The tokamak principle

Fusion research currently is focused on two types of devices for magnetic confinement, the tokamak and the stellarator. Both are being studied at Max Planck Institute for Plasma Physics. ASDEX Upgrade is of the tokamak-type – like most of the fusion devices in operation today. Two superimposed magnetic fields confine the plasma in a ring-shaped vacuum vessel: one is a ring-shaped field produced by external magnet coils and the other is the field of a current flowing inside the plasma itself. The combined field produces the twisting of the field lines necessary for confining the plasma. A third field, a vertical field produced by external ring-shaped coils, defines the plasma shape and the position of the current in the plasma.
The current is induced in the plasma by a transformer coil located in the axis of the plasma ring. Owing to this transformer a tokamak does not run in a continuous, but in a pulsed mode. However, since this is unfavourable for power plant operation, methods are being investigated to generate the current in continuous operation.

photo: DAAD / Jan Zappner

Objectives of ASDEX Upgrade

Investigating the core issues of fusion under conditions similar to those in power plants, particularly in preparation for the ITER international experimental reactor and a demonstration power plant:

- particle and energy transport in the plasma
- plasmas with improved thermal insulation
- physics of plasma boundary layer and divertor
- plasma instabilities
- wall materials

Material for the vessel wall

Carbon has proven to be particularly resistant in sections of the vessel wall that are exposed to particle and energy flows from the plasma. However, since this material binds hydrogen, a power plant using carbon would lose too much fuel. Uniquely in the world, the plasma vessel of ASDEX Upgrade was therefore cladded with tiles made of the metal tungsten. The successful experiments made tungsten the reference material for a demonstration power plant.

You want to learn more about ASDEX Upgrade and the state of research?
Visit us: www.ipp.mpg.de/visitors

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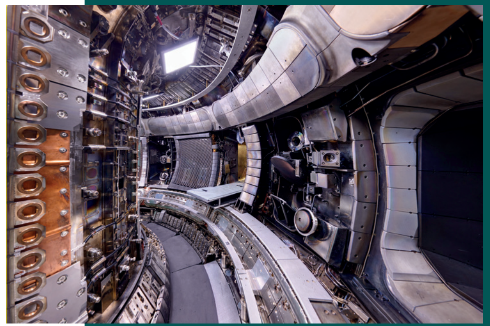
ASDEX Upgrade
interactive panorama:
www.sonnenmaschine.eu

cover picture: View into the plasma vessel · photo: Bernhard Ludewig

MAX PLANCK INSTITUTE
FOR PLASMA PHYSICS



ASDEX UPGRADE FUSION DEVICE

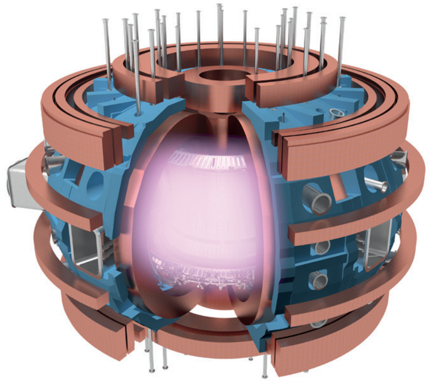
ASDEX Upgrade fusion device

The "Axial-Symmetric Divertor Experiment" ASDEX Upgrade, a tokamak-type fusion device, has been in operation at Max Planck Institute for Plasma Physics in Garching near Munich since 1991.
The research is aimed at developing a power plant that generates energy from the fusion of atomic nuclei – as takes place in the sun. The fuel is an ionised low-density hydrogen gas, a "plasma". To ignite the fire of fusion, the plasma must be confined in magnetic fields and heated to temperatures above 100 million degrees.

Maintenance work in the plasma vessel

ASDEX Upgrade fusion device

ASDEX Upgrade is intended to investigate crucial problems in fusion research under power plant-like conditions. For this purpose, the arrangement of the magnet coils, the shape of the plasma, and essential plasma properties have been adapted to the conditions that will be present in a future power plant.
An important component is the divertor. A special magnetic field directs the outer boundary layer of the plasma – and with it particles and energy from inside the plasma – to specially equipped, cooled sections of the vessel wall. These divertor plates are placed well away from the hot centre. Thus, the vessel is protected from particles from the plasma and, conversely, the plasma is protected from impurities from the wall. This safeguards the wall and provides good thermal insulation of the plasma. At the same time, the disturbing impurities can thus be removed from the plasma. In a burning, self-sustaining plasma this would also include the “fusion ash”, i. e. helium.
To investigate the interaction between plasma and wall under realistic conditions, ASDEX Upgrade can still do without a burning plasma and full power plant size. It is sufficient to simulate only th e plasma boundary layer, i.e. the outer ten centimetres of a power plant plasma. To achieve a wall load like in a power plant, up to 27 megawatts of heating power are available to heat the plasma.



Graphic: Mathias Dibon

Schematic illustration of the plasma vessel with magnetic coils

Essential data of ASDEX Upgrade

Size of the device	diameter 10 metres; height 9 metres
Weight	800 tons
Major plasma radius	1.65 metre
Plasma cross-section	width 1 metre; height 1.6 metre
Plasma	
• composition	hydrogen, deuterium
• volume	14 cubic metres
• quantity	3 milligrams
Magnetic field	up to 3.2 tesla
Plasma current	up to 1.4 million ampere
Discharge time	10 seconds
Plasma heating	
• neutral particle heating	20 megawatts
• ion cyclotron heating	6 megawatts
• electron cyclotron heating	6 megawatts
Plasma temperature	up to 150 million degrees
Plasma density	up to $2 \cdot 10^{20}$ particles per m^3
Energy confinement time	up to 0.2 seconds

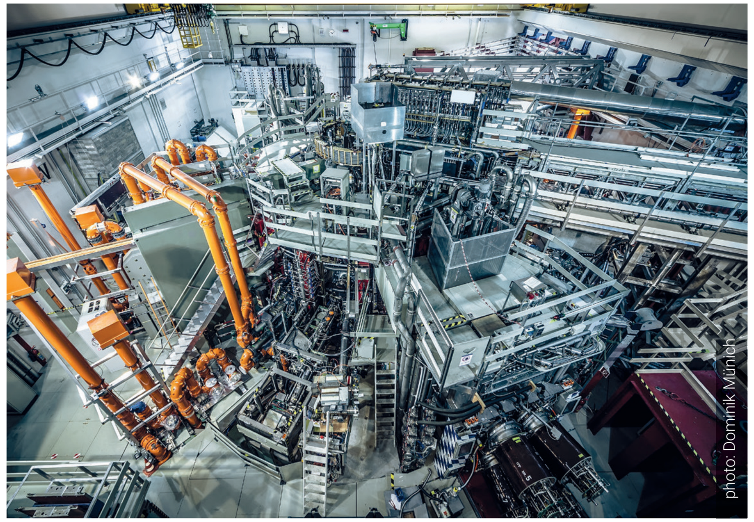


photo: Dominik Münich

Experimental hall with ASDEX Upgrade

ASDEX Upgrade, ITER and DEMO

Because the construction, equipment, and important plasma properties are adapted to a future power plant, ASDEX Upgrade is particularly suitable among the facilities of the European fusion programme for preparing the operation of the ITER international experimental reactor and the planning for a DEMO demonstration power plant. Investigations for DEMO – for example, on the thermal insulation of the plasma, on the stability of the plasma confinement, and on particle and power removal – essentially determine the experimental programme of ASDEX Upgrade. It is drawn up by a European programme committee. Research scientists from all over Europe use the device for their experiments.

photo: Frank Fleschner

Work inside the plasma vessel

Plasma discharge

Divertor and plasma boundary layer

Transferring the proven divertor operation to larger facilities such as ITER or a power plant is not without problems. The tightly bundled plasma particles flowing into the divertor transport a lot of energy to the divertor plates. ASDEX Upgrade has come up with potential solutions: the area affected can be suitably shaped and enlarged to reduce the peak load. To prevent the entire energy from hitting the divertor plates in the form of fast plasma particles, part of it has to leave the plasma in a gentle way as radiation, i.e. light rays. These may be emitted by impurities, for example, noble gases, injected into the plasma boundary layer. A cushion of cold neutral hydrogen gas can also protect the divertor plates.

Plasma instabilities

The interaction of the plasma particles with each other and with the magnetic field may cause various instabilities inside the plasma that act like a short circuit for heat transport and impair energy confinement. ASDEX Upgrade is successfully doing research into eliminating or mitigating these instabilities.

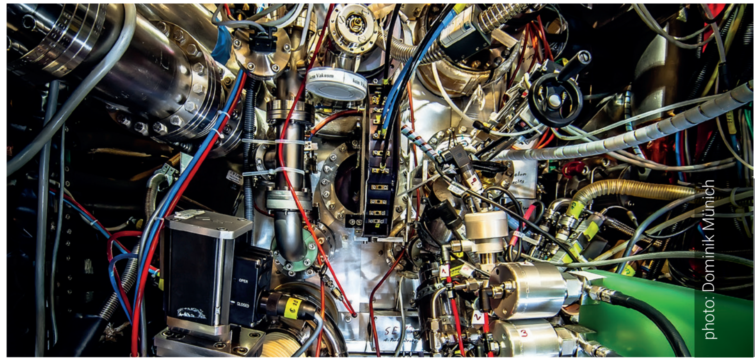


photo: Dominik Münich

Port with compressed air lines and electrical wiring for diagnostics