ASDEX Upgrade Letter

No. 7/March 2005

Foreword

During the 2004 ASDEX Upgrade experiments, the tungsten coverage of all plasma facing components was 65 per cent, thus progressing further towards a C-free machine. The spectroscopic diagnostic of W has been extended and refined in order to identify impurity sources and to study impurity transport. The atomic physics basis for W is being constantly improved including cooling factors of W. The study of impurity transport has revealed that coefficients are close to neoclassical values in the plasma centre. In the absence of MHD instabilities, this can lead to impurity (W) accumulation. However, this problem can be avoided by central wave heating to increase locally the anomalous transport.

In a full high-Z machine carbon radiation must be replaced by feed-back controlled addition of noble gases like argon. This may lead to an unstable behaviour when ELM frequencies become too low. Therefore, integrated exhaust control has to combine ELM pace-making with feedback controlled impurity seeding (see highlight).

The main mission of the ASDEX Upgrade programme is the preparation of the physics base for ITER. This comprises elements that directly influence the design of ITER components, but also, during ITER construction, the preparation of ITER operation. For the latter we envisage two main lines: the consolidation of the standard scenario, i.e. the ELMy H-mode and the exploration of new scenarios, such as Hybrid or AT scenarios. In order to achieve these goals, it will be necessary to continuously upgrade the ASDEX Upgrade tokamak. At the Ringberg programme seminar in October 2004, an intense discussion within the ASDEX Upgrade team including the European partners was held on this subject. The outcome, a possible route for ASDEX Upgrade hardware extensions in the coming framework programme, is described in this issue.

K. Behringer

Possibilities for ASDEX Upgrade Hardware Extensions

Based on discussions at the last Ringberg programme seminar, a strategy for ASDEX Upgrade (AUG) hardware extensions was developed that could put AUG in a unique position for the EU Accompanying Programme in the fields of wall material studies, NTM stabilisation and advanced tokamak studies. Together with the currently discussed enhanced performance phase of JET beyond 2006, synergies from operation of both upgraded tokamaks can be expected and will be beneficial for the preparation of ITER.

Period 2005 - 2007

The following items will enable us to answer immediate questions linked to open design issues or consolidation of the standard scenario for ITER. They are extensions of existing successful programmes, i.e. the W first wall programme and NTM stabilisation by ECCD. They also offer early opportunities to extend studies on advanced operational scenarios.

Tungsten first wall:

W as first wall material is becoming more and more attractive for ITER and even more for DEMO, where C can no longer be tolerated as wall material. Based on the recent success with increasing coverage of the first wall components by W, the aim is to convert AUG into an all-W device. Complete elimination of C is necessary to learn how to radiate substantial fractions of the power from the SOL and divertor plasma, a role presently played by C. It will need at least two further shutdown periods to achieve complete coverage by the end of 2006. This activity must be pursued with high priority to be in time to give input to an ITER decision on first wall materials.

ECRH system:

Based on the pioneering work done by AUG in the area of NTM stabilisation by ECCD, ITER now plans to use this method to guarantee achieving its goal of Q = 10. Therefore, a medium term aim of the AUG programme is demonstration of routine NTM stabilisation. This requires an upgrade of power and pulse length (present system: 2 MW at 140 GHz, pulse length 2 s) as well as fast steerable launchers (see ASDEX Upgrade Letter No. 6) for feedback of the deposition location. Other applications are sawtooth control, ELM tailoring and current profile control in advanced scenarios. The first part of this upgrade has already started, consisting of two multi-frequency gyrotrons at the 1 MW-level and 10 s pulse length. A two-frequency tube (105/140 GHz, see fig. 1) has been delivered to IPP in January 2005. We propose to add two more multi-frequency gyrotrons in the near future, so that with the final system 4 MW for 10 s at variable frequency should be available.

Fig. 1: Two-frequency (105/140 GHz) gyrotron (GYCOM).

Modular generators:

The present flywheel generators are not sufficient to run strongly shaped plasmas at the highest plasma currents, which is very important for developing ITER relevant scenarios. Operation at high plasma current will extend the accessible ρ* range. Therefore, we have explored possibilities to upgrade our generator system using smaller modular units. One unit provides 8 MW and 36 MJ. A medium term goal is the procurement of 5 units, which would enable operation of AUG with strong shaping (δ > 0.4) even at I_p = 1.4 MA.

Period 2007 - 2010

In this period and beyond, ITER preparation will focus more on the exploration of new operational schemes. In addition to the ongoing studies on hybrid scenarios with flat shear, we will also shift focus to reversed shear operation as the ultimate steady state scenario. Due to technical constraints on the current ramp rate, reliable creation of reversed shear plasmas is at present not easily achievable so that an additional current profile control method (i.e. LHCD) is necessary.

In order to overcome the lower stability limits of reversed shear plasmas, we have to rely on wall stabilisation, which needs a passive shell much closer to the plasma than the present wall. In addition, internal coils are foreseen to actively control the MHD instabilities occurring on the timescale of the wall (RWMs). This aspect, important for ITER advanced mode operation, is at present not covered in the EU tokamak programme.

Internal coils:

This system, which is ultimately thought to be part of the wall stabilisation experiments, has several other interesting applications, such as rotation control, ELM tailoring and tearing

Highlight

from a recent ASDEX Upgrade experiment

Integrated exhaust control in ASDEX Upgrade

Radiative cooling by injection of noble gases has recently experienced a revival in ASDEX Upgrade (AUG). The reason is the ongoing transformation of AUG into a full tungsten-coated tokamak, which raises new physics issues essential for an ITER phase with tritium operation and a fusion reactor in general. Maximum radiative power exhaust was the goal of former studies of the completely detached H-mode (CDH-mode). Nowadays, integrated scenarios are the goal where not only one plasma parameter is optimised, but as many as possible at the same time, favourably employing independent feedback control loops.

Radiative power exhaust is an issue of rising importance, since the ongoing process of eliminating carbon in AUG reduces the intrinsic radiative losses. In Fig. 4 the outer divertor power load of the intrinsic discharge phase is compared with the one where integrated exhaust control is applied. This latter phase had simultaneous feedback control of the divertor neutral density, which is a direct measure for the particle exhaust rate, and the divertor temperature, which determines the conductive power exhaust through the divertor plates. Input data for the feedback loop are the neutral divertor flux from an ionisation gauge and the temperature in terms of thermoelectric currents between inner and outer divertor. Actuators are several Deuterium valves and an Argon valve located in the outer midplane. However, the presence of large tungsten surfaces requires control of the ELM frequency as well: radiative cooling reduces the type-I ELM frequency and is accompanied by improved core particle confinement. The combination of both effects often leads to a strong rise of the tungsten concentration in the plasma and to a self-amplifying loop of radiation increase and reduced ELM frequency. Consequently, the latter must be kept above a minimum value, which is achieved by repetitive pellet injection. Each pellet triggers an ELM and thus the frequency stays sufficiently high, while the ELM power pulses are mitigated (see ASDEX Upgrade Letter No. 6). In the 'cooled' phase (see fig. 4) a drastic reduction of the power load between ELMs is observed, while important dimensionless parameters (β_N, H98, $f_{Greenwald}$) meet reactor requirements. By adding central ICRH heating, the tungsten concentration derived from soft-X spectroscopy could be kept below 10^{-5}, which would be sufficiently low for ITER.

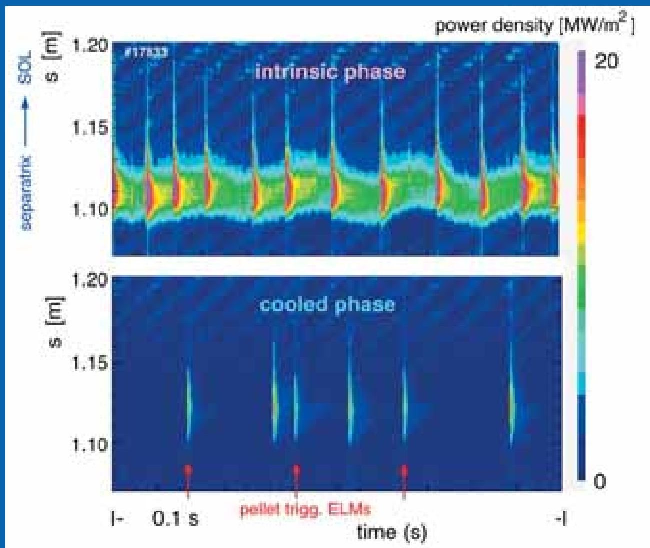

Fig. 4: Power load at the outer divertor for a discharge with integrated exhaust control. Inter-ELM phases show a drastic reduction of power load, while the ELMs have slightly reduced peak power. Important dimension meet reactor requirements: $\beta_N = 2.7$, *H98(y,th,2) =1.15,* $f_{Greenwald} = 0.83$

ITER currently plans a similar transition to W after an initial phase with a material mix of C, Be and W. Here, AUG can already supply key expertise. Furthermore, successful full-tungsten operation may even lead to a revision of the ITER design towards a fast track to a full tungsten machine, which would then require integrated exhaust control from the very beginning.

mode control. Since these applications do not require the nearby conducting shell, we propose to install it as a first step of the package in the years 2007 to 2008. A preliminary design study arrived at a 24 coil-system, with 8 coils along the toroidal circumference, at 3 poloidal locations around the outer midplane (see fig. 2), capable of controlling n = 1 and n = 2 modes at q_{95} of 3 - 5.

LHCD:

This system is needed for off-axis CD to reliably create and maintain reversed shear profiles. A preliminary design study showed that a system with an installed power of 5 MW at 3.7 GHz would be sufficient for this purpose. The launcher could be of the PAM type (about 40 active waveguides to achieve $N_{par} = 2.5$), which is technically

Fig. 2: Schematic drawing of a conducting shell (green) together with active coils (red) close to the plasma with openings to give access for heating and diagnostic systems. The passive stabilizing loop (blue) is part of the current AUG setup.

relevant for ITER. In view of the envisaged increased collaboration between Associations in the Accompanying Programme, we propose to start this activity in collaboration with other EU Associations who would take over substantial responsibility for design, construction and operation of the system.

Conducting shell:

This item should be pursued in combination with the LHCD system. Also here, it is foreseen to find partners in the EU who engage in design, installation and operation of the system. A design study using full 3D-geometry, showed that taking into account the need for diagnostic and heating access, the shell should be located at a radius of $r_{Wall}/a \approx 1.2$. In combination with this item we would also aim at replacing the existing ICRH antennas with newly designed ones that fit the conductive shell constraints, but also have a better spectrum for ICCD.

Preparation of the 2005 experimental campaign

A new Task Force structure for campaigns 2005/6 was defined by the ASDEX Upgrade Programme Committee at its meeting in July. The aim is to streamline the programme and to make it more focussed to slightly fewer high priority topics. The preparation and execution of the experimental programme is now organised under four Task Forces:

Fig. 3: Group photo during a coffee break of the 2004 AUG Programme Seminar at Ringberg Castle.

I. **Improvement of H-mode and integrated scenarios,**
   TFL: V. Mertens / J. Stober
II. **Pedestal physics including tolerable ELMs,**
   TFL: W. Suttrop
III. **SOL & Divertor physics and first wall materials,**
   TFL: A. Herrmann
IV. **MHD instabilities and their active control,**
   TFL: P. Martin, ENEA, RFX Padova

The continuation of the scientific exploitation of AUG by European scientists is reflected by the leadership of Task Force IV by P. Martin, a scientist from ENEA RFX Padova, Italy. He is already the second non-IPP scientist who is managing an AUG Task Force, succeeding D. Borba, IST, Portugal. In August 2004 a Call for Participation in 2005 AUG campaigns was sent to all EURATOM Associates as well as to institutes of EU accession states. It was answered by 16 institutes who submitted more than 40 experimental proposals. Altogether these proposals will make up around 30 per cent of the 2005 programme. The IPP Garching is grateful for this valuable contribution to the AUG Programme. The annual Programme seminar at Ringberg Castle attracted almost 30 non-IPP scientists including participants of the new EU countries. An external participation of almost 40 per cent was reached. The execution of the 2005 Programme has started successfully at the end of January.

ASDEX Upgrade Letter
published by
Max-Planck-Institut für Plasmaphysik
Association Euratom-IPP
Boltzmannstraße 2
D-85748 Garching
www.ipp.mpg.de

Coordination Prof. Dr. Hartmut Zohm
Contact Dr. Josef Schweinzer
Phone +49/89/3299-2205
Fax +49/89/3299-2580
E-Mail josef.schweinzer@ipp.mpg.de