the KATRIN experiment continues to require a close cooperation with the MAT Group of the IKP, as standardised systems and procedures are required for the I&C of the tritium loops. Both MAT groups developed a concept for central PCS7 project administration and planning in the I&C area (slow control) for KATRIN in 2013. Apart from all stations, this concept also covers the data networks up to data transfer to the KATRIN experiment LAN. In this way, operation, maintainability, and extendability will be ensured in the long term. Special contracts, such as a license upgrade service, guarantee use of up-to-date PCS7 software versions. For the PCS7 project of the cryogenic pumping section (CPS) of KATRIN, the MAT Group extended the PCS7-AS/OS module library developed by the TLK, inclusive of the technical functional units (typicals).

Analytics at the TLK

Qualitative and quantitative analysis of the six hydrogen isotopologues H_2, HD, D_2, HT, DT, and T_2 as well as of other tritiated compounds, such as HTO, is the major prerequisite for handling tritium and associated with strict requirements on experimenters and their equipment. As analytics is of crucial importance to TLK, research and development activities are coordinated and executed across programmes and groups. In 2013, R&D work concentrated on the following areas:

- Laser Raman spectroscopy of gaseous tritiated hydrogen isotopologues.
- Beta-induced X-ray spectroscopy (BIXS) of gaseous hydrogen isotopologues and liquid tritiated water (see KATRIN chapter).
- Infrared spectroscopy of liquid hydrogen isotopologues (see Highlight).
- Application of liquid scintillation as inline method to determine the tritium concentration of water.

Parallel to the research and development activities, calorimeters, ionisation chambers, and gas chromatographs as well as existing calibration methods were further optimised. These instruments are used regularly and represent the backbone of analytics at the TLK. Hence, they always have to be ready for operation. Work in 2013 focused on the cold commissioning (without tritium) of a gas chromatograph suited for measuring hydrogen isotopologues. This instrument is to replace a device that is about 20 years old. After inevitable fault diagnosis and some technical optimisations, the first satisfactory measurements were made in summer 2013. In 2014, the instrument is planned to be installed into the corresponding glove box. The necessary technical planning work was accomplished in 2013.

R&D for ITER

Current work on the tritium loop of ITER concentrates on the European contribution "Water Detritiation and Isotope Separation (WDS-ISS)". For this purpose, the TLK develops and studies processes of water detritiation and hydrogen isotope separation in the TRENTA facility under the "Fusion" programme. These activities are aimed at obtaining major data for the WDS and ISS systems of ITER and, in this way, contributing decisively to the ITER design. Apart from this specific R&D relating to the WDS/ISS of ITER, TLK conducts research within the framework of tasks given by ITER and F4E. The CAPER Group also is involved in this work.

In 2013, research in the area of ITER-relevant tritium technologies focused on a study of the so-called capture & exchange (C&E) method. This method consists in the storage of highly tritiated water on zeolite catalysts (capture) and the recovery of tritium bound in water by isotope exchange reactions on the zeolite catalysts (exchange). Highly tritiated water, in which one or both protium atoms (H) in the water molecule H_2O are replaced by tritium atoms (T), represents a highly corrosive medium due to radiolysis of tritium (formation of hydrogen peroxide H_2O_2). Consequently, development of effective technologies to handle and rapidly process highly tritiated water generated in future fusion reactors, such as ITER, is important and necessary.

Based on this requirement, the Karlsruhe Tritium Laboratory, together with ITER, launched an experimental C&E programme to study the use of zeolite materials

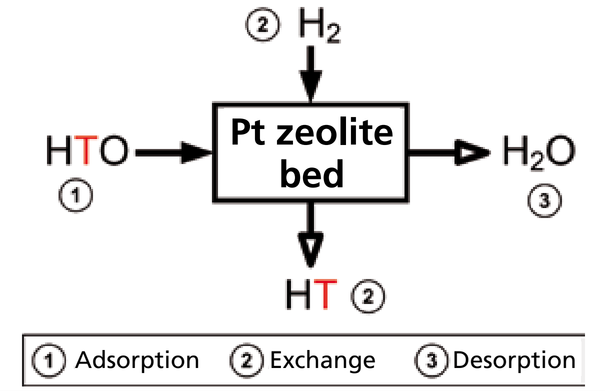


Figure 3: Schematic representation of the capture & exchange method for processing highly tritiated water (HTO) and tritium recovery.

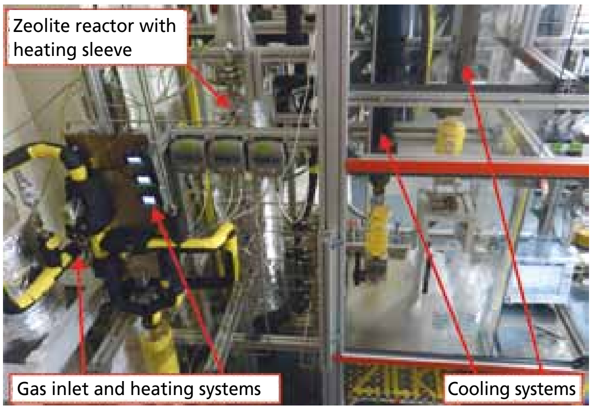


Figure 4: The Zicke experiment – test set-up for studying the C&E method under ITER-relevant technical conditions.

for the safe uptake and storage of tritiated water and for subsequent tritium recovery by isotope exchange reactions. Tritium recovery is an important step, as tritium, together with deuterium, another hydrogen isotope, is used as a fuel in fusion reactors and, hence, represents a valuable material. Figure 3 shows a simplified schematic representation of the steps of the C&E method.

The C&E programme was divided into three phases. In the first phase, various zeolites were analysed for their water storage capacity (adsorption) on a small scale (~ 25 g) in variably dimensioned zeolite beds. Then, isotope exchange reactions were initiated to additionally determine their reactivity. For the first studies, heavy water (D_2O) was used instead of tritiated water. The zeolites were impregnated with platinum metal (Pt) acting as a catalyst for the exchange reactions between the adsorbed water and the protium (H_2) exchange gas. In this way, the most effective zeolite was identified for use in the next programme phases.

The next phase covered the detailed investigation of the zeolite with highly tritiated water and transfer of tritium from water to the gas phase for use in the following process phases. For these experiments with highly corrosive and radiotoxic water and the 25-g zeolite beds, the existing CAPER facility of the TLK had to be modified according to complex reconstruction plans (see Figure 5). In parallel, a new test rig was set up to test the C&E method on the technical scale under ITER-relevant conditions (22 kg zeolite; 2 kg stored water; H_2 flow rates up to 1 m^3 h^{-1}) with heavy water (D_2O). In the CAPER experiments with tritiated water and in the large-scale set-up with heavy water, process parameters, such as pressure, flow rates, and temperatures, were varied in order to determine their influence on the water storage capacity and isotope exchange rate (Figure 4).

The C&E programme revealed that zeolites are suited well for the safe temporary storage of highly tritiated water. Thanks to the additional impregnation of zeolite with metal catalysts for direct isotope exchange on the zeolite, simultaneous effective tritium recovery is possible. After optimising the operation parameters, such as temperature gradients along the zeolite reactor, it was possible to meet ITER requirements (exchange rates > 100; processing of up to 2 kg water) and to determine the efficiency of the C&E method.

Figure 5: Extended CAPER facility for HTO processing.

Highlight: Infrared Spectroscopy of Liquid Hydrogen Isotopologues in the TApIR Experiment

To cover the future energy demand of mankind by low-emission sources, research into regenerative energies is complemented by work on making nuclear fusion technically usable. An important step towards this objective is the International Thermonuclear Experimental Reactor (ITER) that is being built in Cadarache, Southern France.

In the burning chamber of ITER, a plasma of deuterium and tritium is fused to helium with energy being released. To ensure a stable fusion reaction, this fusion plasma has to be cleaned permanently. In addition, the tritium required for fusion can not to be supplied from outside, but needs to be bred directly in the reactor. Impurities have to be removed from the gas flows generated by tritium extraction and plasma cleaning in the fuel cycle, until the remaining gas flow consists of the hydrogen isotopologues H_2, D_2, T_2, HD, HT, and DT only. In a downstream isotope separation system (ISS), they are separated and the pure tritium is passed on to a storage tank. A central element of the ISS is cryogenic distillation. At temperatures of 23 K (-250°C), hydrogen isotopologues are separated due to their different melting points, in analogy to the distillation of alcohol or the refining of petroleum. Cryogenic distillation takes place in a column, at the bottom of which tritium, the isotopologue with the highest melting point accumulates.

In the column, tritium concentration in the liquid hydrogen mixture has to be monitored continuously for process control and tritium inventory balancing purposes. This may be done by infrared spectroscopy. It is tested for applicability in the TApIR experiment at the TLK under conditions similar to those of the ISS. The experiment is aimed at studying absorption spectra of liquid hydrogen isotopologues and identifying the relationship between parameters of the IR spectra and substance concentration. A big challenge is the set-up of an experiment that reproduces physical conditions of cryogenic distillation and can be used for tritium measurements later on. Another challenge consists in obtaining sufficient findings to understand in detail all processes in the liquid hydrogen, which influence the IR absorption spectra. Physical parameters, such as pressure and temperature, influence the variable to be determined, i.e. tritium concentration. Hence, complex data analysis and sophisticated measurement routines are required.

Fundamentals of Infrared Spectroscopy

Infrared spectroscopy and Raman spectroscopy are based on the barbell model of two-atomic molecules. This model considers molecules to be a system of two masses connected by a spring (Figure 6). Hence, they can vibrate against each other and rotate around the common centre of mass. With the help of quantum mechanics, this model can be used to calculate discrete vibration and rotation states corresponding to a precisely defined energy. These energies depend on various molecule-specific parameters, e.g. on the mass.

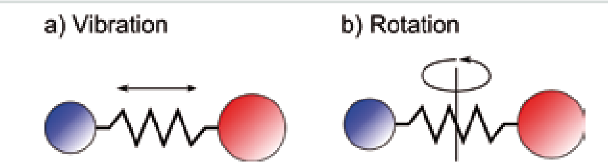


Figure 6: In the barbell model, the molecules can be excited to vibrate (a) and rotate (b). Vibration and rotation influence each other.

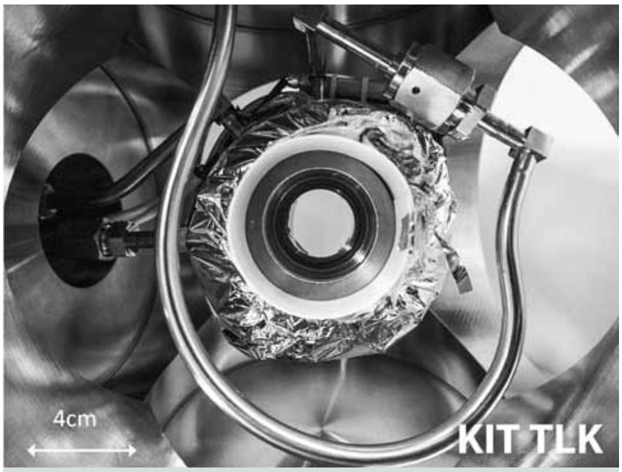


Figure 7: Cryogenic test cell of the TApIR experiment in the vacuum tank used for thermal insulation.

These energy levels result in precisely defined energy differences which are used by spectroscopy. The position of a line allows conclusions to be drawn with respect to the energy difference and, hence, to derive parameters, such as the mass of the molecules studied. From the intensities of the transitions, the concentration of the molecules involved can be derived. Both the type and the concentration of the individual molecules are reflected by the spectra. The underlying theory of interactions involved in the liquid phase, however, is not understood completely. Complex calibration measurements have to be performed to determine the concentration of the isotopologues from the spectrum.

Set-up of the TApIR Experiment

To study infrared spectra under conditions similar to those of the ISS of ITER, the TApIR experiment consists of a cryogenic test cell (see Figure 7) that can be cooled down to about 20 K with gaseous helium. Helium is cooled down to 14 K in a refrigerator made by Linde (250 W refrigeration power at 16 K) with two expansion turbines and passed on to the IR cell via stainless steel tubes and hoses. The cell is located in an insulation vacuum and protected against thermal radiation by a highly reflective foil.

To study liquefied gases by IR spectroscopy, sapphire windows are installed on both sides of the cell. They have to withstand low temperatures and pressures of up to 10 bar. Figure 8 shows the test cell filled with liquid deuterium and neon. The photo was taken during a preliminary test for further experiments using neon mixtures. The hydrogen system of the TApIR experiment consists of two tanks for mixing, a palladium catalyst for chemical equilibration of the gases, and a vacuum pumping system. To analyse the gas mixtures, a Raman spectroscopy system developed by TLK is available. It is based on the rotation and vibration excitations of the molecules (see also 2012 ITEP Annual Report).

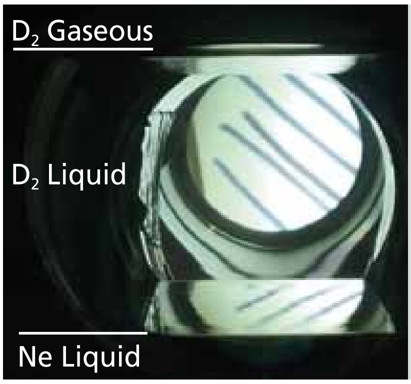


Figure 8: View through the sapphire windows – liquid deuterium above a layer of liquid neon in the TApIR test cell.

The liquefied gas samples are analysed by means of a Fourier transform infrared (FTIR) spectrometer. This spectrometer consists of an infrared source, a detector cooled with liquid nitrogen, and a Michelson interferometer. By moving a mirror of the interferometer, a signal can be generated on the detector. It contains the spectral information desired. However, these data first have to be subjected to Fourier transformation and further data analysis, such as background reduction, to obtain the absorption spectra shown in Figure 9. The advantage of this method consists in the high resolution over a large spectral range. It is possible to represent two vibration bands of the hydrogen isotopologues and to resolve the small substructure due to the rotation of the molecules.

Calibration Measurements with H_2, D_2, HD

To obtain information about unknown substance mixtures with the help of the IR system, the latter has to be calibrated in advance with known mixtures (in this case, H_2, D_2, HD). For recording a single calibration point, i.e. an infrared spectrum of a known gas mixture, several steps are required. First, a gas mixture has to be prepared in a tank. With the help of the Raman measurement system available at TLK, the composition of this gas can be determined. Then, the gas mixture is condensed into the IR measurement cell, where infrared spectra are recorded (see Figure 9). Subsequently, the gas mixture is evaporated again and measured with the Raman system. Recording of a data point with this routine takes about one day. To perform a complete calibration, i.e. to derive the gas composition from the parameters of the IR spectra, measurements at various H_2, D_2, and HD concentrations are required. As an example, Figure 10 shows the calibration curves obtained from a data set. They reveal a quadratic increase of absorbance with deuterium concentration.

Summary and Outlook on Future Experiments

For infrared spectroscopy of liquid hydrogen isotopologues under conditions similar to those of cryogenic distillation in the ITER isotope separation system, the TApIR test experiment was set up successfully at the TLK. This experiment allows to measure IR spectra of known gas mixtures in the liquid phase and to compare them with Raman spectra of the gas phase. Recording of a data point for calibration with this system takes about one day. To evaluate the spectra, a new data analysis chain was developed to filter out disturbing effects. Now, the pure IR absorption spectra are understood well. In the near future, the excellent results of this important experiment will be published in detail.

The next steps on the way towards the development of an analysis system for the ISS of ITER will be the set-up of a tritium-compatible system and recording of IR spectra for all six hydrogen isotopologues. In the long term, it is planned to develop and test an IR spectroscopy system to determine the isotopologue concentration directly in the reboiler of the cryogenic distillation column.

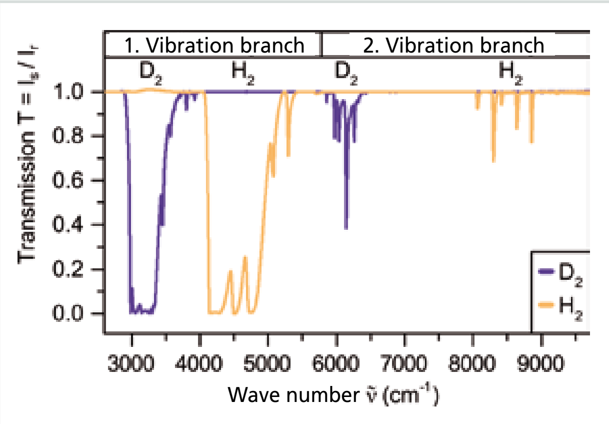


Figure 9: Transmission spectrum of liquid hydrogen (H_2, purity 6.0; yellow) and deuterium (D_2, purity 2.4 + remainder HD; magenta) measured in TApIR.

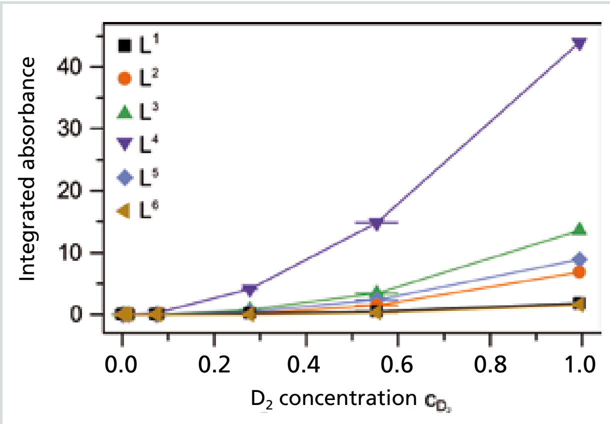


Figure 10: Integrated absorbance of the lines L_1 to L_6 in the second D_2 vibration band as a function of D_2 concentration.

The first mercury liquid ring vacuum pump operated worldwide.

Results from the Research Areas

Vacuum Technology

Head: Dr. Christian Day

Vacuum systems for nuclear fusion continue to be the clear focus of research and development work of ITEP's Vacuum Section. In addition, remarkable successes were reached in the European Metrology Programme as well as in the development of methods for general vacuum gas dynamics.

In the area of fusion, specific contracts awarded by ITER were executed and own development work for a fusion power plant was pursued. The ITER contracts covered support of the manufacture of the prototype torus cryopump as well as thermomechanical analyses relating to components of the ITER neutral beam injectors (NBI). However, research and development work concentrated on the European DEMO programme to prepare a high-performance fusion reactor. The liquid metal-based vacuum pumping concept proposed in the past year was established successfully as a reference solution in the DEMO concept design. In the next years, it will be our main task to develop a design of the novel vacuum pumps based on measurements and numerical simulations. The European Fusion Programme was reorganised completely in 2013 and divided into new work packages. The Vacuum Technology Section of ITEP will not only be responsible for fusion technology development (vacuum/matter supply/tritium package), but also be involved in several plasma physics activities due to its vast expertise in the area of neutral particle gas dynamics. This primary strategic goal was finally achieved in 2013.

Vacuum Systems for ITER

Europe has accepted the obligation to supply all primary cryopumps to ITER. These cryopumps are of two principle designs, i.e. cylindrical pumps for the ITER torus chamber and very large rectangular pumps for the vacuum vessels of the ITER neutral beam injectors. Both designs are based on the same physical concept, namely, cryosorption on activated charcoal.

To minimise the risks for ITER, both pump types will be tested on the 1:1 prototype scale. Manufacture of the prototype torus cryopump started in 2013 and will be completed presumably in mid-2015. A major task of pump manufacture, namely, coating of the cryopanels that are the main components of every cryopump, will be executed by the Vacuum Technology Section. ITER will rely on the vast know-how gained by ITEP in the past two decades of cryopump development.

The cryopanels of the torus and NBI cryopumps – first of the prototypes, then of the series pumps – will be coated with activated charcoal using a technology developed by the Vacuum Technology Section. For this purpose, a semi-automatic coating facility was set up at the Institute (manual charging and automatic coating) in order to ensure reproducible quality. Under a first contract in 2013, coating of 30 cryopanels for the prototype torus cryopump was started. This work is associated with a complex quality assurance programme, as ITER cryopumps are components directly connected with the torus and, hence, have to meet highest safety requirements (safety category 1). Figure 1 shows the first coated panel of this series directly after the coating process and after the liquid nitrogen immersion test.

Figure 1: Examples of the first cryopanel coating series.

Similar to the torus cryopumps, the NBI cryopumps are also planned to be tested on the original scale. This test will be performed in the specially constructed MITICA NBI test bed in Padova / Italy. The pump design was delivered in the past year. In 2013, engineers and physicists worked on the thermomechanical analysis of the NBI components in the beam path. Work concentrated on the residual ion dump (RID), see Figure 2. This component removes the charged particles remaining in the beam downstream of the main neutraliser by electromagnetic deflection to baffle plates. Detailed design studies covered the cooling system of the plates and the support structure of the RID under seismic loading. In addition, a feasible detailed design of a cooling channel was developed and studied. Development work relating to MITICA will be continued in 2014.

ITER Physics Programme

Under the ITER project, the design phase of components with a very long delivery time has already expired. Vacuum pumps also are among the components that will have to be ready for operation for the first plasma already. However, plasma scenarios for ITER are constantly further developed, which always gives rise to the question of how the pumps behave under new conditions beyond the design basis.

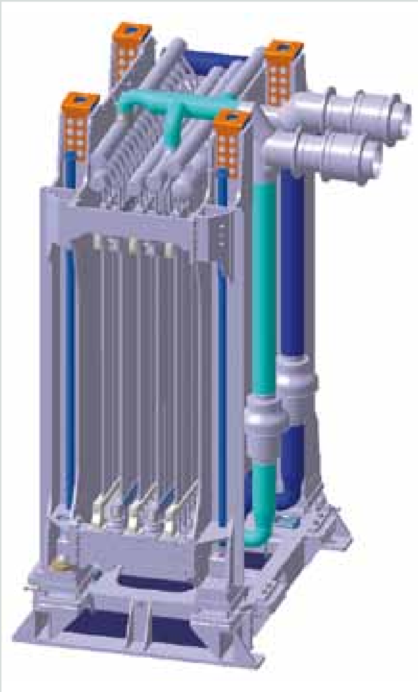


Figure 2: The residual ion dump of a neutral beam heating system with five parallel baffle plates.

In 2013, the behaviour of ITER torus cryopumps in case of massive gas inflows into the plasma vessel was calculated in detail. In particular, it was to be found out whether cryopumps are subjected to spontaneous regeneration (e.g. pumping surfaces are heated up by the energies introduced with the gas flow, such that the pumping effect is lost) or whether they can continue pumping operation. Massive gas inflow is a deliberately caused emergency measure to prevent local power peaks on the first wall in case of undesired plasma disruptions. For this purpose, various gases can be used. It was found that neon and argon exclusively ensure continuous operation of cryopumps without spontaneous regeneration. Figure 3 illustrates effective pumping of the inflowing gas within a period of 2 minutes using neon as an example.

Vacuum Systems for DEMO

Within the framework of the European Fusion Programme, the Vacuum Technology Group is responsible for the development of vacuum systems for a power plant supplying electricity. Contrary to the cryogenic vacuum pumps of ITER, the new concept developed for DEMO is operated continuously without a cryogen. An integrated system for the separation of the divertor off-gas directly recycles most of the unburnt fuel, as a result of which the tritium inventories and processing times can be reduced considerably. This so-called DIR concept (Direct Internal Recycling) consists of three pumping stages. For separation, metal foils are used. They are permeable for atomic hydrogen only and, hence, provide for a certain compression. For high-vacuum pumping, a diffusion pump is applied. To make it tritium-compatible, it will be operated with liquid metal (mercury). A liquid ring pump that is also operated with mercury fluid is used as a mechanical pump for compression to ambient pressure.

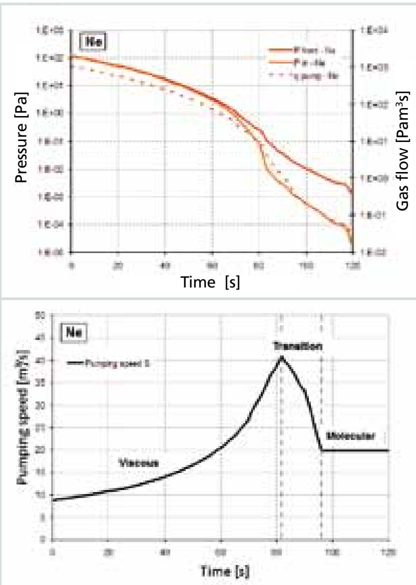


Figure 3: Calculated pump characteristics for neon as a control gas after plasma disruption.

Meanwhile, this concept has been established as DEMO reference concept. In 2013, a complete process, the KALPUREX process (**Ka**rlsruhe **L**iquid Metal Based **Pu**mping Process for **R**eactor **Ex**haust Gases), was developed to realise this concept in practice. The patent was applied for in September. The principle setup is shown in Figure 4.

The mercury diffusion pump was proved to be suitable for DEMO in 2012 already. This year, functioning of the mercury-driven liquid ring pump and a metal foil was demonstrated successfully. Hence, use of cryopumps for DEMO will be considered only, if problems occurring during the further development of KALPUREX cannot be solved.

Further development of the new pump will be one of the main tasks in the next five-year plan of the European Fusion Programme. These development activities will be combined with work on the tritium systems, tritium extraction of the breeder blanket cooling systems, and systems for matter supply (gas, ice). This will open up interesting potentials of synergies and further optimisation.

Modelling of Vacuum Flows

Numerical simulation of vacuum flows in a wide range of dilution (i.e. from the viscous regime to the transition range to free molecular flow) was advanced largely in the past years. Depending on the requirements made, various options are available.

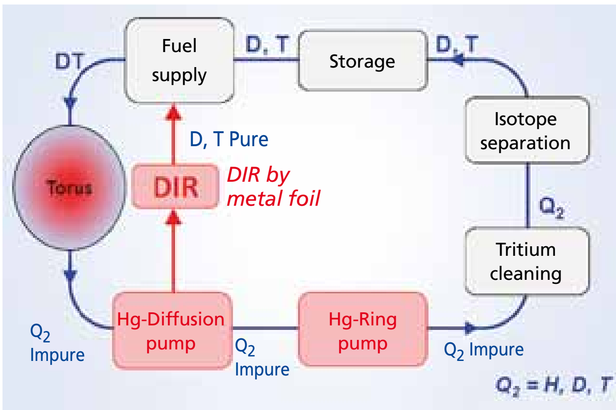


Figure 4: Inner fuel cycle of DEMO with internal recycling.

In 2013, activities focused on the description of neutral particle flow downstream of the divertor in a fusion plant. In the divertor, high temperature gradients exist, as a result of which the plasma on the inner side is reconverted into neutral gas at the bottom. The divertor is one of the most important components, as it ensures stability of the selected plasma mode and reliably removes the helium produced by the fusion reaction. The divertor is a structure open to all sides (also towards the plasma). This gives rise to the problem that the pumping speed of the connected vacuum pumps competes with the pumping effect of the plasma. The resulting neutral particle density in the divertor is a very sensitive parameter that might also be used for plasma control, if flow processes would be understood better. Development of an own code is a first step in this direction.

In 2013, vacuum scientists succeeded in including the complex divertor geometry (2D) into a flow code (DSMC) and considering the plasma contour such that the density distribution in the sub-divertor can be predicted in a physically consistent manner. Figure 5 shows the result of such a calculation for the ITER divertor.

These new findings were presented at the European Plasma Physics Conference in summer 2013 and met with high interest. On this basis, a multi-stage development programme was launched for comparing the new computation code with experiments in the large European fusion machines (AUG, JET) and with calculations using other, more plasma-dominated codes for future machines (ITER, JT60-SA, DEMO). This activity will become another focus of the Vacuum Technology Group.

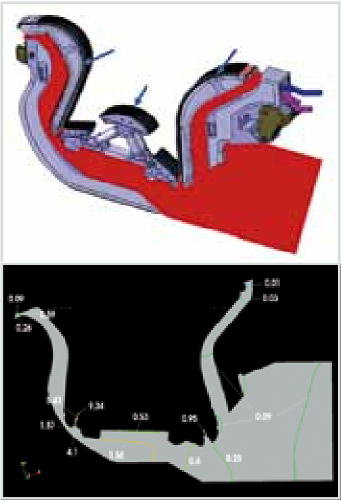


Figure 5: Calculated pressure distribution (in Pa) below an ITER divertor cassette (top). The integral total pressure is 2.6 Pa in this example.

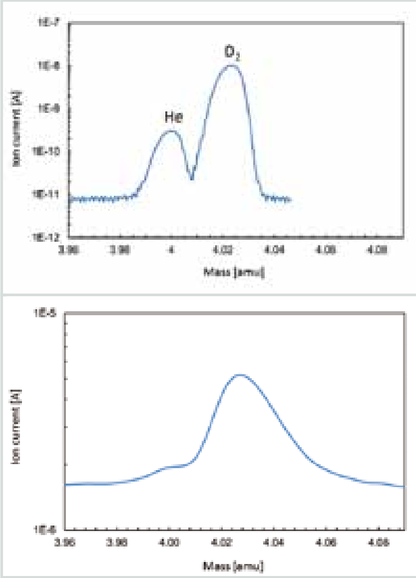


Figure 6: Resolution of He and D_2 in a gas mixture with 3.7% He and 95.4% D_2. The top diagram shows the reference measured with a high-end quadrupole, the bottom diagram represents the best result obtained with the new ART-MS.

Outgassing and Vacuum Pressure Measurement Technology

Last year, the new OMA facility was used to measure outgassing rates of stainless steel (as a standard material of vacuum chambers) subjected to various surface treatment methods. The main result obtained was that defined heating (100 h, 400°C) is sufficient to reduce the outgassing rate by one order of magnitude. It was of no importance whether heating took place under vacuum or under air.

A newly commercialised mass spectrometer (ART-MS) was analysed for its capacity to resolve the gases of (Index 2) and He that are located very closely to each other in the spectrum. It was found that the new instrument is not suited for this purpose, see Figure 6.

Networks and Cooperation

The KIT-coordinated VACU-TEC European network for the development of vacuum technologies for nuclear fusion developed well and was completed largely in 2013. The five trainees showed impressive progress. It is planned to re-launch the very successful programme in 2015, then with emphasis on DEMO work.

The OMA outgassing facility has been included into a programme for the comparison of various plant concepts under the European Metrology Programme. In particular, its relevance to industrial applications is planned to be studied. In this connection, cooperation with PTB, Berlin, and the IMT Research Institute at Ljubljana, Slovenia, will be extended. Within the framework of a round robin test, various samples will be studied at all facilities for comparison.

Highlight: Proof-of-principle Tests of New Vacuum Pumps for DEMO

The major milestone in 2013 was the proof of principle of the mercury ring pump and the metal foil pumps. Both vacuum pumps will play a central role in the fuel cycle of future fusion power plants (DEMO).

In fusion reactors, the hot deuterium/tritium plasma has to be confined in a vacuum vessel with the help of magnetic fields. To "flush" the helium produced during the fusion reaction out of the plasma, a mixture of deuterium and tritium has to be injected continuously into the reactor. To prevent the pressure in the torus from increasing as a result of the gas injected, the latter has to be pumped off constantly with the help of vacuum pumps. The pumped gas is then subjected to cleaning in the tritium system (i.e. helium and impurities are removed) and fed back into the machine.

Figure 7: The mercury ring pump installed in the THESEUS facility

In this cycle, the so-called inner fuel cycle, the vacuum pumps are of high importance: They have to ensure continuous pumping of large amounts of tritium-containing gas and to work reliably and safely irrespective of the rough ambient conditions (dust, high magnetic fields, high neutron radiation, etc.).

Development of a new vacuum pump concept for a fusion reactor with long plasma pulses was started by the Vacuum Technology Section in 2010 already. First, studies were made to identify new, non-cryogenic, and continuously operating vacuum pumps that minimise the tritium inventory in the pumping system and, at the same time, reduce the complexity of the complete system due to lacking regeneration cycles and cryoinfrastructure. The concept developed comprises three types of pumps: A diffusion pump used as a high-vacuum pump, a liquid ring pump serving as a fore-vacuum pump, and a metal foil pump for the specific pumping of pure hydrogen. Functioning of the diffusion pump with mercury as tritium-compatible medium was demonstrated successfully in 2012. In 2013, experimental work focused on demonstrating the functioning of the liquid ring pump, also with mercury as a medium, and of the metal foil pump.

The liquid ring pump that can be operated theoretically with any liquid has never been used with a medium of a density similar to that of mercury (13 times the density of water). Typically, these pumps that are frequently applied in industry are operated with water, oil or various solvents. Due to their vapour pressures, the end pressure of the pump is limited to some 10 to 100 mbar. Consequently, the expertise accumulated for ring pumps is very far away from use envisaged in nuclear fusion. Estimations of their capacity are subject to a very high uncertainty. In 2012, a test pump modified for the density of mercury was developed in cooperation with industry. In 2013, this pump was installed in the THESEUS facility for a first functional test (see Figure 7). First pumping (Figure 8) of the THESEUS test vessel was highly successful and exceeded all expectations. Both the end pressure reached and the smoothness of operation (in spite of a moved mass of more than 100 kg in the pump) were excellent. Simulation of a second pumping stage by a reduction of the outlet pressure resulted in an end pressure below 1 mbar, which might be a new record end pressure for liquid ring pumps! In the next step, a detailed test programme and design activities to develop a completely tritium-compatible pump for the JET tritium campaign in 2017 will be pursued.

The metal foil pump is the key component of the fuel cycle concept with direct internal recycling (DIR). The pump has to separate unburnt fuel (i.e. pure deuterium/tritium) directly at the torus and to feed this pumped gas fraction directly back into the reactor. Due to this direct recycling, the tritium system has to process a much smaller gas flow and, hence, can be designed smaller (i.e. with a smaller tritium inventory).

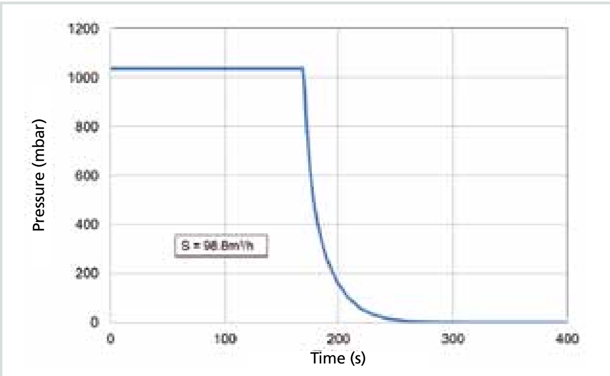


Figure 8: First pumping curve of a mercury ring pump: The 450 l dosage dome of the THESEUS facility was evacuated to an end pressure of a few mbar within 90 seconds at a pumping speed of nearly 100 m³/h.

This pump mainly consists of a heated metal foil and a plasma source. When energy-rich atomic hydrogen (plasma) contacts the metal foil, the latter is penetrated. Recombination on the other side of the foil prevents the already molecular hydrogen from flowing back. As a result, a compression effect specific of pure hydrogen is achieved. To study this pump effect that has never been demonstrated for "cold" microwave plasma so far and to analyse the influence of various foil parameters (e.g. thickness, material, temperature), a plasma experiment (HERMES, see Figure 9) with a linear plasma source on the laboratory scale was set up at ITEP.

Figure 9: The HERMES plasma experiment at ITEP.

Top: Complete set-up – the plasma source is located in the front. Two vacuum chambers are connected to the plasma source with the metal foil adapter in between. Bottom: The linear plasma source with magnetron (background).

Figure 10: View into the hydrogen plasma of the linear source (centre left) with the metal foil (centre right).

This experiment mainly consists of two vacuum chambers, between which a metal foil can be inserted via an adapter. On one side, the foil is exposed to a high-frequency plasma (Figure 10) from a plasma source. In the opposite chamber of known volume, the pressure increases (see Figure 11). From this increase, the gas flow rate through the metal foil can be derived. A first test with a thin vanadium foil already revealed a major pumping effect. Only nine months after the start of construction was the "first plasma" produced. The results were rather promising!

The tests of the metal foil pump and of the mercury ring pump confirmed functioning of the pumping concept proposed by the KIT. This success has far-reaching consequences for future work in this area. It will concentrate on developing the individual pumps in a DEMO-relevant design and characterising them experimentally.

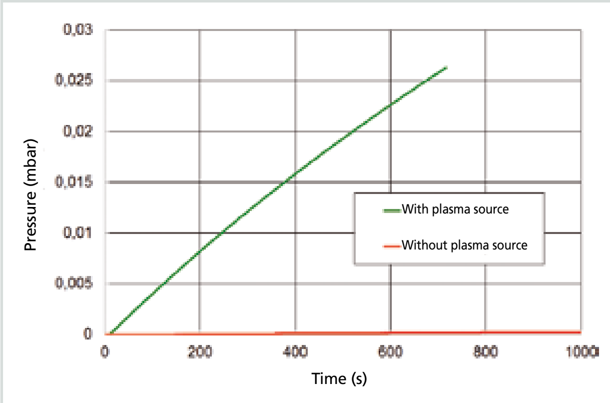
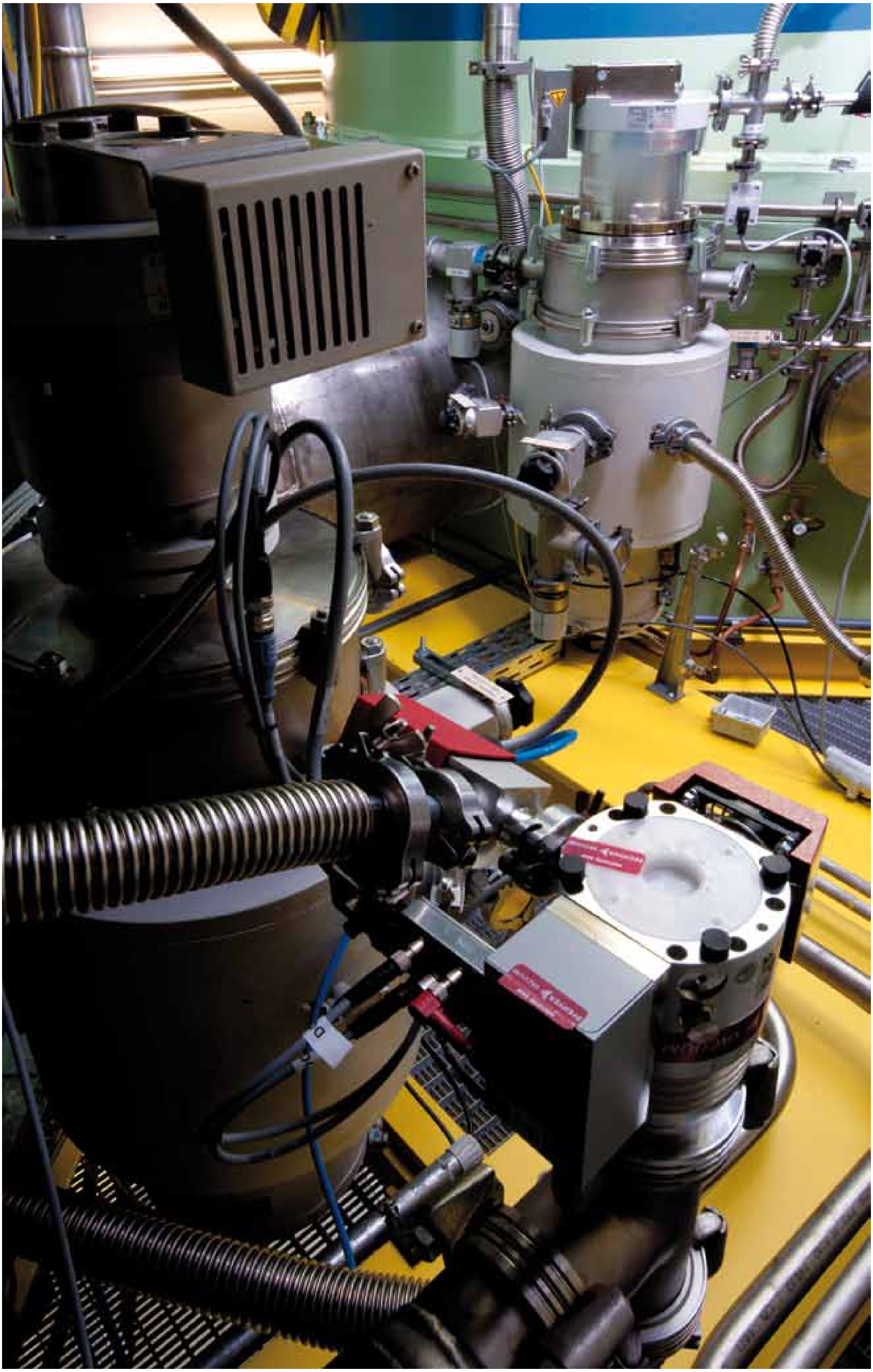


Figure 11: Pressure increase in the vacuum chamber behind the metal foil with and without ignited plasma.

Preparation of the mercury ring experiment in THESEUS and set-up of the HERMES plasma experiment within a few months only were associated with a very tight schedule and considerable efforts of all staff members. We are proud of our results and hope that this successful cooperation of all group members and cooperation with other groups at ITEP will be continued in the future.



Turbomolecular pump of the 2-kW helium refrigerator.

Results from the Research Areas

Cryogenics

Head: Dr. Holger Neumann

Cryogenics for Fusion

In 2013, work of the Cryogenics Group of ITEP under the "Fusion" programme concentrated on the last series test of current leads for the national W7-X project as well as on the set-up of a facility to test 26 current leads for the international JT-60SA project.

Test of W7-X Current Leads in TOSKA

In February 2013, the last two of a total of 16 current leads were tested successfully for the W7-X plasma experiment. The current leads were delivered to Greifswald. On June 26, 2013, the project was completed by handing over the last acceptance protocol during the final colloquium.

Set-up of the CuLTKa Current Lead Test Facility

To test the 26 current leads for JT-60SA, the new CuLTKa (Current Lead Test Facility Karlsruhe) test facility is being set up and integrated into the existing cryo infrastructure of ITEP (see Figure 1). In March 2013, the transfer lines (see Figure 3) were delivered upon successful acceptance and installed by the manufacturer (see Figure 2). After the installation of the transfer lines in April 2013, installation of the piping in the cryostats started. Leak tests of the piping inside the cryostats were completed successfully. Two cryostats have already been closed and subjected to integral leak tests with positive results. In early 2014, it is planned to complete the field cabling work. After that, the facility will start operation.

Figure 1: CuLTKa current lead test facility.

Measurement of Cryovalve Operation Characteristics

Within the framework of the current lead tests for W7-X in TOSKA, a valve measurement section was set up to determine the basic and operation characteristics of cryovalves under operation conditions (see Figure 4). In this measurement section, first characteristics of cryovalves at 4.5 K were determined / verified and compared with calculation models. The results allow for a safer design of cryovalves.

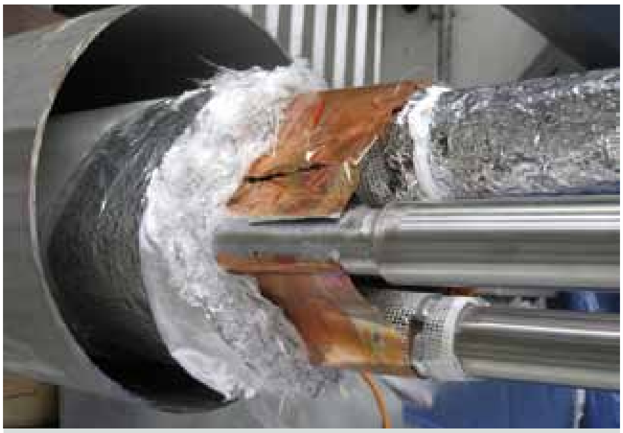


Figure 2: Cryo transfer line between the 2-kW facility and CuLTKa.

Figure 3: Cryo transfer line sections for CuLTKa.

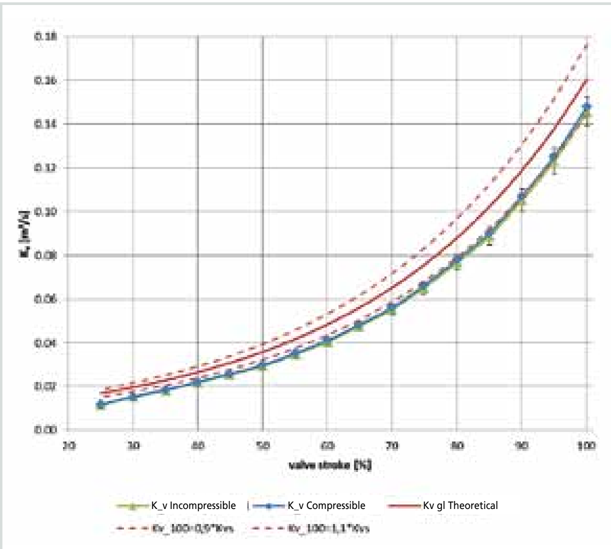


Figure 4: Operation characteristics of cryovalves.

Cryogenics for Efficient Energy Conversion and Use

SUPRAPOWER

In December 2012, the SUPRAPOWER (Superconducting, reliable, lightweight, and more powerful offshore wind turbine) EU project started. In total, nine partners are involved (coordination: TECNALIA Research & Innovation; partners: KIT; ACCIONA Windpower, Acciona Energy, Columbus Superconductor, Oerlikon-Leybold Vacuum, Institute of Electrical Engineering, University of Southampton, D2M Engineering). The project is aimed at developing a superconducting generator for offshore wind turbines of 10 MW power. Currently used wind turbines reach a power of up to 7 MW. Increase in power using conventional technologies reaches materials-related limits in terms of size and weight. Use of superconducting generators is planned to result in a higher power, with the mass, size, and costs of the generator being minimised compared to conventional technology.

Under this project, KIT is to develop, build, and test a cryostat suited for the superconducting coils. First, the scientists analysed the cryostat design of the Tecnalia company (European patent application EP 2 5251 252 A1: "Direct-action superconducting synchronous generator for a wind turbine"; December 07, 2012; PCT/ES2009/070639) with respect to modularity, mass, and heat input in particular. It was found that even under most favourable assumptions the heat input for 60 coils of a superconducting generator of 10 MW whould require about 30 GM coolers made by Oerlikon-Leybold Vacuum. The analysis also revealed that the maximum temperature difference between the GM cooler head and the warmest point of more than 5 K is below the critical temperature of the superconductor, but may be critical for the current coil design (see Figure 5). It is therefore worked on an improved cryostat design to reduce heat input from outside and to reduce the maximum temperature difference to less than 3 K.

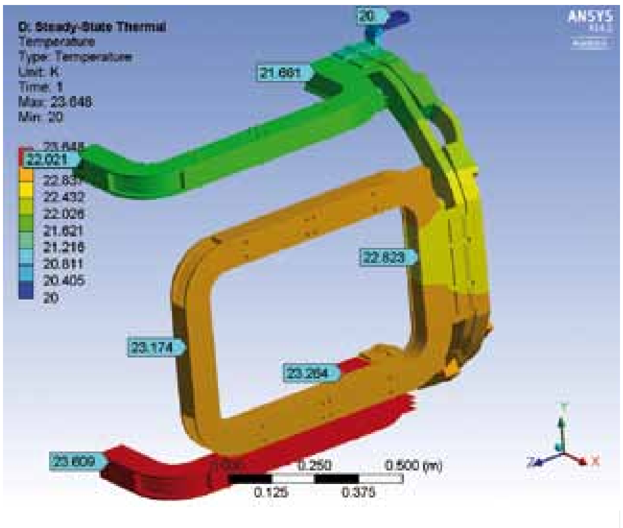


Figure 5: Temperature distribution of the superconducting coils on a copper ring for the demonstrator with four coils.

LIQHYSMES (LIQuid HYdrogen & SMES)

For the hybrid energy storage system based on liquid hydrogen and a superconducting magnetic energy storage system (LIQHYSMES), ITEP performed further studies relating to seasonal power fluctuations. In addition, an existing cryostat was chosen for first experiments (see Figure 6).

The scientists drew up piping and instrumentation diagrams for various modes of operation and discussed them in detail. Within the framework of a diploma thesis, the regenerator/recuperator part was balanced thermodynamically. In addition, a first construction sketch was made based on the dimensions of the selected cryostat. Due to its density and thermal capacity, lead was found to be particularly suited for use as a regenerator material. Furthermore, optimum pressure conditions were determined to reach a maximum liquefaction at the given volume. For the High-field Magnets Group headed by Dr. Theo Schneider, MgB_2 samples were characterised. Under a diploma thesis, charge and discharge of a small coil were studied in HOMER I. Final experiments with LH_2 are planned to be executed at the hydrogen test centre of IKET. A place suited for the experiment has already been chosen.

Figure 6: Cryostat with SMES (MgB_2 coil) and regenerator/recuperator unit.

Cryogenic Infrastructure

In 2013 again did the Cryogenics Group ensure operation of the three refrigerators and of the helium recovery systems of ITEP. In addition, extensive maintenance and repair work was carried out.

Activities included among others:

- Repair of oil pumps in the compressor and turbine units (see Figure 7).
- Revision of power switches.
- Extension of the helium gas return line from the ANKA building and the VATESTA test rig.
- Exchange of measurement transducer cabinets and analytical instruments.
- Renewal of the control of helium gas heaters and turbopumps.
- Removal and revision of valves (see Figure 8).
- Reconstruction of the helium cleaning system.
- Renewal of various cable sections.
- 20,000 hours of service on the V40 recompressor (see Figure 9).
- Renewal of all high-pressure hoses of the recompressors.

Figure 7: Maintenance work on sections of the 300-W refrigerator.

In 2013, the 300-W helium refrigerator was in operation for 1617 hours. Of these, 336 hours were spent for liquefaction operation and 97 hours for purging as well as for cool-down and warm-up of the system. This results in 1184 hours of pure refrigeration time for the experiments in the high-field magnet laboratory.

In 2013, the 2-kW (4.5 K) He refrigerator was run for 917 hours. Of these, 419 hours were spent for liquefaction operation and 221 hours for purging operation as well as for cool-down and warm-up. Hence, 277 hours were spent for pure refrigeration for the fusion experiments.

Figure 8: Exchange of the 2-kW-TTA cryovalves and high-pressure cleaning system.

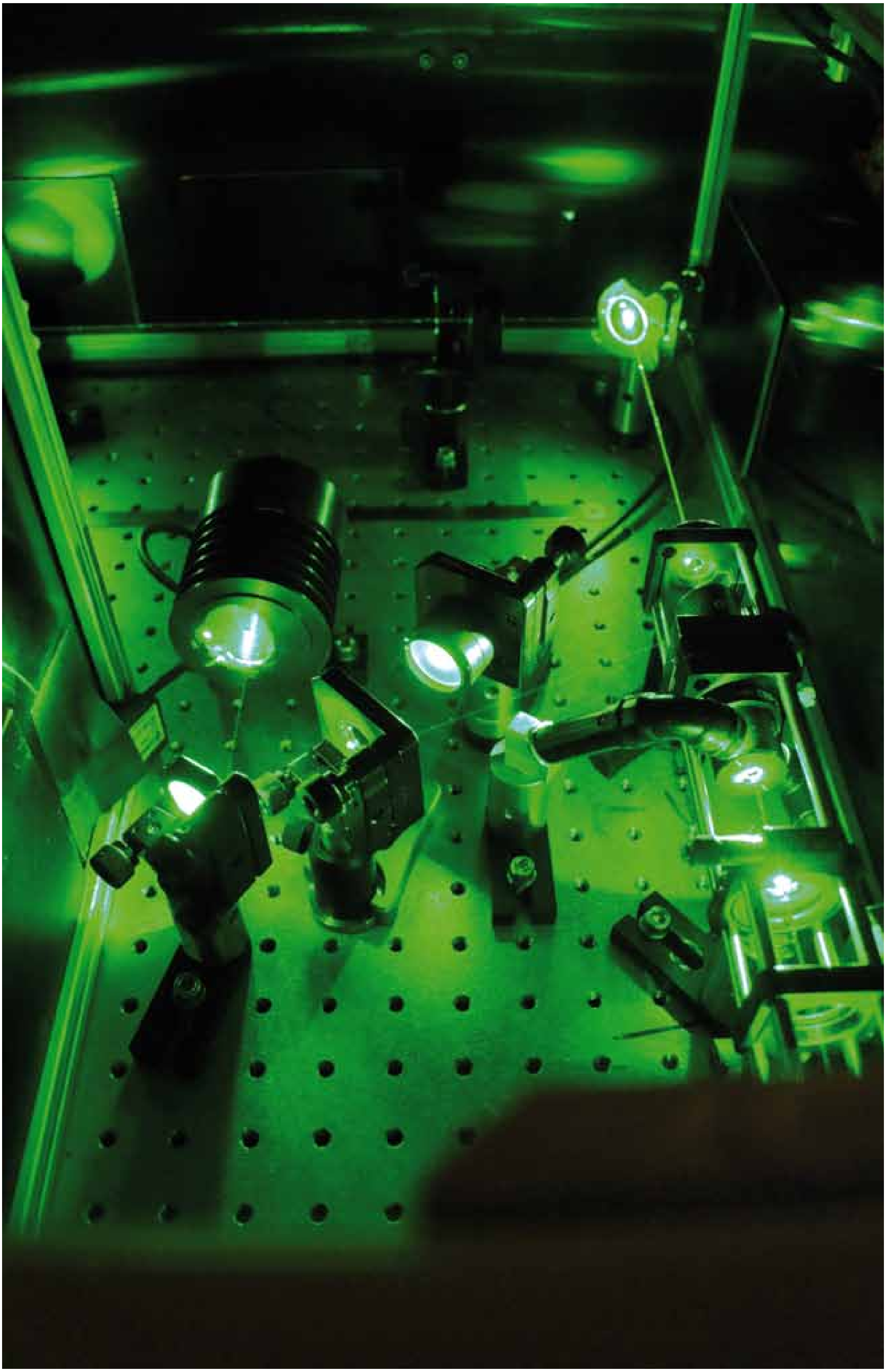
In total, the facilities liquefied about 176,758 l of helium. 122,304 l were used for experiments at ITEP, 54,454 l by other institutes.

The 500-W (4.5 K) Linde refrigerator for the KATRIN experiment was operated for 147 hours only in 2013. Of these, about 62 hours were spent on purging, cool-down, and warm-up of the facility. The refrigerator was operated for 83 hours for acceptance tests of the third section of the transfer line for CPS connection.

Maintenance work was performed as planned due to the high professional skills of the cryogenics team. In 2013, no failures of the systems worth mentioning occurred.

During the set-up of the CuLTKa facility for JT-60SA, the Cryogenics Team was involved in leak tests, planning and coordination of field cabling of the cryostats as well as in the programming of the process control systems.

Figure 9: Revision of the He recompressor V40.



Laser Raman system in action!

Results from the Research Areas

KATRIN Karlsruhe Tritium Neutrino Experiment

Head: Dr. Beate Bornschein

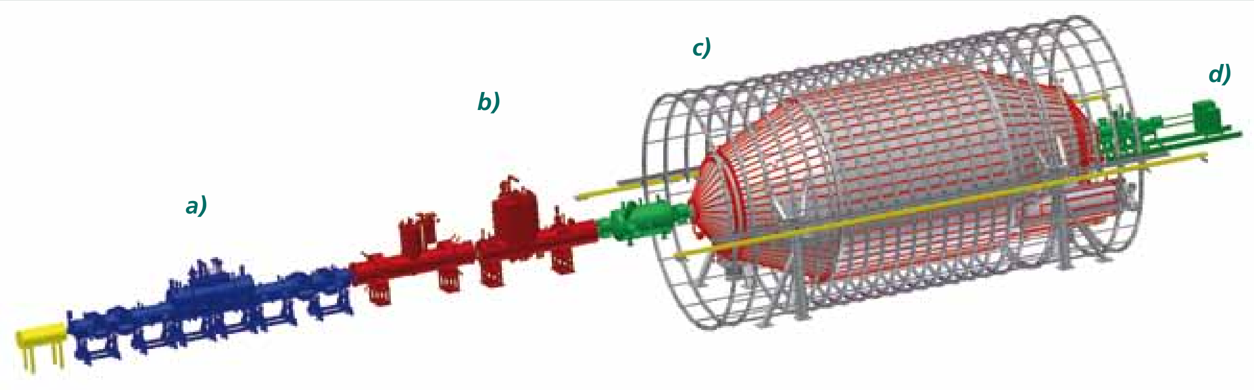


Figure 1: Schematic representation of the KATRIN international large-scale experiment. The electrons produced by β-decays in a high-intensity windowless molecular tritium source (WGTS, [a]) are passed through a tritium pumping station with the active and passive elements DPS2 and CPS (b) to a system (c) consisting of two electrostatic spectrometers (pre spectrometer and main spectrometer). The analysed electrons are counted by a semiconductor detector (d).

KATRIN, the Karlsruhe Tritium Neutrino Experiment, is targeted at measuring the neutrino mass with a sensitivity of 200 meV/c^2 in a model-independent manner. The motivation of KATRIN is the key role played by neutrinos in astroparticle physics: On the one hand, mass-carrying neutrinos as hot dark matter are involved in the evolution of large-scale structures in the universe. On the other hand, the neutrino mass itself is the key to solving the problem of the origin of mass.

The experimental principle of KATRIN is based on the precise measurement of the spectrum of electrons produced by the β-decay of molecular tritium near the kinematic end point of 18.6 keV (maximum energy released by β-decay). For this purpose, electrons from a windowless gaseous tritium source of highest intensity (10^{11} decays/second) are led adiabatically, i.e. without changing their energy, through the 70 m long experimental facility by high magnetic fields of superconducting magnets. A system of two electrostatic retarding spectrometers allows for the determination of the electron energies with a resolution of 0.93 eV (see Figure 1).

A worldwide collaboration of more than 150 scientists, engineers, and technicians under the coordination of KIT is currently in the process of building this key experiment in astroparticle physics at the Karlsruhe Tritium Laboratory (TLK). First data are expected to be obtained in 2016. The design, construction, and successful execution of the KATRIN experiment are associated with highest requirements on process technology, especially tritium process technology, ultra-high vacuum technology, cryotechnology, and high-voltage stabilisation technology. In addition, an adequate project management is required to allocate manpower and funding to KATRIN, such that the goals in terms of time and work packages can be reached.

Within the framework of the KATRIN experiment, ITEP is responsible for tritium process technology as well as for cryotechnology. Several leaders of partial projects (task leaders) in this area come from ITEP. More than 95% of ITEP's scope of work concentrate on the so-called source and transport system (see Figure 2). As large amounts of tritium are used, the system is set up completely within the TLK.

The main component is a superconducting magnet system of 16 m in length, called WGTS (windowless gaseous tritium source). It contains the gaseous tritium source in a cold beam tube at ≈ 30 K. In addition, the so-called calibration and monitoring system (CMS) is located on the beam axis in the rear part, while the transport system is installed in the front part – in the direction of the spectrometer. The transport system guides the tritium decay electrons to the spectrometer and reduces the tritium gas flow into the spectrometer system by more than 12 orders of magnitude with the help of pumps. For this purpose, a differential pumping section (DPS) with turbomolecular pumps and a cryopumping section (CPS) at 3.5 to 4 K are operated. Both the DPS and the CPS are superconducting magnetic cryostat systems of 7 and 9 m in length, respectively. They are manufactured by external companies with the support of teams from IKP, IEKP, ITEP, and PMQ.

The tritium loops (inner loop, outer loop) for controlled tritium gas supply and a tritium purity above

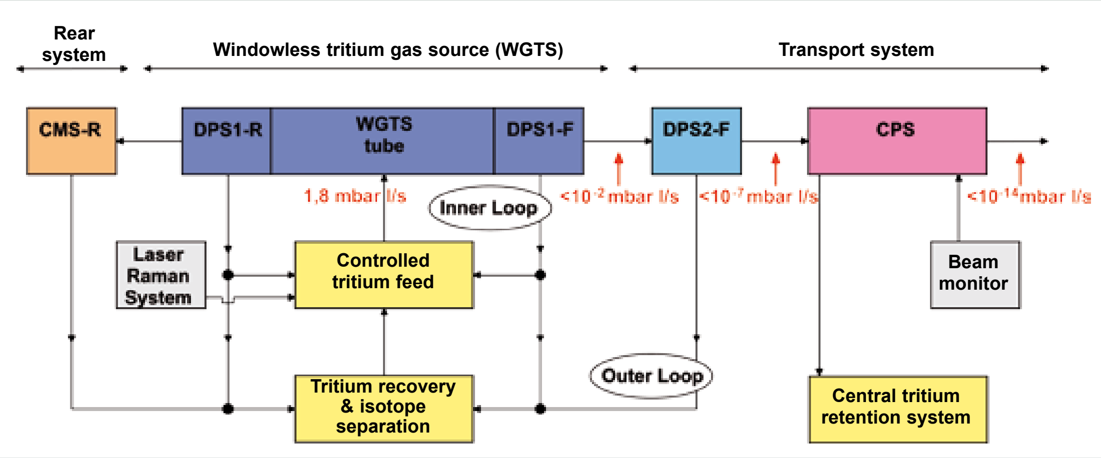


Figure 2: Flowchart of the KATRIN tritium source and interfaces to the TLK infrastructure.

95% are also shown in Figure 2. Simultaneous stable supply and removal of tritium gas by pumping results in a stable gas column density in the beam tube of the WGTS (tritium source).

The status of activities will be outlined in the following paragraphs.

WGTS

In 2013, the WGTS demonstrator was dismantled successfully. In parallel, nearly all still lacking assemblies of the WGTS were completed. All planned magnet tests were completed, such that the WGTS cryostat can now be mounted. In cooperation with the industry partner Research Instruments (Bergisch Gladbach), a detailed assembly concept was developed and an assembly hall was prepared. The assembly of the KATRIN source will start in January 2014 and be completed by summer 2015.

Preparation of the external support systems, by KIT in particular of the cryogenics supply, quench detection, and magnet control systems, proceeded according to schedule. All systems will be ready for operation in early 2015.

DPS2

After a failure of the protection diodes of DPS2-F in 2011, it was no longer possible to repair the system with a reasonable expenditure. It was therefore decided in 2012 to newly construct the DPS with the individual magnet systems and a beam tube developed and to be manufactured by the KIT. The tender and order procedure for the magnets was accomplished in 2012. In spring 2013, the contract was extended to cover a sixth magnet of identical design for the rear system. In 2013, work concentrated on supervision of the manufacture of the six magnetic modules by the company of Cryomagnetics Inc., Oak Ridge (USA) as well as on the construction of the base frame and beam tube system. Particular attention was paid to the reusability of the already manufactured instrumentation of the beam tube (FTICR).

The base frame and beam tube are currently being manufactured by TID-DGT-TEC and are planned to be completed in early 2014. The first three magnet modules – two of which have already been manufactured – will be delivered in January 2014, the remaining three modules in April 2014. After the acceptance tests at KIT, the DPS2-F will be assembled.

CPS

The CPS (Figure 4) is being built by ASG, Genoa. Fabrication is accompanied by an inter-institute project team of KATRIN. In 2013, quality assurance work focused on the supervision of magnet modification and control of the individual fabrication steps by welding inspection and leak tests. For this purpose, KIT contracted external staff. Major milestones were the successful cold test of the modified magnets after the leak test and the successful leak test of the assembly of all beam tubes and magnets. In parallel, the modified protection diode stacks for the superconducting magnets were tested successfully in an ITEP cryotest rig at 4.2 K. The seven control cabinets for cryooperation of the CPS were delivered and accepted successfully.

Figure 3: New concept of the differential pumping section of KATRIN. The five superconducting magnets and the five pumping chambers can be seen.

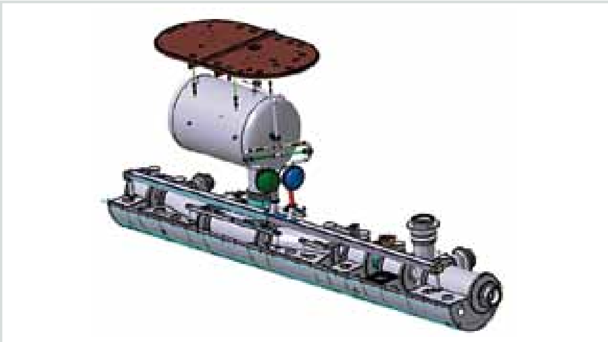


Figure 4: View into the CPS. The individual beam tube sections and the helium reservoir are visible. The protection diodes are planned to be installed below the tank (green, blue).

Assembly of the CPS at Genoa will take another few months. According to the current schedule, the CPS is planned to be delivered to the KIT in October 2014.

Cryofacility and Cryotransfer Line

Work in 2013 focused on supporting the fabrication of the third part of the cryotransfer line and the third valve box required for the cryogenic connection of the CPS. Meanwhile, fabrication has been completed. The components have been delivered and assembled.

Tritium Loops

The tritium loops of KATRIN are developed and built at the TLK, among others within the framework of bachelor, diploma, and doctoral theses. In 2013, work focused on the set-up of new test experiments and on the continuation of measurements in the TriToP (Tritium Test of Pumps) experiment. The important new test experiment TriADE (Tritium Adsorption Desorption Experiment) will be presented as a highlight in this annual report.

In 2012, a Leybold MAG W2800 turbomolecular pump (TMP) with magnetic bearings was tested successfully in long-term operation at an integral tritium flow rate of ≈ 1 kg in TriToP. After this test, the pump was dismantled. In 2013, the experiment was modified for testing the Pfeiffer HiPACE300 turbomolecular pump with hybrid bearings. This type of pump is planned to be used in the WGTS and DPS to reach the prevacuum required for the MAG W2800 pumps.

Tritium purity in the KATRIN tritium loop is to be controlled continuously with the help of laser Raman spectroscopy (LARA). As in the year before, work in 2013 focused on the calibration of the system, investigation of optical windows and coatings for KATRIN, as well as on the further development of the automatic analysis method of Raman spectra for the later long-term operation of KATRIN.

For the optical windows, an optical coating method was identified. Compared to the standard coating process used so far, it promises to provide a better resistance to tritium and the inert atmosphere in the glove boxes. This is planned to be verified in 2014.

Figure 5: Design of the rear section of KATRIN.

In addition, an alternative approach to the LARA installation was demonstrated successfully: Instead of using the existing design of the measurement cell, suitability of a capillary with an inner reflective coating was studied. This cell design could in a far higher signal yield, as the effectively used Raman volume is increased considerably. A corresponding test set-up, called CLARA (capillary Raman system), was commissioned successfully. The principle was demonstrated with tritium. After promising first results were obtained, the set-up is planned to be studied systematically and improved in 2014.

Rear Section

The rear section, also called CMS (calibration and monitoring system), has to cover the important task of calibrating the complete KATRIN system. For this purpose, it is planned to install an electron gun in the rear section. It is presently being developed by the KIT together with a collaboration partner at the University of California in Santa Barbara (UCSB). The KIT contribution to the rear section also covers the development and the set-up of the primary system (inclusive of the beam tube) and the secondary enclosures as well as integration into the infrastructure systems of the Tritium Laboratory. In December 2013, the KATRIN collaboration approved of the proposed design (Figure 5). Currently, the set-up of the system at the Tritium Laboratory is being prepared.

In parallel, so-called BIXS systems (Beta Induced X-ray Spectrometry) are being integrated into the rear section. The BIXS systems serve to precisely determine the intensity of the gaseous source in the WGTS cryostat (0.1% in < 100 s). This parameter is directly considered in the later analysis of the KATRIN data and, thereafter, directly influences the measurement accuracy of the neutrino mass. In cooperation with the University of Mainz, KIT studies potential candidates for a so-called KATRIN rear wall. The rear wall defines the electric potential of the tritium source and, therefore, has a major impact on the uncertainties of tritium mass determination. In addition, other components, such as piezoelectric actuators, glass fibres, and glass fibre feed-throughs, as well as concepts for the specific illumination of surfaces in the vacuum system with UV light are analysed for tritium compatibility and suitability for use in the rear section.

Acknowledgement

Work relating to KATRIN was performed successfully by ITEP in an interdisciplinary manner, with TLK having the major share of the tasks, of course. All areas profited from the close and fruitful cooperation with students, technicians, engineers, and scientists of ITEP, the Institute of Nuclear Physics (IKP), the Institute of Experimental Nuclear Physics (IEKP), the Central Workshop (TID-DGT-TEC), and the KIT Project Management Group, PMQ. Thanks to all of them!

Highlight: Beta-induced X-ray Spectrometry to Determine Tritium Activity on Surfaces

Introduction

Within the framework of the KATRIN experiment, researchers carry out a precise energy analysis of electrons produced by the beta decay of tritium in order to derive the neutron mass with a sensitivity of 200 meV/c². For this purpose, the electrons are guided from the source through the 70 m long KATRIN facility by high magnetic fields. The energy of the electrons is determined with the help of an electrostatic retarding potential that has to be overcome by the electrons in order to be finally counted by the detector.

On the spectrometer side, the end potential is determined by an adjustable high voltage in the range of 18.6 kV and has to be stable in the ppm range. The start potential of the electrons in the source is defined among others by the voltage at the rear wall (RW). The RW is a gold-coated disc that represents the electric end component of the source in the direction of the Calibration and Monitoring System (CMS) (far side from the spectrometer). The material properties of the RW largely influence the sensitivity of KATRIN.

Inside the KATRIN source, tritium may adsorb on the surface of the RW and change the material properties, in particular emission work, during the measurement time of KATRIN. Change of emission work directly affects the value of the start potential of the electrons in the source and, hence, influences the sensitivity of KATRIN. The change depends on the amount of tritium adsorbed and on pressure, time, and temperature.

The TriADE Experiment

The Tritium Adsorption Desorption Experiment (TriADE) is aimed at studying tritium adsorption on RW candidates under close-to-KATRIN conditions. To measure the amount of tritium adsorbed on the solid, the so-called BIXS method is used. Beta-induced X-ray spectrometry (BIXS) uses the X-radiation produced by the adsorption of beta electrons in solids or liquids. These X-rays can be used for material analysis or activity control. As X-radiation has a much longer range than the electrons from beta decay, the detector can be placed outside of the specimen chamber. Consequently, it is not influenced by the conditions in the specimen chamber. A beryllium window separates the specimen chamber from the detector in terms of vacuum technology. It is highly transparent for X-rays and, at the same time, ensures a small leak rate of tritium.

Figure 7: Beryllium specimen for TriADE measurements.

To measure RW candidates under close-to-KATRIN conditions, tritium partial pressures of 10^{-5} mbar to 10^{-3} mbar at a maximum tritium purity (> 95%) have to be reached in TriADE. Background impacts due to tritium adsorption on the specimen holder and recipient have to be minimised. The specimen has to be stabilised in a wide temperature range. Figure 6 shows the CAD drawing of the TriADE specimen chamber and detector chambers. The specimen can be exchanged by removing the rear flange. The specimens may be made of any material that can be manufactured in the form of mechanically stable discs of about 7 cm in diameter and 0.1 to 5 mm in thickness.

Specimen temperature is stabilised in the range from -100°C to +200°C with an accuracy of ± 2°C by a cold gas system or a heating sleeve. Heat is transferred via the flange on which the specimen holder is mounted. The specimen holder itself is made of copper for better heat conduction. To prevent the process gas from being impurified and reduce background sources due to adsorbed tritium, the recipient (Figure 8), specimen holder, and beryllium window are coated with gold. Moreover, the complete system can be heated up to 200°C. The rear wall of KATRIN will be heated up to temperatures of 150°C. A four-stage pumping system, consisting of a metal bellows pump, a scroll pump, and two serial turbomolecular pumps, ensures total pressures of ≤ 10^{-9} mbar.

The spacings of the specimen holder, beryllium window, and SDD are chosen such that the detector is reached by X-rays from the specimen and the surface of the gold-coated beryllium window exclusively, without scattering. The beryllium window serves as a collimator and limits the angle of aperture of the detector to the diameter of the specimen.

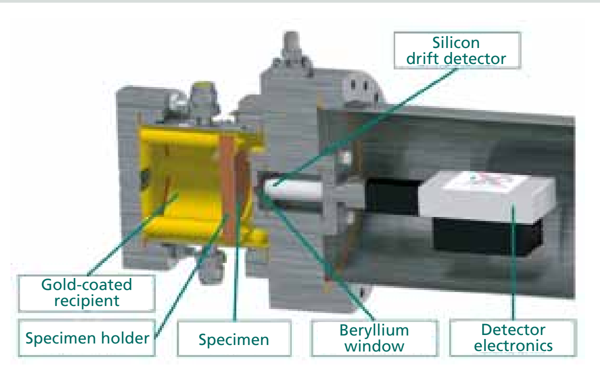


Figure 6: CAD drawing of the main components of TriADE.

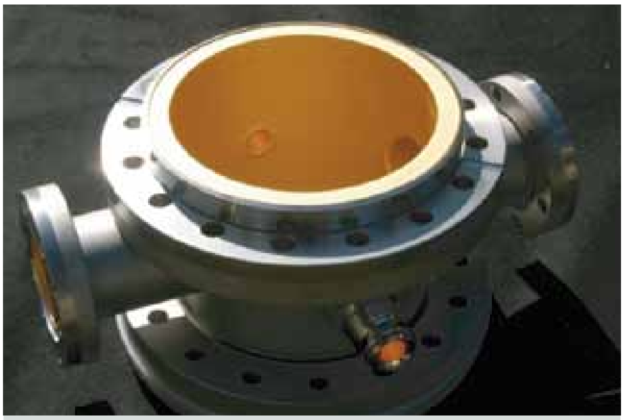


Figure 8: Gold-coated TriADE receptacle.

A silicon drift detector is used as an detector. Compared to conventional semi-conductor detectors, silicon drift detectors have a large active surface area of 25 to 100 mm^2 and a low intrinsic background (≈ 5 x 10^{-3} 1/s) and high energy resolution (125 eV FWHM at 5.9 keV). This is the prerequisite for an efficient detection of low-energy X-rays (< 18.6 keV). Moreover, this type of detector does not require any cooling with LN2, but is cooled thermoelectrically to -55 °C.

TriADE Measurement

A TriADE measurement can be divided into several phases: Upon the insertion of a specimen into TriADE, the recipient is heated up for about two weeks. Then, the desired temperature is set on the specimen and stabilised with the help of the cold gas system or the heating sleeve. The specimen is exposed to the tritium partial pressure between 10^{-5} and 10^{-1} mbar for a specified period of time. Afterwards, the recipient is pumped down to a pressure of < 10^{-9} mbar. With the help of the X-ray detector, adsorption measurements are made. Figure 9 shows a typical BIXS spectrum.

To quantify the amount of tritium adsorbed on the specimen surface, the events in the spectrum are added and a count rate is determined. This count rate is compared with the expected count rate obtained by Monte Carlo simulations for a certain amount of tritium on the specimen. The minimum amount of tritium that can be detected on the specimen is determined largely by the intrinsic detector background. Simulations with Penelope in 2009 revealed that tritium adsorption on the specimen of less than 1 atomic layer can be detected. Hence, the KATRIN requirement for the rear wall (coverage by less than 1 atomic layer) can be verified for the first time. This has not yet been possible with any other system.

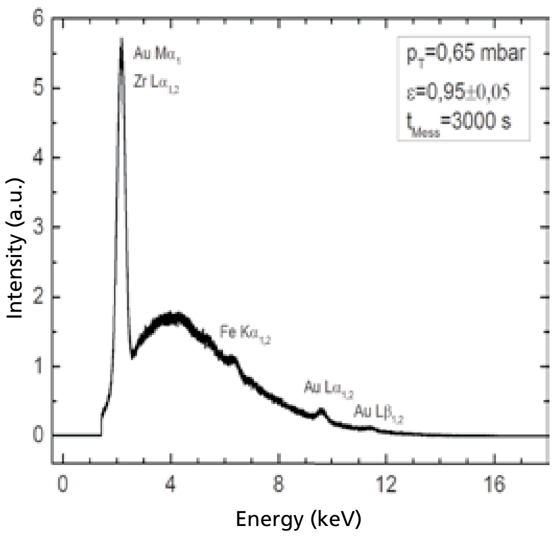


Figure 9: BIXS spectrum of a gaseous tritium source recorded by a silicon drift detector. A continuous bremsstrahlung spectrum is superposed by material-specific fluorescence lines.

After the BIXS measurement, the specimen temperature can be increased. Using the mass spectrometer, it can be determined at which temperatures tritium is desorbed from the specimen. This allows conclusions to be drawn with respect to the binding energy. As an alternative, it can be studied whether purge gas mixtures can be used to decontaminate the specimen and hence, the RW in the later KATRIN facility.

First measurements were made using a gold-coated beryllium specimen, as this KATRIN-relevant material combination is of high interest. It is also planned to use this set-up for later measurements of fusion-relevant materials, such as breeder blankets or materials used for tritium process technology.

Status and Outlook

The TriADE experiment (Figure 10) was set up under two doctoral and one diploma theses in 2012/2013. In 2014, first important tritium measurements will be made and evaluated within the framework of a master's thesis. With the help of these measurements, it will be possible to identify an appropriate RW candidate for KATRIN and to quantify the tritium adsorption-related systematic uncertainty of the KATRIN tritium gas source.

Figure 10: CAD of the TriADE experiment with the pumping station (coloured blue), core components (green), instruments and manual valves (brown), mass spectrometer and the corresponding volume (magenta), as well as the specimen holder (yellow).

Awards and Prizes

2013 turned out to be an eventful and fruitful year for ITEP. The Institute and its staff were granted several prizes in various areas.

KIT Innovation Award NEULAND

Product-oriented idea: Professor Steffen Grohmann of ITEP and the Institute for Technical Thermodynamics and Refrigeration (ITTK) was granted the second prize in the category "Competition of Ideas" of the KIT Innovation Competition "NEULAND 2013". Within the framework of his project "Mass flow sensor", Grohmann develops a completely novel measurement principle to determine mass flow of fluids. It is based on energy conservation. In the NEULAND innovation competition, KIT employees are requested to submit project ideas that are based on KIT know-how and aimed at transferring technologies. After the first round, six ideas and transfer projects were granted awards in two categories in March 2013. An independent jury of industry representatives selected the winners based on the criteria of creativity and innovation level, proximity to the market and market size as well as benefit for the society.

Professor Steffen Grohmann (left) received the award certificate from KIT President Professor Eberhard Umbach.

AMS – Arbeitsschutz mit System

Safety at work: ITEP is the first scientific institute in Europe, whose Safety at work management system was recertified. In April 2013, ITEP was granted the certificate "AMS – Arbeitsschutz mit System" (systematic safety at work) by the accident insurance company VBG and the Unfallkasse Baden-Württemberg (UKBW). The safety at work management system of the Institute was reviewed according to national and international standards and found to fulfil all criteria established by the German Institution for Statutory Accident Insurance and Prevention. Implementation of the safety at work management system by ITEP had been associated with big challenges, in particular in connection with new technologies, for which a generally valid state of the art does not yet exist.

Uwe Marx, Head of the Prevention Section of the VBG District Administration Ludwigsburg, and Wolfgang Kurz, Head of the Prevention Section of UKBW, handed over the certificate to the Head of Institute Professor Mathias Noe (from left to right). On the right, KIT Vice President for Human Resources and Law, Dr. Elke Luise Barnstedt, is visible. (Photo: KIT)

Exemplary Building in the District of Karlsruhe

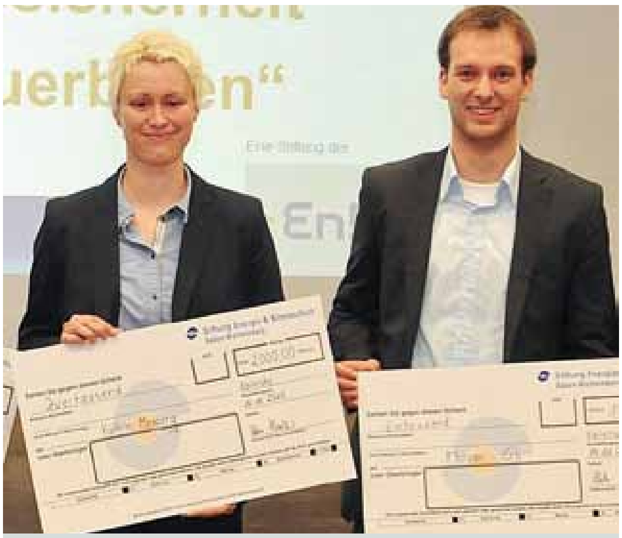
Exemplary research environment: The new building of ITEP was granted a prize for "Exemplary Building in the District of Karlsruhe 2006-2013" by the Chamber of Architects in Baden-Württemberg. The building on KIT Campus North (building 410) was designed by the

The ITEP Building seen from the front and the inner courtyard.

Architectural Office of Behnisch Architekten and opened officially in July 2011 after a construction period of 15 months. The entrance area is rather spacious and covered by a skylight. Offices are located on the neighbouring two floors. The basement accommodates laboratory rooms that open onto a green courtyard. The jury was convinced in particular by the light and open atmosphere of the building. With the "Exemplary Building" award, the Chamber of Architects in Baden-Württemberg wishes to sharpen the awareness for building culture in everyday life. Criteria are the external design, dimensions and proportions of the construction, internal room layout, as well as integration into the urban context and environment. The prize honours the joint commitment of architects and owners.

EnergyCampus Competition of Ideas

Excellent young researchers: Florian Erb, KIT, reached the second place in the Competition of Ideas "EnergyCampus 2013" for his thesis on "Superconducting DC generators for compact and efficient wind turbines." With this competition, the Foundation for Energy and Climate Protection in Baden-Württemberg wishes to support young scientists at the state universities. The heading of the competition in 2013 was "Security of supply with renewable energies". Criteria for the evaluation of the theses were the originality of scientific work, excellent results, research and technology transfer as well as the quality of the presentation. At a symposium in November 2013 at the University of Ulm, the prizes were handed over.



Florian Erb of ITEP, KIT, reached the second place in the EnergyCampus competition of ideas. The first prize was won by Kathrin Menberg, KIT Institute for Applied Geosciences (AGW).

DKV Studies Award

Award for diploma thesis: For her diploma thesis written at ITEP, Carolin Heidt was granted the DKV Studies Award in November 2013. This award granted by the Deutscher Kälte- und Klimatechnischer Verein – DKV (German Association for Cryogenic and Air Conditioning Technologies) honours excellent student projects and diploma theses in the fields of cryotechnologies and air conditioning technologies. Carolin Heidt's diploma thesis focused on "Studies relating to the safety of liquid helium pressure vessels."

Carolin Heidt at the awards ceremony with the supervisor of her diploma thesis, Professor Dr.-Ing. Steffen Grohmann (second from the left), as well as Dr.-Ing. Josef Osthues (left, Chairman of the DKV) and Professor Dr.-Ing. Ullrich Hesse (right, Deputy Chaiman of the DKV).

Teaching and Education

Lectures, Seminars, Workshops, Summer Schools

Lectures

KIT-Fakultät Elektrotechnik und Informationstechnik
Supraleitende Systeme für Ingenieure (Noe, Neumann, Siegel) WS 12/13-13/14
Supraleitertechnologie (Noe) SS 13
Superconducting Materials for Energy Applications (Grilli, Noe) SS 13
Seminar Project management for engineers (Noe, Day, Grohmann) SS 13

KIT-Fakultät für Chemieingenieurwesen und Verfahrenstechnik
Vakuumtechnik I (Day, Varoutis) WS 12/13-13/14
Kryotechnik (Neumann) WS 12/13-13/14
Kältetechnik A (Grohmann) WS 12/13-13/14
Kältetechnik B (Grohmann) SS 13

KIT-Fakultät Maschinenbau
Fusionstechnologie A* (Bornschein, Day, Fietz, Weiss) WS 12/13-13/14
Magnet-Technologie für Fusionsreaktoren (Fietz, Weiss) SS 13
Vakuumtechnik und Tritiumbrennstoffkreislauf (Bornschein, Day, Demange) SS 13

KIT-Fakultät Physik
Messmethoden und Techniken in der Experimentalphysik (Bornschein) SS 13
Hauptseminar Astroteilchenphysik: Neutrinos und dunkle Materie (Bornschein) WS 12/13-13/14 und SS 13

Leibniz Universität Hannover – Fakultät Elektrotechnik und Informationstechnik
Neue Komponenten der elektrischen Energieversorgung* (Noe) SS 13

House of Competence
Blockseminar (4 Tage) Wissenschaftliches Schreiben und Präsentieren für Physiker (Bornschein) WS 12/13 und SS 13
Blockseminar (4 Tage) „Erstellen wissenschaftlicher Publikationen in der Physik“ (Bornschein, Schlösser , Fischer) WS 12/13
Mikromodul Physik/Geophysik (HoC in Kooperation mit Physikpraktikum) (Bornschein) WS 12/13-13/14

Duale Hochschule BW – Fachbereich Maschinenbau
Konstruktionslehre (Bauer) WS 12/13
Arbeitssicherheit und Umweltschutz (Bauer) SS 13
Thermodynamik 1 für Maschinenbauer (Neumann) WS 12/13-13/14
Thermodynamik 2 für Maschinenbauer (Neumann) SS 13

* with participation of ITEP

Seminars / Summer Schools / Workshops

4th ITEP Young Scientists Seminar
14.–17. Januar 2013, Kristberg, Österreich

VDI-Seminar Kryotechnik
27. Februar – 01. März 2013, Karlsruhe

CIGRE Working Group Meeting D1.38*
23.–27. April 2013, Peking, China

7. Karlsruhe-Dresden Doktorandenseminar zur Supraleitung*
19.–20. Juni 2013, Colditz

3rd KIT Fusion PhD Student Seminar*
19.–20. Juni 2013, St. Martin

7th ESAS Summer School on Materials and Applications on Superconductivity
29. Juli – 2. August 2013, Karlsruhe

7th International Summer School on Fusion Technologies*
2.–13. September 2013, Karlsruhe

CIGRE Working Group Meeting D1.38*
18. September 2013, Genua, Italien

VDI Seminar Cryogenics
9.–11. Oktober 2013, Karlsruhe

Haus der Technik Seminar Kryostatbau
16.–18. Oktober 2013, Karlsruhe

KSETA Doktorandenworkshop 2013*
16.–18. Oktober, Freudenstadt

Teaching and Education

Doctoral Theses – Master- and Diploma Theses – Bachelor Theses

2013 Doctoral Theses (*completed)

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

Christian Barth* (FUSION)
High temperature superconductor cable concepts for fusion magnets

Wescley Batista de Sousa (SUPRA)
Transient simulations of superconducting devices

Christoph Bayer (FUSION)
Characterization of high temperature superconductor (HTS) cable for large scale HTS magnet coil application

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

Florian Erb (SUPRA)
Entwurf supraleitender Windkraftgeneratoren

Sebastian Fischer (TLK)
Laser Raman Spectroscopy for the KATRIN Experiment

Patthabi Vishnuvardhan Gade (FUSION)
Optimization of High Temperature Superconductor (HTS) cable concepts for high current capacity to be used in HTS coils for future fusion reactors

Thomas Giegerich (VAKUUM)
Entwicklung eines Vakuumpumpkonzepts für zukünftige Fusionsreaktoren

Cristian Gleason-González (VAKUUM)
Modelling of rarefied neutral gas flow

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

Carolin Heidt (KRYO)
Experimentelle Untersuchungen und Modellierung von Störfällen in Flüssighelium-Kryostaten und die Auswirkungen auf das Schutzkonzept

Sebastian Hellmann (SUPRA)
Technologieentwicklung für supraleitende strombegrenzende Transformatoren

Zoltan Köllö (TLK)
Further Development of Tritium analytic devices

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

Robert Michling (TLK)
Performances Assessment of Water Detritiation Process

Oliver Näckel (SUPRA)
Untersuchungen strombegrenzender Spulen

Florian Priester* (TLK)
Tritiumtechnologie für die fensterlose WGTS von KATRIN

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

Marco Röllig (TLK)
Tritiumanalytik bei KATRIN

Simone Rupp (TLK)
Development and investigation of a tritium-compatible capillary Raman system and a mixing loop for all hydrogen isotopologues

Kerstin Schönung (TLK)
Aufbau Rear-System von KATRIN

Magnus Schlösser* (TLK)
Accurate calibration of the Raman system for the Karlsruhe Tritium Neutrino Experiment

Master- and Diploma Theses 2013 (*completed)

Alexander Beck*
Entwicklung und Test einer Analysesoftware für das Tritium-Absorptions-Infarot (TApIR)-Experiment zur Untersuchung der IR-Absorption in flüssigen Wasserstoffisotopen.

Miroslav Dimov
Untersuchungen zur Entwicklung eines Prototyp-Sensors für ein neues thermisches Messverfahren zur Durchflussmessung

Daniel Fischer*
Gasabgabeeffekte beim Abpumpen von Fusionsreaktoren

Amit Grover*
Development, construction and test of a flexible support structure for multi-layer insulation in a flexible cryogenic transfer line

Enno Heits
Supraleitende Miniaturbahn

Yannick Ille*
Untersuchung eines Versuchsstandes zur Charakterisierung von superpermeablen Metallfolien mittels Wasserstoffplasma

Daniel Kraft*
Auslegung eines Rekuperators/Regenerators für LH2-Speicherung

Sebastian Mirz
Untersuchung des Ir-Absorptionsverhaltens flüssiger Wasserstoffisotopologe von der Weglänge und der Ortho-Parabesetzung

Simon Niemes*
Messung des Bramsstrahlungsspektrums von tritiiertem Wasser mit einem Siliziumdriftdetektor am Tritiumlabor Karlsruhe

Simon Otten
Transverse pressure of IC in coated Conductor Roebel Cables

Manuel Pitsch
Auswertung von Netzzustanddaten – Chancen und Optimierungspotentiale

Clio Saglietti*
Experimental and computational study of vacuum gas flows through short tubes and bellows

Vera Schäfer*
Charakterisierung des „Coating Test Experiments" zur Verbesserung der Langzeitstabilität und der Reproduzierbarkeit

Fabian Schneck*
Untersuchung des Adsorptionsverhaltens von Tritium an Oberflächen und Implikationen für KATRIN

Hendrik Seitz
Entwicklung eines optimierten Kapillar-Raman-Systems für das KATRIN-Experiment zur Bestimmung von Gaszusammensetzungen mit hoher Sensitivität

Rodrigue Tchoumbe*
Berechnung und Untersuchung notwendiger Modifikationen für den Einsatz von Quecksilberring-Vakuumpumpen in der Fusion

Bachelor Theses 2013 (*completed

Tim Brunst*
Durchführung von Messungen mit einem Lumineszenzstandard zur Kalibrierung des Laser-Raman-Systems für KATRIN

Julia Dusold*
Charakterisierung der Amptek X-123 Si-PIN Diode und Identifizierung von Mineralien mithilfe des Amptek Mini-X Röntgensystems

Max Görtz*
Messung von Quench und Rückkühlzeiten verschiedener Supraleiteranordnungen in flüssigem Stickstoff

Felix Heil
Aufbau und Inbetriebnahme der Magnetversorgung eines supraleitenden Energiespeichers

Roxana Helm
Simulation von Generatoren für Windkraftanlagen

Yannik Hörstensmeyer
Simulation von Quecksilberdampfströmungen durch das Düsensystem von Diffusionsvakuumpumpen

Patrick Kabrhel
Experimentelle Untersuchungen des transienten Übergangs an Bandleiter in flüssigem Stickstoff

Thomas Karcher
Entwicklung eines Pumpenventils für eine tritiumkompatible Vakuumpumpe

Milena Kesenheimer (IKET)
Untersuchungen zur Kavitation in einem passiven Rückstrombegrenzer

Dustin Kottonau*
Wirtschaftlicher Vergleich von konventionellen und neuartigen Energieübertragungssystemen auf unterschiedlicher Spannungsebene

Alexander Kraus*
Modellierung und Messung von IR-Absorptionsspektren flüssiger Wasserstoffisotopologe

Michael Mai*
Berechnung einer kalten Gasreinigungskolonne zur Aufreinigung des Abgases von Quecksilberringpumpen

Manuel Mungenast*
Aufbau, Programmierung und Visualisierung einer Temperaturregelung mit einer Steuerung Simatic S7-1200 und einem Touch-Panel

Pakari Oskari
Untersuchung von Beta induzierter Atom Emission

Kevin-Davis Richler
Aufbau, Inbetriebnahme und erste Testmessungen mit einem Ortho/Para-Konverter für flüssige Wasserstoffisotopologe

Sebastian Senft
Untersuchung von Glasfasern auf ihre Tauglichkeit in einer Tritiumumgebung

Sebastian Wozniewski
Relative Kalibrierung der IR Absorptionsspektren gegen H_2, HD und D_2 Konzentration

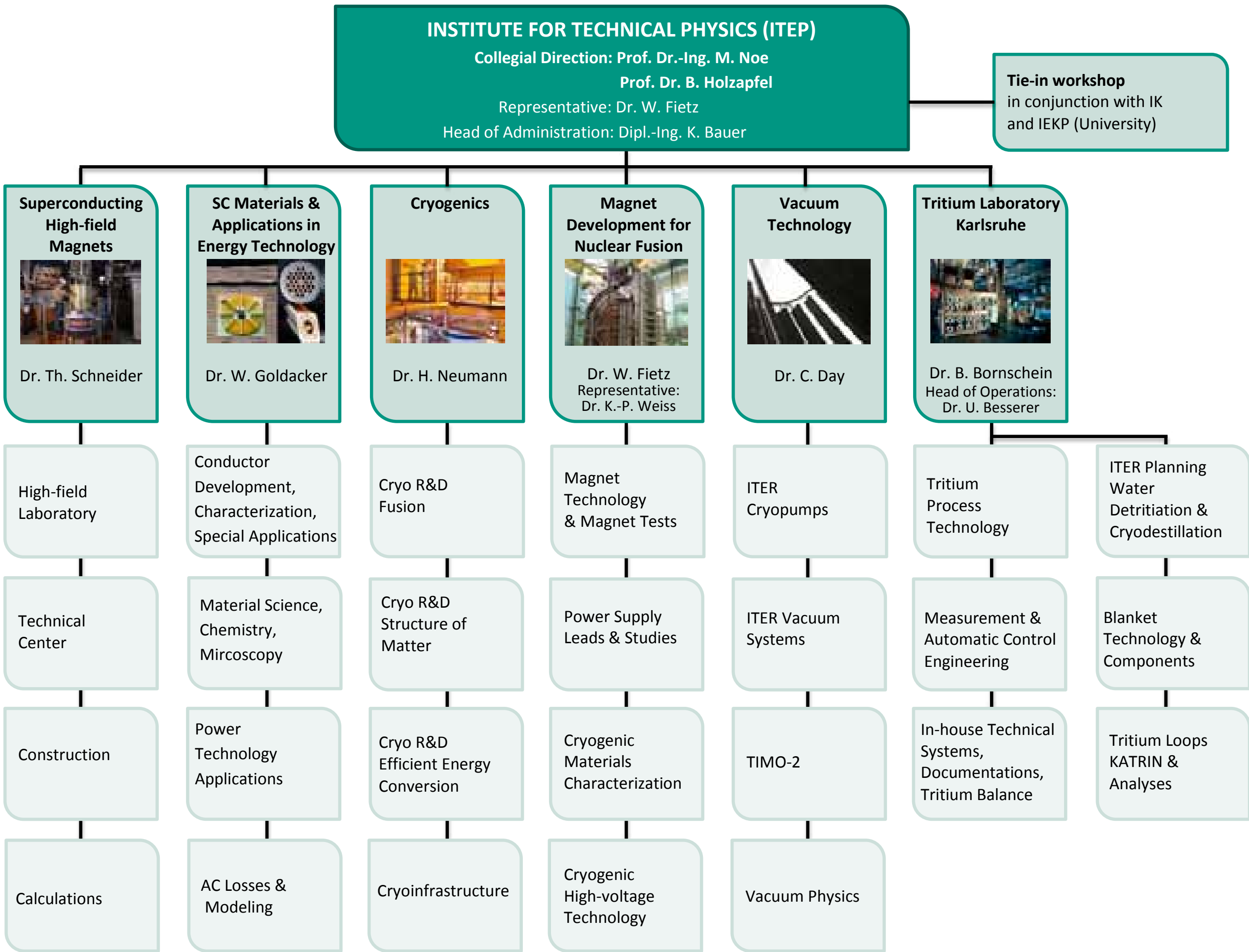
Teaching and Education

ITEP Colloquies

24.01.2013	Cryogenic Properties Assessment at CCMAS Dr. Chuan-Jun Huang Chinese Academy of Sciences; FUSION
26.03.2013	Potenzial interdisziplinärer Forschung Neuromarketing, oder: was verbindet Supraleitung mit einem „guten?" Glas Wein Dr. Goldacker; SUPRA
23.04.2013	Fördermöglichkeiten der DFG Stabsstelle FOR; Administration
29.04.2013	Auxiliary Cryogenic systems for SST-1 and Recent developments Naresh Gupta; Institute for Plasma Research (India); KRYO
30.04.2013	High-Power Stirling-Type Pulse Tube Cryocooler for Operation near 80 K Jiuce Sun Zhejiang; University Hangzhou, China; KRYO
14.05.2013	Untersuchungen zur Sicherheit von Flüssig-Helium-Druckbehältern Carolin Heidt; KRYO
04.06.2013	LIQHYSMES – ein multifunktionales Hybrid Energiespeicher-Konzept Michael Sander; KRYO
18.06.2013	Messung des Bremsstrahlungsspektrums von tritiiertem Wasser zur Konzentrationsbestimmung mit einem Siliziumdriftdetektor Simon Niemes; TLK
02.07.2013	Berechnung eines mehrstufigen Gaskühlers zur Aufreinigung des Abgases von Quecksilberringpumpen Michael Mai; VAKUUM
24.07.2013	Hochtemperatur-Supraleiter-Kabelkonzepte für Fusionsmagnete Christian Barth; FUSION
17.09.2013	ITEP Guide – eine Orientierungshilfe für neue Mitarbeiter/innen Röhnisch/Meinzer; Administration
24.09.2013	Simulation von Quecksilberdampfströmungen durch das Düsensystem von Diffusionsvakuumpumpen Yannick Hörstensmeyer; VAKUUM
01.10.2013	Experimental and computational study of vacuum gas flows through short tubes and bellows Clio Saglietti; VAKUUM
08.10.2013	Kryoventilpräsentation Fa. Stöhr; KRYO
12.11.2013	Auslegung eines Rekuperators/ Regenerators für LH2-Speicherung Daniel Kraft; KRYO
19.11.2013	Gasabgabeeffekte beim Abpumpen von Fusionsreaktoren; Untersuchung eines Versuchsstandes zur Charakterisierung von superpermeablen Metallfolien mittels Wasserstoffplasma Daniel Fischer, Yannik Ille; VAKUUM
26.11.2013	Aufbau und Inbetriebnahme der Magnetstromversorgung eines supraleitenden Energiespeichers Felix Heil; HFM
03.12.2013	Angle-Dependent U(I) HTS Measurements Pauline Leys; HFM
11.12.2013	Optimization of High Temperature Superconductor current leads for nuclear fusion applications Enrico Rizzo; FUSION

Figures and Data

ITEP Chart of Organization (January, 2013)



Personnel Status (30.11.2013)

Total	**200**	Apprentices	2
University graduates	54	Trainees	4
Engineers and technicians	63	**additionally, during 2013**	
Others	28	Guests	13
Pre-doctoral students	23	Trainees	14
Diploma students	16	Student assistants	23
DH students	10	Term Papers, bachelor theses	20

Figures and Data

Personnel Changes in 2013

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

Melanie Bacher

Wescley Batista de Sousa

Axel Bönisch

Flavio Brighenti

Tim Brunst

Andras Bükki-Deme

Daniel Fischer

Marius Frank

Eric Freynhagen

Max Görtz

Felix Heil

Carolin Heidt

Enno Heits

Marvyn Hellmann

Roxana Helm

Bernhard Holzapfel

Yannick Hörstensmeyer

Yannik Ille

Patrick Kabrhel

Thomas Karcher

Dustin Kottonau

Michael Korevaar

Daniel Kraft

Michael Mai

Simon Otten

Oskari Pakari

Kevin-Davis Richler

Hendrik Seitz

Jiuce Sun

Thorben Wahl

Sebastian Wozniewski

Hong Wu

Leaving (Excluding Trainees, Guests, and Student Assistants)

Catalin-Gabriel Alecu

Martin Babutzka

Christian Barth

Sabrina Gerl

Manfred Jung

Benedikt Kuffner

André Opitz

Rolf Simon

Rodrigue Tchoumbe

Michal Vojenciak

Robert Wagner

Figures and Data

Trainee / Student assistants

Trainee 2013 (* completed)

Katharina Battes

Thomas Giegerich*

Benedikt Kuffner

Xavier Lefebvre

Ochoa Guaman Santiago

Michael Schrank

Student assistants 2013

Daniel Barth

Alexander Beck

Sebastian Della Bona

Sylvia Ebenhöch

Felix Heil

Florian Kassel

Manuel Klein

Kyriaki Koutrouveli

Alexander Kraus

Simon Kudella

Sebastian Mirz

Simon Niemes

Sashank Pappu

Manuel Pitsch

Clio Saglietti

Matthias Schaufelberger

Vera Schäfer

Florian Schleißinger

Fabian Schneck

David Schneider

Pia Schulz

Jasmin Seeger

Sascha Singer

Figures and Data

Guest Researcher

Guest Researcher

Jérôme André
21.10.–31.12.13 Gast aus Traineeprogramm GOTP-GIRO, Saclay, Frankreich

Dr. Gheorghe Bulubasa
01.07.–31.07.13 National Institute of R&D for Cryogenic and Isotopic Technologies, Valcea, Rumänien

Dr. Jiwen Cen
23.09.–15.03.14 Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Peking, China

Dr. Chuanjun Huang
22.01.–25.01.13 Chinese Academy of Science, Peking, China

Dr. Rongjin Huang
22.01.–25.01.13 Chinese Academy of Science, Peking, China

Dr. Timothy James
21.04.–09.05.13 Universität Swansea, Wales, Großbritannien

Prof. Kenzo Munakata
28.10.–31.10.13 Faculty of Engineering and Resource Science, Akita University, Japan

Alina Niculescu
17.07.–26.07.13 National Institute of R&D for Cryogenic and Isotopic Technologies, Valcea, Rumänien

Dr. Yoshinori Ono
07.10.–31.03.14 National Institute for Materials Science, Tsukuba, Japan

Catalin Petrutiu
13.05.–07.06.13 National Institute of R & D for Cryogenic and Isotopic Technologies, Valcea, Rumänien
18.11.–06.12.13 National Institute of R & D for Cryogenic and Isotopic Technologies, Valcea, Rumänien

Alexandre Serrand
18.11.–13.12.13 Gast aus Traineeprogramm GOTP-GIRO, Saclay, Frankreich

Prof. Dr. Helmut Telle
22.04.–26.04.13 Universität Swansea, Wales, Großbritannien

Figures and Data

Memberships in relevant Technical and Scientific Organizations

Kai Bauer

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

Beate Bornschein

- Member of the „International Steering Committee“ of the „International conference on Tritium Science and Technology“
- Member of the „Executive Committee of IEA Nuclear Technology for Fusion Reactors Network Co-ordinator for EU network trainee programme 'TRI-TOFY'
- Member of the KATRIN Executive Committee
- Member of the KATRIN Collaboration Board
- Coordinator Source and Transport Section of KATRIN
- Member of the Scientific Technical Assembly of KCETA
- Member of the Executive Board of KSETA (KHYS-Steering Committee)
- Representative member of CRYS at KIT (Council for Research and Promotion of Young Scientists)
- Member of Publication Committee of the KATRIN collaboration

Christian Day

- Member of the Executive Board of the German Vacuum Society (DVG)
- Vice-President of the „Fachverband Vakuumphysik und -technik der Dt. Physikalischen Gesellschaft (DPG)“
- Project Leader „Tritium - Fuelling - Vacuum“ of the European Fusion Programme EUROFUSION
- Project management of the field Tritium-Fuelling-Vacuum in the European Fusionprogram EUROFUSION
- Co-ordinator of the VACU-TEC Goal oriented Training Programme, EFDA (GOT).
- Spokesperson Topic „Vakuum und Tritium“, Deutsche DEMO Initiative
- Rarefied Gas Dynamics Conference Series (RGD), member in the International Advisory Committee
- International Symposium of Fusion Nuclear Technology (ISFNT), Member of the International Programme Committee
- Associated Expert of the Indian Vacuum Society (IVS)
- Chartered Engineer of American Vacuum Society (AVS)

Walter H. Fietz

- Member of International Organizing Committee of Symposium of Fusion Energy
- Head of Task Force Magnets in KIT Program Fusion
- Member of KIT-Senate

Francesco Grilli

- Board member International HTS Modelling working group: http://www.htsmodelling.com
- International advisory board member of the 4th International Workshop on Numerical Modelling of High Temperature Superconductors, 11.–14.5.2014 Bratislava, http://www.elu.sav.sk/htsmod2014/get.html

Wilfried Goldacker

- Vice-President of Board of Directors ICMC (International Cryogenics Materials Conference)
- Mitglied der Kommission Elektrotechnik, Elektronik- und Informationstechnik im DIJN und VDE, Referat K184 „Supraleiter“
- Advisory Board CESUR Universität Ankara (Centre of Excellence for Superconductivity Research)
- Board member ICEC24-ICMC Conference, Twente 7–11. Juli 2014
- Program Committtee Member ICSM-Conference Antalya 2014
- Program Board Member EUCAS-2013, Genova
- Member Executive Board of Eucard-II (EU-Projekt)
- Member and KIT-Representative of Network Wind Energy, Rostock

Steffen Grohmann

- Vice-chairman of „Normenausschuss NA 016-00-07 AA „Flüssighelium-Druckbehälter-Sicherheitseinrichtungen gegen Drucküberschreitung“
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- Member of the KATRIN Executive Board and KATRIN Publications Committee
- Member of the Institute of Refrigeration (IIF/IIR), Commission A1: Cryophysics, Cryoengineering

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- Applied Superconductivity Conference, Member of International Program Committee
- Magnet Technology Conference, Member of International Program Committee
- Computation of Thermo-Hydraulic Transients in Superconductors (CHATS-AS), Board member
- DKE/DIN K 184 – Superconductor
- 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"

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- Applied Superconductivity Conference, Board member
- European Conference on Applied Superconductivity, Member of International Program Committee
- Superconductivity for Energy Conference, Member of International Advisory Committee
- Superconductor Science and Technology, Member of Advisory Board

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- Subprogramme Coordinator of Superconducting Magnetic Energy Storage (SMES) of the European Energy Research Alliance (EERA) joint Program on Energy Storage
- International Council of Large Electric Systems (CIGRE), Convenor of Working Group D.1.38 "Emerging Test Techniques Common to High Temperature Superconducting (HTS) Power Applications"
- International Energy Agency, Implementing Agreement for a co-operative programme for assessing the impacts of high-temperature superconductivity on the electric power sector, German representative
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- Association Steering Committee Euratom-KIT, Member
- Karlsruhe School of Elementary and Astroparticle Physics, Member of Executive Board
- International Conference on Magnet Technology, Member of International Organizing and Scientific Program Committee
- Applied Superconductivity Conference, Board member
- European Conference on Applied Superconductivity, Member of International Program Committee
- Degree course Energy Engineering and Management of Hector School, Program Director
- Advisory Panel of the periodical Physica C, Member
- IEEE Transactions on Applied Superconductivity for Large Scale Applications, Editor
- Smart Grid Plattform Baden-Württemberg, Participant
- Industrial Association Superconductors, Guest member
- Helmholtz Program Efficient Energy Conversion and Use Program, Spokesperson Topic Superconducting Components
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- Member of the Appointment Committee of the "Baden-Württemberg Cooperative State University Kalrsruhe"

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- DKE - German Commission for Electrical, Electronic & Information Technologies in the DIN and VDE Department K 184 "Superconductors", Representative Chairman
- IEC International Electrotechnical Commission/Technical Comittee 90 „Superconductivity" Mitglied
- Sprecher der Arbeitsgruppe "Magnet Design" innerhalb der deutschen Koordination der Fusionsforschung für DEMO

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- Founding member and longtime member of the executive board of the "Deutschen Gesellschaft für Flüssigszintillationschromatographie e.V. (DGfS)", treasurer
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Invited Papers

Beate Bornschein

- B. Bornschein, „Schreibbildung in der Physik – erste Erfahrungen am Schreiblabor des HoC“. Interdisziplinare Tagung Wissenschaft schreiben, 09.–11. Oktober 2013, Universität Karlsruhe
- B. Bornschein, „Das KATRIN Experiment“ 02.10.2013 Ministerium für Umwelt, Klima und Energiewirtschaft in Stuttgart, Abteilung „Kernenergieüberwachung, Strahlenschutz“
- B. Bornschein „Determination of Neutrino Mass – Seven Decades of Tritium Beta-Decay Experiments“ 06.12.2013, Gemeinsamen Seminar des Forschungsschwerpunkts Teilchenphysik des Instituts für Kernphysik der Universität Münster

Christian Day

- Chr. Day, „20 years of customized cryopumps in fusion research“, 24th National Symp. Cryogenics, Ahmedabad, Indien, Januar 2013.
- Chr. Day, „Non-cryogenic pumps for DEMO “, 21st Vacuum Congress, Catania, Italien, Mai 2013.
- Chr. Day, „Exhaust pumping of DT fusion devices – Current state-of-the-art and a potential roadmap to a power plant“, Symp. On Fusion Engineering, San Francisco, CA, US, Juni 2013.
- Chr. Day, „ITER – Der Weg zu einem Fusionskraftwerk“, Bad Honnefer Industriegespräche der DPG, Bad Honnef, Juli 2013.

Wilfried Goldacker

- W. Goldacker, Anna Kario, Francesco Grilli, Andrea Kling, Michal Vojenciak, Andrej Kudymow, Christian Barth, Bernd Ringsdorf, Sonja I Schlachter. “High Current Low Loss 2G HTS ROEBEL- and Rutherford Cables”, MRS-Tagung San Francisco, 1.–5.4.2013

Reinhard Heller

- R. Heller, “Representative device builder points of view – current leads”, special session at European Conference on Applied Superconductivity 2013, Genoa, 15.–19.9.2013

Bernhard Holzapfel

- B. Holzapfel „Supraleitende Materialien für die Energietechnik“, DGM Fachausschuss Werkstoffe der Energietechnik, Oktober 1st, Jülich
- B. Holzapfel „Epitaxial Ba-122 and 11 Thin Films and Heterostructures – Basic Properties and Application Aspects“, International Symposium on Superconductivity, November 19th, Tokio, Japan
- B. Holzapfel „Epitaxial Ba-122 and 11 Thin Films and Heterostructures – Basic Properties and Application Aspects“, International Workshop on Novel Superconductors and Super Materials 2013, November 21st, Tokio, Japan

Anna Kario

- A. Kario, M. Vojenciak, A. Kling, A. Jung, F. Grilli, V. Zermeno, B. Ringsdorf, R. Nast, U. Walschburger, J. Willms, S.I. Schlachter, W. Goldacker, S. H. Hossain, J. H. Kim (University of Wollongong, ISEM), “Superconductivity activities towards application at Supra group”, UOW Wollongong, 20.02.2013

Mathias Noe

- M. Noe, E. Marzahn „Hochtemperatur-Supraleiter Kabel“, 81. Kabelseminar, 26.–27. Februar 2013, Leibniz Universität Hannover
- M. Noe “European project SUPRAPOWER for HTS wind generator”, CIGRE WG D1.38 Workshop on High Temperature Superconductors (HTS) for Utility Applications, April 26th 2013, Peking, China
- M. Noe “Fault Current Limiter Concepts and Applications”, CIGRE WG D1.38 Workshop on High Temperature Superconductors (HTS) for Utility Applications, April 26th 2013, Peking, China
- M. Noe “High Temperature Superconductor Power Applications”, May 1st 2013, CERN Accelerator School, Erice, Italy
- M. Noe „Widerstand zwecklos – Supraleiter erobern Smart Grids“, May 22nd 2013, Talkkit, Karlsruhe
- M. Noe “Superconductivity as a key technology from small electronics to large magnet applications”, Academia – Industry matching event – Fostering collaborations in Superconductivity, May 27th–28th 2013, Madrid, Spain
- M. Noe “History and Prospects of Applied Superconductivity Technology for Fusion Magnets”, June 19th 2013, PhD Student Seminar, St. Martin, Germany
- M. Noe “Opportunities of High-Temperature Superconducting Power Equipment”, July 9th 2013, MPI Colloquium Stuttgart
- M. Noe “Status of Development of Superconducting Fault Current Limiters (SCFCL)”, European Summer School on Superconductivity 2013, July 29th – August 2nd, 2013, Karlsruhe, Germany
- M. Noe “Superconductivity in the power grid, worldwide: trials and opportunities”, High-temperature superconducting workshop at CIGRE D1 meeting, September 11th 2013, Brisbane, Australia

- M. Noe, W. Goldacker, B. Holzapfel „From 2G to Practical Conductors – What Needs to be Improved?" European Conference on Applied Superconductivity EUCAS 2013, 15.–19. September 2013, Genova, Italy
- M. Noe „Supraleitende Betriebsmittel für die zukünftige Energieversorgung – Stand der Entwicklung und Perspektiven" ETI Kolloquium, 18. November 2013, Karlsruhe
- M. Noe „Supraleiter-Transformatoren – Mit hoher Effizienz und mehr Sicherheit in die Zukunft" Netzpraxis, 7. Fachtagung Energie, Leistungstransformatoren im täglichen Betrieb, 2. und 3.12. 2013, Gelsenkirchen

Matthieu Scannapiego

- M. Scannapiego, „R&D and design of the cryogenic vacuum pumps for ITER", IUVSTA Workshop on large vacuum devices, Ahmedabad, Indien, März 2013.

Magnus Schlösser

- M. Schlösser, How one measures the neutrino mass and why one needs raman spectroscopy for it … Vortr.: Instituto Pluridisciplinar, Universidat Complutense de Madrid, E, May 9, 2013

Stylianos Varoutis

- St. Varoutis, „Transient rarefied gas flow through short channels at arbitrary pressure ratios", Frühjahrstagung DPG, Dresden, März 2013.

Publications

Patents Held

(* Neue Schutzrechtsanmeldungen in 2013
** Schutzrechtserteilungen mit Wirkung für Deutschland in 2013)

Strombegrenzer mit elektrischen Ventilen zum Begrenzen des Kurzschlußstromes in einem elektrischen Leistungsstromkreis
Jüngst, Klaus-Peter; Kuperman, Grigory
DE 1149452
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