

ITER IO Urgent Tasks: Pedestal Group Response

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A number of urgent R&D issues have been identified by the ITER IO. This note identifies those that the ITPA pedestal group is best-placed to address, proposes an updated work plan and reports progress since the previous note. This work plan assumes that adequate resources are provided by the organisations of the ITER partners. The plan will remain flexible and will continue to be modified as new devices around the world reach maturity and begin to contribute H-mode data, and as knowledge improves. The first plan was constructed in December, 2008. This is version 2, taking account of developments and summarising progress over the past 6 months. It will continue to be a “live” document, to be updated each six months.

The focus here is on *urgent* ITER issues; less urgent, but nevertheless important, issues will be addressed in parallel with this programme (aiming to avoid them becoming urgent). The interested reader should consult the summaries of the Pedestal group meetings for progress in these areas. There are five main areas (urgent issues) that the group will address:

1. Conditions for ELM suppression using resonant magnetic perturbations
2. Conditions for ELM pacing using pellets
3. Impact of the TF ripple on the pedestal characteristics
4. The impact of heating source on pedestal structure and ELM size
5. L-H transition physics

We have established five working groups to drive these areas forward under the leaderships of (1) Max Fenstermacher, (2) Peter Lang, (3) Naoyuki Oyama, (4) Phil Snyder and (5) Roberta Sartori. Note that area (5), the physics of the L-H transition, is a new area. It will be performed in collaboration with the Transport and Confinement group; this note identifies those tasks for which the Pedestal Group has the main responsibility.

We have defined a number of objectives to address these ITER urgent issues. These in turn will be met through a set of specific tasks that will involve both theory and experiment. In some cases, the necessary data and theoretical models/codes will already exist while in others new experiments and theoretical models will need to be defined. More detailed descriptions of the progress towards meeting the objectives of the Working Groups is described in the summary reports of the ITPA meetings. These, together with individual presentations made at the meetings, can be accessed from the pedestal group web-site at <http://itpa.ipp.mpg.de/>.

1. ELM suppression with RMP coils

Motivation:

It is extremely likely that control of Type I ELMs will be necessary for ITER to meet its objectives fully. Coils to provide resonant magnetic perturbations (RMPs) are presently the only tool available known to suppress the ELMs in such high performance regimes. However, the technique has only been proven on DIII-D to date and the physics remains uncertain. The work plan presented here aims to improve our understanding, and so reduce uncertainties in ELM control scenarios for ITER.

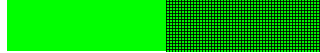
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Objective Task

1.1 (a) Suppress ELMs using RMPs on MAST



1.1 (b) Suppress ELMs using RMPs on AUG



1.1 (c) Explore potential to mitigate/suppress ELMs with mid-plane coils (NSTX, JET)



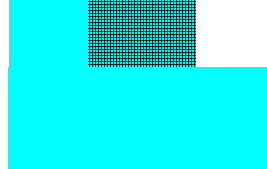
1.2 (a) Model and compare vacuum RMP field for MAST and DIII-D with suppressed ELMs



(b) Test model based on min stochastic width and alignment of perturbation with q against MAST and DIII-D data. Identify other important parameters



1.2 (c)



- 1.3 Quantify the impact of ELM suppression by RMPs on the pedestal pressure and core confinement and develop/validate theoretical models
- 1.4 Quantify the power loading on the walls and divertor with RMP-suppressed ELMs; make recommendations on any requirement for rotating RMPs
- 1.5 Explore the capability to suppress or mitigate ELMs during the current ramp phase (ie close to the L-H transition threshold, and with q_{95} varying with time).
- 1.6 Demonstrate ELM control with ITER-like pellet fuelling
- 1.7 Model the performance of the ITER ELM control coil set, and propose changes to the design as appropriate. This is likely to require further developments in modelling the plasma response, which is very challenging.

Capability:

A large number of tokamaks have ELM control coils, including DIII-D, MAST, NSTX and JET. Of these, only DIII-D and MAST have coils off the mid-plane, as planned for ITER, and therefore these have a particularly key role to play in this area. In addition, ASDEX Upgrade will have ITER-relevant RMP coils from mid (to late)-2010, that should provide important input on the required time-scale. A number of codes exist that can calculate the vacuum response to

Related joint experiments

A number of the joint experiments play an important role in meeting the objectives:

PEP-19 “*Basic mechanisms of edge transport with resonant magnetic perturbations in toroidal plasma confinement devices*” DIII-D, MAST, NSTX, TEXTOR-DED

PEP-23 “*Quantification of the requirements for ELM suppression by magnetic perturbations from internal off mid-plane coils*” ASDEX Upgrade, DIII-D, JET, MAST, NSTX

PEP-25 “*Inter-machine comparison of ELM control by magnetic field perturbations from midplane RMP coils*” ASDEX Upgrade, DIII-D, MAST

2. ELM pace-making with pellets

Motivation: If pellets can be used to trigger ELMs and increase their frequency

Objective Task	Q1-09	Q2-09	Q3-09	Q4-09	Q1-10	Q2-10	Q3-10	Q4-10
2.1 (a) Demonstrate pellet-triggered ELMs at ten times the natural ELM frequency in JET in a low natural ELM frequency regime (b) Demonstrate pellet-triggered ELMs at ten times the natural ELM frequency in JET in ITER-relevant scenarios								
2.2 (a) Quantify the dependence of ELM size on frequency for pellet triggered ELMs and constant, ITER-relevant density (JET)								
2.3 (a) Quantify the minimum pellet size required to trigger an ELM (AUG, DIII-D, JET) 2.3 (b) Quantify the minimum penetration required to trigger an ELM (AUG, DIII-D, JET)								
2.4 (a) Explore whether ELMs can be triggered by pellets arbitrarily close to the L-H transition (JET, AUG, DIII-D) 2.4 (b) Compare pellet-triggered and natural ELM phenomenology (JET, AUG, DIII-D) 2.4 (c) Measure edge flow profiles at the time of pellet injection (JET, AUG, DIII-D) 2.4 (d) Compare proximity to peeling-ballooning boundary for cases when pellets do, and do not, trigger ELMs (JET, DIII-D, AUG) 2.4 (e) Based on above measurements, develop a model for pellet-triggering by ELMs (modelling)								
2.5 (a) Explore ability to trigger ELMs at different injection angles and compare (JET, AUG, DIII-D)								
2.6 (a) Explore compatability of pace-making/fuelling; do ELM-triggering pellets fuel same as fuelling pellets? (JET, AUG, DIII-D) 2.6 (b) Compare pedestal structure with and without pellet pace-making (JET, AUG, DIII-D)								
2.7 (a) Explore alternative pellet options, such as C, B, etc, for triggering ELMs (AUG) 2.7 (b) Assess impact of alternative pellets on edge impurities and confinement (AUG)								
2.8 (a) Model pellet pace-making in ITER and provide input to ITER pellet launcher								

Figure 2: Work plan for pellet pace-making studies for ITER. Hashed areas denote extensions to deadlines.

Work plan and time-scales

Figure 2 shows the work plan and time scales for the devices that are expected to contribute. JET is a key device for ELM pellet pace-making experiments (high volume, so minimal fuelling from small pellets), but it is expected to be unavailable for experiments from autumn 2009 to the end of 2010. It is important, therefore, to carry out the necessary JET experiments in the next few months so that the key results for ITER are obtained and further research to firm up/expand these findings can progress in ASDEX-Upgrade and DIII-D until the end of 2010.

Progress

Delays in the new pellet-pacemaking system on JET have meant that experiments have been confined to using the fuelling pellets. Results confirm those found on AUG. On DIII-D, the pellet dropper has yet to successfully trigger ELMs. The high frequency pellet injector is expected to be available on JET towards

the end of the summer to enable a campaign directed towards the objectives of this working group before JET shuts down for an extended period. There is information on the minimum pellet depth required to trigger an ELM: the pellet triggers the ELM before it is half way into the pedestal region. On DIII-D, when RMPs are applied, the pellets must penetrate a little deeper into the pedestal to trigger the ELM.

Related joint experiments

A joint experiment has been proposed that makes a substantial contribution to the objectives:

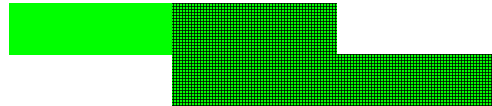
PEP-24 “Minimum pellet size for ELM pacing” ASDEX Upgrade, DIII-D, JET

3. Impact of TF ripple

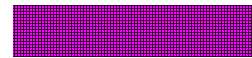
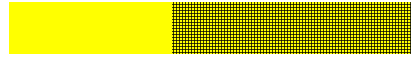
Motivation: Toroidal field (TF) ripple can a

Objective Task

- 3.1 (a) Analyse existing data to quantify the link between TF ripple amplitude and pedestal performance (JET, JT-60U, DIII-D, AUG)
- (b) Assess the impact of the ripple on pedestal performance, varying the ripple size by radial displacements of the plasma



3.2



Work plan and time-scales

4. Pedestal structure

Motivation: The overall performance of ITER will depend to a large extent on the pressure at the top of the pedestal. Two effects influence this: the pedestal width and the pressure gradient in the pedestal region. Ideal MHD is likely to set the maximum achievable gradient (though it is possible that two-fluid effects like diamagnetism may permit higher gradients in certain regimes). Recent experimental data suggest that the pedestal width scales as the square root of p , and weakly with n . Together, these results provide a prediction for the pedestal height on ITER. One issue where uncertainty remains is whether or not the pedestal height depends on the heating source. It is important to test this before a final decision on the mix of heating power for ITER is taken, so this is an urgent issue. A related issue is how ELM type/size depends on the heating power mix. Other, less urgent (but nevertheless important), issues to address include characterising the transport processes in the pedestal, and developing an understanding of the density and temperature pedestal heights.

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Objectives:

- 4.1 Explore whether the pressure pedestal height and width depend on the heating source, quantify any differences and interpret in terms of emerging models for pedestal height
- 4.2 Explore whether the density pedestal properties depend on heating source (e.g. through modified fuelling sources; i.e. enhanced core fuelling with NBI compared to that with ICRF)
- 4.3 Assess the impact of heating source on ELM size and explore prospects for interpretation in terms of peeling-ballooning theory
- 4.4 Quantify the impact of torque on the pedestal structure and ELMs
- 4.5 Assess the potential viability of QH mode as a high pedestal, ELM-free regime for ITER
- 4.6 Develop theoretical models for the observed scaling of pedestal width with plasma parameters

Capability

Several devices have the capability to address the urge

4.1 (b) Test EPED1 model for pedestal height holds independent of heating power mix (theory, All H-mode tokamaks)								
4.2 (a) Compare density pedestal structure with different mixes of NBI and RF heating (DIII-D, AUG, JET, NSTX)								
4.3 (a) Quantify impact of heating mix on ELM type (DIII-D, JET, AUG, NSTX, CMod, JT-60U)								
4.3 (b) Interpret experiments in 4.1(a) and 4.4(a) in terms of peeling-ballooning theory								
4.4 (a) Quantify impact of torque input on pedestal structure for beam-heated discharges (DIII-D, JT-60U)								
(b) Quantify impact of torque input on ELM type for beam-heated discharges (DIII-D, JT-60U)								
4.5 (a) Identify the required range of density expected to allow QH mode operation in ITER								
(b) Identify the required range of flow (or radial electric field) shear required for accessing the QH mode								
4.6 (a) Provide a theoretical/computational model for observed scaling of pedestal width with plasma parameters.								

Figure 4: Work plan for Urgent Pedestal Structure issues for ITER

Progress

Stability calculations have continued to provide a useful way of exploring the pedestal structure and ELM characteristics in terms of the peeling-ballooning theory. Experimental observations continue to suggest weak or no dependence of the pedestal width on gyroradius. Plans have been discussed, including a range of tokamaks and lead people, to initiate experiments to explore how (or whether) pedestal structure depends on heating source. Some data is available on the impact of torque on the pedestal structure and ELMs, but more work is planned. One result is that JT-60U finds a slightly lower pedestal height in counter injection, while DIII-D results indicate a weak, or no, effect at fixed (JT-60U experiments were at fixed power, not fixed). In light of recent progress in extending the parameter range of Quiescent H-Mode (QH) to a broad range of input torque, rotation, and density values, we have created a new objective focused on determining the potential viability of QH mode as a high pedestal, ELM-free regime for ITER.

Related joint experiments

A number of the joint experiments make important contributions towards meeting the objectives:

PEP-20 “*Documentation of the edge pedestal in advanced scenarios*” AUG, DIII-D, JET, JT-60U (analysis of existing data)

PEP-22 “*Controllability of pedestal and ELM characteristics by edge ECD/ECCD/LHCD*” AUG, C-Mod, DIII-D, JT-60U (analysis of existing data)

5. L-H Transition

Motivation: The aim of this Working Group, in collaboration with the Transport and Confinement ITPA group, is to reduce the level of uncertainty in achieving and maintaining H-mode on ITER.

The mechanism(s) responsible for the LH transition remain poorly understood. While it is thought that sheared flows play an important role, the mechanism for the spontaneous generation of flows remains unclear. There is therefore considerable uncertainty related to the trigger mechanism for the LH transition and, as a consequence, the power threshold for ITER. This is important as the heating power available to ITER may be marginal for accessing the H-mode, according to some scaling laws. There are three key issues that this group will address: (1) Does ITER have sufficient power to access H-mode and how can this be optimised? (2) Can it stay in high performance H-mode as density and current are increased to achieve the fusion performance? (3) Is the quality of the H-mode with the heating power available on ITER sufficient to access $Q=10$ regimes? In the second issue, the group will document and aim to understand the circumstances under which there is a transition to a lower confinement (Type III ELMing or dithering) H-mode, or indeed L-mode (e.g. due to the density increase, large ELM events, etc). These questions need to be addressed for each of the ion species planned for ITER.

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Objectives

- 5.1 Develop an understanding of the impact of radiated power on the L-H transition power threshold
- 5.2 Identify any possible dependence of the LH transition power threshold on the plasma heating mechanism and the impact of momentum injection.
- 5.3 Determine the characteristics of the H-mode when the power is marginally above threshold.
- 5.4 Characterise the conditions under which a high performance H-mode plasma makes a back-transition to a regime of reduced performance (e.g. Type III or dithering H-mode, L-mode) for fixed global plasma parameters (power, fuelling, etc)
- 5.5 Determine whether, and how, the LH power threshold is modified by current ramps.
- 5.6 Determine the dependence of the LH transition and pedestal characteristics on the plasma ion species
- 5.7 Provide a first-principles model of the LH transition.

Capability

There are many tokamaks around the world that can provide data on the LH transition: JET, DIII-D, JT-60U, MAST, TCV, ASDEX-Upgrade, NSTX, Alcator Cmod and, most recently, HL-2A. These have available a wide range of heating mixes: electron and/or ion heating: beam and/or rf; co, counter and balanced beams, etc. In addition, there are new diagnostics that are probing the pedestal characteristics with ever increasing spatial and temporal resolution. The international fusion community is therefore

well-placed to make a renewed attack on this long-standing issue for fusion to address urgent issues for ITER, particularly related to the level and mix of heating power, dependence on ion species, and scenarios to take the ITER plasma from L-mode, through the L-H transition and up to full performance, Q=10 H-mode.

Objective Task

5.1 (a) Quantify the impact of radiated power on the L-H transition power threshold and local parameters at the transition



5.2 (a) Compare the power threshold and pedestal/edge parameters required to enter H-mode for dominant electron and ion heating schemes



(b) Quantify the impact of momentum injection on the L-H power threshold, and develop an understanding in terms of local parameters

5.3

