ASDEX Upgrade LETTER

Max-Planck-Institut für Plasmaphysik

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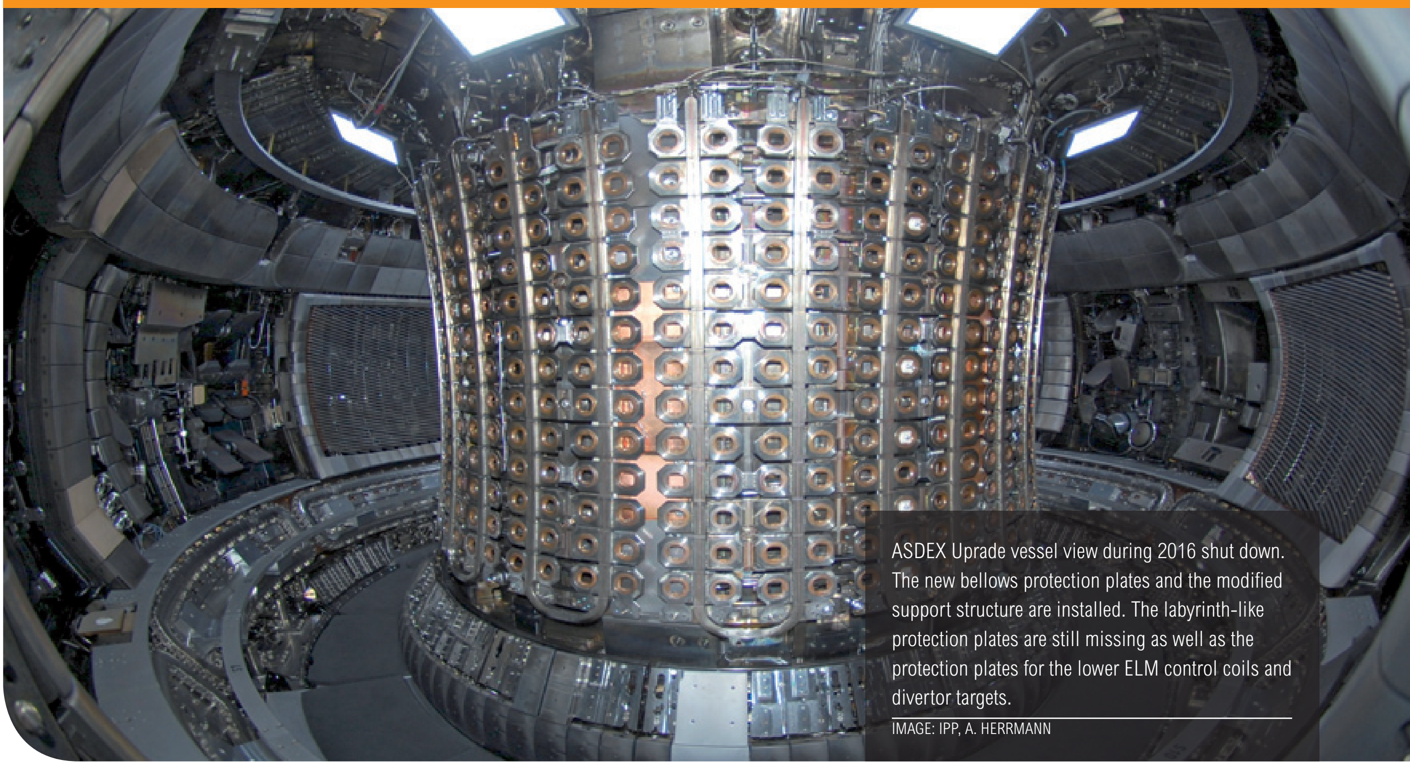
IN GARCHING FOR EUROPE – FUSION RESEARCH WITH THE ASDEX UPGRADE TOKAMAK



ASDEX Uprade vessel view during 2016 shut down. The new bellows protection plates and the modified support structure are installed. The labyrinth-like protection plates are still missing as well as the protection plates for the lower ELM control coils and divertor targets.

IMAGE: IPP, A. HERRMANN

Dr. Josef Schweinzer
Managing Director
of Max Planck Institute
for Plasma Physics

PHOTO: IPP, A. GRIESCH

EDITORIAL

The current issue of this letter describes the programme planning process for the 2017 campaign, which is the 4th year of ASDEX Upgrade operation since the foundation of the EUROfusion Consortium in 2014. The preparation process of such an experimental campaign at ASDEX Upgrade is complex, but streamlined, showing a high level of linkage between the so-called 'internal' and the external EUROfusion MST1 programme. This has also been recognized by the EUROfusion Consortium management. Therefore, the whole ASDEX Upgrade programme is now considered to be necessary to achieve the goals of the EU Roadmap. Besides preparation of ITER operation, the ASDEX Upgrade programme focuses more and more on DEMO-relevant issues, another proof of its full alignment with the EU Roadmap.

With respect to funding by the EU Commission, no distinction is therefore made between internal and external programmes. As the whole ASDEX Upgrade programme is well aligned with the Roadmap, the EU Commission contributes 55 per cent for the operation costs of ASDEX Upgrade to the Consortium. The part of this income received by IPP is however determined by the fraction of operational time devoted to the MST1 programme.

Besides national funding, the additional funds raised by the operation of ASDEX Upgrade through EUROfusion are an important contribution to financing regular hardware upgrades, which will help to keep the scientific attractiveness of ASDEX Upgrade alive for years to come. During the 2016 shutdown, protection of in-vessel components against ECRH stray radiation had to be improved because more ECRH power will be available from 2017 onwards. The improvements made to the heating systems in general and in particular to the ECCD in 2016 have already allowed investigations on advanced scenarios. These aim at preparing steady-state tokamak operation in a machine with a metal wall – a combination certainly deserving to be called DEMO-relevant. Such new scenarios can now also be analysed with much more accurate diagnostics; a prerequisite to improving basic physics understanding.

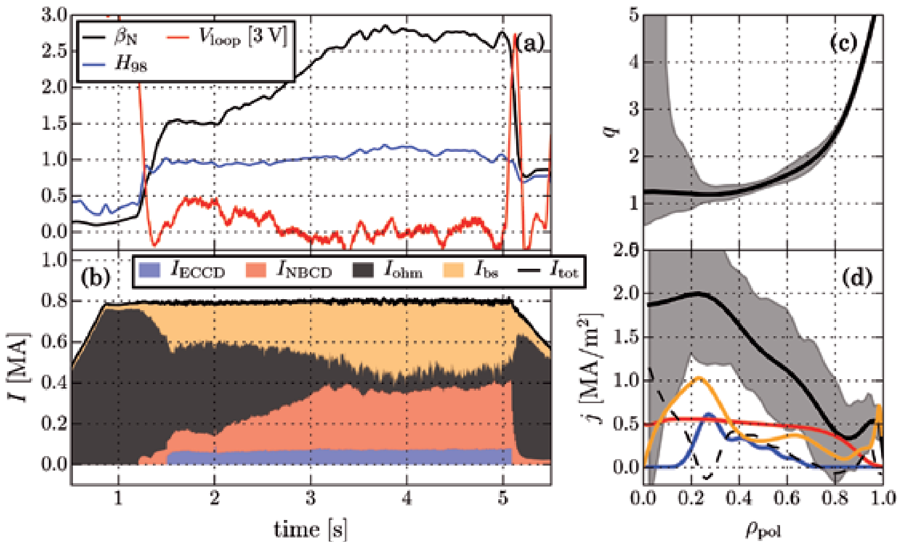
J. SCHWEINZER

Highlight from a recent ASDEX Upgrade experiment

Investigations for a steady-state DEMO discharge

The H-mode high-confinement operation regime is set to be the standard for future tokamak fusion power plants. However, there remains the problem of its susceptibility to deleterious magnetohydrodynamic (MHD) instabilities, such as neoclassical tearing modes (NTM). The dependence of the tokamak on the ohmic current induced by the central solenoid, which makes it inherently pulsed, also needs to be addressed.

So-called advanced scenarios aim to alleviate these drawbacks by modifying the safety factor profile, q. By raising q above critical values, where NTMs and other MHD instabilities are resonant, these instabilities no longer occur. Moreover, the plasma's self-generated bootstrap current increases with q, which is why advanced scenarios are less reliant on the ohmic current. Ideally, the bootstrap current together with non-inductive external current drive sources allows fully non-inductive operation.



ASDEX Upgrade discharge #32305: key plasma parameters (a) and composition of plasma current (b); q profile (c) and current distribution in stationary phase (d).

FIGURE: IPP, A. BOCK

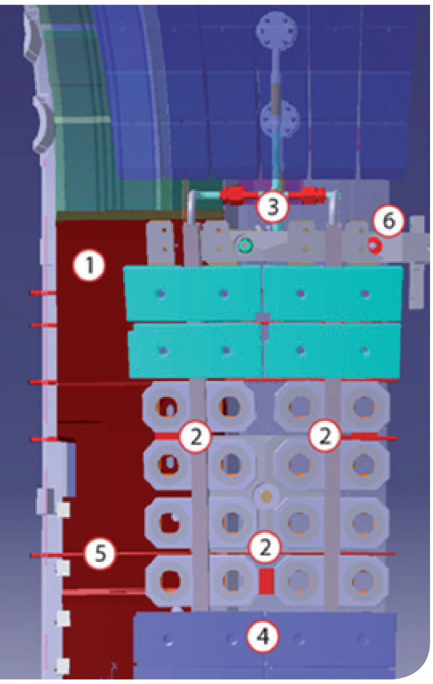
Advanced scenarios are currently being investigated in other machines and have also been studied in ASDEX Upgrade before. Several improvements over the last few years have made renewed investigations in ASDEX Upgrade worthwhile. On the one hand, improvements to the electron-cyclotron resonance heating system and to the neutral beam injection (NBI) heating system have improved the external current drive capabilities. Furthermore, control system upgrades have made it possible to maintain plasma conditions by feedback-controlling the NBI, which allows steady-state investigations. On the other hand, much effort has been dedicated to the diagnostic systems, which are necessary to determine the q profile. Two lines of sight of Faraday rotation polarimetry are operational. The conventional Motional Stark Effect (MSE) diagnostic has been overhauled and will soon be upgraded to account for polarised background light. Finally, a new imaging MSE system with high temporal and spatial resolution has been installed. The new heating and current drive systems allow the q profile to be modified, while the new diagnostic capabilities allow these applied modifications to be accurately studied.

Specifically, the current drive systems are used to initiate a current redistribution by providing off-axis co-current drive. Then, the plasma pressure is increased by slowly raising the control system's target β up to β ≈ 2.7. Such a case is shown in the figure, where over 90 per cent of the total toroidal plasma current is provided by non-inductive current. Moreover, the confinement exceeds expectations since the confinement factor H98(y,2) is well above unity for the entire feedback-controlled steady phase.

Subsequent discharges showed that the non-inductive phase can be significantly extended and that entering this regime is independent of the initial conditions. Future investigations will aim at increasing the plasma current by 25 per cent and the plasma pressure by about 30 per cent to match the European steady-state DEMO scenarios.

A. BOCK

Protection of in-vessel components



CAD view of one section of the heat shield. Modifications are shown in red:
1. New bellows protection plates (dark red),
2. Weld insert for stiffening the support structure,
3. New water connections to disentangle upper divertor and heat shield.
4. New targets made from P92 with labyrinth (blue).
5. Shielding of magnetic loops by stainless-steel tubes and PEEK.
6. Isolation between the two support structures inside an octant. The water connectors are visible behind the upper divertor and the bellows protection plates (transparent).

FIGURE: IPP, A. HERRMANN

ASDEX Upgrade operation is regularly shut down for repairs and enhancements. The 'highlights' of the most recent shut downs were the installation of ELM control coils, the transformation of the outer divertor into a solid tungsten divertor, including the installation of the new divertor manipulator, and the new ICRH antenna design with reduced sputtering, bringing ICRH as a heating method back into a tungsten environment. In 2016 an essential step was taken to increase the machine operability by hardening in-vessel components against ECRH stray radiation and to stiffen the support structure of the heat shield on the inner column to cope with the DEMO-like ferritic steel (Eurofer) tiles and the resulting strong forces.

The ECRH heating system is widely used during ASDEX Upgrade operation. Owing to its flexibility, it happened on occasions that the ECRH power was not fully absorbed by the plasma but partly by in-vessel components. Resulting damage to protection plates, cables and isolation components, including ELM control coils, was found during in-vessel inspections. In parallel to the installation of higher ECRH power with ECRH-III, protection of in-vessel components against stray radiation and unabsorbed power was started in 2012. In addition to the implementation of active control systems such as sniffer probes to detect and avoid stray radiation, passive measures were taken. In a first step, labyrinth-like plates were installed to protect the ELM control coils and the components behind the heat shield. The labyrinth-like structure reduces the heat flux by a factor of about 10, as shown in an ECRH test rig, resulting in a tolerable heat load for most in-vessel components, except for the isolation bellows. These bellows, made from 1.2-mm-thick Inconel, are welded between the octants to increase the toroidal resistance of the vacuum vessel. The integrity of the isolation bellows is vital for operation and since their repair time would be at least one year, they must be protected to withstand a few seconds of full ECRH-III power into the vessel. This is achieved by installing dedicated bellows protection plates in addition to labyrinth-like protection plates at the heat shield. Owing to the limited space between the heat shield and inner vessel wall, the bellows protection plate is designed as a sandwich, which consists of a 2-mm-stainless steel plate, sprayed with PEEK on one side to electrically isolate it from the bellows and copper-coated on the plasma side to reflect more than 99.5 per cent of incoming ECRH radiation.

Further modifications of the inner column support structure were done in parallel. Additional cooling water connections will in future allow single heat shield modules to be dismantled independently of the corresponding two upper divertor modules. On the basis of extensive FEM calculations, the support structure was mechanically stiffened and disruption forces were reduced by isolating heat shield protection units to prevent currents flowing in the support structure. This allows DEMO-relevant ferritic steel to be installed on 7 rows of the heat shield (see figure).

Further improvements included an upgrade of the ECRH launching system, installation of a new aperture to protect the NBI valve, installation of diagnostics and the mounting of modified solid tungsten tiles in the lower outer divertor to avoid deep cracks.

A. HERRMANN

Professor Dr. Hartmut Zohm

FIGURE: IPP, S. WINKLER

Hannes Alfvén Prize for Hartmut Zohm

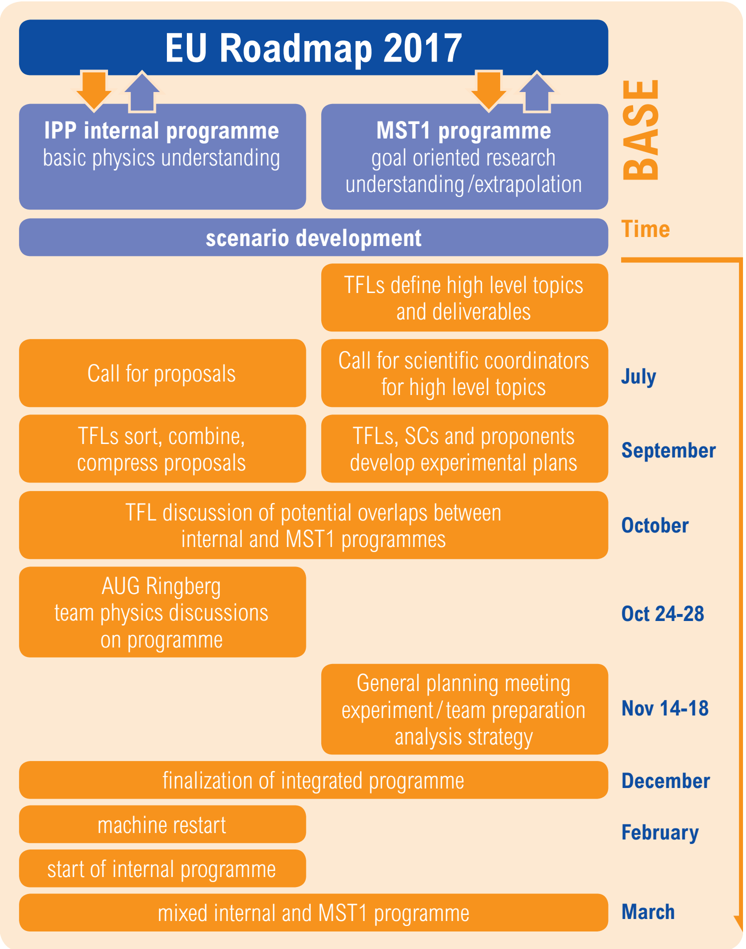
In recognition of his "experimental and theoretical contributions to the development of large-scale next-step devices in high-temperature plasma physics research" IPP scientist Hartmut Zohm was awarded with Hannes Alfvén Prize 2016 of the European Physical Society. He was being honoured particularly for his theoretical derivation and subsequent experimental demonstration that Neoclassical Tearing Modes can be stabilised by microwaves. In large devices like ITER such perturbations would be particularly detrimental. The investigations being conducted in his Europe-wide networked DEMO Studies Group are advancing even beyond ITER requirements – including stable confinement of high-density plasmas and limitation of the wall load caused by a high-power plasma, which had both been demonstrated on the ASDEX Upgrade device.

I. MILCH

ASDEX Upgrade experiment planning

ASDEX Upgrade experiment planning took place in the second half of 2016, as usual during a major break. Since the EUROfusion start in 2014, this is a parallel, but integrated procedure for the internal IPP and the external EUROfusion MST1 parts, overseen by two separate groups of Task Force Leaders (TFL) (see figure).

The basis for both programmes, internal and MST1, is the 2012 European roadmap to the realisation of fusion energy, which is currently being updated. The roadmap comprises eight missions, the ASDEX Upgrade programme being mainly concentrated on the first two missions, viz. plasma operation and heat exhaust. Both programmes are focussed on the physics understanding needed to predict the plasma behaviour in a future fusion reactor. The internal part can be broader, whilst the MST1 part is oriented towards specific milestones defined in the roadmap. Obviously, both parts are closely linked via plasma scenarios as well as plasma theory, modelling and code development.



Finding the optimum experimental programme for ASDEX Upgrade is a stepwise procedure. First of all, the number of discharges available has to be determined: After a commissioning phase end of February, 75 days are expected for programme execution in 2017. Thus, with an average number of 16 discharges per day – a cautious estimate providing flexibility to cope with unavoidable technical failures and time losses – 1,200 discharges are anticipated in 2017.

The internal ASDEX Upgrade programme is based on experiment proposals of individuals or small teams, but is also open to long-term external collaborators, who operate an important diagnostic or actuator. A considerable fraction is related to the work of PhD students and postdoctoral researchers, often associated with the development of new or improved diagnostic tools.

The MST1 programme development started with a call for scientific coordinators and proposals related to previously defined high-level topics. MST1 also supports development of a few major diagnostics which are important for accomplishing topics defined in the roadmap.

Evaluation of the proposals for 2017 showed oversubscription by more than a factor of three, which could be partly ameliorated by merging proposals with overlapping aims. The internal and MST1 proposals were also reviewed to look for discharges with common goals. However, cuts appeared inevitable, as well as postponement of proposals to 2018. For the internal programme, this was decided at a meeting at the end of October; EUROfusion held a general planning meeting in mid-November. The next level of programme planning consists of team meetings where physics background and experimental needs are reviewed.

Finally, the 2017 programme will be defined in terms of proposals with associated discharge numbers and a timeline which assigns all MST1 experiments to weeks and also determines major technical boundary conditions, like boronization dates, operation in hydrogen or with reversed I_p/B_t. The proposals are usually executed in parts, which are called via shot requests. The programme of a week is finalized in the ASDEX Upgrade Monday morning meeting.

A. KALLENBACH

The figure shows the procedure chart for 2017, but can also be regarded as a principal outline for ASDEX Upgrade experiment planning.

FIGURE: IPP, A. KALLENBACH

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