ASDEX Upgrade LETTER

Max-Planck-Institut für Plasmaphysik

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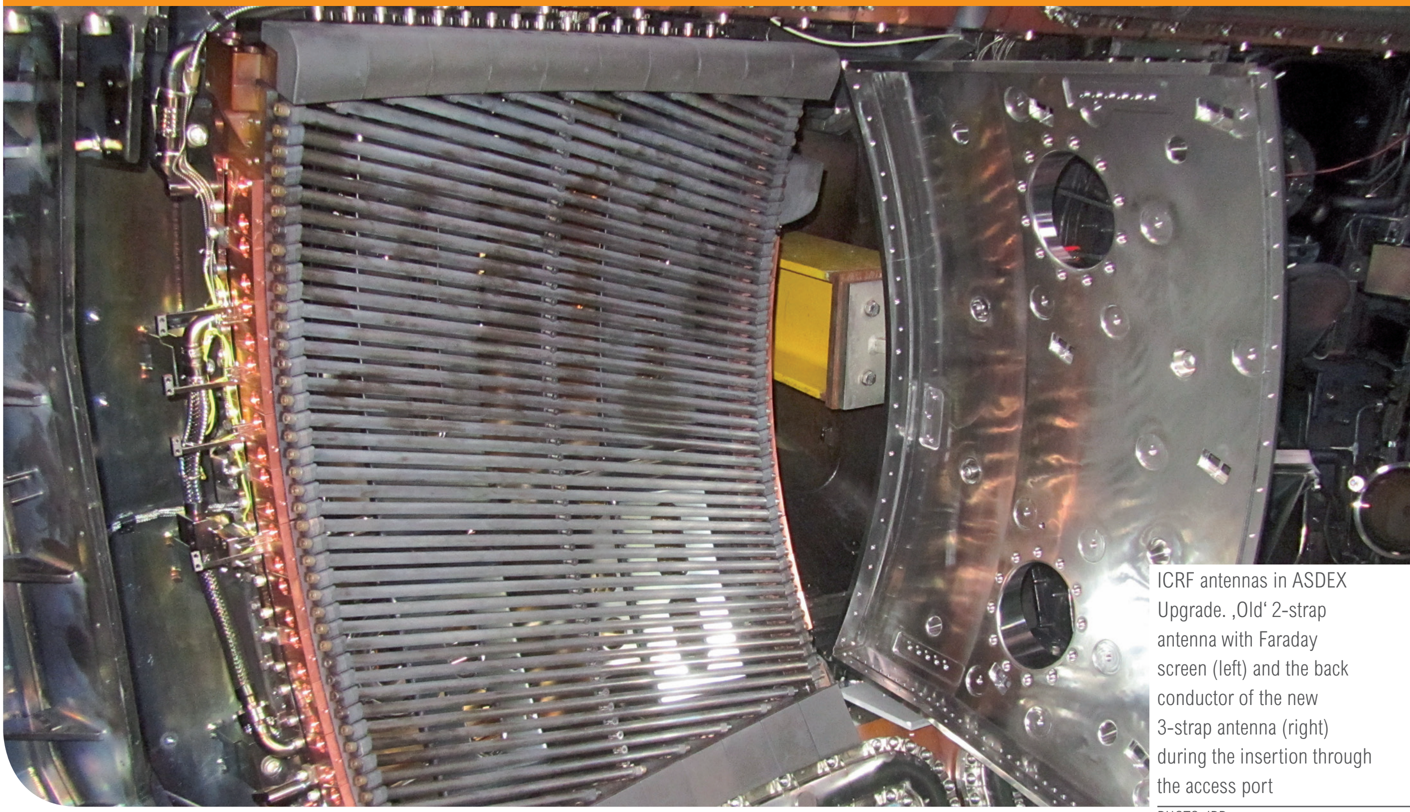
IN GARCHING FOR EUROPE – FUSION RESEARCH WITH GERMANY'S LARGEST TOKAMAK DEVICE



ICRF antennas in ASDEX Upgrade. ‚Old' 2-strap antenna with Faraday screen (left) and the back conductor of the new 3-strap antenna (right) during the insertion through the access port

PHOTO: IPP

Prof. Dr. Arne Kallenbach
Head of ASDEX Upgrade project

PHOTO: IPP

EDITORIAL

The 2014 ASDEX Upgrade experimental campaign brought important changes to the organization, execution and evaluation of experiments. With the establishment of the EUROfusion consortium, new procedures for shared exploitation of the tokamak had to be developed. The first contingent of visiting scientists, belonging to the Medium Sized Tokamak Programme (MST1), arrived just as their office building was being handed over to IPP. IT infrastructure had to be upgraded to cope with the much higher load, and experiments were delayed owing to failure of an NBI gate valve. Thanks to great individual efforts, the goodwill of guests having to wait for certain deliverables and the very good team spirit between MST1 Task Force Leaders, the Programme Management Unit and the Operator, most of the problems could be sorted out by late spring. Ultimately, a quite smooth and successful campaign could be concluded at the end of October. Not all experiments envisaged could be fully completed, but in the end 592 discharges were performed under the MST1 Programme and 541 for the internal IPP programme, not far short of the original plan.

The major enhancements for 2014, the bulk tungsten divertor III and the DIM-II large-scale divertor manipulator performed very well, and also the new B-coil AC power supply BUSSARD was successfully commissioned. Many interesting experiments, e.g. on ITER scenario development, impurity seeding, MHD control and the physics of magnetic perturbations were conducted. These results have already been partly reported at conferences in 2014 or are in the course of their final analysis.

Experimental planning for 2015 is ongoing, with TCV at Lausanne available as a new device in the MST1 portfolio. According to the feedback received, participants were mostly happy about the 2014 operation. Some improvements have been proposed for the 2015 campaign. Planning and reporting will be streamlined, and common EUROfusion science meetings featuring talks from ASDEX Upgrade, JET and TCV will further improve scientific exchange within the European team.

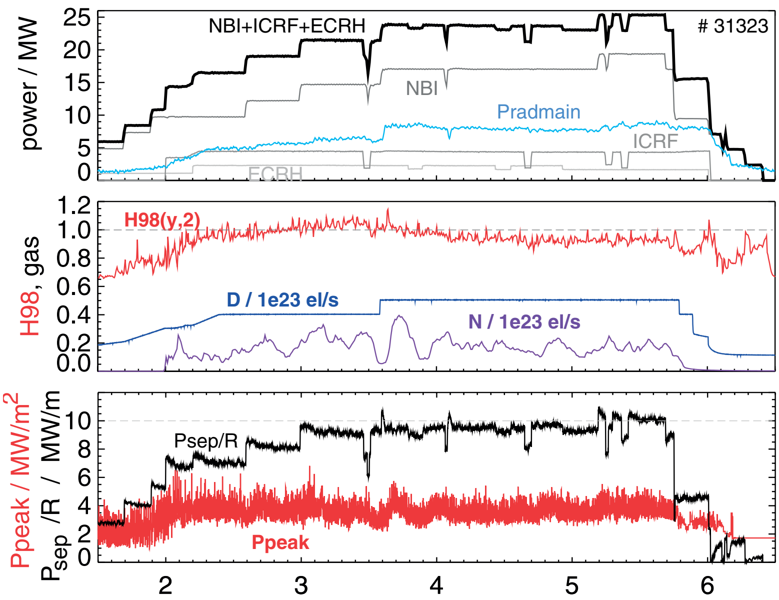
ARNE KALLENBACH

Highlight from a recent ASDEX Upgrade experiment

Divertor performance studies for ITER and DEMO

ASDEX Upgrade operation at high P_{sep}/R

The experimental parameter which quantifies the heat load challenge of a divertor is the power flux through the separatrix normalized to the major radius of the machine, P_{sep}/R. This is due to the fact that the width of the power-carrying layer at the separatrix strike point of a divertor is almost independent of the size of the machine ('Eich scaling'). The wetted power area therefore increases just



Time traces of the ASDEX Upgrade discharge with the highest P_{sep}/R. Top: heating powers by neutral beam injection (NBI), electron and ion cyclotron radiation (ECRH and ICRF) together with radiation power from the confined area. Middle: gas fluxes of deuterium and nitrogen and confinement factor H98(y,2). Bottom: P_{sep}/R and peak target power load in the critical outer divertor, P_{peak}.

FIGURE: A. KALLENBACH

linearly with the major radius R, which is an unfavourable scaling for a larger tokamak since the power is expected to rise more than linearly. No tokamak experiment hitherto has produced – and controlled – a value of P_{sep}/R of about 15 MW/m, as expected for ITER or DEMO, but ASDEX Upgrade with its strong and versatile heating systems and power supplies has accepted the challenge.

The figure shows time traces of the ASDEX Upgrade discharge with the highest P_{sep}/R of 10 MW/m achieved so far, with full control of the divertor heat flux using nitrogen for radiative cooling. P_{peak} remains below about 5 MW/m^2, a value fully in line with ITER requirements. Also the normalized energy confinement stays close to the required H98 = 1 value despite the very high gas flux. The discharge was part of the internal ASDEX Upgrade 2014 programme, but the underlying scenario was developed within Medium Size Tokamak campaign. The high neutral pressure, in combination with a high divertor electron density, is believed to be essential for the power dissipation in the divertor by a combination of nitrogen radiation, charge exchange and other atomic processes, which finally causes the desired partial detachment of the divertor. The high neutral pressure of more than 4 Pa, the typical value envisaged for ITER, was achieved by deuterium flux close to the technical limit, combined with reduced pumping speed of the cryo pump. The latter took advantage of an ASDEX Upgrade extension done in parallel to the divertor III installation, namely a cryo valve which allows the liquid helium flow to be controlled and thus operate at one-third of the divertor cryo pump capacity.

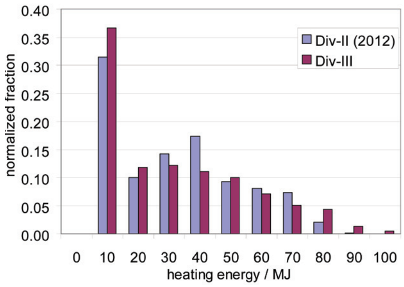
The present achievement is not only about P_{sep}/R. In addition, ASDEX Upgrade has an absolute plasma density similar to that of ITER, and thus similar absolute divertor parameters such as electron density, electron temperature and neutral pressure are expected. Consequently, physics studies in the ASDEX Upgrade divertor at high P_{sep}/R find conditions very similar to those expected for ITER and DEMO, e.g. the mean free paths of neutral particles or the concentration and impact energy of sputtering seed impurities. This allows benchmarking and improvement of present plasma edge modelling codes, which are essential for quantitative predictions of the divertor performance expected in future high-power devices.

Currently, a reactive power compensation system is being installed at the EZ4 generator. As already with EZ3, this will enhance the capability of energy and power delivery to ASDEX Upgrade, allowing the use of all present heating systems at full power, and providing a margin for ECRH III enhancement. Planned upgrading of the pumping system will enable even higher neutral pressures. The ongoing ASDEX Upgrade enhancements will allow the ITER/DEMO value of P_{sep}/R to be closely approached, and potential limitations of the standard, vertical target divertor to be explored.

A. KALLENBACH

New ICRF antennas, steel tiles and diagnostics

The experimental campaign 2014, from January to October, was the first campaign with a full solid tungsten divertor (Div-III) in ASDEX Upgrade. More than 1,200 discharges were run with heating energies of up to 100 MJ and durations of up to 10 s. These energies exceed those of the previous campaign with a tungsten-coated graphite divertor (Div-II). As reported in this newsletter, stable high-performance plasma operation with a solid tungsten divertor could be demonstrated.



Normalized distribution of the plasma heating energy for the last campaign with Div-II and the first Div-III campaign.

FIGURE: A. HERRMANN

Making tungsten-coated Ion Cyclotron Resonance Heating (ICRF) antennas compatible with high-performance plasma operation and central plasma heating is in the focus of the present six-month shutdown. Two of the four ICRF antennas will be replaced by new ones optimized for reduced tungsten sputtering. This reduction will be achieved by a new antenna design with three straps instead of two, which provide a more homogeneous distribution of the currents flowing in the straps and return connector. This results in a lower electric field in front of the antenna and thus ions accelerated in this field will stay below the critical energy for sputtering.

The new antenna was designed in cooperation with the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA). Production was shared between the Institute of Plasma Physics of the Chinese Academy of Sciences in Hefei (antenna base) and ENEA-Frascati (Faraday cage and cooling frame). IPP provided the antenna design, project coordination and antenna testing. One antenna will be equipped with a seven-channel reflectometry diagnostic for antenna characterization.

Both antennas were mounted and installed in a test octant to check the mechanical integrity before installing them in the vessel.

Installation in ASDEX Upgrade started in 2014. The old antennas were dismounted inside the torus. Remaining large components had to be transported by a small crane inside the machine and then taken out with the crane in the torus hall, a special arm being provided to feed the components through the 40x80 cm^2 wide entrance port.

Machining inside the vessel was started in January 2015. Cooling pipes had to be cut, modified and welded. The new antennas need more space, which requires replacing the support bridges between upper and lower PSL each by two smaller bridges with the same load bearing capacity. Following the machining work the two new antennas have been installed. Vessel closure and start of commissioning are scheduled for the end of April.

In parallel to the installation of the ICRF antennas, the shutdown is being used for enhancements, maintenance and hardening of in-vessel components:

- At the inner column, another toroidal row of tiles made of DEMO-relevant ferritic steel, Eurofer, will be installed in addition to the two existing rows made of Eurofer-like P92.
- 12 new diagnostics will be installed and about 20 diagnostics will be modified and refurbished.
- During operation a few modules of the outer divertor became misaligned during a disruption. To avoid this in future, the divertor structure will be insulated and the pre-tension at the fixture will be increased. In addition, all tungsten tiles in the divertor will be inspected and where necessary replaced.

By these modifications and enhancements the options for physics investigations in the upcoming experimental campaign will be significantly increased.

A. HERRMANN

PHOTO: PRIVATE

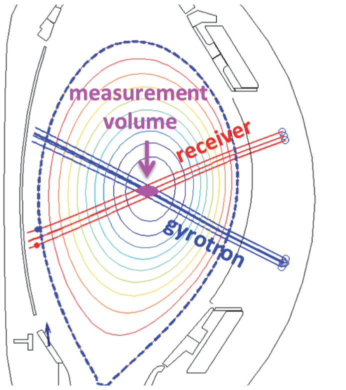
EUROPEAN-AMERICAN LANDAU-SPITZER PRIZE

The Landau-Spitzer Prize for Plasma Physics 2014 was awarded to two scientists at IPP in Garching, Dr. Manuel Garcia-Munoz, at present delegated to the University of Seville, and Dr. Benedikt Geiger, together with American plasma physicists Dr. David Pace and Dr. Michael Van Zeeland for their investigation on confinement of fast particles in tokamaks, a profound understanding of which they jointly achieved. Their collaboration on the two tokamak devices, ASDEX Upgrade at Garching and DIII-D at San Diego, led to the development of new methods of observing the motion of fast particles. The prize is jointly awarded by the American and European Physical Societies. It is awarded every two years to up to four scientists who together have made outstanding theoretical, experimental or technological contributions to plasma physics and hence to European-American cooperation.

J. SIEBER

A new approach to ion dynamics

Understanding ion dynamics and specifically the energetic ion populations is of fundamental importance in fusion research. The energetic ions in tokamaks represent a large source of free energy and are known to interact with various magnetohydrodynamic (MHD) instabilities such as sawteeth and Alfvén modes. Additionally, energetic ions give rise to current drive. Furthermore, the properties of the bulk ions, such as temperature, rotation and composition, play an important role in virtually all core plasma physics topics.



Example of CTS geometry
DRAWING: DTU

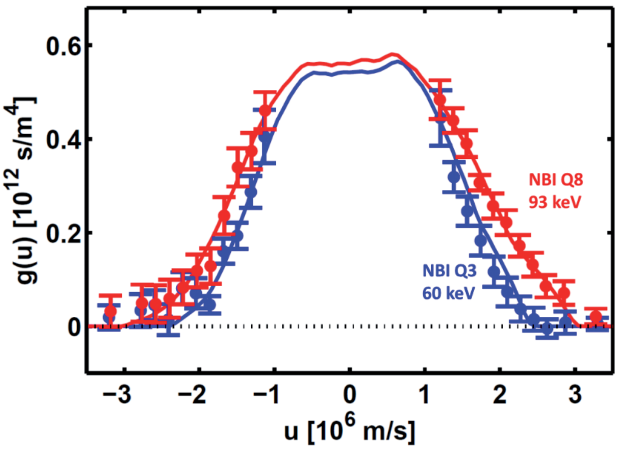
The ion dynamics can be resolved by microwave collective Thomson scattering (CTS), where high-power microwave beams are used to scatter off plasma fluctuations induced by the ion motion. This allows information on the confined ion populations to be obtained without perturbing the plasma. On ASDEX Upgrade a CTS system based on probing radiation from a 105-GHz gyrotron of the electron cyclotron resonance heating (ECRH) system has been developed by the Technical University of Denmark (DTU) in close collaboration with IPP. Highly sensitive receiver systems are installed on the ECRH II transmission lines, eliminating the need for additional in-vessel installations. In recent years the joint IPP/DTU CTS team has significantly advanced the technique such that successful measurements of both energetic and bulk ion properties are now feasible in both L-mode and H-mode plasmas. These new measurements are made possible by using a second receiver to estimate the background microwave radiation.

The CTS diagnostic was benchmarked against the charge exchange recombination spectroscopy (CXRS) diagnostic at ASDEX Upgrade. The two techniques provide similar ion temperatures and bulk ion rotation velocities, which adds to the confidence in both techniques. CTS now allows ion temperature and rotation measurements in discharges without neutral-beam injection, which opens the way to new intrinsic rotation studies.

From the scattering spectra a 1D projection of the fast-ion velocity distribution can be extracted. The CTS data were compared with fast-ion distribution functions simulated by the transport analysis code TRANSP in MHD quiescent plasmas, and good agreement was found. An investigation of the fast-ion re-distribution due to sawtooth crashes based on the CTS and the Fast Ion D-alpha diagnostic was initiated in 2014, and an assessment of the neutral-beam current drive efficiency is planned for the near future.

Finally, the CTS system can also be used to acquire unique information on the plasma particle composition. Information on minority concentrations of hydrogen, helium-3 and helium-4 was obtained for specific scattering geometries. A comparison study of the helium-4 concentration measured by CTS and CXRS is ongoing, and preliminary results indicate good agreement.

Besides shedding light on a number of different physics topics, the ASDEX Upgrade CTS system is also adding vital knowledge and experience to the field of CTS operation and design. In 2014 a joint DTU/IST consortium initiated a design of a CTS system for ITER. Being a microwave-based diagnostic, CTS is also one of the few diagnostics suitable for reactor environments, such as DEMO. In these diagnostic design considerations, the knowledge from the ASDEX Upgrade CTS system will be extensively used in order to provide reliable ion measurements in future fusion devices.



Projected fast-ion distribution, g, as function of projected velocity, u. Measurements from CTS are shown with error bars, the continuous lines represent simulations by TRANSP.
FIGURE: DTU

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