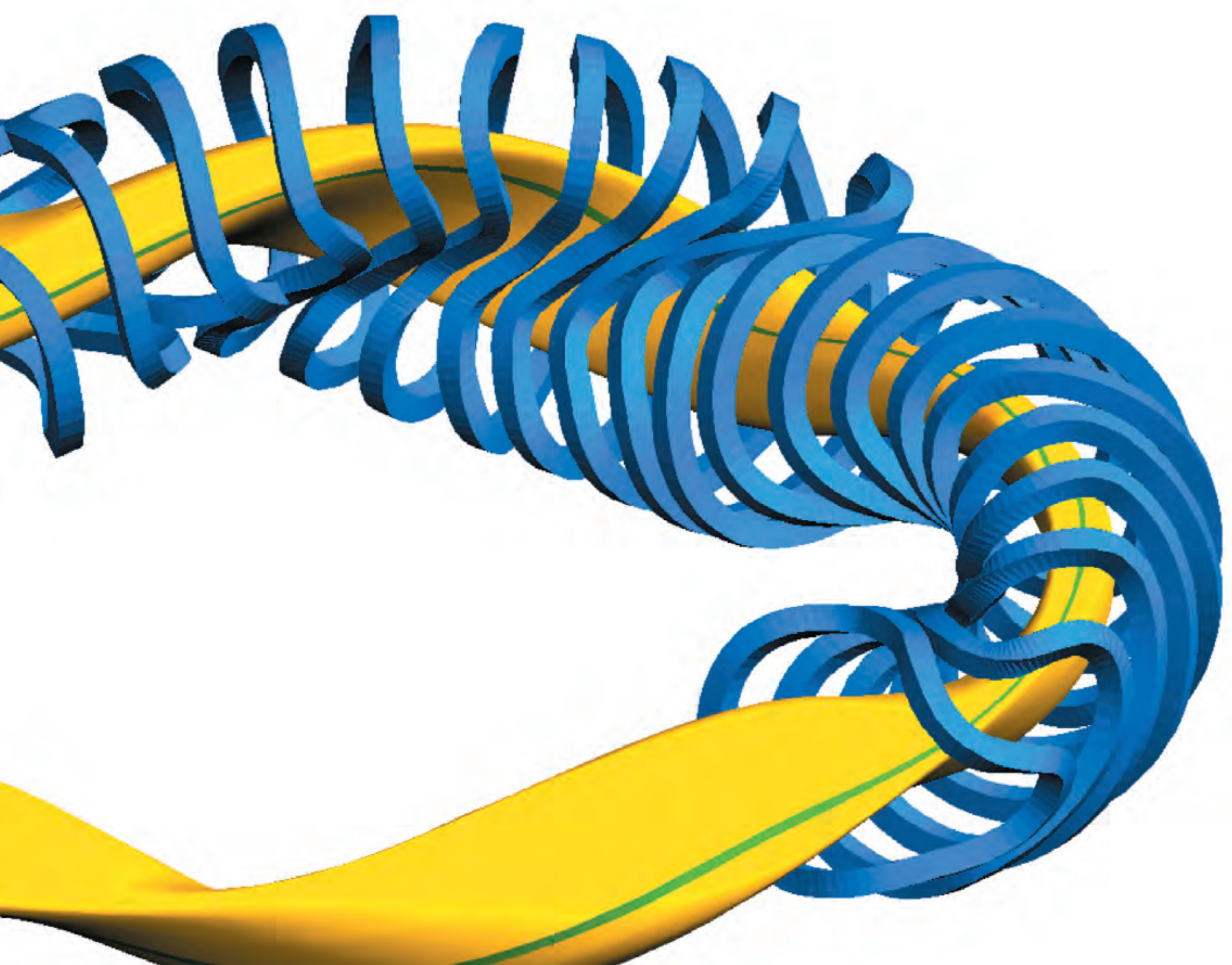
Max-Planck-Institut
für Plasmaphysik

Research for the Energy of the Future



Research Programme

The research conducted by the Max-Planck-Institut für Plasmaphysik (IPP) at Garching and Greifswald with its workforce of approx. 1,200 is aimed at investigating the basis for a fusion power plant. As in the sun, such a plant will generate energy from the fusion of atomic nuclei. The raw materials needed for the fusion process, deuterium and lithium, are available in almost unlimited quantities throughout the world. Since a fusion power plant also promises a high level of safety and favourable environmental properties, nuclear fusion could make a sustainable contribution to future world energy supply.

A magnetic-field cage for confining the fuel

Like a wood fire, the fusion fire does not burn by itself, but only under the appropriate ignition conditions. The fuel for fusion is an ionised, low-density gas – a "plasma" – composed of the two hydrogen isotopes, deuterium and tritium. It has to be heated to an ignition temperature of 100 million degrees. The plasma therefore cannot be directly confined in a material vessel. Any wall contact would immediately re-cool the hot, low-density gas. Instead, magnetic fields are applied to confine and thermally insulate the plasma and keep it away from the vessel walls.

Fusion research currently concentrates on devices of two types, the tokamak and the stellarator. Both confine the plasma in a ring-shaped magnetic field cage. In tokamaks, part of the field is generated by external magnet coils, the other part by an electric current flowing in the plasma. This current is induced in a pulsed mode by a transformer. Stellarators, on the other hand, operate with a field generated solely by complex-shaped external coils. This allows stellarators to work in a continuous mode.

JET, the European joint experiment at Culham, UK

Tokamaks and stellarators

Both of these devices are being investigated at the Max-Planck-Institut für Plasmaphysik: Garching is operating the ASDEX Upgrade tokamak; whereas the Greifswald branch is building the Wendelstein 7-X stellarator, which is to demonstrate whether the improved stellarator concept developed at IPP is suitable for use in a reactor.

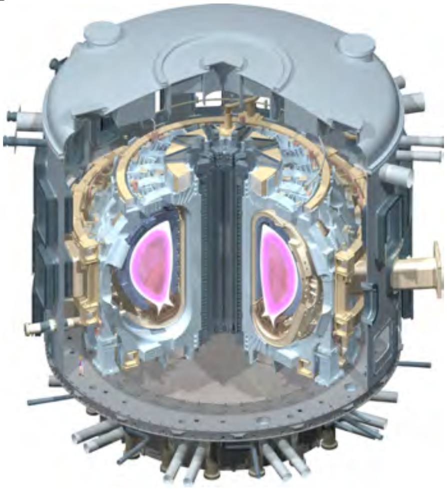
IPP at Garching research site

Founded 1994 – the Greifswald branch of IPP

European and international cooperation in fusion research

Within the context of the European Fusion Programme, IPP is variously involved in the Joint European Torus (JET) experiment at Culham, UK – including delegation of personnel. In many respects the plasma of this, the world's largest fusion device, already closely conforms to that of a power plant. In 1997, the JET tokamak briefly achieved a fusion power of 16 megawatts in deuterium-tritium operation and succeeded in recovering, as fusion energy, 65 per cent of the energy required for plasma heating.

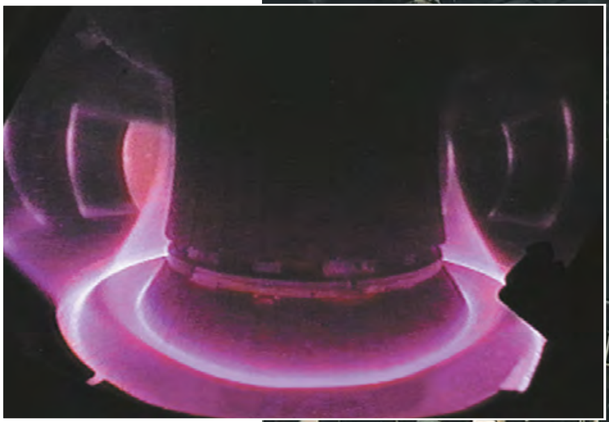
IPP scientists are also involved in the next step on the way to a power plant, the ITER (Latin for "the way") experimental reactor. This fusion device of the tokamak type is being built at Cadarache in France as an international cooperation. ITER is to produce a fusion power of 500 megawatts – ten times as much as needed to heat the plasma – and at the same time investigate technical components of a fusion power plant.



The ITER international experimental reactor

Tokamaks

The ASDEX Upgrade tokamak, Germany's largest fusion device, has been operating at Garching since 1991. This experiment is aimed at investigating key questions of fusion research under power-plant-like conditions. For this purpose, the plasma properties are adapted to the conditions that will prevail in a future fusion power plant. The device owes its name – **A**xially **S**ymmetric **D**ivertor **E**xperiment – to a special magnetic-field configuration, the divertor. This facility can influence the interaction between the hot fuel and the surrounding walls: the divertor field deflects the outer boundary layer of the plasma to collector plates. This removes perturbing impurities from the plasma. At the same time, the vessel wall is protected and good thermal insulation is achieved. These studies, both on ASDEX Upgrade and its predecessors ASDEX, have paved the way for the ITER experimental reactor.



Plasma of ASDEX Upgrade

The ASDEX Upgrade tokamak: the plasma vessel

Section of the plasma chamber for Wendelstein 7-X

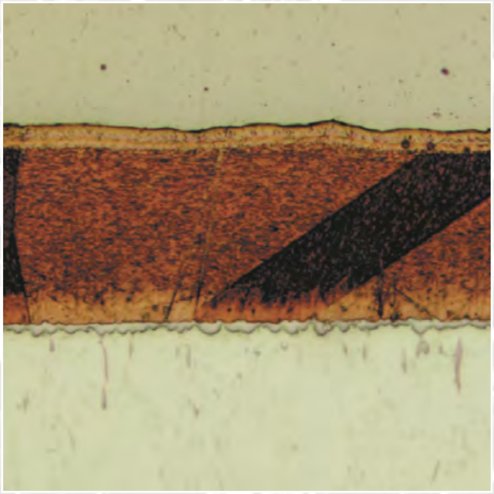
Stellarators

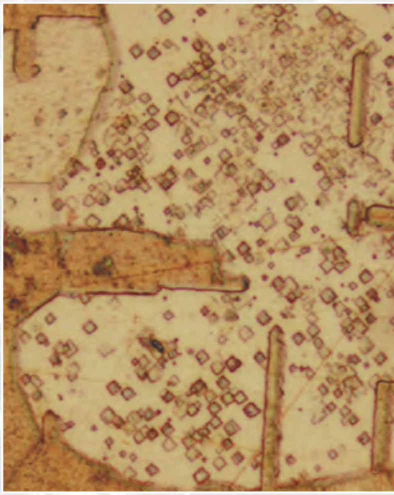
The Wendelstein 7-A experiment was the first in the world to demonstrate the stellarator principle with a hot plasma. Its successor was the Wendelstein 7-AS advanced stellarator. Featuring an improved magnetic field, it was in operation in Garching from 1988 until 2002. Its 45 three-dimensionally shaped coils were also testing a modular structure of the coil assembly for the first time. Wendelstein 7-AS has confirmed the basic optimisation principles and broken all records for stellarators of its size.

During construction of the device numerical and theoretical studies continued. These yielded the plans for the follow-up experiment, Wendelstein 7-X, the magnetic field of which has been optimised to meet power plant requirements. The device is now being built at the IPP branch institute in Greifswald. The microwave heating for Wendelstein 7-X will be provided by the Karlsruhe Research Centre; the Jülich Research Centre is involved e.g. in the development of plasma diagnostics equipment. The 50 non-planar superconducting magnet coils of Wendelstein 7-X are to demonstrate its essential stellarator property, viz. continuous operation. The purpose is to show, without yet producing an energy-yielding plasma, that the new stellarators are suitable for a power plant. Information on energy production is to be provided by the international ITER experiment.

Magnet coils for Wendelstein 7-X

Surface Physics





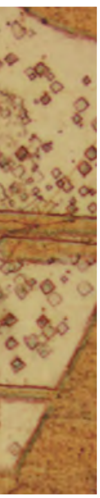
The strong loads to which the inside surface of the plasma vessel is subjected are being closely investigated in the Materials Research Division. For example, high-energy plasma particles can dislodge particles from the walls of the plasma vessel and thus contaminate the plasma. This may also cause erosion of the wall material and change its properties. Ultimately, hydrogen deposited on the wall can re-enter the plasma as a cold gas and cool it down.

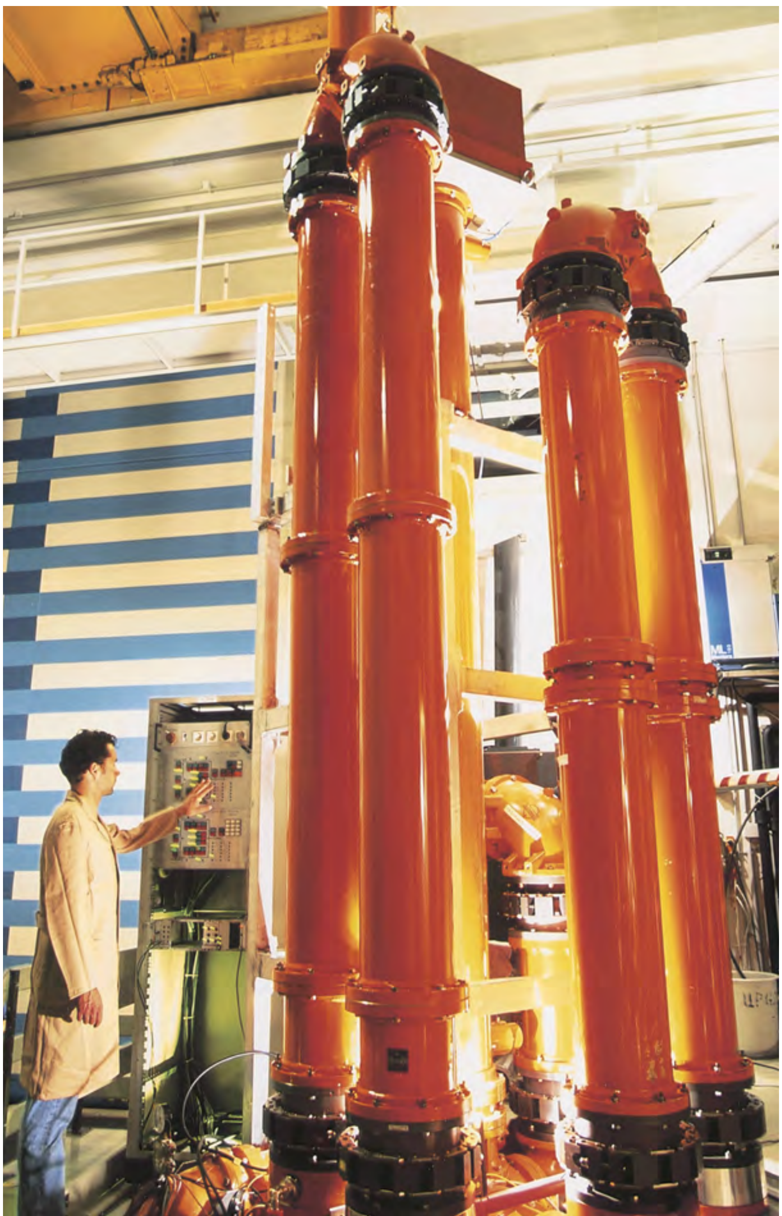
The Devision is also developing and testing new materials for fusion devices under plasma load conditions. Particularly exposed sites require materials and coatings which – like, for example, carbon-fibre-reinforced graphite – are heat-resistent, thermally conductive and resistant to erosion.

Copper structure – material investigation for Wendelstein 7-X

Background image: sample of carbon-fibre-reinforced graphite

Plasma Heating



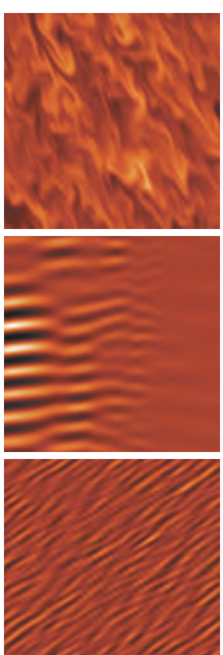


The plasma heating systems used in the fusion devices are also developed at IPP. The plasma is heated by firing high-energy neutral hydrogen atoms into it by means of injectors with powers of a few megawatts; the particle energy is transferred to the plasma via collisions. High-frequency waves are also used for heating: transmitter antennas at the plasma boundary or waveguides radiate large quantities of energy into the plasma at selected frequencies.

Wave-guides for high-frequency heating of the plasma in the ASDEX Upgrade fusion experiment

Theory

Theoretical investigations are indispensable for evaluating experimental results. The computer simulation of the physical processes involved is a major feature of such studies: Theoretical physicists at Garching and Greifswald investigate and calculate the motion of plasma particles in the magnetic field and their confinement behaviour, equilibrium states of hot plasma, the origin of instabilities, and new types of magnetic-field coils.



Computer simulations: instability and turbulence in the plasma

Cooperation with Universities

Major components of the microwave heating for the Wendelstein 7-X experiment are being developed at the University of Stuttgart. In particular, they are planning and supervising production of the transmission lines. In conjunction with the University of Augsburg IPP are developing an ion source for the heating of the ITER plasma. Joint appointments link IPP with the University of Greifswald and the Technical University of Berlin and have also been agreed with the Technical University of Munich. In addition, IPP scientists are involved as professors and lecturers in training students at many other universities.

Instability simulation for a stellarator plasma

Garching Computer Centre

Powerful computer systems are required to calculate magnetic fields, for the numerical simulation of plasma behaviour and for the fast acquisition and evaluation of large quantities of experimental data. In collaboration with the Max Planck Society, IPP runs a computer centre at Garching for this purpose. The computer centre also provides computing capacity to many other institutes of the Max Planck Society throughout Germany. Users have access to supercomputers – IBM p575 (Power 6) and BlueGene/P – as well as Linux clusters, supported by large mass storages.

Technical Services

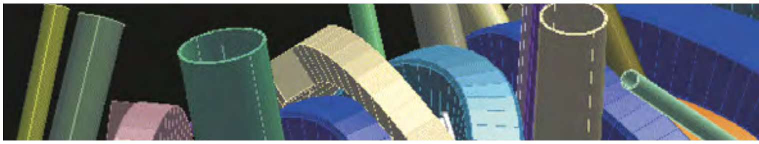
The projects constructing and operating the plasma experiments at IPP in Garching and Greifswald use various resources provided by the technical services. These include laboratories for electronics, materials research, high-voltage and vacuum technology, design offices and workshops for electrodeposition, mechanical, electrical and electronic production and building technology.

Energy Supply

At Garching, the energy for the ASDEX Upgrade device is supplied by large flywheel generators, the biggest of which can deliver a power of 150 megawatts for approx. 10 seconds with a flywheel weighing 230 tons. For the long-term discharges expected at Greifswald Wendelstein 7-X will be supplied directly from the high-voltage grid.

One of the three flywheel generators in Garching

Development and Organisation of IPP



IPP was established in 1960 as "Institut für Plasmaphysik GmbH", a private limited company, owners of which were the Max Planck Society and Professor Werner Heisenberg. In 1971, IPP was incorporated into the Max Planck Society as the "Max-Planck-Institut für Plasmaphysik". A Plasma Diagnostics Division worked in Berlin from 1992 to 2003; the Greifswald branch institute was founded in 1994.

Since 1961, the research carried out at IPP has been integrated in a joint European fusion programme coordinated by the European Atomic Energy Community (Euratom). The institute is also a member of the Helmholtz Association of German Research Centres. IPP is funded by the German federal government, the state governments of Bavaria and Mecklenburg-Western Pomerania and the European Union. The income from these sources in 2009 amounted to approx. 150 million Euro. With its workforce of approx. 1,200 – about 450 of these in Greifswald – IPP is one of the largest fusion research centres in Europe.

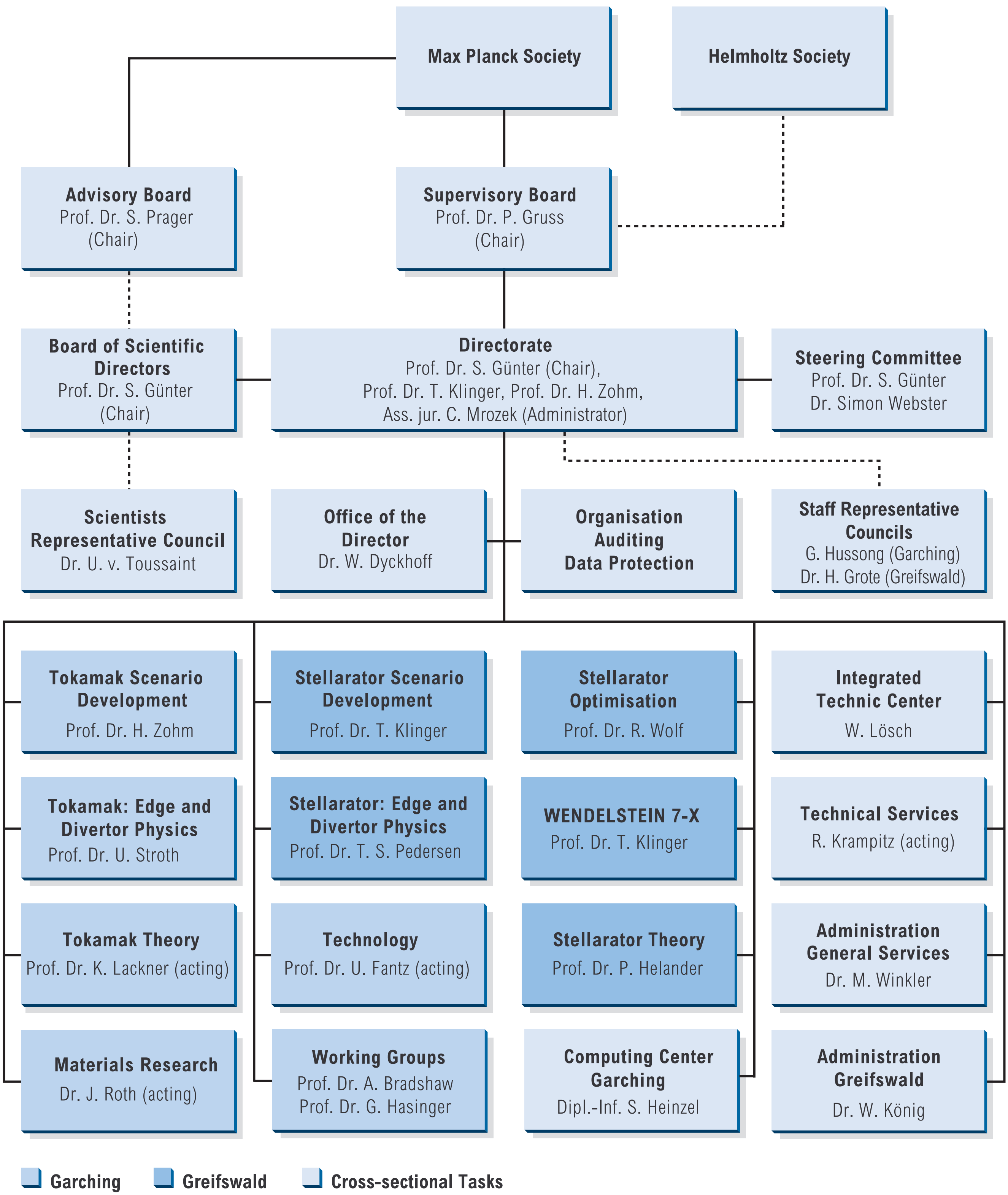
The research programme of IPP is drawn up by the Board of Scientific Directors: Prof. Dr. Sibylle Günter (Chair), Prof. Dr. Günther Hasinger, Prof. Dr. Per Helander, Prof. Dr. Thomas Klinger, Prof. Dr. Thomas Sunn Pedersen, Prof. Dr. Ulrich Stroth, Prof. Dr. Robert Wolf and Prof. Dr. Hartmut Zohm.

The Directorate represents IPP both internally and externally: Prof. Dr. Sibylle Günter (Scientific Director), Prof. Dr. Thomas Klinger and Prof. Dr. Hartmut Zohm for the scientific sector; Ass. jur. Christina Wenninger-Mrozek for the administrative sector. Prof. Dr. Robert Wolf is spokesman for the Greifswald branch.

From the design offices of IPP: design for Wendelstein 7-X

Organisational structure of

Max-Planck-Institut für Plasmaphysik (status 2/2011)



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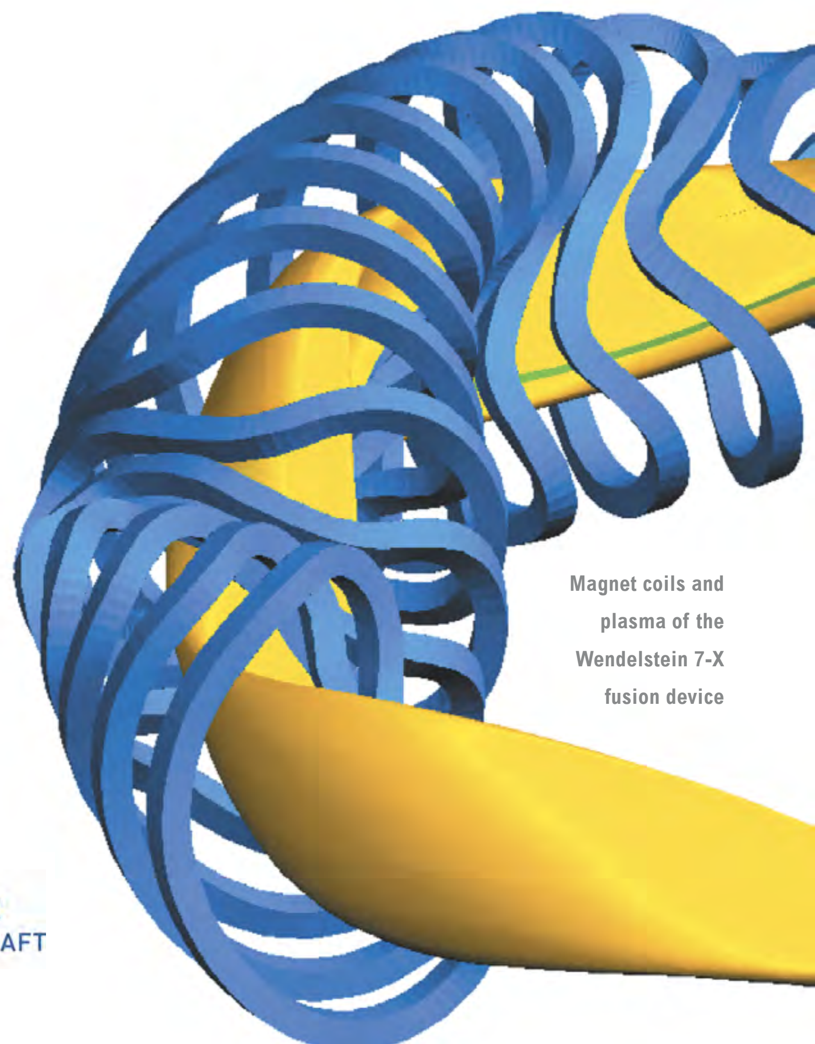
Max Planck Institute for Plasma Physics is associated with the European Fusion Programme and the Helmholtz Association of German Research Centres.



Magnet coils and plasma of the Wendelstein 7-X fusion device

MAX-PLANCK-GESELLSCHAFT

HELMHOLTZ
GEMEINSCHAFT

Das Forschungsprogramm