USBPO U.S. BURNING PLASMA ORGANIZATION

eNews

July 22, 2011 (Issue 57)

CONTENTS

Dear Burning Plasma Aficionados:

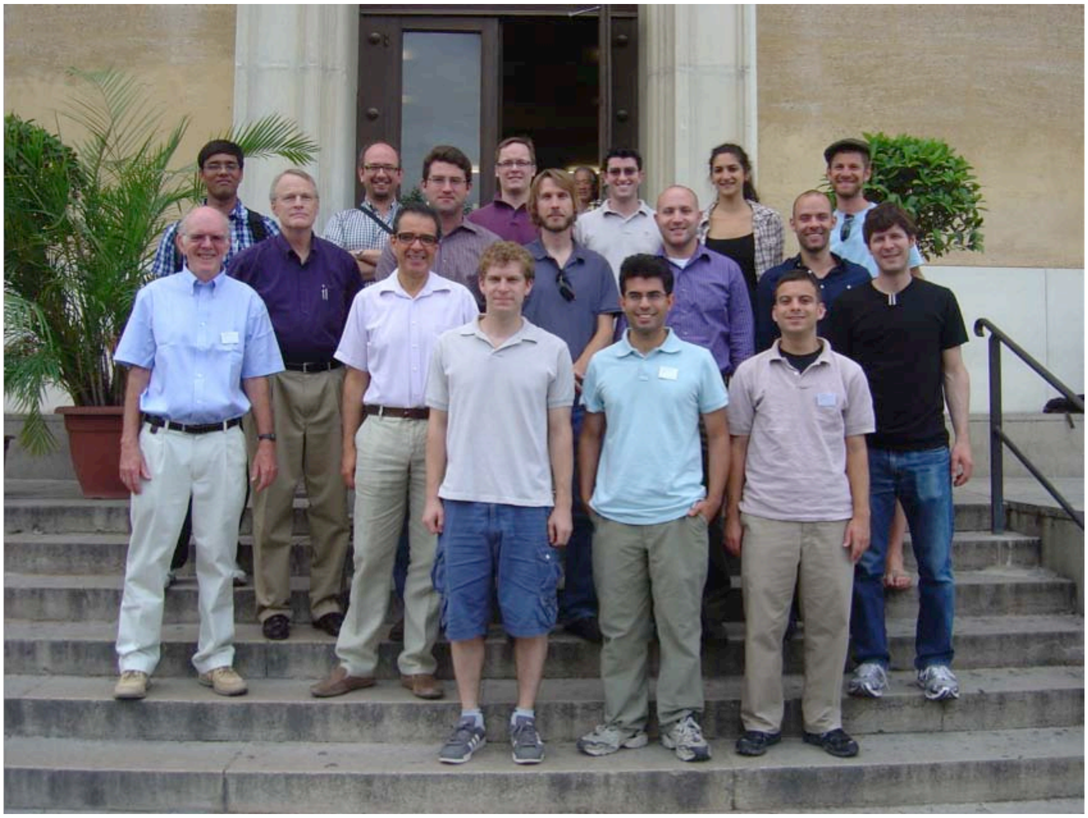
This newsletter provides a short update on U.S. Burning Plasma Organization activities. E-News is also available online. Comments on articles in the newsletter may be sent to the Editor (Tom Rognlien) or Assistant Editor (Rita Wilkinson). Thank you for your interest in Burning Plasma research in the U.S.!

Director's Corner by Jim Van Dam

2011 ITER International Summer School

The fifth in the annual series of ITER Summer Schools occurred recently in Aix-en-Provence, France, June 20-24. The School was held on the Aix campus of the Faculty of Law and Political Science of Paul Cezanne University. The theme of this year's School was "Energetic Particle Physics and Magnetohydrodynamics." The 18 lecturers, who gave 19 lectures during the week, were from the US (7 lecturers), Europe (6), Japan (2), Russia (1), India (1), and ITER Organization (1). I personally attended the School and presented one of the lectures. The schedule of lectures is posted on the School's web site.

Half of the "students" at the School were graduate students, the others being postdoctoral researchers, along with some more senior scientists interested in the topical area. There were approximately 65 student participants in total, coming from six continents (Europe, Asia, North America, South America, Australia, Africa). About half of the students (29) were collectively from Europe. In terms of official registrants, the most students from a single country came from the US (14). Of these, eight were USBPO scholarship awardees. I am grateful that the other US student participants received travel support from their home institutions—Princeton (PPPL), Tulsa, and Wisconsin. The US student participants invited me to have lunch with them on Tuesday, which I really enjoyed. We talked about their interest in burning plasmas and ITER, how to make a career in fusion physics research, and what they thought about the School. It was great to meet these talented young scientists.

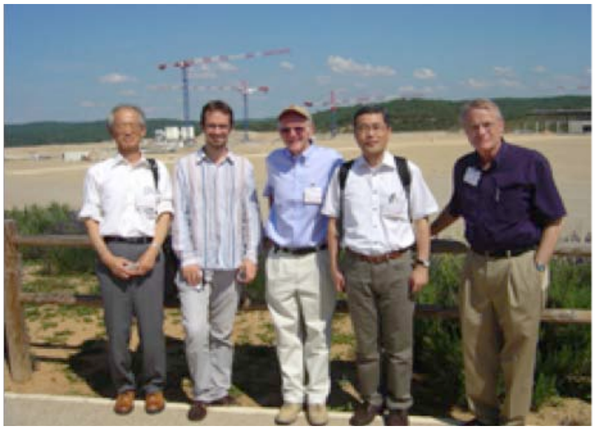


ITER International Summer School student participants from the US. Front level, left to right: Jonathan Koliner (Wisconsin), Carlos Paz-Soldan (Wisconsin), Aaron Bader (MIT). Second level: Wendell Horton (Texas), Sadruddin Benkadda (School organizer), Jason Sears (LANL). Third level: Jim Van Dam, Matthew Lanctot (LLNL), Ben Tobias (PPPL), Eric Bass (GA), Chris Muscatello (UC Irvine). Fourth level: two non-US students, then Josh King (UC Berkeley), Brendan Lyons (PPPL), Katy Ghantous (PPPL), Alex James (UCSD). Not shown: Michael Halfmoon (Tulsa).

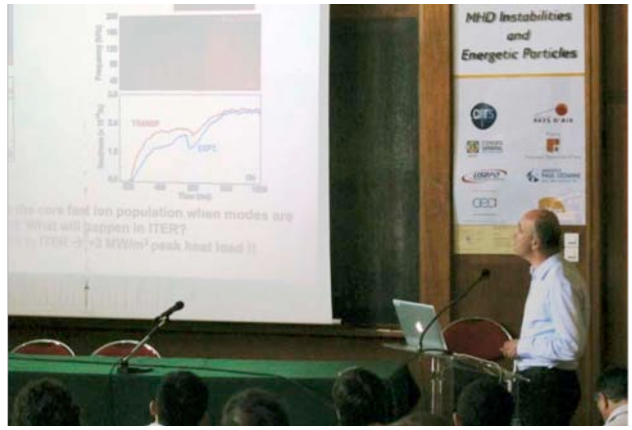
On Wednesday afternoon, the organizers of the School arranged a bus tour to visit the Tore Supra tokamak experimental facility at the CEA Cadarache laboratory and then to tour the ITER site. Amazingly, the bus drove us right onto the ITER site platform, alongside the Poloidal Field Coil Building, and then next to the tokamak pit, before we stopped at the Visitor Center.

Tokamak pit for ITER, 18 meters deep.

Future office headquarters for ITER Organization.



Standing at the Visitor Center, overlooking the ITER site.



Raffi Nazikian lecturing in the amphitheatre room at Paul Cezanne University in Aix.

On Thursday afternoon, during a two-hour poster session, many of the student participants exhibited their own work. I have to say that I was quite impressed by the high quality of the research described in these posters.

For the Closing Ceremony on Friday afternoon, ITER Organization Director-General Motojima was present to hand out the diplomas of participation to all of the students, congratulating each of them individually.

Members of the Steering Committee and the Scientific Committee for the School met on Wednesday evening. We heard a report about this year's meeting and discussed various suggestions for modifying the format and style of the School. Also, it was decided to hold the next School in Ahmadabad, India, hosted by the Institute for Plasma Research, probably in December 2012, on the theme of radio-frequency heating and current drive.

ITER Council Meeting

The eighth meeting of the ITER Council was held in Aomori, Japan, June 14-15, 2011. The location of the meeting in northern Japan was especially significant, coming three months after the Great East Japan Earthquake and associated tsunami catastrophe. A press release summarizing the two-day meeting can be found on the ITER web site.

Participants at the 8th ITER Council meeting in Aomori, Japan

Following the ITER Council meeting, ITER Organization Director-General Motojima toured the JAEA Naka Fusion Research Institute. Buildings for ITER-related technology testing—namely, the Superconducting Coil Test Facility Building, the Gyrotron Test Facility and the MeV-Class Ion Source Test Facility—were badly shaken by the earthquake, even though 300 km south of the epicenter. For safety reasons, entrance to the buildings is prohibited at the present time. DG Motojima viewed the damage and discussed the recovery plan with JAEA leadership. An article describing his visit to Naka can be found at the ITER web site.

New Leadership for ITPA Topical Groups

Each of the seven topical groups for the International Tokamak Physics Activity (ITPA) has an international leader and deputy leader, who serve three-year terms. This year is the year for leadership rotation. Recently, Dr. Yutaka Kamada, chair of the ITPA Coordinating Committee, with concurrence from the Contact Person for each of the ITER Members, announced the new line-up of leaders and deputy leaders.

Topical Group	New Leader	New Deputy Leader	ITER Organization Co-Leader
Diagnostics	Hyeon Park (KO)	Yasunori Kawano (JA)	George Vayakis
Energetic Particles	Kouji Shinohara (JA)	Sergei Sharapov (RF)	Sergei Putvinski
Integrated Operation Scenarios	Adrianus Sips (EU)	Tim Luce (US)	Joseph Snipes
MHD Stability	Ted Strait (US)	Piero Martin (EU)	Yuri Gribov
Pedestal	N. Oyama (JA)	Rajesh Maingi (US)	Alberto Loarte
SOL and Divertor	Emanuelle Tsitrone (EU)	Houyang Guo (CN)	Richard Pitts
Transport and Confinement	Darren McDonald (EU)	Ratneshwar Jha (IN)	Wayne Houlberg

Of the new leaders, Park, Shinohara, Sips, Strait, Oyama, and Tsitrone had been the former deputy leaders of their respective topical groups and are now promoted to the leader positions. (Actually, Dr. Shinohara had already moved up to leader of the Energetic Particles Topical Group early this year, when the previous leader stepped down early.) The recently announced ITPA leaders and deputy leaders will officially assume their positions in January 2012.

Let me also note a new US member of the Energetic Particles Topical Group: Dr. David Pace, currently working at the Plasma Science Fusion Center at MIT and soon to move to the University of West Virginia. He replaces Dr. Johan Carlsson (Tech-X). Our thanks to both of them.

National Undergraduate Fellowship Program in Fusion Plasmas

Some of the US students whom I had the pleasure of meeting at the ITER International Summer School in June had become interested in the field of fusion physics through their previous participation in the National Undergraduate Fellowship (NUF) Program in Plasma Physics and Fusion Energy Sciences. This summer program is funded by the U.S. Department of Energy, Office of Fusion Energy Sciences. The undergraduate participants, who have usually completed their junior year, spend one week at Princeton Plasma Physics Laboratory for an introductory course in plasma physics and then travel to participating universities and national laboratories throughout the country for nine weeks to carry out research projects. Mike Mauel, Chair of the USBPO Council, was one of the lecturers during the introductory first week this year. This is a really excellent program, and we should encourage our bright undergraduate students to apply for admission.

The NUF Program was initiated in 1992 by now Congressman Rush Holt together with Professor Nat Fisch, who has been serving as the Academic Director of the Program. (He, by the way, was also one of the lecturers at the ITER International Summer School this year.) The Program, which is run by Dr. Andrew Zwicker, draws about 25 students each year from universities all over the US, including those with no exposure to plasma physics as a discipline. Recently, the program was enlarged to allow for a few French students to participate at the same time that alumni of the NUF Program are studying in France. (My thanks to Nat Fisch and Mike Mauel for information about this program.)

USBPO Web Seminar

Mark your calendars: The next USBPO web seminar is scheduled for Tuesday, July 26, from 12:00 noon to 1:30 p.m. (Eastern Time). The topical groups and the speakers for this upcoming seminar are the following:

- *Diagnostics* — Rejean Boivin
- *Integrated Operational Scenarios* — Amanda Hubbard and Chuck Kessel

An email with instructions for connecting to the web seminar will be sent to all USBPO members.

Fusion Miscellany

I'm indebted to Steve Dean of Fusion Power Associates for pointing out this article: "*Dreams of Fusion Power: I'm Not the Only One*", by Steven Pomeroy (May 16, 2011).

ITER *Newsline* has published a photograph of the 500-seat amphitheater that is being constructed in the new headquarters office building. We all hope to be sitting in this room some day soon, hearing exciting results from ITER experimental operation.

Future amphitheater in the ITER office building (photo courtesy of ITER Organization)

USBPO Topical Group Highlights

(The BPO Integrated Scenarios Topical Group works to facilitate U.S. efforts to understand and predict the behavior of whole-device operation in existing and future fusion devices including collaboration with international partners [leaders are John Ferron and Amanda Hubbard]. This month's highlight summarizes a collaborative activity involving US and international researchers through the ITPA Integrated Operations Scenario Group to benchmark six codes being used by different partners in modeling ion-cyclotron heating for ITER. BPO members are invited to propose future Research Highlight articles to the editor.)

Simulations of ICRF heating scenarios in ITER comparing multiple electromagnetic field solvers

P. T. Bonoli (Massachusetts Institute of Technology), on behalf of the ITPA Integrated Operations Scenario Group

Ion-cyclotron range of frequency (ICRF) heating will be an important component of the ITER heating system. The planned heating power is 20 MW and the range of frequency is 40-55 MHz. Simulations of ICRF heating, current-drive, and toroidal rotation profiles are needed for assessing the effectiveness of the ICRF system in helping to create and sustain high fusion power. An integrated modeling approach is typically used [1] to investigate these scenarios, and because the plasma profiles and applied ICRF heating are strongly coupled, it is important to assess the predictive capability of the ICRF models that are used. An extensive benchmarking activity [1] for ICRF codes was recently carried out by the ITPA Integrated Operations Scenario (IOS) Group as part of a broader effort to validate these actuators against experiment.

Six electromagnetic field solvers, including two that are coupled to Fokker Planck codes for the ion velocity distribution functions are applied to four cases of interest in ITER. In this highlight we shall describe two cases of particular interest from this study. The first (Case 1) is a high performance (so-called H-mode) baseline plasma a toroidal magnetic field of 5.3 T, a plasma current of 15 MA, and electron and ion temperatures on axis of $T_e(0) \sim T_i(0) \sim 25$ keV. The ion species is a D-T majority with a He-3 minority (2%), and an ICRF source frequency of 52.5 MHz. Here the dominant absorption mechanisms are electron Landau damping and ion damping at the fundamental cyclotron resonance of the doubly charged He-3, with weaker absorption occurring at the second cyclotron harmonic of the tritium species. In this case we expect a fair level of agreement among the code predictions owing to the strong absorption. The second discharge (Case 2) corresponds to an low-confinement L-mode plasma in the pre-activation phase of ITER at half-field (2.7 T), half-current (7.5 MA), $T_e(0) \sim T_i(0) \sim 10$ keV, and 52.5 MHz, with bulk hydrogen (H) and 3% He-3 minority population. The primary absorption mechanisms in Case 2 are all weak relative to Case 1 and include second harmonic He-3 ion cyclotron damping, electron Landau damping, and ion absorption at the fundamental cyclotron resonance of (H). It is expected that this case will present a challenge for the various models being used in the benchmarking study because of the comparatively weak absorption.

The six field solvers that are used include the AORSA, TORIC, CYRANO, EVE, PSTELION, and TASK / WM codes. Simulation results are also presented for the AORSA and TORIC field solvers self-consistently coupled respectively to the CQL3D and FPP bounce-averaged Fokker Planck codes, so the non-thermal minority tail could be evolved. A summary of the radio frequency (RF) physics and algorithms used in each of the codes can be found in Ref. [1] along with appropriate references. Target plasmas for these cases are obtained from time-dependent simulations that are done using the integrated modeling code PTRANSP [2]. The most notable RF physics differences in the models employed in these field solvers are two-fold: First, the AORSA, TORIC, EVE, and PSTELION codes are the only solvers that treat the phenomenon of mode conversion, whereby the incoming long wavelength ICRF wave is mode converted to short-wavelength modes (ion-cyclotron waves and ion Bernstein waves). This can be an important effect when the minority ion fraction is high. The AORSA code treats mode conversion exactly, whereas TORIC and EVE use a reduced model. The second difference is that the AORSA solver employs a conductivity operator that is valid for arbitrary values of perpendicular wavelength ($\lambda_\perp$) relative to the ion gyro radius (ρ_i), whereas the other five solvers assume $\rho_i / \lambda_\perp < 1$, which could be violated if the minority ion tail energy becomes too energetic.

(a) Case 1: Full-wave EVE simulation **(b) Case 2: Full-wave AORSA simulation**

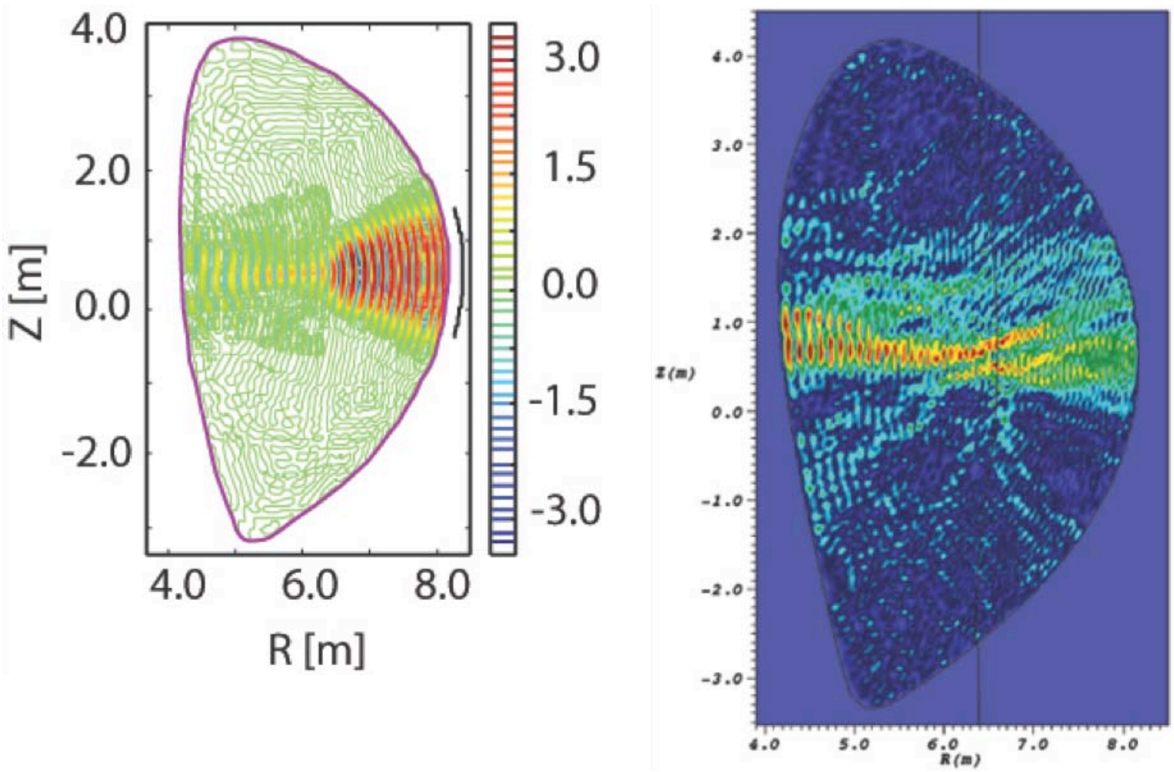


Figure 1: (a) EVE simulation of the ICRF wave fields for the ITER full-field, strong absorption Case 1 (5.3 T, 15 MA). (b) AORSA simulation of the ICRF wave fields for the half-magnetic-field, weak absorption Case 2 (2.7 T, 7.5 MA). Both panels plot the Re{E-} and the electric field strengths in the EVE legend are [kV/m] for 20 MW of absorbed power. Figures reproduced from Ref. [1].

Figure 1(a) shows a representative electric field simulation from the EVE code for the ITER full-field Case 1. An indication of the strong single-pass damping in this case is the absence of high amplitude wave fields on the tokamak high magnetic field side (to the left). All the field solvers predicted ~50% of the wave power damped via minority He-3 ion-cyclotron absorption except for the CYRANO and PSTELION codes which differ somewhat. Figure 1(b) shows a representative field simulation from the AORSA solver coupled to CQL3D for the half-field, Case 2. Here it can be seen that significant wave field amplitudes exist on the tokamak high field side owing to the weak nature of the second harmonic He-3 absorption, resulting in multiple passes of the wave front before complete absorption of the injected wave occurs. Although there is variation in the absorption totals among the code predictions for Case 2, they all reveal a similar trend in that only 10-20% of the injected power is absorbed via second harmonic He-3 damping with 65-70% absorbed via electron Landau damping.

An important and somewhat unexpected consequence of this benchmarking activity is to focus attention on the weak absorption that may be expected for the ITER pre-activation phase if one relies on second harmonic He-3 absorption. Indeed weak absorption is generally seen experimentally using this heating scheme. Possible ways to enhance the absorption for this phase were examined during the benchmarking activity by studying an additional case at half-field (2.7 T) and reduced ICRF frequency

(42 MHz) with a He-4 majority and (H) minority plasma. In this case, strong fundamental (H) absorption (~80%) is predicted by all the field solvers, again in agreement with what is found experimentally using the fundamental (H) minority heating scheme. More detail on all the comparisons mentioned in this article will be forth coming in Ref. [1].

This benchmarking activity is planned to continue into the future, with new cases to be examined that will further help to define where various field solvers are verified/validated and can be used with confidence in integrated modeling simulations. Ultimately it is expected that this activity will be helpful in identifying the most attractive ICRF heating schemes for the different ITER operating scenarios.

References

[1] R.V. Budny, L. Berry, R. Bilato, P. Bonoli, M. Brambilla, R.J. Dumont, A. Fukuyama, R. Harvey, E.F. Jaeger, K. Indireshkumar, E. Lerche, C.K. Phillips, V. Vdovin, J. Wright, and members of the ITPA-IOS, submitted to Nuclear Fusion (2011).

[2] R.V. Budny, R. Andre, G. Bateman, F. Halpern, C.E. Kessel *et al.*, Nuclear Fusion **48**, 075005 (2008).

ITPA Reports

Summary of the 20th Meeting of the ITPA Diagnostics Topical Group, Noordwijk, The Netherlands

R. Boivin *(General Atomics)*

The Twentieth Meeting of the ITPA Topical Group (TG) on Diagnostics was organized by the FOM Institute and held from May 23 thru 26, 2011. Discussions focussed on the following High Priority Items:

1. ***Development of methods of measuring the energy and density distribution of escaping alpha particles***

   A possible implementation of an escaping-alpha detector based on a reciprocating probe was presented. The concept takes advantage of brief probe incursion to "catch" fast ions on escaping orbits while reducing heat flux issues. However, the need for a comprehensive analysis of feasibility remains.

   Progress of the conceptual design of an escaping fast-alpha diagnostic based on activation technique has been presented. Improvement of the activation technique by using special detector material is possible. Materials that exhibit both high alpha-activation-yield and high purity properties are attractive candidates. A sample detector highly enriched in isotope 76 germanium, and of high purity (99.9999%), was tested in an experiment at the TEXTOR tokamak. Compared to previous experiments, the time between the exposure and the measurement was reduced considerably, allowing for the measurement of gammas emitted by short-lived radio-nuclides. Preliminary results indicated that both fusion products and ICRH accelerated ions might have been detected.

2. ***Determination of the lifetime of plasma facing mirrors used in optical systems***

   Extensive predictive modeling of the mirror lifetime in ITER was reported. This modeling focused on particle transport in the presence of mirrors and ducts with relevant species (D, C, Be). Deposition of material onto the mirror surface is dominated by particles reflecting or originating from the surface of the optical ducts. A flexible modeling tool is capable of simulating deposition to ITER mirrors of different size, located at different distances from the plasma at various angles of view, and having variable conicity of the diagnostic ducts. Promising results were shown for deposition mitigation by the fins installed in long diagnostic ducts. However, the large scatter in the input data for fluxes of particles, their energies, and re-erosion coefficients presently leads to a relatively large uncertainty in predictions. Benchmarking experiments based on the modeling predictions are under preparation to narrow significantly the scatter in predictions and to reveal the mitigation effect of fins.

These tests are presently being designed and implemented at various devices (TEXTOR, EAST, LHD, DIII-D). These dedicated experiments, made with various geometries of diagnostic ducts exposed under well-diagnosed plasma conditions, are important in validating these predictive models.

A few options for corrective mitigation of deposition have been described. These include laser cleaning, a cascaded-arc source, and microwave source particle flux cleaning. Each method presents some challenges, and R&D is presently being pursued at many laboratories.

The properties of several ITER-candidate mirror materials under erosion conditions were reported. Two exposures were performed in TEXTOR with single-crystal, Mo-nanostructure coated molybdenum mirrors along with an Rh-coated mirror deposited by an evaporation technique. The mirrors were kept under the same plasma conditions, allowing for a direct comparison of the change in optical properties. During the first exposure at relatively mild erosive fluence, all studied mirrors demonstrated an acceptable performance. The maximum decreases of the reflectivity did not exceed 4%. However, after exposure to higher fluences, the Rh-coated mirror demonstrated a significant drop of reflectivity, reaching 25% in the ultra-violet (UV) range. Mo-coated mirrors demonstrated acceptable performance in the infrared (IR) and visible (VIS) wavelength ranges, but with a 12% of decrease of reflectivity in the UV range. No significant change for the reflectivity of a single crystal mirror was detected, which seems to confirm the selection of single-crystal molybdenum as a prime candidate to be used in ITER diagnostics. Mirrors coated with fine-grain molybdenum layers represent another attractive concept for ITER first mirrors. Apart from good resistivity under erosion conditions, such coated mirrors are free from size limitation. Tests of industrial prototypes of magnetron coated Rh and Mo mirrors are underway. Additional tests were also performed on re-crystallized tungsten mirrors at various temperatures to study the potential formation of blisters, which appeared to be dependent on sample manufacturing.

3. ***Assessment of the measurement requirements for plasma initiation and identification of potential gaps in planned measurement techniques***

The early phase of plasma formation and control in ITER may require additional or special measurements different than during the nearly stationary flat top phase. A special session was organized to discuss plans and capabilities envisioned for the diagnostic techniques for supporting plasma initiation.

The first aspect of plasma initiation relates to the planned implementation of diagnostics for first plasma and first campaign. The second related aspect concerns the initial part of a discharge (breakdown, ramp-up).

For the first aspect, discussions were held in regards to the present implementation plan. Of particular concern is the lack of a density measurement, and possibly a reduced visible/IR viewing coverage. Issues may arise in the measurements of radiated power, as levels may be too low for the standard set. Concerns have been expressed for diagnosing run-away/slide-away energetic electrons during that phase, and action items have been generated to help in further defining the requirements for this measurement.

For the second aspect, concerns have been raised about the capability of measuring current profiles during ramp-up. Further discussions will be held to see the combined capabilities of the motional Stark effect (MSE) and polarimeter systems and the impacts of additional constraints imposed by implementation aspects.

In both cases, implications of early electron cyclotron heating (ECH) application need to be further discussed, especially in terms of systems protection.

Other topics

Discussions were also held in regard to diagnostics for future devices. For the first time in fusion research, diagnostic needs and implementation difficulties will have to be taken into account at a very early stage of the device design, and are likely to influence that design and engineering choices at a quite basic level. This, in turn, will be fed back into diagnostic development, meaning that new approaches and techniques will certainly be needed in some areas, and these will need to be developed on existing machines, including ITER.

It is proposed to hold the 21st Topical Group meeting in China, on October 17-20, 2011. The Chinese Academy of Sciences' Institute of Plasma Physics (ASIPP) in Hefei has kindly offered their support to act as host. The provisional location of the 22nd meeting in the spring of 2012 is Russia.

Summary of the 20th Meeting of the ITPA Pedestal and Edge Topical Group, Cambridge, MA

R. Maingi *(Oak Ridge National Laboratory)**, summarizing the full meeting report by H. Wilson et al.***

The 20th ITPA Pedestal and Edge Physics (PEP) group meeting was hosted by the Alcator C-Mod group at MIT, Cambridge (US) from 30 March to 1 April 2011. The focus was on presentation of new results from facilities including discussion of the resulting physics. The topics were pedestal structure and stability, low-to-high (LH) confinement transition physics, and edge localized mode (ELM) control. There was also a session on first-time H-mode results from the Chinese tokamaks HL-2A and EAST and the Korean tokamak KSTAR. Another session reviewed the status of nonlinear magnetohydrodynamic (MHD) modeling of ELMs. Finally, there was a session devoted to a discussion on the pedestal group's contributions to the cross-ITPA working group on particle transport, as well as an ongoing discussion of the status of existing inter-machine PEP experiments.

Pedestal structure

Presentations from the Alcator C-Mod discussed the characteristics of the I-mode on C-Mod, and on the progress in the area of external pedestal modification with combined ion-cyclotron range of frequencies (ICRF) and lower hybrid (LH) radio frequency (RF) heating. The I-mode talk focused on the transition criteria, pedestal properties and fluctuations. During the transition from L-mode to I-mode, the heat diffusivity at the edge drops, leading to an increase in the temperature gradient there and formation of a temperature pedestal (electron and ion). Particle transport, on the other hand, is not affected and no density pedestal is formed. Recent progress in the LHRF area has demonstrated that the density reduction is related entirely to LHRF interactions in the edge plasma, rather than current drive in the core. The effect has recently been found to be insensitive to the direction of the ion grad-B drift, but requires a sufficient particle removal rate from cryo-pumping (either in upper or lower single null).

A presentation from JET explored the pedestal and core confinement in JET baseline ELMy H-mode and hybrid plasmas. Exploring peaking as a function of collision frequency, it was shown that density is more peaked at lower collision frequencies, while the inverse is true for the electron temperature; indeed, the electron pressure profile is approximately independent of collision frequency. The ion temperature peaking exhibits a minimum as collision frequency is varied, following the electron temperature peaking only at the higher collision frequencies. Looking at the effect of triangularity of the magnetic equilibrium on confinement, it is argued that at low triangularity, the improvement in confinement between the two scenarios is due to improvements in both core and pedestal confinement. Plans for the coming campaign were also presented.

The MAST group presented a model of the pedestal structure during the inter-ELM cycle. The model builds on the ideas of the General Atomics (GA) EPED model; that is, it postulates that kinetic ballooning modes play a role in determining the pedestal width, along with finite toroidal-mode-number, n, ideal MHD modes. Flux tube gyrokinetic calculations have been performed in the pedestal region of MAST using the GS2 code, and show good agreement between the radial extent over which kinetic ballooning modes and the n=infinity ballooning modes calculated by HELENA, are unstable.

Presentations from NSTX focused on characterization of the pedestal dynamics through the ELM cycle, and an update to research on the Enhanced Pedestal (EP) H-mode regime. A clear build-up of the pressure pedestal height is observed for three different plasma currents during the inter-ELM phase, which tends to saturate prior to the onset of the ELM. The pedestal height just prior to the onset of ELM is found to increase quadratically with plasma current, but is independent of toroidal magnetic field. The pedestal width increased with the square root of pedestal beta. In the EP H-mode research, more routine achievement of this scenarios required running at high plasma current I_p=1.3 MA, low magnetic safety-factor q95=6 discharges with heavy lithium coatings to reduce the occurrence of natural ELMs. The importance of low q95 is thought to be that the q=3 surface is brought near to the steep gradient region of the H-mode pedestal.

The status of the GA EPED model development and experiment comparison was updated. The EPED model predicts the H-mode pedestal height and width based upon two constraints: 1) onset of non-local peeling-ballooning modes at low to intermediate mode number, and 2) onset of nearly local kinetic ballooning modes (KBM) at high mode number. The model has been successfully tested against observations from five tokamaks in prior studies. The simplified version of the model, EPED1, has recently been automated. Comparing EPED1 predictions to a data set of 137 JET hybrid and baseline discharges yields a ratio of predicted to observed pedestal pressure of 0.97 ± 0.21, with a correlation of 0.86. Statistical analysis is consistent with a model accuracy of ~20% or better in this comparison. New results with the full EPED1.6 model were also presented.

Particle transport

A talk was given on density transport modeling using the FACETS code, which provides an integrated simulation framework across the core and edge plasma. A number of DIII-D discharges are analyzed, testing the paleoclassical model. It is found that the predicted outward diffusion and inward particle pinch approximately balance at the top of the pedestal, which is consistent with the model that the density pedestal adjusts so that there is very small net particle flux.

A. Loarte from the ITER Organization led a discussion on the scope of the cross-ITPA working group on particle transport, focusing on the contributions of the pedestal group. Five areas were addressed: 1. Identification of edge particle transport mechanisms, edge density behavior and edge fueling in H-mode plasmas approaching ITER-like conditions. 2. Evaluation of changes to edge particle transport associated with the application of source-free ELM mitigation and suppression techniques. 3. Evaluation of the effective plasma transport and effective pellet fueling efficiency of H-modes with peripheral pellet fueling. 4. Characterization of the relation between core and edge density for the main ions and impurities of various species (with emphasis on high Z) and control by heating and fueling sources. 5. Characterization of the edge and core particle transport in He L-mode and H-mode plasmas.

Characteristics of the first H-modes in HL-2A, EAST, and KSTAR

A talk was presented on the progress on H-mode physics that has been made on EAST in 2010. An ELMy H-mode plasma was achieved by lower-hybrid current drive (LHCD) and ICRF heating with lithium wall conditioning. With a toroidal field of 1.8-2 T, and a plasma current of 0.6-0.8 MA, a maximum H-mode pulse duration in the region of 6.5 s was achieved. Discharges with a plasma current of 1MA were also achieved, as well as long pulse (up to 100 s), diverted plasma discharges using LHCD.

An overview of the status and plans of H-mode experiments in KSTAR was presented. H-mode was obtained using a combination of ECRH and NBI heating. These were produced in a magnetic field in the region of 2 T, a current ~600 kA and a density up to $4\text{x}10^{19}\,\text{m}^{-3}$, with up to 1.5 MW of total heating power. Preliminary results indicate that the power threshold shows signs of increasing relative to the scaling law at low density, and the energy confinement is broadly consistent with H-mode confinement scaling laws. Initial ELM studies have been performed. There are different regimes, containing small ELMs, large ELMs or ELM-free. A state-of-the-art electron-cyclotron emission (ECE) system provides evidence of a precursor stage to the ELM, followed by formation of filaments, which burst out of the pedestal into the scrape-off layer (SOL) at the time of the ELM.

H-mode experiments on HL-2A were summarized. Typical ELMy H-mode discharges have been achieved on HL-2A with combined neutral beam injection (NBI) heating and electron-cyclotron resonance heating (ECRH). The minimum power required is about 1.1 MW at a density of $1.8\times10^{19}\,\text{m}^{-3}$ and increases as the density is decreased. The typical energy loss per ELM is less than 3% of the total energy, with some exceptions exceeding 10%. Supersonic molecular beam injection fueling is found to be beneficial for triggering an L–H transition as a result of reduced recycling and higher fueling efficiency. The confinement time in the H-mode discharges increases approximately linearly with both plasma current and density.

ELM control

A. Loarte presented an overview of ITER outstanding issues on ELM control and modeling plans. He argued that ITER could likely handle uncontrolled ELMs if the plasma current is limited to 6-9 MA, but the standard Q=10 scenario will require some form of control. There remains some uncertainty over the prediction of ELM heat loads due to uncertainty over the area that the load is spread over the target plates, and this requires further research by the community. The present RMP coil design on ITER is three rows of eight coils with a maximum current capability of 90 kAturns, providing a 20% margin over the DIII-D ELM suppression criterion. This would allow ELM control even in the event of three coils failing (at a plasma current of 14.5 MA). As for pellet pace making, more R&D is required to identify the optimum pellet size, velocity and launch geometry for ITER, although ITER is relatively flexible in its pellet injection capability. Multiple ELM control techniques will be required to provide the necessary flexibility and reliability. Indeed, there are a number of uncertainties in extrapolating results on ELM control from existing tokamaks to ITER, largely because of incomplete physics understanding, and this needs increased emphasis.

New results from the first ELM mitigation experiments with the new active in-vessel saddle coils in ASDEX Upgrade were presented. Four coils above and four coils below the mid-plane allow n=2 operation with different up/down parity. This allows one to compare resonant and non-resonant field perturbations in the same plasmas, for example in a scenario with q95=5.5. ELM mitigation in H-mode is observed in plasmas with I_p=1 MA, and varying heating power (3 to 12 MW). Type-I ELMs are replaced with small ELM-like transport events. The particle confinement increases with the absence of ELMs; however the tungsten impurity concentration does not increase. The main empirical access condition for ELM mitigation is a minimum density, about 64% of the Greenwald density. The transition occurs at different collisionalities for different plasma currents, namely $n_{*,e}$~1.5 (I_p=0.8 kA) and 3 (I_p=1 MA), so this is not thought to be related to a collisionality threshold. Also application of the perturbation field in H-mode has not led to a discernible change of plasma rotation so far, as measured by edge charge exchange spectroscopy. Edge density profiles steepen slightly, while the edge pedestal temperature appears to drop slightly (by about 5-10%) in the ELM-mitigated regime. Pellets injected into ELM-mitigated plasmas have not been found to trigger ELMs. The results appear qualitatively similar to the high collisionality regime in DIII-D, but additional work between DIII-D and ASDEX-Upgrade is planned to look at the low collisionalty results.

New analysis of RMP experiments on MAST was presented. At present, the only parameter that is correlated with observed density pump-out in L- and H-mode: when the plasma displacement, calculated from MARS-F, near the X-point is large, density pump-out is observed.

Linear pedestal stability and calculations of the plasma response to resonant magnetic perturbations (RMPs) using the new M3D-C1 code were presented. Linear ideal MHD stability agrees with ELITE; the stabilizing influence of diamagnetic effects was quantified. Calculations of the plasma response to a magnetic field perturbation indicate that resonant perturbations tend to be screened by the plasma, while non-resonant perturbations are enhanced. Plasma rotation tends to enhance the screening, but can still result in a stochastic field at the plasma edge. As found for earlier slab results, the RMP can best penetrate the plasma when the electron fluid is stationary.

The effect of 3D fields on divertor detachment and pedestal profiles on NSTX was presented. It is found that the application of 3-D fields can reattach a detached divertor plasma if the divertor gas puff is insufficient. Divertor reattachment not only increases the inter-ELM heat flux, but also increases the ELM heat flux, i.e. the ELM size. The pedestal Te profile jumps increases when the reattachment occurs, while there is little change in the density profile. This leads to a higher pedestal pressure and its gradient, and therefore is consistent with the observation of increasing ELM size at the divertor. If the gas puff is sufficiently high, divertor detachment remains even with the application of the 3-D field; the pedestal Te also remains at its reduced level.

The status and plans for pellet ELM pacing at JET were presented. Experiments have been performed using the high-frequency pellet injector (HFPI). In the ITER baseline-like scenario the ELM frequency could be raised from about 7 Hz (spontaneous ELMs only) to 29Hz (spontaneous and triggered ELMs interleaved). Every pellet triggers an ELM but not all ELMs are pellet-triggered. This contrasts with an experiment in a low-triangularity magnetic configuration where a train of pellets injected at 10 Hz frequency leads to ELMs at the same frequency, each one triggered by a pellet. However the ELM energy loss of pellet triggered ELMs (compared in the ITER-like configuration) is larger than that of the spontaneous ELMs (4% vs 2% of the stored energy, respectively). Also, infrared measurements show additional heat flux at a larger radius, which can be traced along a field line to the location of the pellet injection. For the first time, a minimum pellet size for ELM triggering is observed: pellets must have more than $1\text{-}1.6\times10^{19}$ deuterium atoms to trigger ELMs. In order to trigger an ELM, pellets in JET have to penetrate the plasma to the pedestal top, while in ASDEX-Upgrade and DIII-D the necessary penetration depth appears to be smaller. The wetted area in the JET divertor varies with ELM loss and becomes smaller for smaller ELMs. This narrowing of the profile can reduce a possible benefit of peak ELM energy loss reduction by pace making. The JET HFPI is currently being upgraded from 10 Hz to a maximum of 30 Hz pellet frequency.

Recent results of pellet ELM triggering and pacing on DIII-D were presented. The analysis has explored the filament triggered by the pellet and where it ends up in the divertor as it moves across the SOL. The local infrared (IR) camera measurements are being examined with this in mind. The new injection line on DIII-D for low-magnetic-field side (LFS) pellets near the divertor has been installed. This injection will be tested in the early part of the upcoming run period with the existing 1.8 mm size pellets before changing the injector to the smaller 1.3 mm size. This will enable the team to verify whether or not this injection geometry is viable for ELM triggering, as anticipated. The injector modifications were in the fabrication stage at the time of the meeting, with testing due to commence in the following month. All three guns will be modified with >10 Hz capability, more than doubling the previous pellet ELM triggering rate.

Non-linear MHD modeling of ELMs and their control

ELM simulations using the M3D code were presented. The simulations included a core plasma with free boundary, a region of open field lines, and a partially conducting wall, with realistic resistivity. It was shown that the growth of the perturbation was not restricted to the mid-plane, and fingers burst out over most of the outboard side, not just where the linear perturbation is largest. A magnetic tangle helped to drive direct plasma loss near the X-points, reducing the density gradient and the drive for the initial ballooning mode. The tangle wraps around the inboard side and can cause a secondary instability driving further density loss there. Simulations had also been performed for NSTX, where it was found that the ELM is more localized to the outboard midplane than for DIII-D.

The status of ELM modeling using the JOREK code was presented. The formation of strong density filaments was observed; somewhat weaker temperature filaments are also seen, which, due to the strong parallel thermal transport, are well aligned with the perturbed magnetic field lines. Filamentary structures also form in the current density. The ELM perturbs the magnetic field structure near the X-point, and this leads to spiral patterns in the heat flux at the outer divertor target plate; the inner divertor deposition profile has almost no structure, similar to the measurements from ASDEX-Upgrade and JET. The nonlinear prediction for the energy loss from the first few filaments is found to correlate with the predicted linear eigenmode radial width, although simulations of larger ELMs do show additional losses from deeper in the plasma, not related to the linear eigenmode. A key result on ELM size is that, provided one uses an experimentally relevant value of the plasma resistivity, the ELM size increases with decreasing collisionality, as observed experimentally. The main reason for the increase is due to a greater temperature drop in the ELM, again as observed experimentally. The physics is related to the increased parallel thermal diffusivity in the SOL at higher plasma temperature. JOREK has also been used to simulate pellet-triggered ELMs. The mechanism is related to a localized increase in pressure caused by the pellet, as parallel thermal transport rapidly heats the relatively cool density perturbation caused by the pellet. This pressure increase results initially in a single, large filament as observed in experiments.

An overview of NIMROD simulations of peeling-ballooning modes was presented. The NIMROD code is designed to model the macroscopic dynamics of high-temperature magnetized plasma by solving a full set of extended MHD equations. The code has been applied to study the peeling-ballooning instability of a tokamak edge pedestal. NIMROD simulations have confirmed theoretical predictions of the exponential growth of the ballooning instability in the intermediate nonlinear regime. Recently, NIMROD simulations have started to reveal the blob formation process in the late nonlinear stage of peeling-ballooning evolution. The nonlinear plasma response to the imposed resonant magnetic perturbation (RMP) from internal coils was also recently studied.

ELM simulations with the BOUT++ code were presented. The challenge associated with resolving narrow current sheets in the vicinity of rational surfaces was highlighted. This problem is often avoided using an artificially high plasma resistivity, which introduces a stronger linear MHD drive, resulting in misleading results. An alternative is to introduce hyper-resistivity (which involves higher order perpendicular derivatives), and this is the approach in these new BOUT++ simulations. At fixed hyper-resistivity (at a value comparable with turbulent diffusivities), simulations indicate very large ELMs at high resistivity, falling as resistivity is decreased to a value of Lundquist number $S=10^6$, beyond which the ELM size becomes independent of resistivity; this is the regime of modern tokamaks. The dominant energy loss mechanism is thought to be a consequence of stochastic magnetic field generation during the nonlinear evolution of the ELM.

Results from a survey of pedestal stability in DIII-D, NSTX and ITER using the GYRO gyrokinetic code to study micro-instabilities (DIII-D) and the BOUT++ MHD code to study MHD modes (NSTX and ITER) were presented. Micro-instabilities in the pedestal have fine structure in the ballooning angle, requiring higher resolution than core modes in DIII-D. The mode growth rate is strongly influenced by both collisions and electromagnetic effects. The MHD studies focused on the ITER 15 MA inductive H-mode discharge, with the X-point geometry incorporated into the BOUT++ modeling. An ideal MHD peeling-ballooning mode was identified. A similar study on NSTX also identified a range of unstable peeling-ballooning modes in the ideal MHD limit, but these are stabilized when two-fluid effects are included.

LH transition physics

Experimental studies of the LH transition on C-Mod were presented. It was shown that the low-density threshold has a more complicated dependence on magnetic field and density than can be described by a simple scaling law. The length of the outer SOL leg has a substantial impact on the power threshold, falling a factor of three as the outer leg length doubles. Also, there is no clear scaling of the local density and temperature at the LH transition with plasma current, although there is some evidence that gradients scale quadratically with current. A preliminary study of the scaling with magnetic field **B** indicates that the temperature scales as B^2 at low density and as B at higher density.

A presentation on zonal field generation in ELMy H-mode discharges was given. BOUT++ simulations indicate that as the edge pressure drops during an ELM, the current continues to rise. This is a consequence of turbulence driving the current (and related zonal fields) by an inverse cascade mechanism, which could explain the result from MAST motional Stark effect (MSE) measurements that the edge current density does not fall significantly during an ELM, despite the drop in pressure gradient, and associated bootstrap current.

Next meeting

The 21st Pedestal and Edge Physics Topical Group meeting will be held in York, UK. The dates of this meeting are 5-7 October 2011, just before the H-mode Workshop, which will be held in Oxford, UK the following week.

Announcements

Submit BPO-related announcements for next month's eNews to Tom Rognlien.

Upcoming Burning Plasma Events

2011 Events

Fall 2011
ITPA Diagnostics Topical Group Meeting
CHINA

Sep 5-7, 2011
IAEA Technical Meeting on Theory of Plasma Instabilities
Austin, Texas USA

Sep 8-10, 2011
IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems
Austin, Texas USA

Sep 12-13, 2011
7th Meeting of the ITPA Energetic Particles Topical Group
Austin, Texas USA

TBA---tentatively scheduled
ITPA MHD Topical Group Meeting
Padova, ITALY

Sep 11-16, 2011
10th International Symposium on Fusion Nuclear Technology
Portland, Oregon USA

Sep 14-16, 2011
BOUT++ Workshop
LLNL, Livermore, California USA

Sep 19-21, 2011
13th International Workshop on Plasma Edge Theory in Fusion Devices
South Lake Tahoe, California USA

Oct 5-7, 2011
ITPA Transport & Confinement Topical Group Meeting
Cadarache, FRANCE

Oct 5-7, 2011
ITPA Pedestal and Edge Topical Group Meeting
York, UK

Oct 10-12, 2011 abstract deadline June 30, 2011
13th International Workshop on H-mode Physics and Transport Barriers
Oxford, UK

Oct 16-21, 2011
15th International Conference on Fusion Reactor Materials (ICFRM-15)
Charleston, South Carolina USA

Oct 18-21, 2011
ITPA Integrated Operational Scenarios Topical Group
Kyoto University, JAPAN

Nov 14-18, 2011
53rd APS Division of Plasma Physics Annual Meeting
Salt Lake City, Utah USA

Dec 12-15, 2011
ITPA CC & CTP-ITPA Joint Experiments Meeting
Cadarache, FRANCE

Dec 2011 or Jan 2012
ITPA Divertor and SOL (PSI Selection Committee) Topical Group Meeting
Jüelich, GERMANY

Directories of Other Plasma Events

IEEE Directory of Plasma Conferences
Fusion Ignition Research Experiment (FIRE) Physics Meetings

Please contact the administrator with additions and corrections.