Karlsruhe Institute of Technology

ITP – Institute for Technical Physics

Research and Development
2008 Annual Report

Institute for Technical Physics

KIT – the cooperation of Forschungszentrum Karlsruhe GmbH and Universität Karlsruhe (TH)

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Preface

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

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

The activities of ITP are part of the long-term programs on fusion, efficient energy conversion, and use and structure of matter run by the Karlsruhe Research Center and the Helmholtz Association of German Research Centers.

The complex and, in most cases, multidisciplinary challenges are handled by very large, unique experimental facilities, laboratories, and the technical infrastructure, such as the Karlsruhe Tritium Laboratory, the TOSKA facility, the TIMO facility, the high-field magnet laboratory, the cryogenic high-voltage laboratory, and the materials laboratory.

2008 was characterized not only by the scientific results outlined in the next few chapters but also by some special challenges and events referred to briefly below.

Qualified training and education are major cornerstones of the activities of this Institute, and I am happy to state that our common efforts in this area are now showing the first visible success. The number of staff members undergoing training, such as students at a university of cooperative education, diploma students, pre-doctoral students, and trainees, has risen to a most satisfactory level, and it has been possible to integrate into our Institute some of the first graduates. As a result of many experienced staff members retiring for age reasons in the past few years, training and familiarizing younger staff members is an important process which has not come to an end by far.

For the W7-X project and the Japanese JT60-SA tokamak, ITP develops, builds, and tests the current leads with high-temperature superconductors. Important modules of these current leads have been tested successfully, and construction of the test facility has been continued. Conversion of the TOSKA facility for testing the non-planar superconducting torus coils for W7-X was completed in 2008. However, the planned coil tests in TOSKA are no longer considered necessary.

The Karlsruhe Tritium Laboratory is to handle important packages for water detritiation and cryogenic isotope separation in ITER. Both work packages have made important progress. Thus, the decontamination factor in water detritiation has been raised to very high levels in excess of 2700.

Participants in the first Karlsruhe-Dresden post-graduate seminar about materials and applications of superconductivity held at Bad Liebenzell castle.

The Vacuum Technology Group in ITP is responsible within ITER for designing, supplying, and testing the cryovacuum pumps. In 2008, the TIMO facility for testing cryovacuum pumps was converted further and adapted to future tests. Moreover, the ITERVAC flow simulation code for vacuum flows developed at ITP has been validated successfully.

The development of high-current, low-loss conductor concepts is one of the major activities in superconducting materials development at ITP. In 2008, the very successful development of Roebel-structured strip conductors with 2nd-generation superconductors was continued, reaching another milestone by developing a demonstrator cable with a current carrying capacity in excess of 2600 A at 77 Kelvin. Work on applications of superconductivity in power technology was focused on the development of current limiters and on cryogenic high-voltage technology.

After more than 25 years of operation, upgrading of the HOMER I test facility was continued, and some first successful tests were performed about the characterization of high-temperature superconductors of the second generation for future 25 T high-field use.

Work in cryotechnology mainly comprised the advanced development of complex, very large cryosystems, such as those for TOSKA and KATRIN, and the safe and reliable operation of croyfacilities. Important modules of the cryosupply line and cryomeasurement systems for the KATRIN project were commissioned successfully.

A post-graduate seminar on materials and applications of superconductivity was initiated in 2008 together with the Leibniz Institute for Solid State and Materials Research in Dresden. The first event of this kind was organized at Bad Liebenzell castle in the Black Forest and run by ITP. Moreover, the House of Technology offered a seminar about superconductivity for the first time run by ITP.

Together with the German Federal Ministry for Economics, IFW Dresden, and the Industrial Association for Superconductivity, a first workshop was organized on a historic site, the so-called waterworks, the former venue of the German national parliament in Bonn, about the future and innovation of high-temperature superconductors in power technology. More than 150 participants from research, universities, and industry clearly documented the great interest in superconductivity technology. The event will be repeated every two years from now on.

Dr. Christian Day, Head of the Vacuum Technology Unit of ITP, was awarded a special honor: In 2008, Dr. Day was elected member of the Executive Board of the Deutsche Vakuumgesellschaft (DVG). The DVG promotes all technical activities in the field of vacuum-based sciences, representing them in international associations. Dr. Day, whose research area develops the high-vacuum system for the ITER reactor, in particular works for excellent scientific training in the field of vacuum technology within the DVG.

Dr. Christian Day, Head, Vacuum Technology Unit, has been appointed member of the Executive Board of the Deutsche Vakuum Gesellschaft.

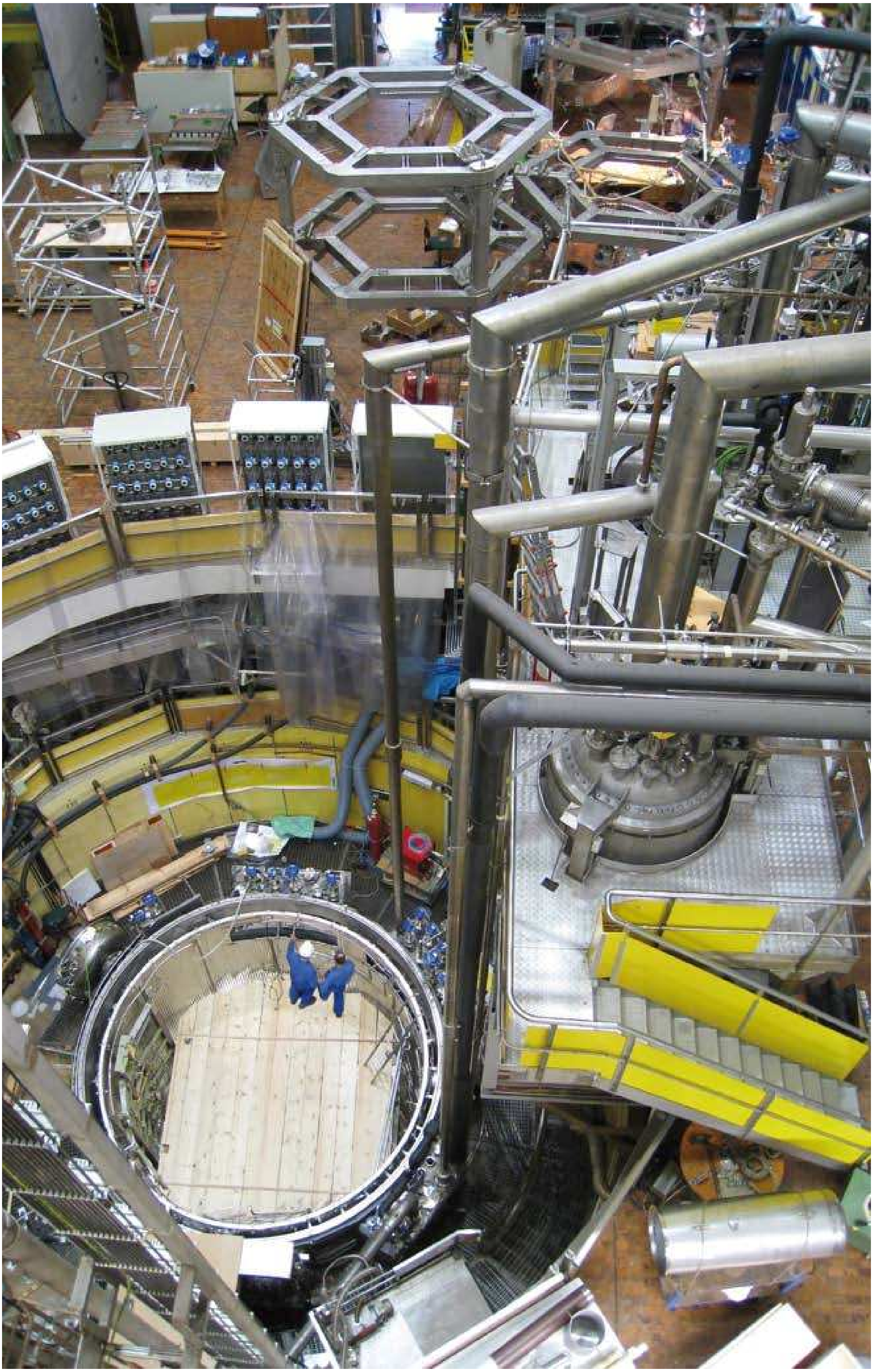
The International Council of Large Electric Systems (CIGRE) established a new working group on the subject of current limiters in 2008, of which I have been appointed an international expert member for superconducting current limiters. The main activities of the working group are studies of various possible applications of new kinds of current limiters, and a summary of all requirements.

In late 2008, a successful re-audit by the Industrial Insurance Associations for Administrative Professions was held at ITP. The subject of that audit was the management system for safety at work first introduced in Europe in 2005 for a scientific-technical institute. Safety at work and, consequently, the health of our staff are major factors determining the performance and the success of the Institute. I am grateful to all participants from the Institute and the partner organizations for their excellent performance.

My special thanks also go to all partners of ITP at universities, research institutions, and industry for the close and extremely fruitful cooperation in 2008.

Cordially yours,

Mathias Noe



TOSKA: preparation for the W7-X coil tests.

Results of the Research Areas

Fusion Magnets

Head: Dr. Walter Fietz

In the fusion magnet area, ITP contributes to the national W7-X project as well as to the international JT-60SA and ITER projects, and is performing preparatory work for the magnet system of the future DEMO demonstration reactor.

Preparation of W7-X Coil Tests in TOSKA

In order to avoid further delays in the construction of the W7-X stellarator as a consequence of coils not tested positively in time, it was decided in 2007 to back-up the test of the non-planar W7-X coils at the test facility of CEA Saclay by preparing an additional test possibility at the TOSKA ITP coil test facility.

For this purpose, the cryo-infrastructure of TOSKA was expanded on a large scale enabling installation, to simultaneous cooling of three W7-X coils and subsequent sequential testing. The instrumentation control and measurement systems were adapted to the new purpose by upgrading and matching. Four power supply leads were integrated into the TOSKA cryostat, which allows a power connection to be achieved by a link ("ladder") made available by IPP. The high-current switch and connection to the 50 kA power unit were converted to match the required short switching times, and sequential operation of the three coils was ensured by appropriate high-current connectors. The data acquisition system was replaced completely; all relevant data are stored in a database made available by IPE (FZK). After a successful vacuum test the TOSKA facility has been operational since November 2008.

High-current current leads allowing three coils to be fed current individually up to 18.2 kA.

Development and Construction of Current Leads for Wendelstein 7-X and JT-60SA

Work for Wendelstein 7-X

In late 2006, ITP took the responsibility for developing, constructing and testing of 16 current leads for the Wendelstein 7-X plasma experiment (W7-X). W7-X is under construction at Greifswald by the Max Planck Institute for Plasma Physics (IPP) for commissioning in 2014. The current leads (two prototypes and fourteen series current leads) must be installed upside down and, therefore, are equipped with Bi-2223 high-temperature superconductors, which reduces the necessary cryocapacity significantly. The current leads are designed for a maximum current of 18.2 kA and operating in a large magnetic stray field environment.

After the boundary conditions had been settled and a rough design completed in 2007, the current leads were designed in 2008 and checked in a number of preliminary tests. Moreover, nearly all components were purchased which are necessary to build the prototype and standard current leads. Manufacture of the two prototype current leads has begun. A Paschen-resistant high-voltage insulation was tested successfully together with industry.

End of 2009, the two prototype power supply leads are to be completed and will then be combined into a test unit together with a superconducting power connector prepared by IPP. That test unit is to be tested in the TOSKA coil test facility in 2010.

Work for JT-60SA

In 2007, Germany agreed to take over part of the package promised to Japan by the EU for construction of the JT-60SA satellite tokamak. Again, ITP took the responsibility for building the current leads. The first part of the funding scheme was agreed upon in the autumn of 2008, guaranteeing sourcing of all materials for subsequent industrial-scale production of the power supply leads. At present, the framework data are being agreed upon in negotiations with the EU and Japan which are to be laid down contractually in 2009.

The design of the 26 current leads for JT-60SA is similar to that of the W7-X power supply leads, but needs to be adapted to the new boundary conditions (26 kA maximum current, and pulsed mode operation, respectively). The rough concept was established in 2008. Once the basic data have been agreed upon, the overall design is to be worked out in 2009. Design work is to be finished in 2010. The design will be based on the results of the prototype test. For this purpose, the test unit built for the W7-X prototype test will be tested again under conditions relevant for JT-60SA (pulsed mode).

CuLTKa Current Lead Test Facility

A total of 16 current leads are to be tested in the frame of the W7-X project, another 26 for the JT-60SA project. For these purposes, a new test facility, CuLTKa (**C**urrent **L**ead **T**est facility **Ka**rlsruhe) is being constructed and integrated into the existing cryo-infrastructure of ITP. CuLTKa will be designed in such a way that both upside-down operation of the current leads for W7-X and the "normal mode" operation for JT-60SA are possible.

High-current contact of a current lead for connection with coils at low temperatures (top).

Demonstrator of a high-temperature superconductor module for a current lead (above).

Heat exchanger for a current lead (left).

The main work to be done for CuLTKa is the cryotechnical design; however, both the power connection to the existing 30 kA power supply unit must be established, and the electrical (high-voltage resistant) wiring, data acquisition, and signal processing systems must be built and integrated, respectively, into the existing infrastructure.

Outlook

The politically motivated priority assigned to construction of the TOSKA facility for testing non-planar W7-X coils in 2007/2008 has caused delays in the current lead work for W7-X. In addition, the construction of CuLTKa had to be advanced because the TOSKA infrastructure was not available for the envisaged test of the prototype power supply leads. Current plans assume the completion of the prototype pair by late 2009, and of the CuLTKa test facility by late 2010. The construction and acceptance tests of the series current leads for W7-X are to be completed by 2012. Afterwards, the 26 current leads for JT-60SA are to be built by industry and tested in CuLTKa by 2015.

Studies of Transient High Voltages in ITER Coils

During fast discharges, large magnet coils build up high voltages which must be managed especially in fast switching operations and also under fault conditions. The complex structure of the coil system of a fusion reactor and the given high inductances and capacitances result in a sophisticated electrical network in which fast switching operations can give rise to brief internal local voltage overshoots. These transient voltages cannot be measured directly, but must be detected by means of complex simulations in order to obtain clear information about the necessary insulation concepts.

ITP has taken responsibility for the calculation of the transient voltages in toroidal (TF) and poloidal (PF) field coils of ITER. For this purpose, exemplarily, the PF3 and PF6 coils of ITER were simulated in a detailed finite-element code to detect the particularly critical resonance frequencies of the coils. In this process, resonance frequencies were found at 20.6 kHz and 28.6 kHz, and a strong influence of the instrumentation cables used was detected.

In the next step of the task, error scenarios are to be defined jointly with ITER and the European ITER Domestic Agency which may give rise to the voltage overshoots potentially following later. In this way, the necessary insulation and test concepts can be designed for ITER.

Tests of Cryogenic Materials and Mechanical Tests of Superconducting Cables

W7-X and ITER

A number of mechanical tests were performed along with the construction of the W7-X and ITER fusion experiments. Thus, approx. 200 tensile tests were performed in 2008 on various materials, such as glass fiber reinforced polymers, welded aluminium, aluminium bronze (2.0966), steel (1.4429), or Inconel 716, at temperatures of 77 K and 4.2 K. The tensile tests were supplemented by other characterizations, such as fracture mechanics properties and the thermal expansion of steel and insulating materials.

Specifically for ITER, a systematic study has been started to measure the mechanical behavior of the thin steel jacket surrounding the superconducting cable for the toroidal field coils (TF). In this case, several tubes of stainless steel 316 LN in various conditions of compaction were exposed to subsequent temperature treatment comparable to annealing a superconducting cable. Finally, so-called flat tensile specimen were produced from these pipe sections for measurements of both tensile and fracture mechanics properties. The specimens measured at 4.2 K showed at a deformation by approx. 12%, on the one hand, an increase of the proof strength $R_{p0.2}$, and, on the other hand, a pronounced reduction of maximum strain. This needs to be taken into account in the fabrication of TF conductors because obvious hardening and embrittlement of 316 LN due to compaction of the steel sheath may cause problems in subsequent winding of the coil.

During manufacturing of the ITER magnets, a large number of additional routine tensile measurements at cryogenic temperatures must be expected (in W7-X, more than 200 tensile measurements are performed annually). In order to be able to cope with this number of measurements, an additional cryostat was prepared with a test system with a maximum load of 100 kN.

316 LN pipe degree of deformation	$R_{p0.2}$	Total strain
0 %	~1100 MPa	> 30 %
12 %	~1300 MPa	< 20 %
Data obtained at 4.2 K		

In one cooling process to 4.2 K, a special designed specimen carriage allows to test up to ten specimens successively up to failure. This allows a much more efficient execution of these routine tests. At the present time, the necessary measurements and design activities for the specimen carriage are carried out.

Electromechanical Studies in the Magnetic Field – FBI

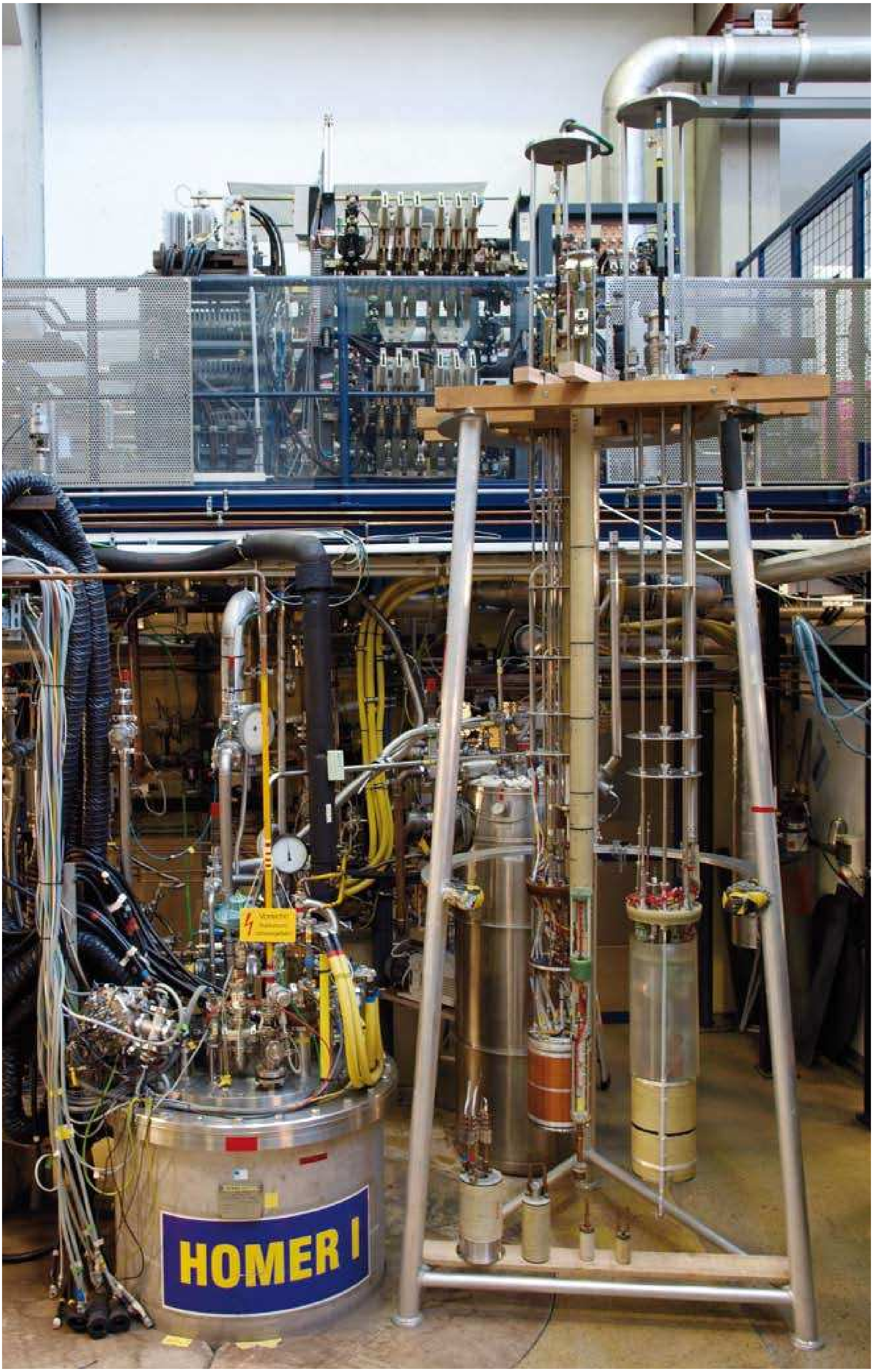
For application of high-temperature superconductors (HTS) in fusion technology, corresponding HTS tapes are to be studied in the FBI facility. However, temperatures between 4.2 K and 77 K must be achieved for this purpose. This requires a variable-temperature insert that can be used in the limited volume of the existing magnet. Various designs have been completed and tested in preliminary experiments. In the very near future, these are going to be tested in the FBI facility under real conditions.

Provided the results obtained with HTS tapes and stranded cables turn out to be positive, experiments are to be run also with HTS cables of a proper size for fusion magnets. This demands a much larger test volume in the magnet. Within the framework of a diploma thesis, various concepts were elaborated to show how this can be put into practice. In principle, a gap magnet with a sufficiently large gap and a homogeneous magnetic field range is necessary which may be used also in future studies for DEMO, provided funding can be arranged.

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

As early as in 2007, ITP conducted studies and analyses of high-temperature superconductor materials available at the time. The results of these studies clearly show that the RE-123 high-temperature superconductor (also referred to as "coated conductor") offers the chance in future fusion reactors to run magnet coils at comparatively high temperatures of 65 K. This opens up an opportunity for a simpler cooling concept, saving cryogenic cooling power and thus designing a simpler and more efficient fusion reactor.

As a consequence, ITP has started to develop first concepts of high-current cables made of YBCO material, so called "coated-conductor". Details of these activities will be described under the heading of the "Development of Superconducting Materials and Applications in Power Technology" research unit.



HOMER I 25 years: background magnet system plus variable high field insert coils.

Results of the Research Areas

Superconducting High Field Magnets

Head: Dr. Theo Schneider

The activities in 2008 of the "Superconducting High Field Magnets" group covered two important areas. The first focused on the study of voltage current relations of potential commercially available technical high current superconductors for use in high magnetic fields ($B \geq 20$ Tesla) at low temperatures down to 1.8 K. The second involved the experimental facilities of the high field laboratory, which have been in routine operation for more than 25 years, were modernized and further upgraded for higher magnetic fields, as required, for forthcoming projects.

Superconductor Characterization

In the experimental facilities of the high field laboratory in 2008 mainly modern $(NbX)_3Sn$ and 1st and 2nd generation high temperature superconductors were studied with respect to their potential use in building high field insert coils. As a consequence, the focus was put on the E(I)-characteristics of these conductors in magnetic fields of up to 20 T, currents of up to 1500 A, temperatures of down to 1.8 K, and Lorentz force loads in excess of 200 MPa. In addition, experiments were conducted investigating quenching behavior, thermal stability, stability under external field changes, and hot-spot behavior. In particular, 2nd generation HTS superconductors (YBCO coated conductors), due to their layered structure (Fig. 1), were seen to suffer irreversible degradation including thermal destruction caused by disturbances of the superconducting state and under the influence of high transport currents. In the future, this behavior will be further studied both theoretically by FEM model calculations and in experimental setups. Despite this problem, successful measurements were carried out for Ic(B)- and n(B)-determination of notably the YBCO coated conductors made primarily by SuperPower and American Superconductor, and also Bi2223 conductors made by Sumitomo, in magnetic fields up to 20 T and bath temperatures down to 1.8 K.

Experimental Facilities

Component Development

• Ramp Generators

To ensure safe, stable operation of up to three superconducting coil circuits with strong inductive coupling, the mode of operation of the high current power supplies was changed from voltage control to current control. Unlike voltage control, where external disturbances can cause current fluctuations in the magnet circuit followed by voltages induced in the superconducting coils and therefore undesired shutdown of the entire system, the current controlled mode uses an external ramp generator to set a fixed highly stable rate of current change. The control system in the power supply generates the necessary charging voltage. External spurious influences, such as changes in resistance of the feed lines, are corrected. Voltages induced in the individual sections are thus reduced, and operation is more reliable. However, high stability ramp generators are not available commercially. Consequently, in house development began with the underlying idea being realized by modern board technology and highly stable electronic com-

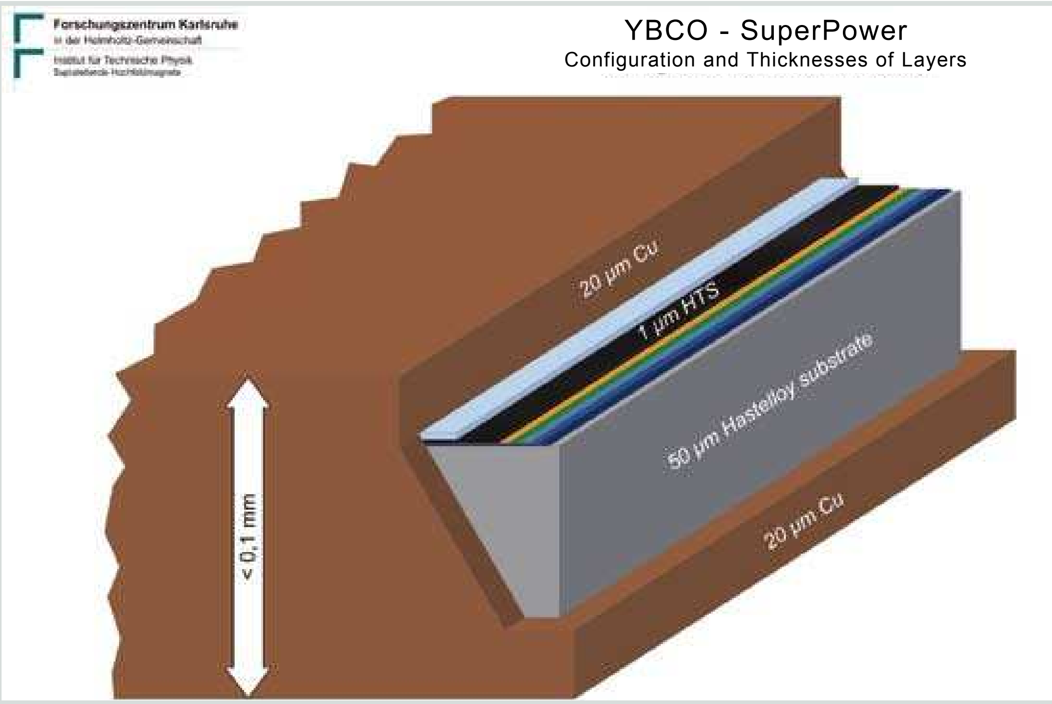


Fig. 1: Structure of an YBCO coated conductor.

ponents. The prototype generators built in this way achieve a maximum accuracy of the set value of approx. 1 mT for the HOMER I system at a minimum rate of field change of 0.1 mT/s and a long term stability better than 1 mT. In addition, they are optimally shielded against external electromagnetic disturbances.

• Current Leads
The current leads transporting the magnet operating current from the flange at room temperature (RT) in the cryostats to the coil connectors are a major component in the operation of superconducting coils. As this implies overcoming a temperature gradient of approx. 300°C, and as currents of up to 3000 A must be carried, the current leads must cause low thermal losses. For the new internal part of the HOMER II facility, a fourfold current lead with a total current of 8000 A is required. In designing this current lead, FEM analyses and accompanying measurements were used to study and optimize both the current lead head (Fig. 2) and all current carrying copper parts with respect to electric losses. All necessary components, radiation shields, and the current feed-throughs for the 1.8 K magnet bath were designed, built, and passed on to the ITP workshop for assembly.

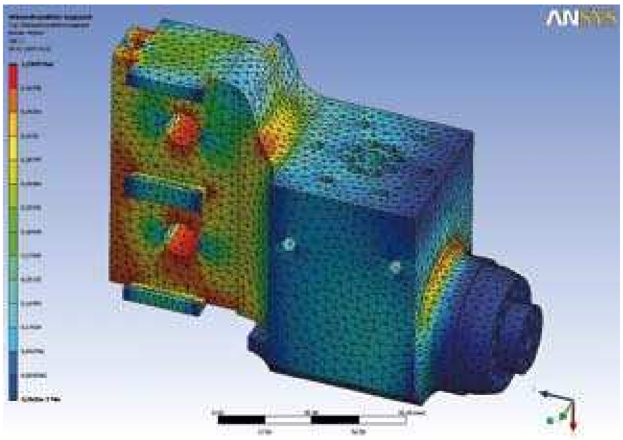


Fig. 2: FEM analysis of the RT current lead head.

• Insulation breaks
Within the framework of the fusion activities for the W7-X project, insulation breaks were required for commissioning the TOSKA facility. Insulation breaks separating the magnet potential from the protective ground potential are essential components in the cryogenic and electric supply systems of a magnet cryostat. The specifications of cryogenic insulation breaks demand not only mechanical stability but also resistance to high voltage and pressure in a design occupying a minimum of space. The know- how available from in house manufacture of insulation breaks was used for the specifications of the TOSKA facility (high voltage strength 13 kV, pressure proofed 30 bar, leak rates <10-6 mbar l/s). A miniature series of ten units was manufactured, examined for high voltage capability in a new test system in the high field laboratory, and delivered to the TOSKA team in the spring of 2008.

JUMBO
Due to its compact structure and low operating costs the Jumbo facility is an indispensable experimental system for measurements standardizing the Ic(B)-characteristics of technical superconductors and, also, for new and more complex problems, such as electricity redistribution in these conductors. Another problem relates to studies of electrodynamic flux instabilities of the HTS layered superconductors and conventional superconductors with filament diameters > 100 µm. A new program for continuous measurements of the U(I) characteristics specially developed for this purpose requires minimization of the external transient electrical disturbances to a level below the actual signal to be measured. For this reason, grounding of the metal components was checked in the whole facility in 2008 and adjusted where necessary. All signal and data lines were equipped with new shieldings. The protective and shielding measures carried out were examined by the TÜV Mannheim and certified. In addition, our new, innovative ramp generator was implemented in the power supply unit for transport current control.

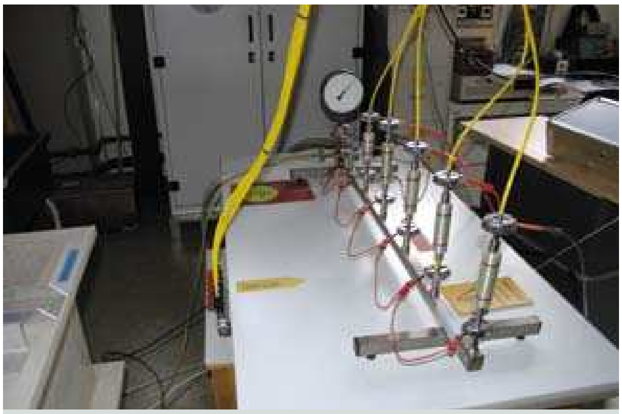


Fig. 3: High voltage test station for insulation breaks.

HOMER I
After extensive revision in 2007 of the electrical circuitry and the 1.8 K cryogenic unit of the NbTi magnet system of the HOMER I facility, last year saw modernization of the coil current control and monitoring system and of quench detection. The new, highly stable ramp generators were integrated to enhance the safety and reliability of current control of the power supplies. Each generator was individually adapted to the requirements of the desired current (3000 A, 1500 A, and 1000 A, respectively) and the permissible current ramps. Introduction of continuous monitoring both of the magnet currents and of the entire magnetic potentials, pickup coils, and Hall probes now constitutes a new online control unit of the HOMER I magnet system. Incipient renovation of the quench detection system was extended to the 15 T magnet configuration. Moreover, because of strong inductive coupling of the high current superconductors under study and the background magnet coils, the redundant quench detectors had to be assigned dual functions, and intelligent tuning of the detectors had to be introduced in cases of internal or external field changes.

HOMER II
The present magnetic field configuration with 20 T in 185 mm free bore is being expanded towards higher field strengths of the central magnet. In order to obtain maximum magnetic field contributions of future coils, the transport current carrying capability of the superconductors used must be exploited to the maximum possible extent. It is necessary, therefore, to characterize the potential technical superconductors close to the intended operating point with respect to their critical current and their simultaneous Lorentz force carrying ca-

pacity. For this purpose, a triple test coil set was designed and built. The necessary internal insert was designed in the period under review and approved for manufacturing in the ITP workshop (see Fig. 4). This internal insert consists of a stainless steel flange as a base of the mechanical support structure, Al radiation shields to reduce thermal radiation, a thermal barrier between the 4.2 K and the 1.8 K baths with HeII compatible current feed throughs, the fourfold current lead mentioned above for a total of 8000 A transport current, low loss current connections between the current lead and the test object, and terminals and feed throughs for measurement lines in the range between 1.8 K and RT.

Magnet Test Facility II (MTA II)

The MTA II serves as a test bed for bath cooled magnet systems with a total volume of approx. 1.7 m_3 which can be operated with a maximum of three magnet current circuits at temperatures between 4.2 K and 1.8 K. The MTA II is a vertical helium wide necked bath cryostat approx. 5 m long, consisting of a vacuum tank, nitrogen and helium shields, and a helium insert.

The MTA II cryostat was installed and tested successfully. On the way to completion of the entire facility, the operating platform was enlarged around of the MTA II. The platform accommodates the piping of cryogenic supply, i.e. liquid nitrogen and liquid helium supply and removal pipes, pump down tubes for 1.8 K operation, flue gas conduits, control unit of the current lead cooling system, and quench gas pipes. In addition, the electrical needs of the facility consisting of the power supplies, bus bars, switching device, and dump resistors will be installed there. The entire operating platform was designed and finished by the end of the year (Fig. 5).

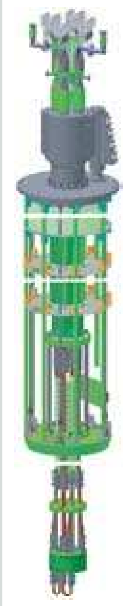
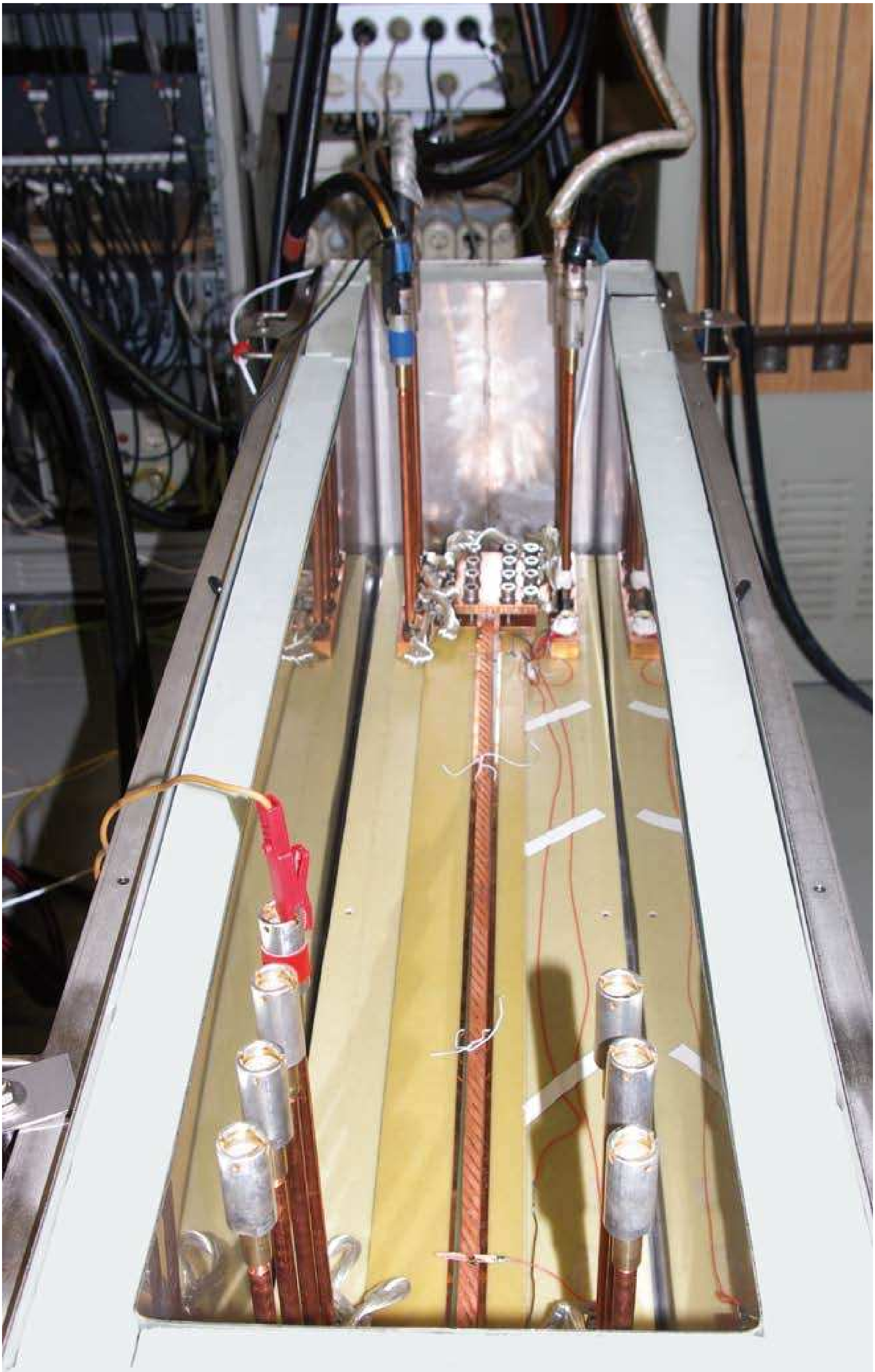


Fig. 4: Internal insert for HOMER II with fourfold current lead and triple test coil set.

Fig. 5: New operating platform around of MTA II.



A 2.6 kA Roebel cable in the LN_2 test cryostat with a transport current feed system split sevenfold.

Results of the Research Areas

Development of Superconductor Materials and Applications in Power Technology

Head: Dr. Wilfried Goldacker

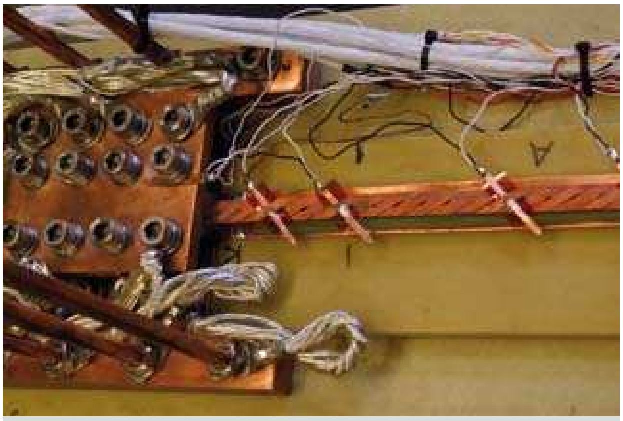
Development of Superconductor Materials
The development of superconductor materials was focused on magnesiumdiboride (MgB_2), the high-temperature superconductor YBCO and with limited efforts also on BSCCO(2212) round conductors with a view to potential applications in fusion magnets. For all materials, the development of stranded cables was started in the interest of high transport currents for AC applications . In addition, the development of very thin wires of magnesiumdiboride was continued; they were made available to partners for test purposes in space application.

Development of YBCO Strip Conductors
For future low-AC-loss strip conductor variants studies of lamination and superconducting connection of strip conductors were carried out. A variety of thin contact layers of deposited metals or solution-deposited superconducting materials were used. Some first low-resistance contacts were completed.

Roebel Cable Made up of YBCO Strip Conductors
Low-AC-loss Roebel cables for high operating currents have been under continuous development for use in a variety of future power technology applications since their first introduction by the ITP in 2005. The cable concept is in particular suitable to use in windings. Depending on the intended application, current carrying capabilities from several kiloamps (motors, transformers) up to > 20 kA (future fusion magnets) are required. A new cable design was able to triple the number of strands to 45 while keeping transposition as short as before. In a cable section 1.1 m long, this achieved a transport current of 2.6 kA in the stable mode of operation cooled by liquid nitrogen (77 K). The new cable design allows the number of bundled strands to be increased further, thus making it possible in general to design cables of the 5 kA class. The new cable design permitted valuable studies to be conducted of current distribution behavior within the cable and of current application at the cable end.

Roebel cable 1.1 mm long with a transport current of 2.6 kA at 77 K.

A second line successfully started development of narrow Roebel cables for use in future fusion magnets as low-loss strands in a very-high-current cable. Measurements of AC losses were carried out.

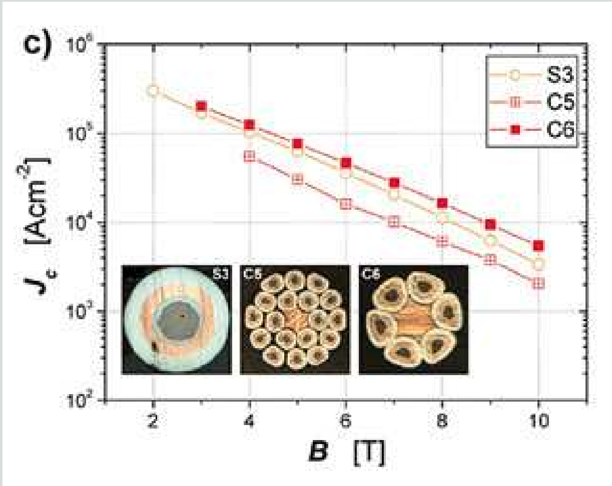


Cable section and area of current application in the Roebel cable shown in Fig. 1.

Reduction of Roebel cable width from 12 mm (bottom) to 4 mm (center), and steel strip experiments for structures 2 mm wide (top).

Stranded BSCCO(2212) Conductors
Thin, high-strength BSCCO wires were prepared for a stranding concept producing high-current cables on the basis of the bundle technique of conventional fusion magnet conductors; the conditions of preparation were examined in detail. Some first specimens were made available for characterization.

Magnesiumdiboride Cables and Applications
Over the past few years, the superconducting properties of magnesiumdiboride (MgB2) conductors have been improved continuously. Although MgB2 conductors, unlike HTSL strips, can be produced rather easily with round or square cross-sections, very little has been done so far worldwide to reduce the AC losses of such conductors, or develop low-AC-loss high-current cables from this material. Low-AC-loss MgB2 cables are used in



Field dependence of current densities of a single MgB_2 strand (S3) with a composite sheath of Nb/Cu/ stainless steel, and of cables prepared from 6 and 18 of these strands.

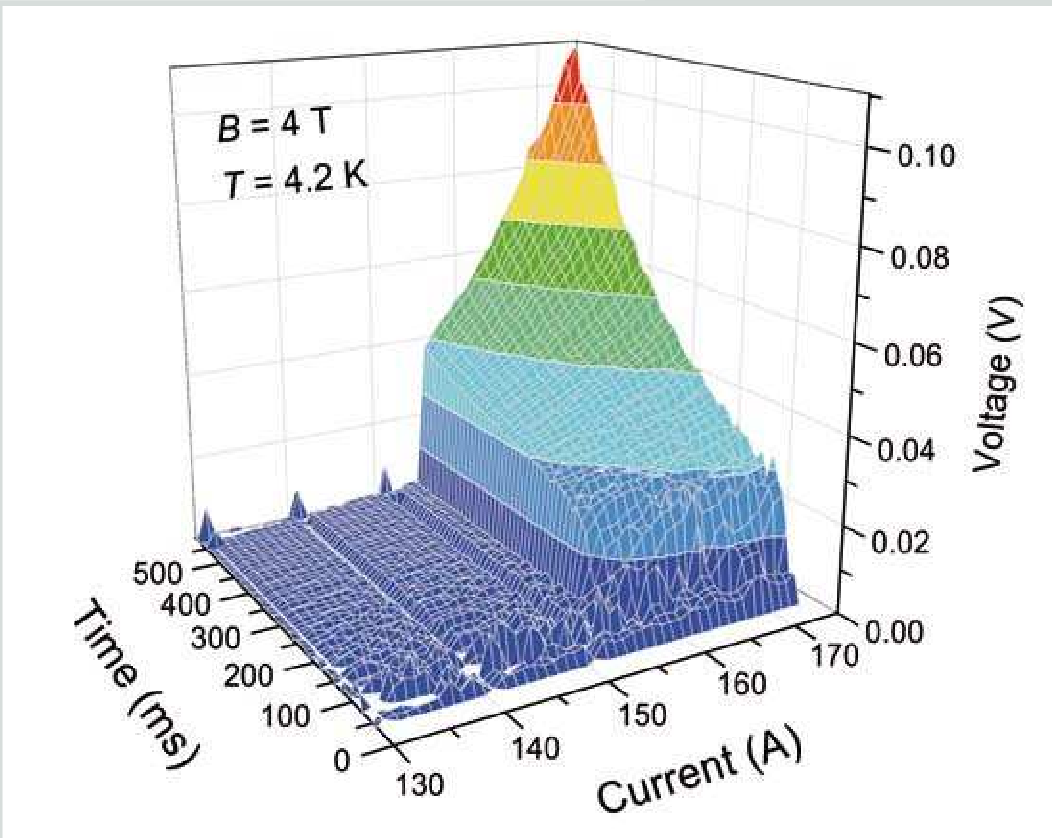
rotary machines, transformers, or magnets with high ramp rates.

Within the "NESPA" EU project, some first short MgB_2 cables were made out of electrically and mechanically stabilized MgB_2 wires by means of the "cable-and-react technique" (C&R technique). In this process, six or eighteen thin unreacted single wires (346 µm diameter) of different twisting lengths were stranded around a Cu core. The finished cables then were compacted by deformation and subsequently underwent heat treatment in which the MgB_2 phase was generated. Thanks to mechanical stabilization of the single wires, and thanks to the application of the C&R technique, short twisting lengths between 11 mm and 5 mm were achieved, which guarantee effective reduction of AC losses compared to untwisted conductors. When compared with single wires, the majority of cables produced in this way showed no major reduction in current density. Some of the cables even achieved higher current densities than comparable single strands over the entire field range examined or in limited field areas. Some first measurements of AC loss were carried out to determine the contributions by the superconductor and the composite sheath. Now that the use of the C&R technique in manufacturing short MgB_2 cables has been demonstrated, a facility is under construction for stranding higher cable lengths.

Superconducting wire connections with a residual resistivity <10 – 12 nΩ were developed for the "persistent-mode" operation of superconducting magnets. Their current carrying capacity in the magnetic field shows a similar field dependence as has been measured in the single strands used.

Pulsed Current Measurement

A piece of equipment was developed for systematic studies of the thermal properties of superconductors which allows current pulses with pulse lengths of a few milliseconds up to several seconds and current intensities of up to 1500 A to be generated. Variation of the length of the current pulse permits the heat input to be studied systematically. Figure 6 shows a U(I) measurement performed on the C6 MgB_2 cable in which the voltage rise at every current level was observed for the duration of the rectangular pulse (500 ms). This allows conclusions to be drawn about the thermal stability of conductors.



Pulsed U(I) measurement of a 6-filament C6 cable at 4.2 K and a background field of 4 Tesla. A rectangular pulse of 500 ms duration was applied for each current level, and voltage measurements were conducted over the entire pulse duration.

Superconducting Applications in Power Technology

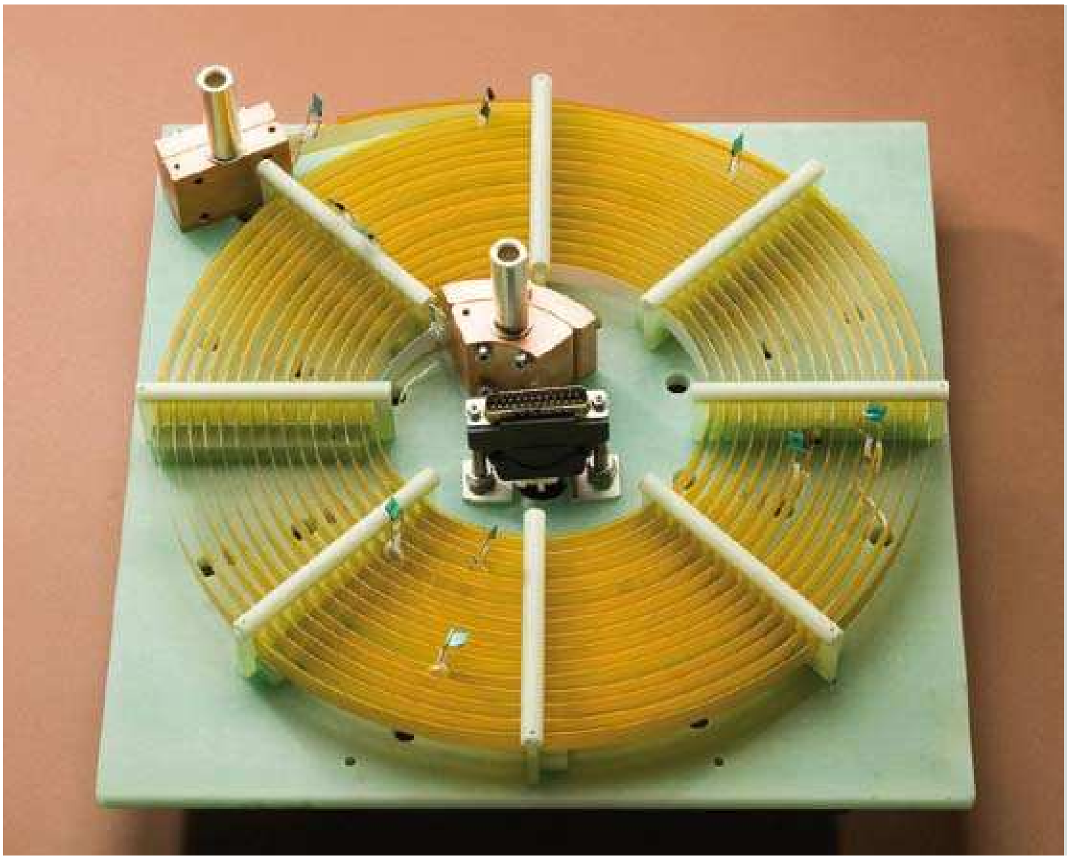
Work on new types of equipment for application in power technology based on YBCO strip conductors was expanded by a number of further applications. Besides work on modules for superconducting resistive current limiters, activities were extended to superconducting current-limiting transformers and lines for extra-high current transmission.

The studies performed to develop superconducting transformers included the integration of fault-current-limiting properties and recooling behavior after a limiting event. In the field of extra-high-current transmission sections, a feasibility study was completed taking into account both technical and economic aspects.

The laboratory systems for testing superconducting equipment were augmented and upgraded. The test facilities now available allow high-temperature superconductors to be characterized comprehensively for applications in power technology.

A new test field was qualified for high-voltage measurements. The use of cryofluids as dielectrics in equipment for high-voltage applications requires precise knowledge of the respective dielectric strength. To determine the dielectric strength of liquid nitrogen at pressures of 1 – 3 bar (abs), breakdown voltage and withstand voltage experiments were performed in a sphere – plate arrangement in a new experimental booth of the cryogenic high-voltage laboratory. The experimental targets of 200 kV (effective) for alternating voltage and 360 kV for standard surge voltage as defined in a work package for the design of a superconducting current limiter were met.

A new test procedure, Power-Hardware-in-the-Loop (PHIL), was tried successfully for the first time in the world for transient studies of a superconducting current limiting module for studies of high-power prototypes of new power technology equipment designed in cooperation with the Florida State University in Tallahassee. This test procedure allows power technology equipment to be examined without requiring the usual costly, time-consuming preparations.



Superconducting current-limiting module made out of an YBCO strip conductor.

Fig. 3: Electrolysis units in the caisson.

Results of the Research Areas

Tritium Laboratory Karlsruhe (TLK)

Head: Dr. Lothar Dörr

The TLK is a semi-technical scale experimental facility unique in Europe and America, holding a permit to handle 40 g (1.5 x 10^{16} Bq) tritium, 100 kg of depleted uranium as well as rubidium and krypton as test emitters for calibration. An experimental area in excess of 1000 m² holds more than ten glove box systems with an aggregate volume of approx. 125 m³ as enclosures for the experimental equipment carrying tritium. The purpose of the TLk when it was founded, and the most extensive research item to this day, is the development of technologies for the fuel cycle of fusion reactors. The second main area of activity is the construction of key systems for the Karlsruhe Tritium Neutrino Experiment (KATRIN) measuring the rest mass of the electron antineutrino.

TLK Operation and Infrastructure

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

The official requirements contained in the new operating permit were met at all times. There were no complaints as a result of supervisory visits by the licensing authority. No notifiable events occurred.

For operation of the cryo transfer line of the Karlsruhe Tritium Neutrino Experiment (KATRIN), the software was written for automation and visualization of the process. However, most of the work on instrumentation and control focused on the development of a library of modules as a basis of PCS7 project work on visualization and automation of the KATRIN tritium loops, the main spectrometer, the pre-spectrometer, and the monitoring spectrometers. These libraries are used to achieve uniform automation functions for the facilities designed and built with them, and also to provide a standard operating interface for the operator (see Fig. 2).

MSRE work concentrated on upgrading the automation technology for parallel operation of the experimental facility for water detritiation and the facility for cryogenic hydrogen distillation (TRENTA experiments).

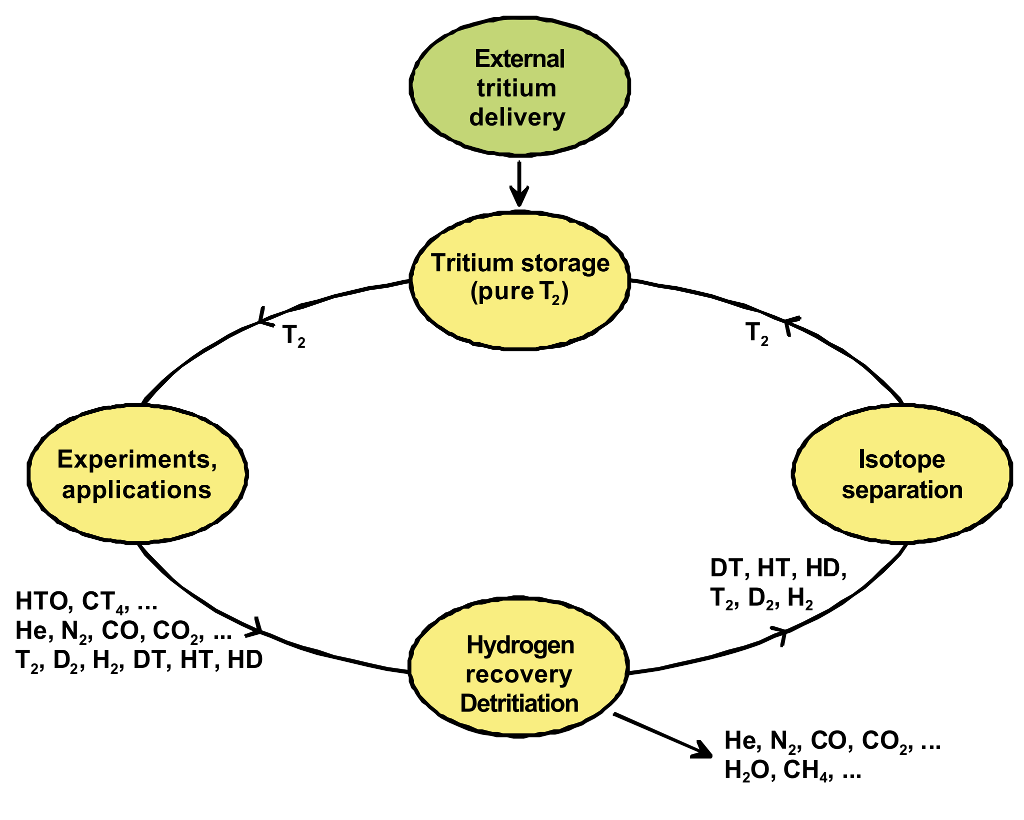


Figure 1: Current tritium loop at the TLK.

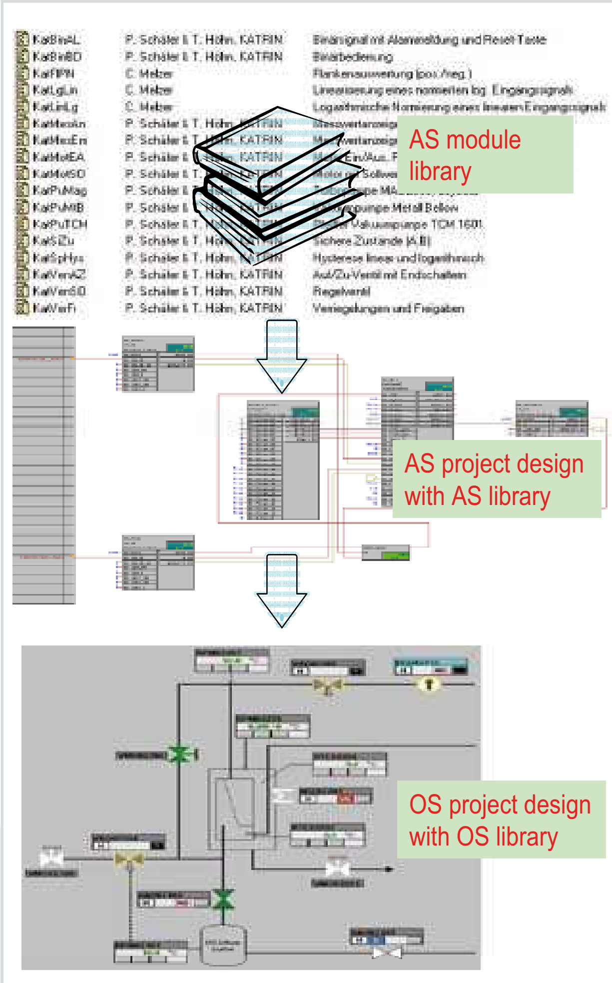


Fig. 2: PCS7 Project work from a module library to complete visualization.

For the planned connection of the KATRIN transport hall to the TLK hall, the existing ventilation system was beefed up and additional tritium air monitors were purchased.

TRENTA Experiments

Water detritiation and hydrogen isotope separation processes are developed and studied within the Nuclear Fusion Program at the Tritium Laboratory. These technologies are needed for the fuel cycle of future fusion reactors, and are being designed to meet the respective requirements and adapted accordingly. At the TLK, the technologies for the TRENTA experimental program are developed and combined.

In TRENTA3, the water detritiation system (WDS), the familiar CECE (Combined Electrolysis Catalytic Exchange) process for tritium recovery from tritiated water is employed. The two main systems of the CECE process, on the one hand, are two electrolysis units with an total capacity of 2 m^3h^{-1} of hydrogen gas (see Fig. 3), and an 8 m long LPCE (Liquid Phase Catalytic Exchange) column.

After successful commissioning in 2008, two long-term experiments (of four weeks each) were performed with TRENTA3. For the first time, water with up to 40 GBqkg-1 tritium was processed in the WDS facility; a decontamination factor of up to 4E+4 was achieved.

Cyrogenic distillation at temperatures of 20 – 30 K is used for hydrogen isotope separation. In a first step, various packing materials for the cryocolumns were tested within the framework of TRENTA4 (see Fig. 4). The focus was on effective separation of isotopes and on the smallest possible hydrogen inventory in the column. The first few experiments showed the Sulzer CY packing to be most promising. This packing will be further examined in the experiments to follow in TRENTA4-pre, especially with regard to the influences of various combinations of protium, deuterium, and tritium in the process gas.

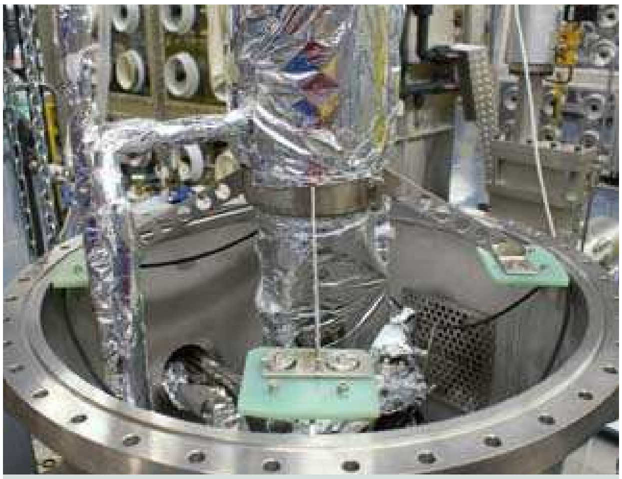


Fig. 4: Top of the cryo column in the cold box.

The objective of the series of experiments is TRENTA4, in which the two systems (WDS and cryogenic distillation) are combined. In this way, the recovered enriched tritium can be returned from the WDS to the cryogenic system for further enrichment and separation from the other two hydrogen isotopes. Figure 5 shows the flowsheet of the combined system, which is going to be used for tritium recovery also in future fusion reactors.

Blanket and Tritium Technologies

Another main activity in the Nuclear Fusion Program is the development of processes for quantitative recovery of tritium from a variety of offgases. A three-step CAPER

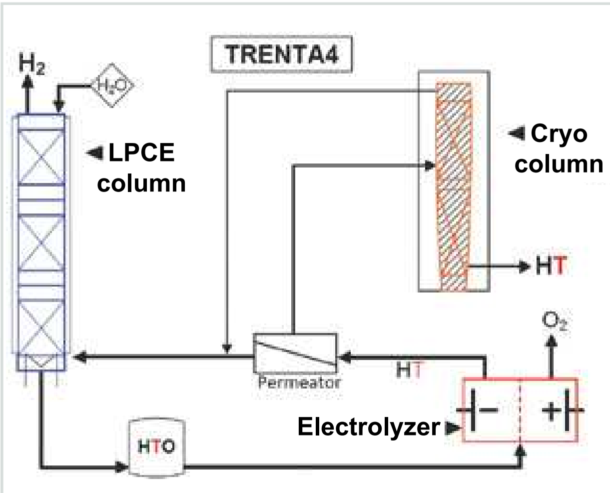


Fig. 5: TRENTA4: WDS + Cryo distillation.

process has been developed for this purpose over the past few years. The third and last stage in the CAPER process, PERMCAT, is a direct combination of a catalyst and a palladium/silver permeator operated in a countercurrent flow by an isotopic exchange with protium. A new, technical-scale PERMCAT reactor, which is more robust, of simpler design and easier to manufacture, was produced in a collaborative effort with FZK/BTI. Figure 6 shows the interior structure with 13 parallel membrane tubes in a pipe surrounded by a common catalyst bed. This component was designed also to process highly tritiated water. Non-radioactive commissioning and some first experiments with exchange reactions of H_2O and D_2 showed highly promising results. Despite a higher throughput, the results obtained were better than those of the earlier design. The results also look promising with respect to new applications of the PERMCAT process outside the "Tokamak Exhaust Processing System".

Within the Fusion Program, the recovery of tritium from the breeding blanket is a major challenge for DEMO. So far, only concepts were studied with semi-continuous processes (various traps in the adsorption or regeneration modes). Last year, a new, continuous concept was proposed (Fig. 7). The major core components of the process

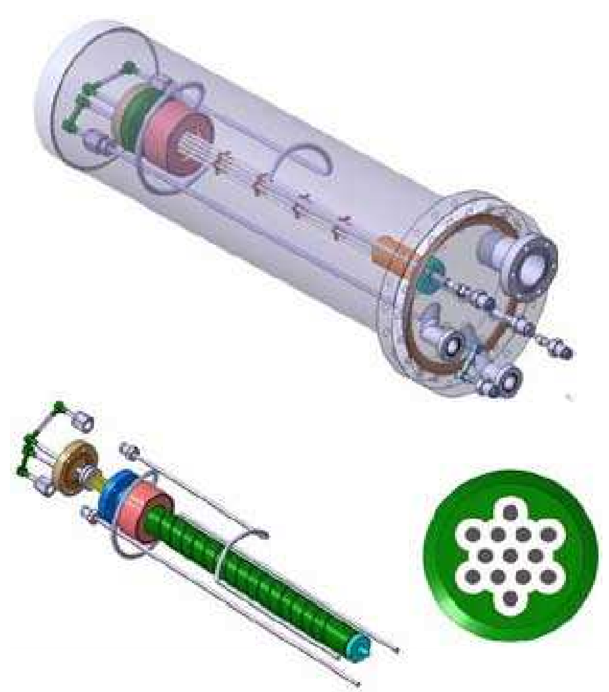


Fig. 6: The new PERMCAT reactor.

are a PERMCAT for recuperating tritium from water, and a selective permeator as a pre-stage. Materials with high selectivity to one component, and, at the same time, compatible with tritiated water, must yet be identified. Processing tritiated water by the PERMCAT reactor will be tested in the CAPER facility next year.

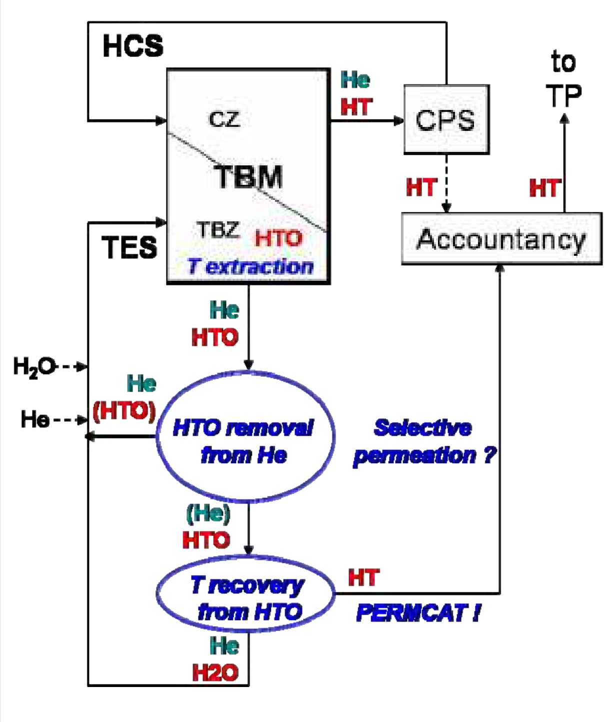


Fig. 7: Concept of tritium recovery from breeding blankets.

Analytics at TLK

Managing qualitative and quantitative analysis of the six hydrogen isotopologs, H_2, HD, D_2, HT, DT, and T_2, as well as other tritiated compounds (such as HTO) is a necessary prerequisite for any handling of tritium, making great demands on experimenters and equipment alike.

In order to be able to adequately meet the analytical challenges arising in connection with ITER and DEMO (Fusion Program) as well as KATRIN (SdM Program), the TLK in 2008 streamlined the organization of analytical work within the framework of its restructuring. R&D in the analytical field is now coordinated and carried out so as to cut across many programs and institutes.

R&D key points in 2008 were the development of an infrared spectroscopy system for liquid hydrogen and laser Raman spectroscopy measurements of gaseous tritiated hydrogen isotopologs (for the first time at the TLK). For this purpose, two diploma theses were started in cooperation with the IEKP of the University of Karlsruhe; cooperation with the University of Swansea, Wales, was intensified.

Fig. 2: The new cryotransfer line of the ITER prototype is commissioned in TIMO-2.

Results of the Research Areas

Vacuum Technology

Head: Dr. Christian Day

2008 was a year characterized by continued design work on the large cryopumps of ITER, i.e. those for neutral-beam injection and the torus vacuum system. Under existing contracts, the foundation was laid for construction of the prototypes of both pumps, a European tendering process for which is to be started in the near future. In addition, the TIMO-2 test facility was upgraded in large parts and prepared for the tests to be conducted. In this way, the time until late 2008 was used meaningfully while the "Fusion For Energy" fusion agency (F4E) was not yet functional and, consequently, was not in a position to award new development contracts. As a highlight of this year, a complete, very detailed computer model of the divertor and torus pump system was established. Some first results show possibilities of further optimization of the flowsheet. Discussions of this point with ITER are going on.

ITER Cryopumps

As a consequence of commercial problems, construction of the prototype torus cryopump was not yet started by the manufacturing company envisaged. This made it possible to take into account this year's design changes in ITER in a revision step. The revised design is to be completed by 2010, and a new tendering procedure for manufacturing the pump is to be started.

The design of the cryopumps for the ITER neutral-beam injector (NBI) for diagnosis and heating has reached a high level of detail. For this purpose, a new cryopump concept was employed with clearly higher capture probabilities compared to the classical concept, and also fully compatible with ITER requirements with regard to thermal loads. A catalog of supporting calculations (mechanical FEM analyses, vacuum technology calculations by Monte Carlo simulation, pressure loss calculations, verification of regeneration states, calculations of electromagnetic loads) were necessary to validate the design for all operating scenarios of ITER. The interfaces with the ITER cryosupply system were defined together with CEA Grenoble. The cryopump system of a neutral-beam injector consists of two identical pumps (8 m long; 2.4 m high), each of which is made up of eight identical modules. Figure 1 shows such an NBI cryopump model. The cryopump for the ITER neutral-beam heating system, with its 36 m² of coated pumping area, represents a pumping speed of 4800 m³/s for the hydrogen processed. In the classical design, this would have required 50 m².

For neutral-beam injection, a comprehensive test bed is going to be built under the leadership of Consorzio RFX in Padova, Italy (capital costs approx. EUR 200 million). We are responsible for the cryopumps also in that case. Under a contract from F4E, we have begun adapting the design of the NBI cryopump to the specific conditions of the test bed (different cryosupply, additional space requirement for extensive measurement instrumentation, especially for tomography of the particle beam).

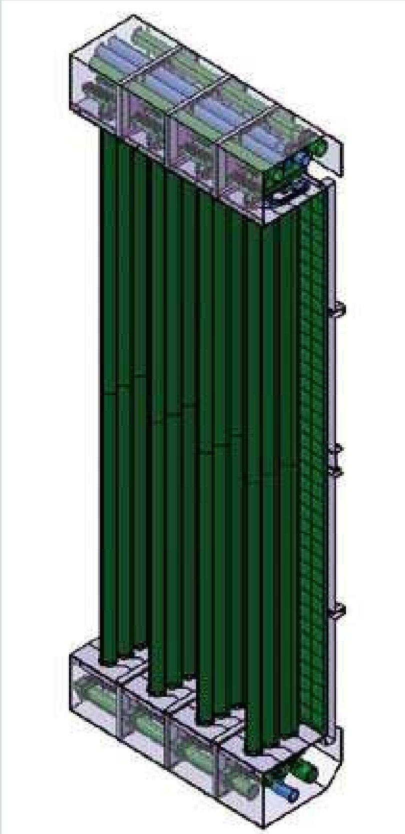


Fig. 1: Design of a cryopump module for neutral-beam injection.

Cooperation with JET has been going on for several years. Within that project, a separate cryopump was built which was operated in JET under real tokamak conditions, especially under tritium. This year, the residual tritium inventory in the pump after decontamination was measured; this was one of the last open points in the proposed cryosorption concept for ITER. The measured findings were uncritical. For the time being, this completed the highly successful cooperation with JET. The pump remains installed in JET and is to be used there as a powerful cryopump in future test campaigns.

In cooperation with GSI Darmstadt, the typical cryopanels coated with activated carbon as developed by the group were characterized successfully for applications at very low pressures (below the levels of fusion applications). This reveals a number of new uses of this technology in the area of ultrahigh vacuum usually encountered in particle accelerators.

TIMO-2

The TIMO-2 plant is going to play a key role in the tests to be conducted of the prototype torus cryopump. In 2008, a new flexible cryoline was manufactured and installed between the cold valve box and the test vessel (see Fig. 2). In the tests of series-produced pumps, this ensures the shortest possible time for switching between pumps. The design of this line was conducted in accordance with ITER requirements. A cryoline with the PN25 pressure stage and flexible Johnston couplings thus was built for the first time. Experience in running the line in TIMO-2 will be very important to ITER.

During acceptance of the line, also the brand new data acquisition and storage system and the new control system (Siemens PCS7) of TIMO-2 were tested successfully.

Finally, the explosion-proof roughing vacuum pump system of TIMO-2 was replaced. Roughly 2000 m³/h will now be available, allowing full-scale simulation of the pump conditions in ITER.

Vacuum Physics

In the area of vacuum physics, fundamental work about vacuum flow in the transition region between highly rarefied and laminar flows is continued further. The measurement program in the TRANSFLOW facility for long channels (i.e. length/diameter ratio of 60) in a fully developed flow was completed. The measurements show excellent agreement with the predictions based on simulations with the ITERVAC code. In a joint effort with the University of Volos, Greece, a newly developed mathematical procedure was used to solve the Boltzmann equation for the cases examined in TRANSFLOW (circular, square, triangular and trapezoidal cross sections), see Fig. 3, in the entire flow region. These data, too, are in very good agreement with the measurement and ITERVAC.

A corresponding measurement process for short channels (i.e. length / diameter ratio of 10) was begun on a simple circular tube. Comparison with ITERVAC shows greater deviations (on the order of 10 – 15%) than with longer tubes. But, as the Boltzmann equation for short tubes cannot be solved at reasonable expense, we decided to calculate the mass flows by the direct simulation Monte Carlo method. The necessary codes, however, are still being developed.

A major milestone was reached in modeling the ITER divertor vacuum system, which comprises 54 individual cassettes, see Fig. 4. For the first time, the ITERVAC program package was able to model all relevant subflows of an extremely sophisticated vacuum network.

The model contains 1500 cells; the average computation time for one operating point is 8 hours. The key finding demonstrated that the mass flow recycled into the plasma is at least of the same order of magnitude as the pumped mass flow. This is an impressive quantitative demonstration of the effectiveness of the divertor system in discharging the fusion exhaust gas from the torus chamber. The next step is an attempt to modify the divertor system in such a way that larger mass flows towards the torus pump system become possible.

Finally, the new ProVac3D Monte Carlo code was further developed for computing density and pressure profiles for complex vacuum systems, and finally used rou-

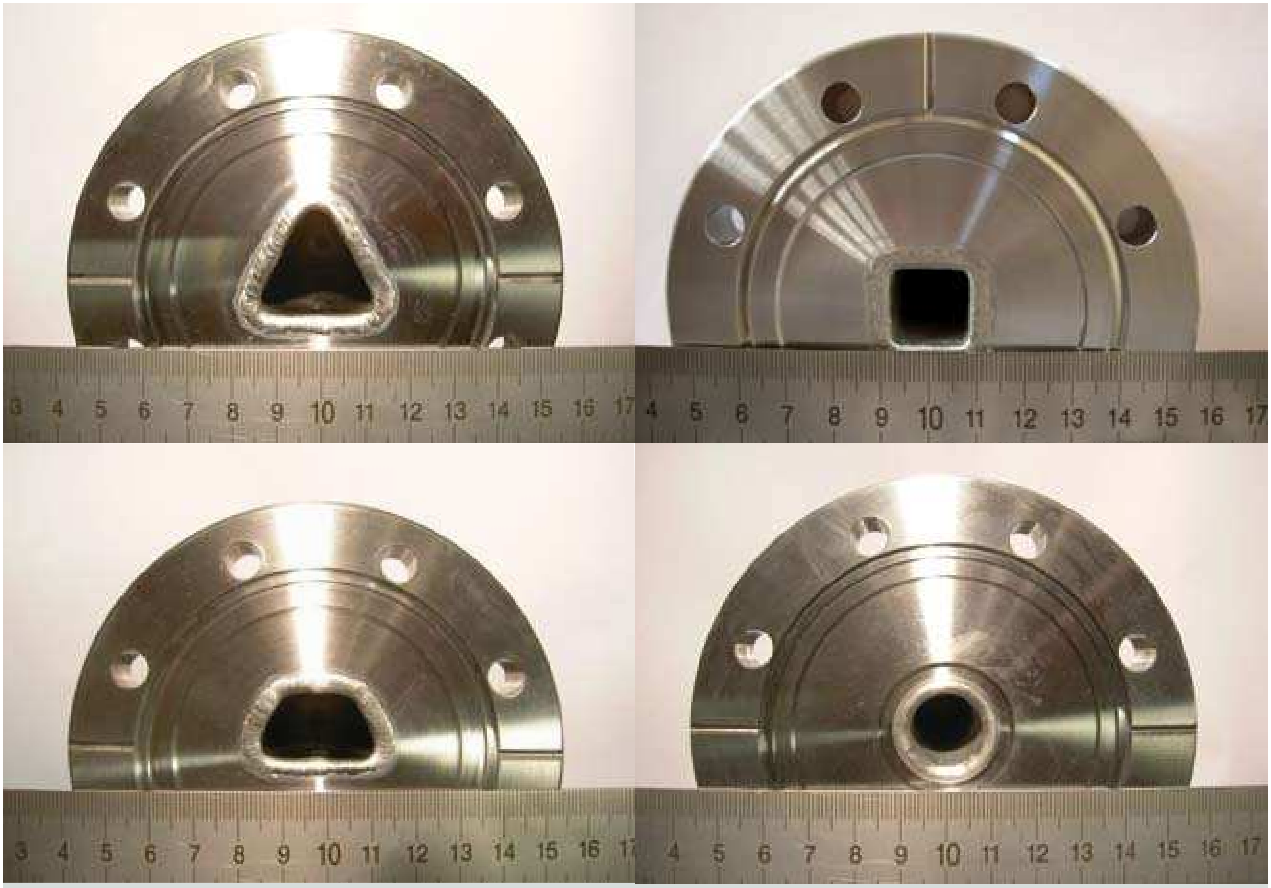


Fig. 3: Channel profiles measured in TRANSFLOW.

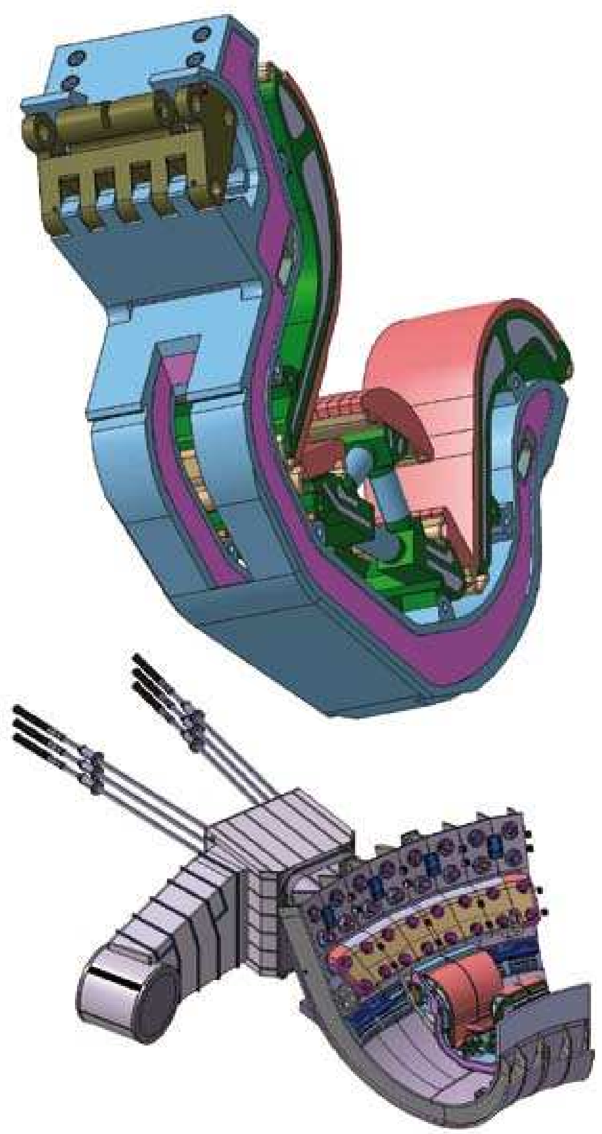


Fig. 4: 3D design of a divertor cassette and its position in the vacuum vessel of ITER.

tinely to describe the density profiles in the ITER neutral-beam injector. In this way, it became possible to define the positions of the individual beam line components so that an optimum pressure profile for the neutral particles is obtained.

ITER Vacuum Systems

Work in the area of ferrofluidic shaft seals for tritium-compatible mechanical roughing pumps was discontinued because the roughing pumps will be part of the American package for ITER.

Instead, a new main point will be the development of technologies for searching, identifying and quantifying vacuum leaks in ITER. In a first study, methods of optical infrared and UV spectroscopy for the detection of water and its dissociation products were examined in greater detail for application in ITER.

Under another contract with ITER, the large ITER vacuum systems were begun to be subjected to a systematic risk analysis. In that effort, the complex systems and their cooling water loops are characterized in terms of reliability and availability so that the effects of potential leaks on the operation of ITER can be estimated.

Helium transfer lifting system.

Results of the Research Areas

Cryotechnology

Head: Dr. Holger Neumann

Cryotechnology for FUSION
Cryotechnology work for the FUSION program was focused mainly on modifying TOSKA for tests of superconducting magnets, developing and building superconducting power supply leads, and on the conceptual design of the supply of a corresponding test rig (CuLTKa) including integration into the existing cryo-infrastructure. All these activities are intended for the W7-X fusion experiment at Greifswald.

Modification of TOSKA for Testing Superconducting Magnets
Revision and modification for testing W7-X fusion magnets was completed this year. For this purpose, the new piping and sensor systems were completely manufactured, new cryovalves installed and successfully tested for leaks. This includes all activities in B300, B250, the flange boxes, and the measurement sensor system. Also the support frame accepting the steel racks with the superconducting coils was mounted on supports made of glass fiber reinforced plastic material and abutments. New switching cabinets were installed, capillaries moved in place and soldered in the lead-through of the B300.

Valves and sensors in B300.

The power supply leads were insulated electrically, reworked, leak tested and installed inclusive of new sensors.

Preparations for Testing W7-X Power Supply Leads
Work was started to build a facility for testing power supply leads. For this purpose, all boundary conditions were summarized again. Work about the R&I scheme, adaptations of the platform, and a rough design of the test cryostat were started.

Erection of new switching cabinets with pressure transducers.

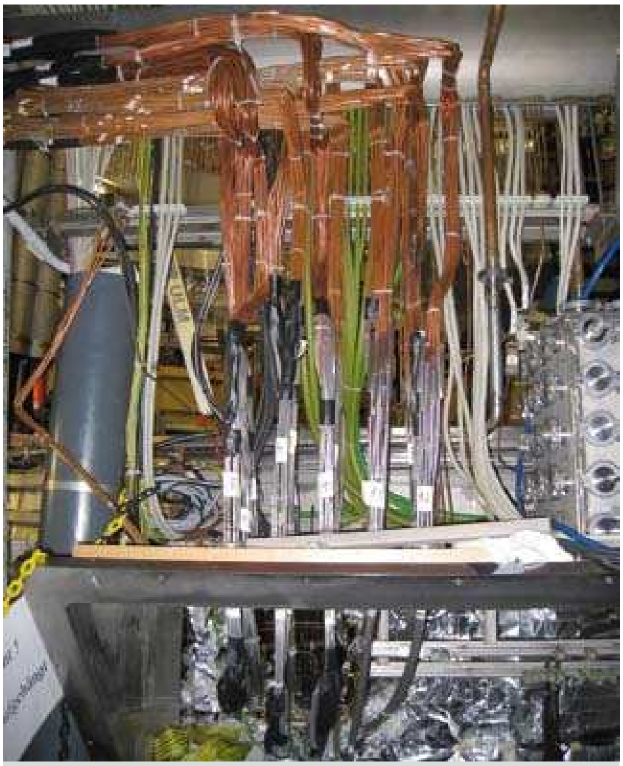
Cryotechnology for REU
This year, tests of various superinsulation varieties again were conducted for industry.

In addition, a new test cylinder with several T-spots was built which has the same surface as an existing cylinder, with $Ø_a$ = 219 mm and a height of approx. 1.9 m.

A capacitive level metering system for liquid neon developed in 2007 was subjected to extensive studies to determine measurement uncertainty.

For the first time, it was possible to use the optical fiber Bragg sensors as displacement sensors. Up to a temperature of 77 K, the initial results were very satisfactory, showing the expected linear behavior. Further studies at lower temperatures, using suitable materials, are to be conducted next year.

Measurements of the temperatures of individual superinsulation layers employed an FBG sensor with a wavelength multiplexer. For this purpose, some preliminary tests were run in order to see also whether mechanical attachment by means of an aluminium tape affects temperature measurement, which is seen not to be the case.



Capillary lead-throughs into B300.

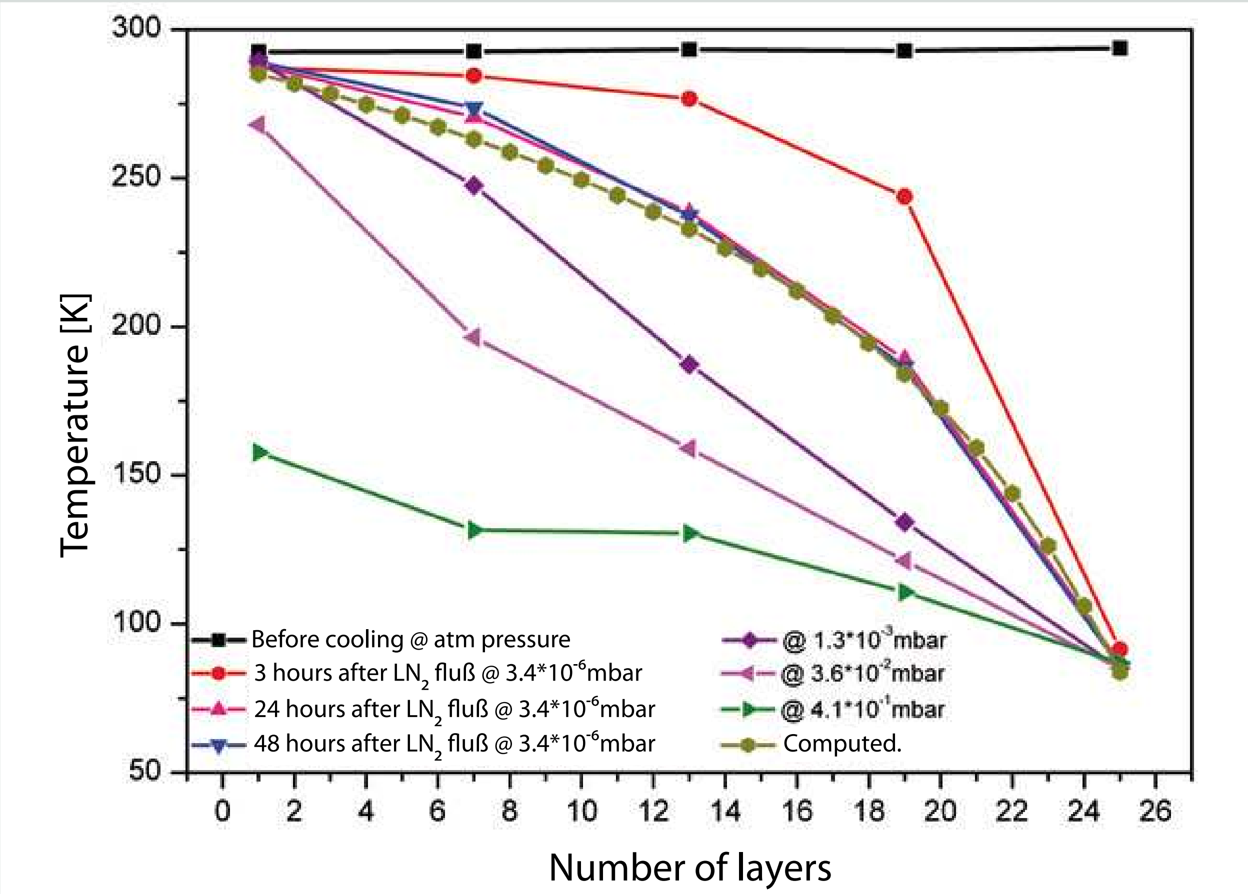
In order to determine temperatures below approx. 25 K by means of FBG sensors, it is necessary to coat these sensors with a material not shrinking even in the low temperature range and thus reducing the lattice spaces of the Bragg lattice. For this purpose, other contacts with industries and research institutions were established.

The cooling system of a future HTSL generator, which is to be operated with neon, is to be studied in cooperation with Siemens. A simulation program was developed to calculate thermodynamic conditions in this rotating thermosiphon process. Rotation mechanically compresses the envisaged superinsulation stack, which is known from experience to have a highly degrading impact on insulation. For this purpose, some first experiments were run with the thermal insulation test rig, THISTA. Other theoretical work is to result in calculation of the heat transfer through a superinsulating stack loaded by rotation. Measurements of neon temperatures and mass flow can be carried with the FBG sensors, as these do not influence flow and thus do not cause any pressure loss. An optical rotary lead-through system was purchased for studies of signal transmission. Moreover, the FBG sensors are to be qualified for measurements of mass flow. In order to run a future rotating test rig with an outside diameter of 1 m and rotation of up to 4200 rpm, an experimental hall of IHM was cleared, and the ventilation system was restarted.

Cryo-infrastructure

In addition to extensive maintenance and repair work, activities included expansion, adaptation, and operation of existing as well as planning, construction and commissioning of new low-temperature experimental facilities for the research projects.

The 300 W (1.8 K) He low-temperature facility was in operation for approx. 1987 hours in 2008, of which 88



Measured and computed layer temperatures in a superinsulation stack.

hours were for liquefaction, 149 hours for sweeping and cooling and heating the facility, which leaves 1750 hours for cryogeneration for experiments in the high-field magnet regime.

The 2 kW (4.5 K) He low-temperature facility was in operation for approx. 824 hours in 2008, of which 405 hours were for liquefaction, 197 hours for sweeping and cooling and heating the facility, which leaves 222 hours of cryogeneration for experiments in the FUSION field.

The facilities liquefied an approximate aggregate of 125,197 liters of helium, with 80,951 liters used for experiments in ITP, while 44,246 liters were made available to other institutes.

In addition to the services performed, numerous improvements were made in existing facilities. Thus, the water cooling system of the compressors of the 2 kW facility was connected to the recooling water system.

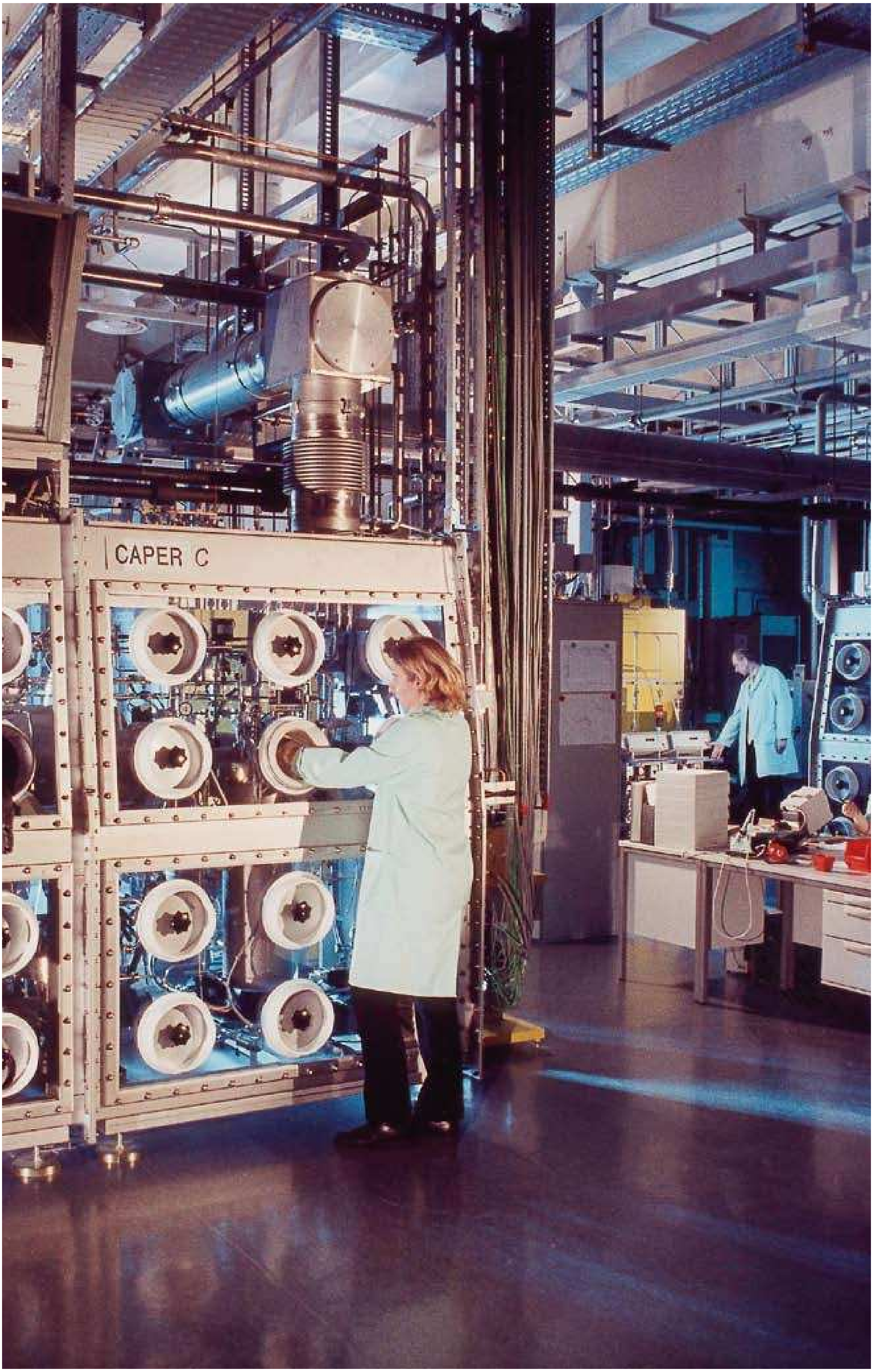
Moreover, migration of the 300 W and 2 kW plants to PCS7 was continued and the necessary servers and clients were installed. A new data concentrator based on PCS7 was installed and a gateway between the Teleperm CS275 and PCS7 Ethernet bus systems was established.

The compressor of the 300 W plant underwent revision, in the course of which some wear parts were replaced. A new cooling system was installed for improved oil separation. Also, the defective Joule-Thompson valve of the 5000 l tank was repaired by adjusting the valve rods, which had shown clear traces of seizing.

In many plant components, the connecting points were equipped with plugs for faster replacement in case of component failure.

Connection of the 2 kW facility to the recooling water plant.

PCS7 server and clients for the 300 W and 2 kW plants.



View of the Karlsruhe Tritium Laboratory.

Results of the Research Areas

Karlsruhe Tritium Neutrino Experiment KATRIN

Coordinator: Dr. Beate Bornschein

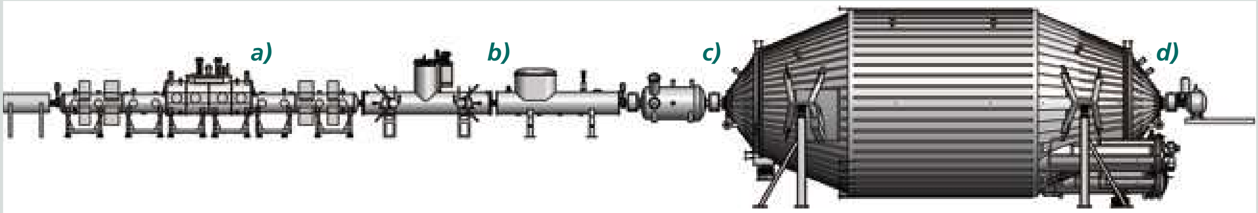


Fig. 1: Schematic diagram of the KATRIN international large experiment. The electrons produced in β-decays in a high-intensity windowless source of molecular tritium (WGTS, (a)) are passed through a tritium pumping section with the active and passive elements, DPS2-F and CPS (b), to a system (c) of two electrostatic spectrometers (pre- and main spectrometers). The electrons analyzed are shown in a solid-state detector (d). The experimental setup is 70 m long and has more than 20 superconducting solenoids whose magnetic field adiabatically runs the decay electrons from the source to the detector.

Introduction

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

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

Fig. 2: WGTS magnet cryostat. The technical requirements to be met by the 16 m long cryostat are challenging, and its technical design is extremely complex. The system has twelve cryogenic loops and uses six different fluids (He, Ne, N_2, Ar, T_2, and Kr).

A worldwide collaborative venture of more than 130 scientists and engineers under the leadership of the Forschungszentrum is currently in the process of building up this key experiment in astroparticle physics at and in the Karlsruhe Tritium Laboratory (TLK). The first data are expected to come forth in 2012.

Design, construction, and successful execution of the KATRIN experiment impose very strict requirements in terms of process technology, especially tritium process technology, ultrahigh vacuum and cryotechnologies, and high-voltage stabilization technology.

Within the framework of the KATRIN experiment, the ITP is responsible, as the leader, for the tritium process technology and for magnet and croytechnologies. More than 95% of ITP's scope of work in the KATRIN project lies in the so-called source and transport system shown as a block diagram in Fig. 3, which is being built up completely within the TLK because of the need to handle tritium.

The main component is a 16 m long superconducting magnet system called WGTS, which contains the source of tritium gas in its beam tube at 30 K. In addition, the so-called calibration and monitoring system (CMS-R) is situated in the rear part, the transport system in the front part of the beam axis (in the direction of the spectrometer). The transport system has the function of conducting the tritium decay electrons into the spectrometer and, at the same time, reducing by pumps the tritium gas flow into the spectrometer system by more

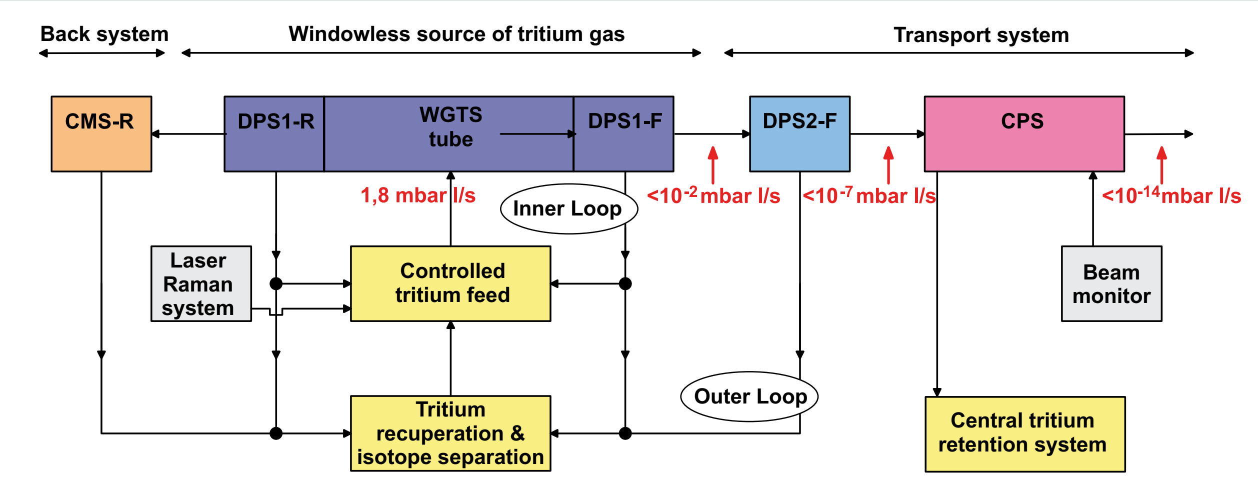


Fig. 3: Block diagram of the KATRIN tritium source and its interfaces with the infrastructure of the Karlsruhe Tritium Laboratory.

than twelve orders of magnitude. This is done, on the one hand, by means of a differential pumping section (DPS2-F) and, on the other hand, - as the last stage – by means of a cryopump section (CPS) operated at 3.5 to 4 K. Also shown are the tritium loops (inner loop, outer loop) ensuring controlled tritium gas feeding, and keeping tritium purity at levels above 95%. Simultaneous feeding and removal of the tritium gas finally produces a steady state gas column density in the beam tube of the WGTS (= "tritium source").
Both DPS2-F and CPS are superconducting magnet systems 7 and 9 m long, respectively. Like the WGTS, they are manufactured by external companies, with the ITP supervising fabrication. The status of these activities will be outlined below.

WGTS

The WGTS is designed and built under contract by ACCEL. Technical supervision by the ITP of design and fabrication by ACCEL is very expensive. On the one hand, the WGTS is a very complicated system, and requirements to be met in the cooling system are extremely high (30 K, stabilized to 0.1 K) and, on the other hand, the WGTS later will have a tritium throughput of 1.5 x 10^{16} Bq per day (40 g), thus having to meet strict quality requirements as a system carrying tritium.

The main activities in 2008 were processing the preliminary inspection documents, execution of QA tests accompanying fabrication, and construction of the eleven switching cabinets for crycontrol of the WGTS.
Another key point was the development of special sensors for the WGTS; they were built and tested by the in-house sensor laboratory. This included a liquid-neon filling level device whose measurement uncertainty was studied in a diploma thesis supervised by the cryogroup. In addition, more than 20 vapor pressure sensors (for temperature measurement in the 30 K range with a precision of 30 mK) were built and tested for the WGTS, thus continuing the development of new kinds of sensor systems for KATRIN begun in 2006.

DPS2-F

In DPS2-F, which is manufactured by ASG of Genova, the focus of ITP activities was on the execution of quality assurance tests (e.g. leak tests) during fabrication, and on preparing quality inspection of the overall system at Genova. This inspection includes cooling down the system as well as extensive magnet tests. For this purpose, the system for cryocontrol developed and built by the cryogroup of ITP was transported to Genova (including five switching cabinets) and commissioned there. Quality inspection will be conducted in February 2009.

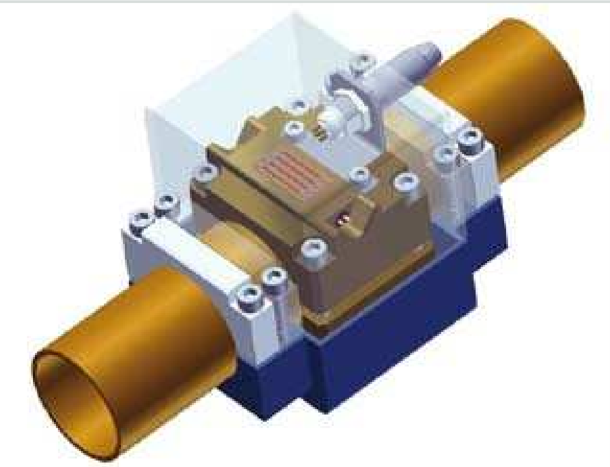


Fig. 4: Temperature sensor with a device for external attachment to a pipe (in this case, prepared for use in the WGTS).

Fig. 5: DPS2-F at Genova. Preparation for quality inspection with ASG.

Fig. 6: Cryotransfer line; the valve box for the WGTS was installed at the TLK in 2008.

CPS

The CPS magnet cryostat was tendered in January 2008. The procedure ended with ASG of Genova receiving the contract. The CPS project team established on the KATRIN side, in which the ITP holds both deputy project leaderships, started work in the spring of 2008; this allowed cooperation with ASG to start quickly and efficiently.

Most of the team's work in the first six months of the period of contract was concentrated on settling open technical questions and harmonizing important interfaces. At the same time, the specialists of the cryogroup started working on the design of the CPS control system.

In December 2008, ASG submitted a first draft of the Technical Design Report. In this way, the first milestone was reached on time.

Cryofacility & Cryotransfer Line

In 2008, the first two sections of the cryotransfer line to connect the cryofacility with the WGTS and DPS2-F systems was completed by Cryotherm, assembled on the spot, and commissioned successfully and without major problems. The ITP cryogroup accompanied the manufacturing process by processing the preliminary inspection documents and running quality assurance tests on the shop floor, thus ensuring smooth, successful project work.

Tritium Loops

The tritium loops of KATRIN are being developed and erected at the TLK (also within the framework of a doctoral thesis).

Fig. 7: Installation of parts of the tritium loop into the ISS glovebox of the TLK.

Work in 2008 concentrated on building the part responsible for controlled tritium gas feeding. For space reasons, the system was built in an existing glove box (see Fig. 7). Some 50% of the piping and MSR work had been completed by late 2008. This also applies to the creation of a new AS+OS library for the automation system established by TLK specialists. Work was accompanied by compiling extensive quality assurance documents.

The main point of physics research was laser Raman spectroscopy (LARA), performed on the hydrogen isotopologs H_2, HD, D_2, HT, DT, and T_2. Within a diploma thesis begun in 2008, this is where the first tritium spectra were recorded at the TLK.

Acknowledgment

KATRIN work was addressed and completed successfully by all ITP groups. Cooperation with students, technicians, engineers, and scientists of IK, BTI-F, and HAP of FZK and IEKP of the University of Karlsruhe was close and fruitful on all subproblems.

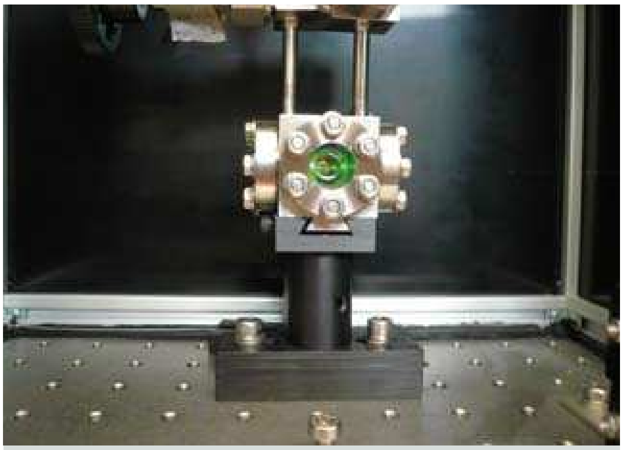


Fig. 8: Laser Raman cell. The laser beam (green) is visible when passing through the gas-filled cell.

Teaching and Education

Lectures, Seminars, Workshops, Summer Schools

Lectures

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

U Karlsruhe – Fakultät für Chemieingenieurwesen und Verfahrenstechnik
WS 08/09 Vakuumtechnik I (Day)

U Karlsruhe – Fakultät Maschinenbau
SS 08 Fusionstechnologie (Fietz, Day)
WS 08/09 Fusionstechnologie (Fietz, Day, Weiss)

U Hannover – Fakultät Elektrotechnik und Informationstechnik
SS 08 Neue Komponenten der elektrischen Energieversorgung (Noe, Berger)

Berufsakademie Karlsruhe – Fachbereich Maschinenbau
SS 08 Arbeitssicherheit und Umweltschutz (Bauer)
WS 08/09 Konstruktionslehre I (Bauer)
SS 08 Technische Thermodynamik III für Maschinenbauer (Neumann)
WS 08/09 Thermodynamik I für Maschinenbauer (Neumann)

Seminars / Summer Schools

VDI-Seminar Kryotechnik
27.–29. Februar 2008
Karlsruhe

Haus der Technik, Seminar Kryostatbau
11.–12. September 2008
Essen

Haus der Technik, Seminar Supraleitung
23.–24. September 2008
Karlsruhe

Karlsruhe-Dresden Doktorandenseminar Supraleitung
28.–30. Mai 2008
Bad Liebenzell,

Summer School on Materials and Applications on Superconductivity
11.–18. Juni 2008
Pori, Finnland

International Summer School on Fusion Technologies
01.–12. Sep. 2008
Karlsruhe

MATEFU Trainee Programm
01.–19. Dez. 2008

Teaching and Education

Term Papers, Diploma Theses, Doctoral Theses

Term Papers Supervised in 2008
(* completed)

Oliver Näckel*
Untersuchung des Induktivitätsverhaltens von Spulen bei verschiedenen Frequenzen und Temperaturen

Stanislav Cherevatskiy
Verlustberechnung supraleitender Transformatoren

Yuvens Tantra
Untersuchung elektromechanischer und thermischer Eigenschaften technischer Hochtemperatursupraleiter und Strukturmaterialien

Florian Josten*
Prozessevaluierung und -optimierung administrativer Vorgänge im Rahmen einer Datenbankentwicklung

Diploma Theses Supervised in 2008
(* completed)

Florian Josten* (BA Karlsruhe)
Konzepterstellung der Versuchsanlage FBI (Anlage zur Untersuchung des elektromechanischen Verhaltens supraleitender Kabel im Magnetfeld bei kryogenen Temperaturen

Philipp Keller* (U Hd)
Elektromechanische und thermische Untersuchung an technischen Hochtemperatursupraleitern auf Bi-2223 Basis

Andreas Kosmider (IEKP, U Ka)
Analyse von Wasserstoffisotopomeren in der flüssigen Phase durch Infrarotspektroskopie

Christin Melzer* (BA Karlsruhe)
Entwicklung einer Systemeinheit zur Druckregelung und Überwachung einer Handschuhbox und Erstellung zugehöriger Ausschreibungsunterlagen

Harald Moosmann* (BA Karlsruhe),
Bestimmung der Messunsicherheit eine Flüssig-Neon-Füllstandsmesseinrichtung

Alexander Reiner (HS Karlsruhe)
Entwicklung eines 3D Messtisches für eine Magnetfeldmessung im Raum

Magnus Schlösser (IEKP, U Ka)
Laser-Raman Messungen an gasförmigen H-Isotopomeren für die KATRIN Tritiumquelle

Christopher Entzeroth (Fa. Sulzer Pumpen GmbH, BA Karlsruhe)
Optimierung einer Pumpengrundplatte bezüglich Verformung und Bestimmung der Eigenfrequenz
Zweitgutachten

Carolin Benz (IKET, BA Karlsruhe)
Entwurf für das QM-Handbuch des Instituts für Kern- und Energietechnik nach DIN ISO 9001
Zweitgutachten

2008 Doctoral Theses
(* completed)

André Berger
Entwicklung supraleitender strombegrenzender Transformatoren

Frank Eichelhardt (IEKP, U Ka)
Bestimmung des Tritiumrückhaltevermögens mit einer Argonfrostpumpe

Aleksandra Gotsova (IK, U Ka)
Investigation of the DPS2-F (Differential Pumping Section) for KATRIN

Olaf Mäder
Gleichstrom-Höchststromübertragungsleitungen mit Hochtemperatur-Supraleitern

Robert Michling (U Heidelberg, FB Chemie), Info: bei Prof. Fanghänel
Performances Assessment of Water Detritiation Process

Christian Schacherer
Theoretische und experimentelle Untersuchungen zur Entwicklung supraleitender Strombegrenzer

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

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

Michael Sturm (IEKP, U Ka)
Aufbau und Test des Inner Tritium Loop von KATRIN

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

Alexander Winkler
Transient electrical behaviour of ITER PF coils

2008 BA Education (*completed)

Florian Josten*
Wirtschaftsingenieurwesen, BA Karlsruhe

Christin Melzer*
Elektrotechnik, BA Karlsruhe

Christian Friedmann
Technisches Management, BA Mannheim

Christian Pulch
Wirtschaftsingenieurwesen, BA Karlsruhe

Elisabeth Weiss
Technisches Management, BA Mannheim

Kerstin Brohl
Wirtschaftsingenieurwesen, BA Karlsruhe

Isabelle Ehleben
Maschinenbau, BA Karlsruhe

Clemens Frenzel
Wirtschaftsingenieurwesen, BA Karlsruhe

Fabian Hammerstiel
Maschinenbau, BA Mannheim

Marcus Oberle
Maschinenbau, BA Mannheim

Pit-André Singer
Elektrotechnik, BA Karlsruhe

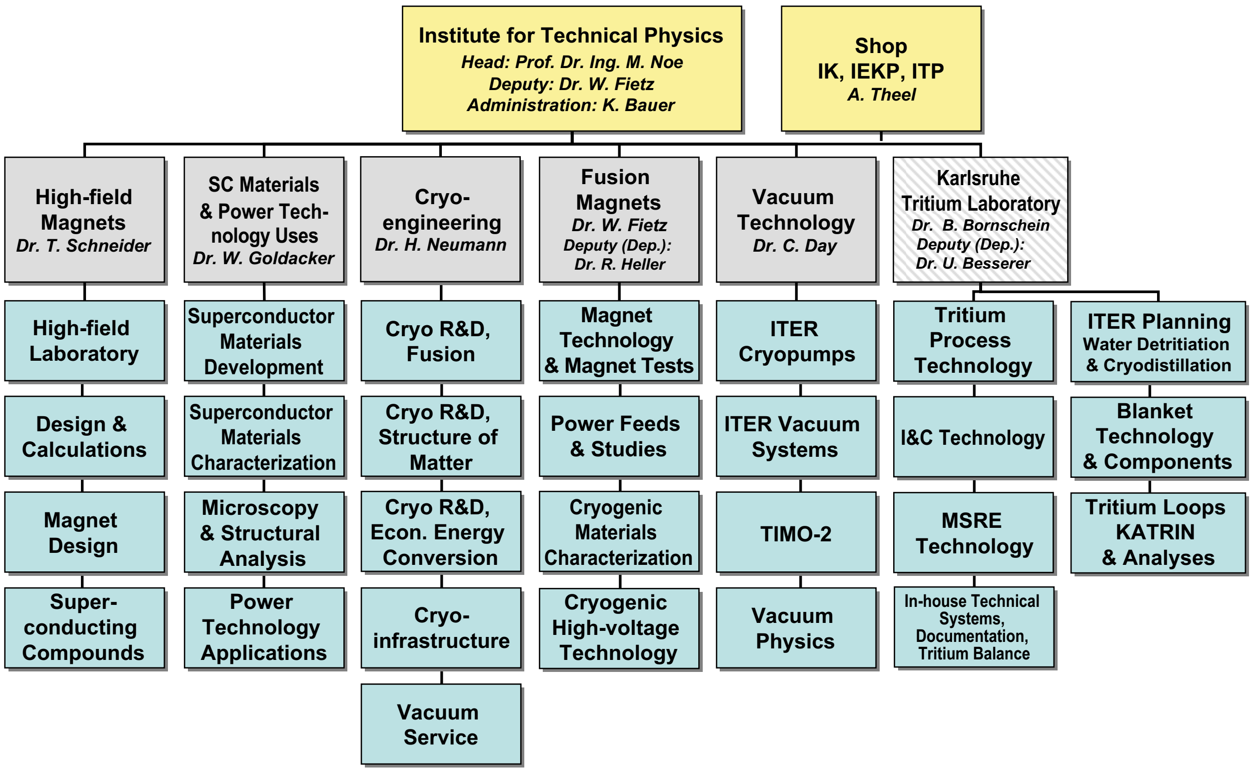
Teaching and Education

ITP Colloquia

29.01.2008	Kryotechnik für KATRIN S. Grohmann
22.04.2008	Berechnung des transienten Spannungs-verhaltens des ITER CS PF – Spulensystems A. Winkler
29.04.2008	Untersuchung des Induktivitätsverhaltens von Spulen bei verschiedenen Frequenzen O. Näckel
06.05.2008	Das kryogene Hochspannungslabor am ITP S. Fink
13.05.2008	Entwicklung supraleitender strombegrenzender Transformatoren A. Berger
03.06.2008	ROEBEL-Kabel aus YBCO-Bändern: AC-Verluste und Anwendungspotential C. Schmidt
10.06.2008	Superconducting detectors for VIS and THz radiation M. Siegel (Univ. Karlsruhe)
17.06.2008	Bi-2223 Hochtemperatursupraleiter in Stromzuführungen P. Keller
01.07.2008	Messung der Pumpeigenschaften eines 4,2 K Argon-Kondensats für Tritium für die kryogene Pumpstrecke von KATRIN F. Eichelhardt
08.07.2008	Designarbeiten für die Kryopumpen der ITER-Neutralteilcheninjektoren M. Dremel
30.09.2008	Wasserdetritiierung R. Michling
07.10.2008	Mess- und Regeltechnik M. Süßer
14.10.2008	Die Tritiumkreisläufe von KATRIN M. Sturm
21.10.2008	KATRIN – Magnetsystem R. Gehring
29.10.2008	Charakterisierung von YBCO-Bandleitern für supraleitende Strombegrenzer C. Schacherer
04.11.2008	HTSL für Hochfeldmagnete F. Hornung
11.11.2008	Im Auftrag der Fusion – Beispiele aus 35 Jahren Tätigkeit für die Kernfusion H. Jensen
14.11.2008	Measuring and modelling ac losses in HTS F. Grilli
18.11.2008	Perspektiven der Energieforschung am KIT K.-F. Ziegahn
25.11.2008	Gleichstrom-Höchststromübertragungsleitung mit Hochtemperatur-Supraleitern O. Mäder
16.12.2008	Wärmeleitfähigkeit supraleitender Kompositleiter im Temperaturbereich von 4 K bis 300 K M. Schwarz

Figures and Data

Chart of Organization (December 31, 2008)



Personnel Status (December 12, 2008)

Total	**159**	**In 2008**	
University graduates (of these, 3 trainees, 3 EU delegates)	51	Guests	16
		Trainees	7
Engineers and technicians	60	Student assistants	12
Others	25	Term papers	3
Pre-doctoral students (of these, 3 not funded by ITP)	9		
Diploma students	5		
BA students	9		

Publications

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