

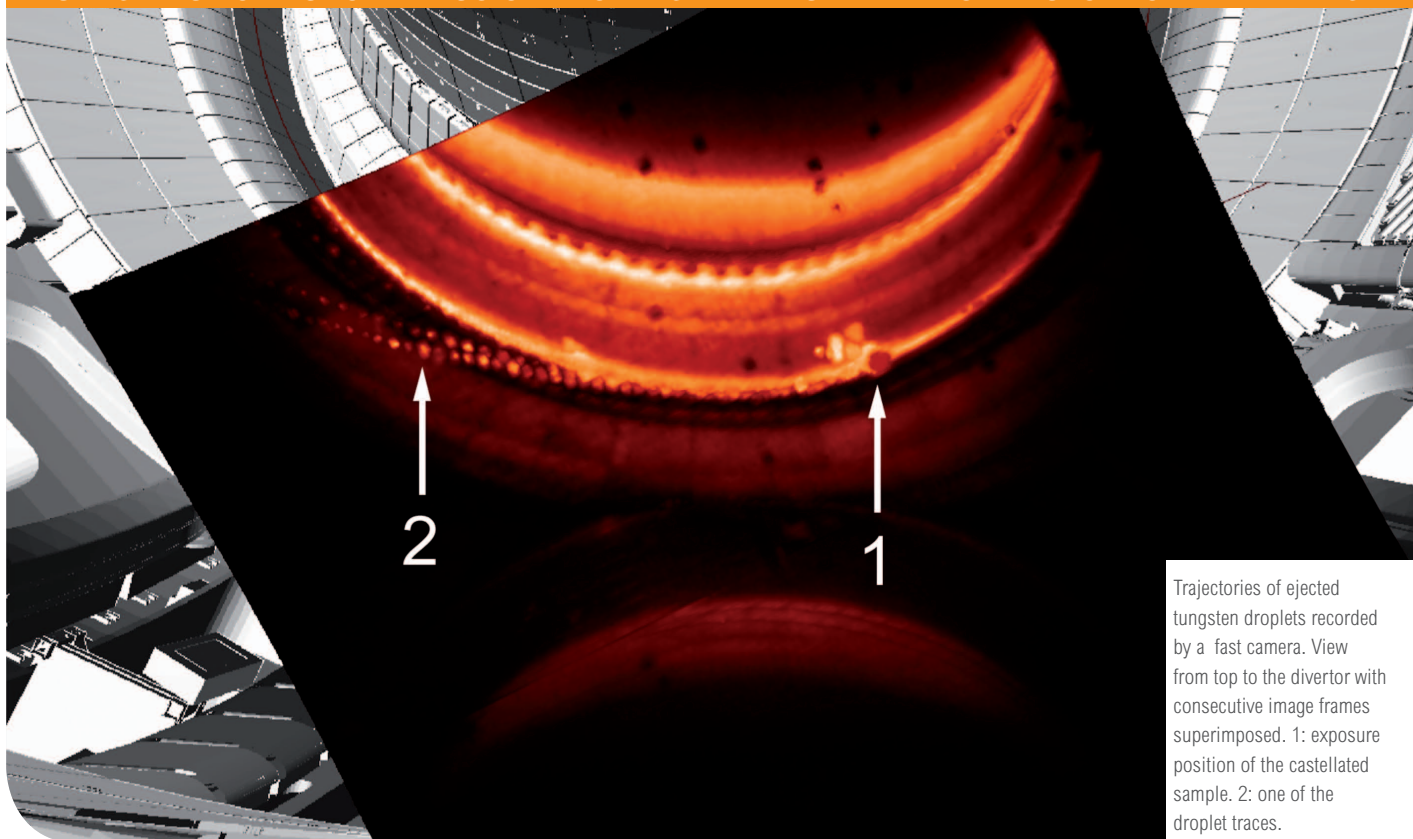
ASDEX Upgrade LETTER



Max-Planck-Institut
für Plasmaphysik

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



Trajectories of ejected tungsten droplets recorded by a fast camera. View from top to the divertor with consecutive image frames superimposed. 1: exposure position of the castellated sample. 2: one of the droplet traces.

PHOTO: T. LUNT, K. KRIEGER



Piero Martin,
MST1 Task Force Leader

PHOTO: EFDA

EDITORIAL

Three hundred and thirty three scientists for 2014, twenty-four laboratories, three tokamaks in three different countries. Well, you certainly don't lack diversity when you are task force leader of the new-born Medium Size Tokamak campaign task force. But this is indeed what makes it fun and an interesting job.

That managing such a complex enterprise would be a professional challenge was immediately clear to us task force leaders (my colleagues Marc Beurskens, Stefano Coda, Thomas Eich, Hendrik Meyer and myself), but after the first few months I think we can say that the process has started and that – even though there will certainly be things to improve – we are satisfied by how the task force is working. A key contribution to the success of the activities is given by the continuous support of the Garching-based EUROfusion Program Management Unit and of the IPP management and staff, and of course by all the task force members.

On the experimental side 2014 is a year fully dedicated to ASDEX Upgrade, since both TCV and MAST are presently shut down for upgrades and maintenance. The community showed strong interest in participating in the MST1 2014 campaign – which was concretely expressed with 3000 plasma discharges proposed in the experiment call. Such a large number exceeds the experimental time allocated to MST1 2014 in ASDEX Upgrade, but with the cooperation of the proponents and by exploiting synergies we have been able to optimise the programme and cluster most of the key proposals in 41 integrated experiments, which will be realized with approximately 600 plasma discharges. To ensure the best integration with the local team, two scientific coordinators have been selected for many experiments, usually with one from IPP and one from one of the other participating laboratories. ► 2

► Experiments have started and are proceeding smoothly according to the timeline, and an enthusiastic mixed IPP/international team is being built and is growing from week to week. In parallel we have also started a number of tasks, which deal with coordinating of modelling and analysis activities on specific areas – which will also help in strengthening the collaboration with the code development activity – and with activities in preparation of the TCV and MAST future exploitation within the MST1 campaigns.

We are working hard to make MST experience better and even more interesting and appealing. In this respect, comments, proposals and criticisms from the community are welcome and will all be very carefully considered. The hope is to build all together a well-focused science programme, which helps the advancement of fusion and is attractive and inclusive. A program where everyone “feels at home” and all have opportunities to exploit their skills and creativity.

PIERO MARTIN

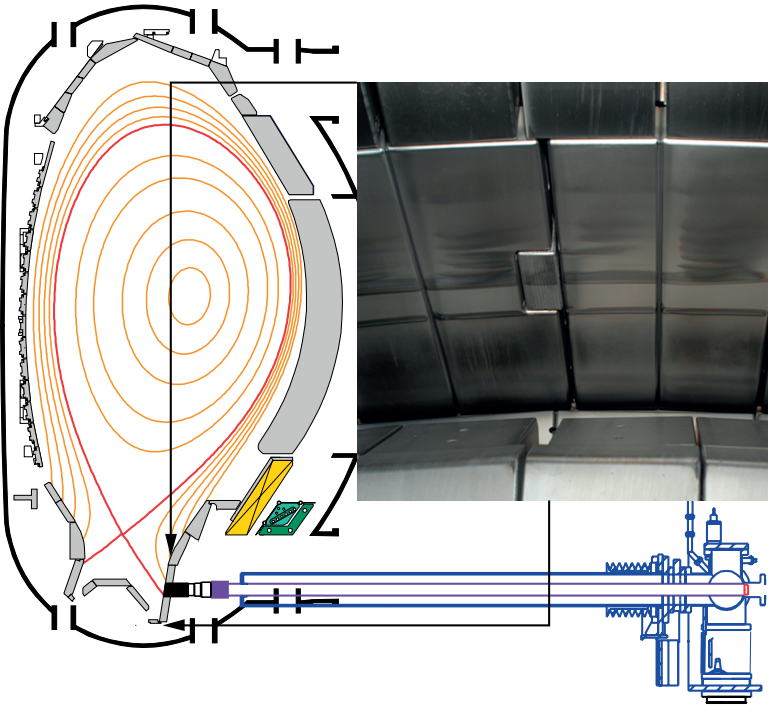
Investigating tungsten melt events in ASDEX Upgrade

Surface melting – a key issue for ITER operation

Highlight from a recent ASDEX Upgrade experiment

▼ Divertor manipulator (blue) included in drawing of ASDEX Upgrade cross-section and frontal view of the outer target plate with inserted sample.

GRAPHICS: V. ROHDE, K. KRIEGER



Current tokamak designs such as ITER foresee tungsten as material for the divertor target plate armour, based on the successful operation of ASDEX Upgrade with a full tungsten first wall. However, because of the much higher energy content of transient power excursions in larger devices, flash surface melting is an important issue for ITER. By repeated melting and re-solidification of the target plate surface tungsten melt can potentially pile-up over time. The resulting corrugated surface can lead to a serious degradation of the power-handling capability of affected wall components.

which can have a dramatic impact on the discharge, in some cases leading to thermal collapse and disruption of the plasma current. To assess the impact of these problems on ITER operation the evolution of melt damaged surfaces and the consequences of material ejection during melt events were studied in ASDEX Upgrade using a divertor manipulator, which allows exposure of material samples at the outer divertor plate where the power flux is highest. The samples featured castellated structures similar to those foreseen in ITER, however, with intentional misalignment as well-defined proxy for elevated surface corrugations.

Exposure of these structures in high power plasma discharges indeed provoked melting including ejection of molten tungsten into the divertor plasma. Films recorded with fast camera systems revealed that the ejected small droplets with a typical size of less than 100µm can survive for up to 0.1s and are generally retained in the divertor where they are carried away along the torus over distances of several meters (see cover page). Their trajectories can be well described by theoretical models of the main forces acting on the droplets, such as friction with the plasma and gravity. The additional tungsten atoms introduced into the divertor plasma by the evaporation of the droplets are mostly retained in that region similar to tungsten eroded even at well aligned target plates. Therefore ejected tungsten droplets generally do not impair the performance of the plasma discharge.

Moreover, during melt events droplets and re-solidified debris may be ejected from the target plate surface into the plasma,

Analysis of retrieved samples revealed, however, that molten tungsten is not only ejected but also flows along the material

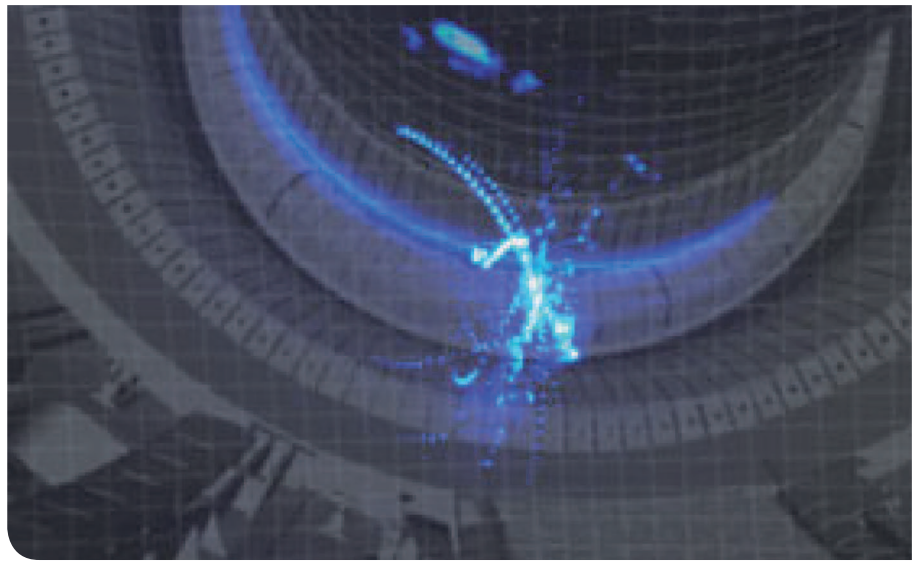
surface due to gravity and electromagnetic forces. The re-solidified melt is only loosely attached to the surface. Because of its thermal insulation subsequent plasma exposure will heat the deposits to much higher temperatures than that of the surface underneath. The resulting thermal stress can lead to spallation of the solid debris typically in perpendicular direction to the surface. Such trajectories allow the solid tungsten particles to cross the divertor and directly penetrate the main plasma (figure below). Even a tungsten grain as small as a pinhead contains enough atoms to produce impurity radiation losses exceeding the entire heating power. In this case the plasma discharge will

ultimately collapse. In ASDEX Upgrade this process occurs only with excessive steady state heat loads. However, in larger tokamaks such as JET, hot plasma filaments from unmitigated edge localised modes (ELMs) may carry enough energy to cause repetitive flash melting, which ultimately will also lead to pile-up of re-solidified material. These results demonstrate that the avoidance of frequent surface melt events is a key issue for sustained plasma operation in devices with tungsten divertors. Consequently the mitigation of ELM energies is one of the main objectives of current fusion research.

K. KRIEGER

► Trajectories of solid tungsten debris spalled from the sample surface after melting in the preceding discharge. View from top to the divertor with consecutive image frames superimposed.

PHOTO: J. COENEN (FORSCHUNGSZENTRUM JÜLICH), K. KRIEGER



Joint appointment by IPP and TUM

Rudolf Neu: Professor at the Technical University of Munich and head of a research group at Max Planck Institute for Plasma Physics

In January 2014 Dr. Rudolf Neu was jointly appointed professor at the Faculty of Mechanical Engineering of the Technical University of Munich (TUM) and head of IPP's Plasma-Wall Interaction project. Together with his group he is investigating the interaction between the hot plasma and the surrounding in-vessel components. Rudolf Neu started as a postdoc at Max Planck Institute for Plasma Physics in Garching in 1992. After serving as visiting scientist at Massachusetts Institute of Technology in the USA, he took his lectureship in Experimental Physics at the University of Tübingen in 2004, where

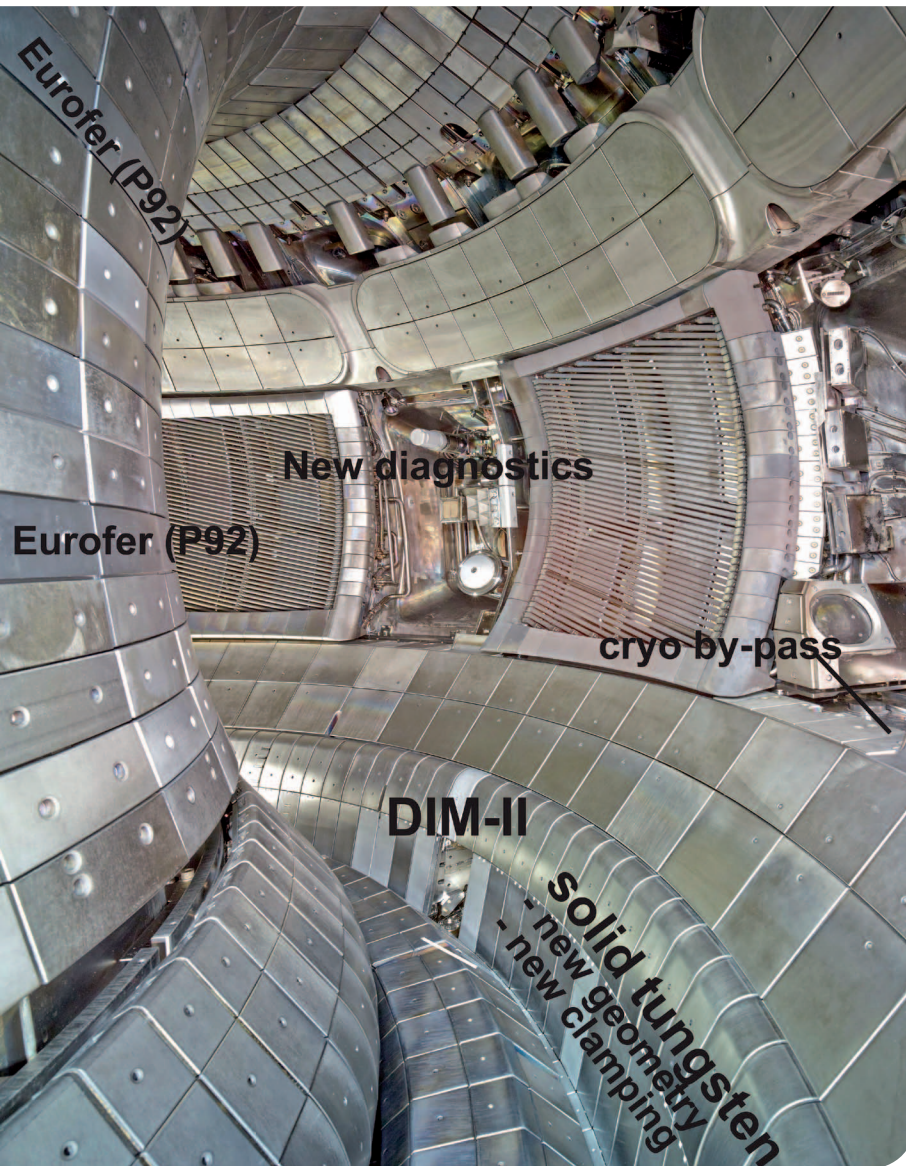


he was appointed professor extraordinary in 2011. From 2009 till 2012 he acted as a task force leader at the Joint European Torus (JET) coordinating the first experiments with the JET ITER-like wall. In 2012 he took charge of the ITER Physics Department at the EFDA European organisation. The joint appointment by IPP and TUM is to intensify their cooperation in the field of fusion and promote the research subject amongst young engineers.

Rudolf Neu

PHOTO: EFDA

Another step towards a reactor-relevant environment



▲ ASDEX Upgrade view with Div-III and the opening for DIM-II.

PHOTO: IPP

The ASDEX Upgrade mid-size tokamak has been in operation for more than 20 years or 30 000 discharges. During this period the operation capabilities have been permanently evolved in accordance with the physics research programme, which is focused on the development of a commercial fusion reactor. Major improvements were the installation of a second NBI box and the upgrade of the ECRH heating system. The need to operate a divertor with a technologically compatible heat load drives the divertor evolution. Accordingly, the open-divertor Div-I was replaced in a first step by an optimized lyre-shaped closed divertor, Div-IIa. Later divertor modifications kept the advantage of a vertical target plate for divertor cooling

but were more flexible with respect to the magnetic configurations allowed. Additionally, diagnostics were upgraded and new diagnostics were installed.

The modifications carried out during the shutdown in 2013 expanded the operational range of ASDEX Upgrade and facilitated significant contributions in solving physical but also design problems of future fusion reactors. The eight-month shutdown started at the end of April and ended early in December with two-week delay beyond the original schedule. The following main projects were realised:

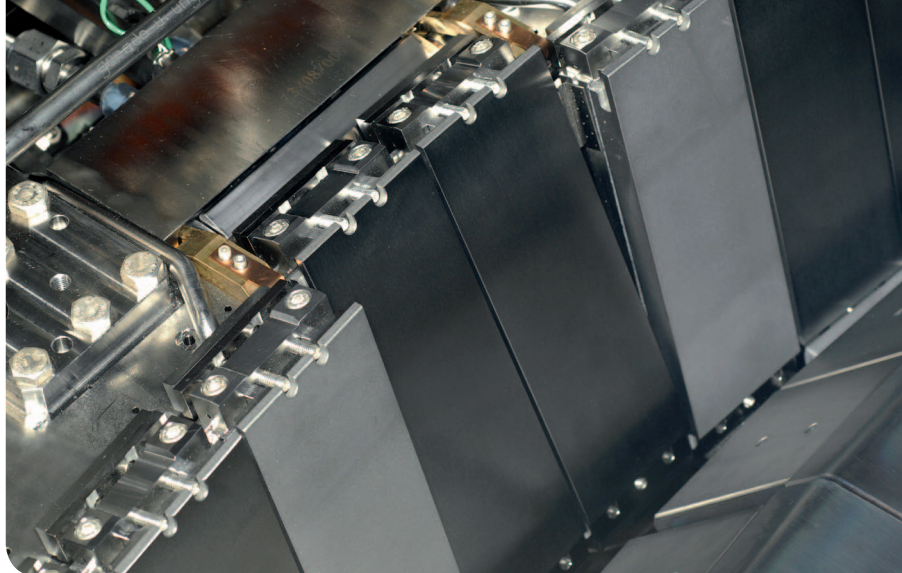
- installing a lower outer divertor with solid tungsten targets,
- modifying the divertor geometry to increase the effective pumping speed below the roof baffle,
- upgrading the cryo-pump to adjust the pumping speed,
- making a part of the outer divertor replaceable without venting of the vessel,
- replacing two rings of tungsten-coated graphite tiles with Eurofer-compatible ferritic steel in preparation for DEMO,
- upgrading the diagnostic capabilities for divertor, edge and core investigation.

ASDEX Upgrade became a full-tungsten experiment in 2007. At this time all plasma facing components were coated with tungsten. To overcome the disadvantages of the coating – i.e. delamination of thick coatings, fast erosion of thin coatings – ASDEX Upgrade started in 2010 to prepare a new outer divertor with solid tungsten at the outer strike line. Using solid tungsten instead of tungsten-coated graphite required a modified support structure, mainly because of the ten times higher specific density of tungsten. This is why the new Div-III design allows assembly of solid-tungsten target tiles inside the vessel onto the pre-assembled support and cooling structures.

The Div-III design was verified by extensive FEM calculations and high heat load testing of the target and its clamping structure up to a three fold overload in the high heat flux test facility GLADIS. The Div-III concept was approved early in 2012 and the in-vessel modifications were prepared.

► View into the outer divertor, Div-III, with DIM-II. The two retractable target tiles are shown shortly before reaching the final position.

PHOTO: V. ROHDE

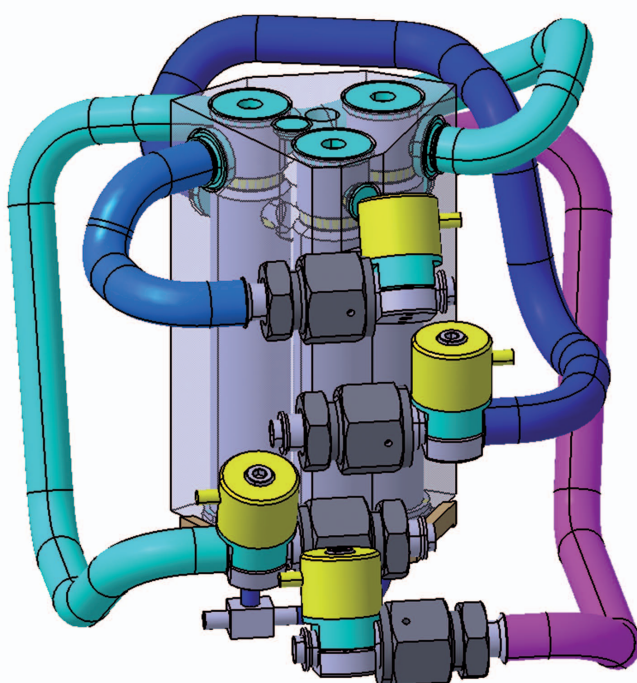


► During the 2013 shutdown, the outer divertor structure was dismantled, the old cooling structure was removed from the mechanical support, and the new cooling and target clamping structures were installed. The completed and leakage-tested new divertor structure was then installed and aligned inside the vessel. In a last step, the new solid-tungsten tiles were fixed to the cooling structure.

The redesign of the outer divertor geometry was a chance to increase the pumping efficiency in the lower divertor by increasing the gap between divertor and vessel. This increases the conductance between roof baffle and cryo-pump, which is

▼ CAD model of the cryo by-pass valve, consisting of three single valves for liquid helium. Shown are also the external connectors and temperature sensors.

CAD: M. SOCHOR



located behind the outer divertor. We expect that this results in a lower density in the outer scrape-off layer and consequently in a better overlap between ASDEX Upgrade, JET and ITER SOL parameters.

To keep the option for operation with high SOL densities, a by-pass valve was inserted in the cryo-pump, allowing ASDEX Upgrade to be operated with full or 1/3 of the pumping speed. The cryo by-pass developed and manufactured by IPP had to be integrated in a very limited volume. Extensive tests of functionality and qualification of the welding and assembly procedure were conducted before installation at a spare octant of ASDEX Upgrade to minimize the risk of malfunction.

Safe divertor operation and heat removal is becoming more and more significant for future fusion devices. This requires developing ‘tools’ for divertor heat load control and optimising divertor technology and geometry. Whereas the target concepts can be tested in high heat flux test facilities such as GLADIS at Garching, the target behaviour under plasma conditions has to be investigated in a fusion experiment. Here, the new divertor manipulator, DIM-II, offers a variety of possibilities. DIM-II allows a two-target-wide part of the divertor to be retracted into a target exchange box without venting ASDEX Upgrade via a rail and driving-rod system. Different ‘front ends’ can be installed and exposed to the plasma. At present, front ends for probe exposition, gas puffing, electrical probes and actively cooled prototype targets are under construction.

Installation of solid tungsten, control of the pumping speed and flexibility for divertor modifications on a weekly basis is a unique feature of ASDEX Upgrade and offers, together with the extended set of diagnostics, the possibility of investigating dedicated questions for a future divertor design.

A. HERRMANN

ASDEX Upgrade starts operation as MST

Reorganisation of the European Fusion programme, starting in 2014, has significant implications for ASDEX Upgrade operation. According to the EU Fusion Roadmap, there is a programme on 'Medium Sized Tokamaks' (MSTs) that is managed by a European Task Force and is open to all former EU Associations, now called Research Units. The eligible MST tokamak experiments are ASDEX Upgrade, MAST and TCV. With MAST and TCV undergoing major upgrading in 2014, ASDEX Upgrade is the only device running under the MST programme in 2014. This leads to a large percentage of the 2014 ASDEX Upgrade programme being run under MST – about 40 days of operation, which is about 50 per cent of the 2014 campaign!

While this entails a major change in the way the programme is managed, IPP is well prepared since EU collaboration has been a major part of ASDEX Upgrade operation for the last ten years, with formal structures such as the International ASDEX Upgrade

Programme Committee and the programme being organised in Task Forces, typically four to five in number, with one Task Force Leader coming from the associations. In the new MST structure, however, there is a more formal separation between the ASDEX Upgrade part of the MST programme and the IPP internal programme, but the main goal in all preparation has been to converge to a single

scientific programme, avoiding duplication and friction. For that purpose, the internal ASDEX Upgrade Task Force Leaders act as Contact Persons for the MST Task Force. Also, the ASDEX Upgrade publication rules are adapted to the new situation, but still in

the spirit that on-site presence and scientific discussions with the whole ASDEX Upgrade Team are a necessary part of a successful experiment. Finally, while there is now a clear formal separation of MST and IPP internal discharges, which is also needed to provide the necessary accountability, the programme is executed as a single, scientifically coherent programme.

As a consequence of the new structure, the first general Planning Meeting for MST was held jointly with the Annual ASDEX Upgrade Programme Seminar in Beilngries, Germany, October 21-24, 2013. This was well accepted by the scientific community, resulting in participation of 130 scientists, roughly 50 per cent of them being from outside IPP. In the discussions, it became clear that the MST part of the ASDEX Upgrade programme in 2014 has major programme features in common with the goals of the IPP internal part, meaning that there should be great synergy between the two. Strong added value from the increased collaboration is thus expected.

Meanwhile, the 2014 campaign has started and the MST Task Force holding regular meetings, aided by video communication, as is evident from the snapshot. The number of preparatory meetings at IPP has definitely increased, and the logistics of hosting a large number of scientists who have chosen to work on ASDEX Upgrade is proving to be challenging. However, with the first discharges under the MST programme, IPP can take advantage of the new possibilities. Furthermore, from 2015 on, work under MST will also integrate part of the operation of TCV, and later MAST Upgrade, substantially enhancing the possibilities for excellent scientific work in the EU Fusion Programme.

H. ZOHRM

▼ Video communication:
Snapshot from the first weekly MST Task Force Meeting – an impressive participation.

SCREENSHOT: P. MARTIN

