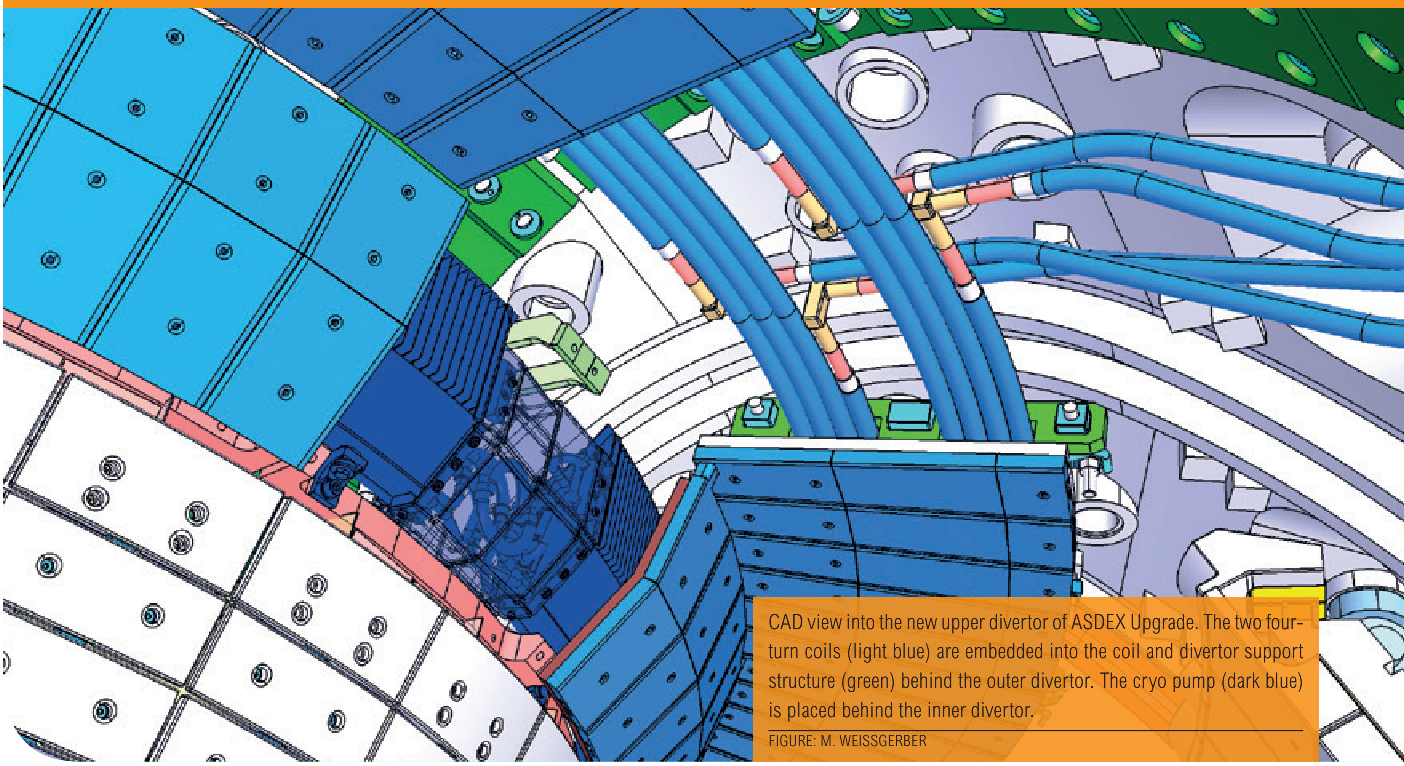
ASDEX Upgrade LETTER

IPP Max-Planck-Institut für Plasmaphysik

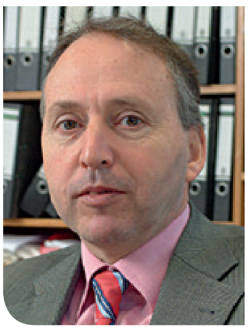
No. 19 | August 2018

IN GARCHING FOR EUROPE – FUSION RESEARCH WITH THE ASDEX UPGRADE TOKAMAK



CAD view into the new upper divertor of ASDEX Upgrade. The two four-turn coils (light blue) are embedded into the coil and divertor support structure (green) behind the outer divertor. The cryo pump (dark blue) is placed behind the inner divertor.

FIGURE: M. WEISSGERBER



Prof. Dr. Arne Kallenbach
Head of ASDEX Upgrade project

PHOTO: IPP

EDITORIAL

The 2017 experimental campaign on ASDEX Upgrade was prematurely stopped by a steam water leak during vessel baking following repairs after a cold-water leak during operation of the divertor manipulator. Normally the machine operation would have been quickly recovered had the hot water of many baking cycles not brought about the corrosion of several copper seals. Thus, the ASDEX Upgrade team had to learn the hard way that a steam leak is much more severe than a 'conventional' water leak. The hot steam condensed even in very remote locations and caused corrosion damage to in-vessel components, in particular to electrical vacuum feedthroughs. This led to a longer opening than initially foreseen. Measures have now been put in place to prevent this from happening again, like controlling the pH value of the cooling water and the option to cut the water supply in case of problems during baking without producing excessive thermal strain on the vessel.

In parallel to the substantial cleaning measures, a number of important extensions were installed in ASDEX Upgrade, including the new divertor Thomson scattering diagnostic and a new steering system for ECRH III. The team is now looking forward to the 2018/19 campaign, which is planned from end of September till early summer 2019.

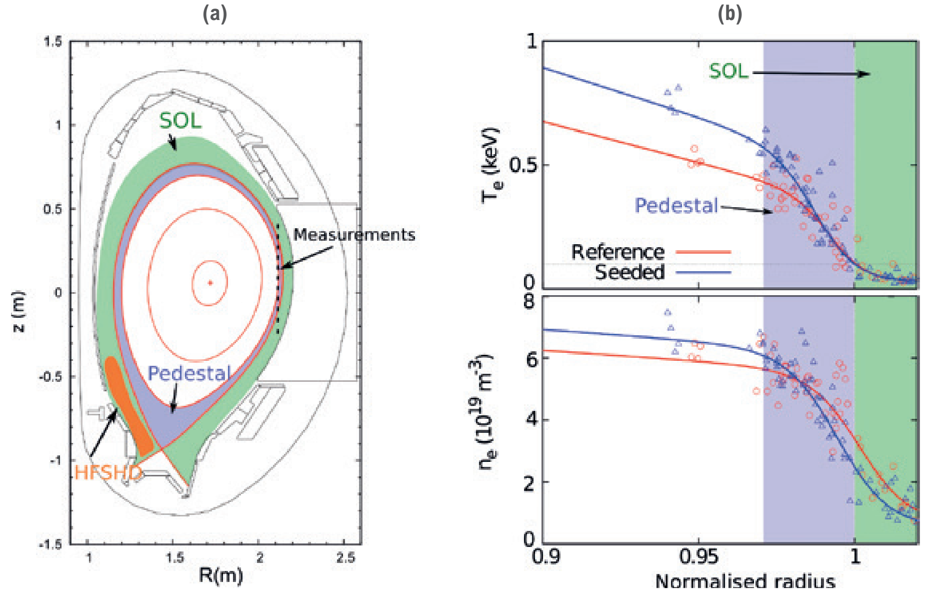
Much knowledge and understanding has been gained on the influence of the edge density profile on the pedestal stability and plasma performance, which is shown in the contribution by Mike Dunne. The pedestal is also the key player for the I-mode, a potential ELM-free operation scenario for ITER or DEMO, sitting in-between L- and H-mode. Tim Happel reports recent achievements of a stationary NBI-heated I-mode in ASDEX Upgrade. In a few years from now, ASDEX Upgrade will be equipped with an alternative upper divertor – the result of a risk mitigation strategy in case the standard divertor is not able to manage the DEMO power exhaust requirements. Albrecht Herrmann describes its technical setup, which should not only allow more efficient power exhaust, but also will supply valuable data for understanding and predictive modelling.

A. KALLENBACH

Highlight from a recent ASDEX Upgrade experiment

Pedestal studies

Bridging the gap between scrape-off layer and pedestal



(a) Plasma geometry illustrating the pedestal, SOL and HFSHD regions, **(b)** electron temperature and density profiles showing changes due to impurity seeding.

FIGURES: M. DUNNE

The power entering the scrape-off layer (SOL), the region just outside the main confined plasma, must be removed before it reaches the divertor. This is a requirement for a future fusion power plant. Seeding of light- to medium-Z impurities (such as nitrogen, neon, argon, etc.) is foreseen as the main mechanism to reduce the power load to the plasma facing components.

It has been observed in both ASDEX Upgrade and JET that adding nitrogen to standard H-mode discharges can significantly improve their confinement, particularly if the confinement was low to begin with. Initial investigations identified the pedestal, a narrow region of high temperature and density gradients, as the source of the confinement improvement, although it remained unclear how the stability of this region was changed.

Several discharges on ASDEX Upgrade were analysed, employing both SOL and pedestal diagnostics and modelling tools. The SOL research revealed the existence of a region of high density in the high-field side SOL (towards the inside of the machine), known as the high-field side high density (HFSHD). The density in this region can reach up to ten times that of the main plasma, and it can extend poloidally from the inner divertor to at least the inboard mid-plane. Its potential importance was realised when it was observed that the HFSHD was reduced in density and extent with the application of nitrogen seeding. Based on SOL modelling, it is thought that power exhausted from the main plasma travels along field lines in the SOL and ionises recycled neutrals at the HFS divertor entrance. When impurities are present in the SOL this power instead ionizes the impurities, thus starving the HFSHD.

Pedestal investigations revealed that the location of the pressure gradient is important for the pedestal stability. Movement of the same pressure gradient closer to the separatrix resulted in a lower pedestal top pressure. Combined with the HFSHD a hypothesis was developed suggesting that the HFSHD modifies the separatrix density, resulting in an outward "shift" of the pedestal density profile, specifically of its peak gradient. With nitrogen seeding, the HFSHD is reduced and the gradient can return to its unperturbed location. Predictive pedestal simulations with the IPED code showed that such a shift of the gradient could be responsible for a +/- 25% change in the pedestal top pressure, similar to the changes observed in the experiments.

Analysis of the pedestal profiles showed a strong correlation between the separatrix density and pedestal top pressure, as predicted. An important implication of this model is that it does not matter how the HFSHD is suppressed, which suggests that different impurities can be used. Recent experiments in ASDEX Upgrade comparing nitrogen, neon, and argon have shown that after matching the radiated power, a similar increase in the pedestal top pressure results. Detailed analysis of a matched pair of nitrogen and neon seeded discharges shows that the pedestal stability in both cases is almost identical.

Future plans for these experiments will focus on the role of the divertor geometry. This has been observed to have a large impact on the formation of the HFSHD and confinement in JET. Comparisons of the effect of impurity seeding on JET, TCV, and Alcator C-Mod are underway to determine the impact of the HFSHD in other areas of operational space, as well as to examine the more fundamental question of how the density profile gradient is affected by machine and operational conditions.

M. DUNNE

Alternative magnetic configurations

The new upper divertor for ASDEX Upgrade

ASDEX Upgrade was designed to tackle plasma boundary and first-wall problems, which can be investigated by discharges without thermonuclear heating. It came into operation in 1991 with an ITER-like geometry and an open divertor configuration. During the past decades hardware changes were driven by the physics program in preparation for ITER. In particular, the lower divertor was modified from an open to a closed geometry with vertical target plates. While the physics motivation for the extension towards alternative magnetic configurations was presented in the last newsletter, now the status of the hardware modification is reported.

Most of the discharges in ASDEX Upgrade are operated with the strike line in the lower divertor with vertical targets. The existing upper divertor, an open divertor with a limited heat load capability, was not modified since 1991. In order to access alternative magnetic configurations without reducing the present operational range, it is planned to modify the upper divertor, while retaining the capabilities of the lower divertor for the physics program.

The lower single null magnetic configuration with largest elongation sets an upper limit for the space available for the internal coil, the new divertor structure and a cryo-pump. The coils will be integrated into the support structure of the upper outer divertor, while the cryo-pump is placed behind the upper inner divertor, as shown in the cover illustration. Minimising the distance between coils and divertor surface and the limited space require a high current density of about 50 A/mm^2 to realise the required 52 kA coil current. This heats the coils by about 50 K over a period of about 5 s. Water cooling removes the heat over a few minutes so that the discharges can be started with well-defined conditions.

The cryo-pump with a pumping speed of about 50 m^3/s is connected via a gap between the inner and outer divertor to the X-point region. Here the envisaged pumping speed is 20 m^3/s. Activated charcoal coating of the cryo panels is an option under investigation. This would allow investigating Helium pumping in alternative configurations.

The outer divertor structure serves simultaneously as the coil casing. It is designed as a toroidally stiff ring to reduce the shear stress to the coil conductor. The well-aligned ring is a prerequisite for well-aligned divertor tiles with a gap size of about 1 mm with +/- 0.1 mm offset between adjacent tiles. These tolerances would allow operating the divertor in both helicities without unacceptable high temperatures at the edges of divertor tiles.

The most critical component is the coil. Two concepts, a Copper-conductor embedded in an isolating structure and a Teflon-isolated Copper-conductor embedded in a stainless-steel protection tube, are under investigation with respect to the electrical strength and the in-vessel handling. A plasma disruption with induced voltages up to 1 kV per turn can result in an arc and strong forces in case of a winding short circuit. Another aspect is that a toroidally closed conductor reduces the toroidal resistance and could hamper the discharge start-up. Both effects are modelled with a realistic electro-magnetic FEM model, checked against magnetic probe data from ASDEX Upgrade for start-up phases and disruptions. Prototype tests of the two conductor concepts are ongoing and will result in a final decision on the conductor type in 2018.

A further critical point is the power supply. It has to be fail-safe to avoid too strong a force acting on the coil during normal operation. In addition, it has to limit the induced current during disruptions. Here the concept of an 'intelligent fuse' is being developed and a prototype test will be performed next year.

The new upper divertor with internal coils, Div-IIo, is the next step for ASDEX Upgrade towards the investigation of alternative fusion reactor concepts. The design of the divertor structure, the cryo-pump and the coil is ongoing. First hardware installations will be carried out in 2020/21.

A. HERRMANN

AWARDS

François Ryter received the Nuclear Fusion Award 2017 for his paper "Experimental evidence for the key role of the ion heat channel in the physics of the L-H transition" on experiments in ASDEX Upgrade. The annually awarded prize is in recognition of outstanding work published in the journal Nuclear Fusion. François Ryter's paper shows that of the various factors accounting for the transition from the low- to the high-confinement regime it is the thermal flux of the ions at the plasma edge that plays the key role. This allows to determine more exactly the heating power needed to trigger the transition.

IPP postdoc **Wei Zhang** is one of four prizewinners honoured by the Plasma Physics Division of the European Physical Society for the superior quality of their doctoral theses with the PhD Research Award 2018. Wei Zhang started his thesis, Plasma Edge Modeling with ICRF Coupling, in 2014 at the University of Ghent in Belgium – much of his research having been done at IPP in Garching. The most efficient possible coupling of the radiowaves and their impact on the plasmas of ASDEX Upgrade and JET were calculated in numerical simulations the results of which he extrapolated to the conditions prevailing in ITER and a demonstration power plant.

I. MILCH

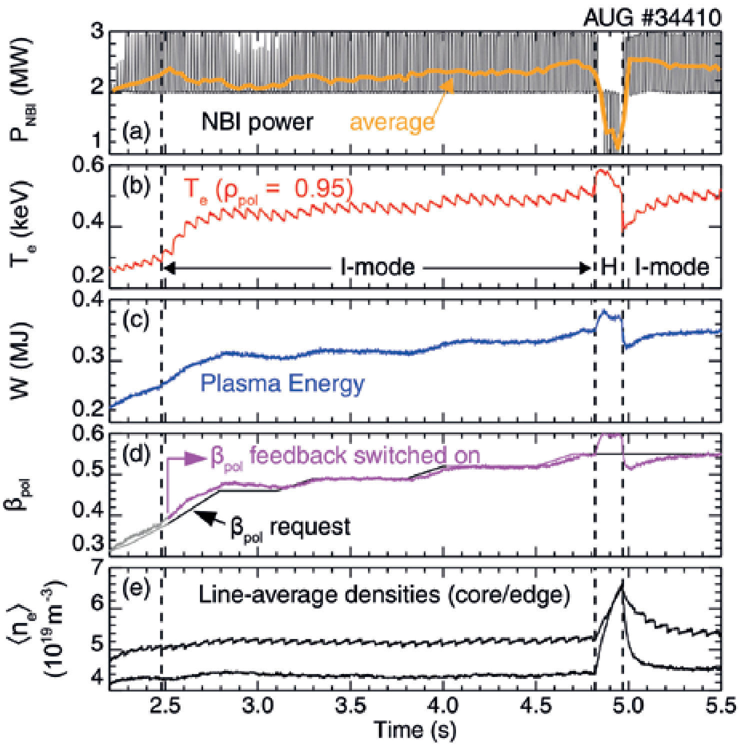
Stationary I-modes through NBI feedback control

The standard scenario for future fusion devices is the high-confinement mode (H-mode), characterized by large temperature and density edge profile gradients. These are connected to good particle and energy confinement but also to two problematic features: periodic instabilities (edge-localized modes - ELMs) cause high power transients to plasma facing surfaces and can even damage components. Furthermore, high-Z impurities in the plasma centre can diminish the fusion reaction by energy losses through radiation.

Thus, the improved energy confinement regime (I-mode), which is intrinsically ELM-free, could be an attractive alternative scenario. It has large edge profile gradients in the electron and ion temperatures, but not in the density. Hence, energy confinement is high, while particle confinement is low like in L-mode. So far, no impurity accumulation has been observed in I-mode plasmas.

The I-mode is obtained when the L-H power threshold is kept high, which is usually achieved by the ion grad B drift pointing away from the active X-point. This opens a window for I-mode access, which has been shown to widen with increasing magnetic field strength, as is the case for future fusion devices. Owing to the comparably low magnetic field strength of ASDEX Upgrade, I-modes have so far often been non-stationary.

Recently, a major advancement in I-mode scenario development has been achieved on ASDEX Upgrade: for the first time, stationary I-modes have been achieved by feedback control on the poloidal plasma beta using the neutral-beam injection (NBI) heating power as actuator. Apart from enabling a variety of studies it shows that I-modes can be obtained over several seconds with NBI power, which is an important heating method for future devices.



Stationary I-mode by feedback control on the plasma beta: (a) feedback-modulated NBI power (orange curve: averaged power), (b) pedestal top electron temperature, (c) plasma energy, (d) poloidal plasma beta (target and measured values) (e) line-average electron densities.

FIGURE: T. HAPPEL

The figure shows a discharge in ASDEX Upgrade in which the average NBI power is ramped in the beginning of the time window. The L-I transition (2.48 s) can be observed in the increase of pedestal top electron temperature (T (ρ_{pol} = 0.95)) and energy confinement. During the transition, the density is nearly constant.

In the I-mode phase the NBI power is increased three times. Both pedestal top electron temperature and plasma energy follow the power steps, while the density is unaffected, which is typical for I-mode. After the third power step (4.6 s) a transition to H-mode occurs (4.82 s), which leads to a strong rise in density. The feedback system reacts by immediately reducing the NBI power such that the I-mode can be recovered within less than 200 ms with the same characteristics as before.

Now that the I-mode has been established as a robust stationary scenario on ASDEX Upgrade, it will be studied further in the upcoming campaign. There are several key questions which have yet to be resolved, e.g. the nature of the decoupling of energy and particle transport channels or whether divertor detachment can be obtained.

T. HAPPEL

IMPRINT

ASDEX Upgrade Letter – published by

Max-Planck-Institut für Plasmaphysik

Boltzmannstraße 2
85748 Garching/Munich
Germany

Coordination: Prof. Dr. Hartmut Zohm
Contact: Dr. Anja Gude
Phone: +49 89 3299 1274
Fax: +49 89 3299 2580
E-Mail: anja.gude@ipp.mpg.de
Subscribe at augletter@ipp.mpg.de

For more information see the website www.ipp.mpg.de
Archive: www.ipp.mpg.de/augletter

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