USBPO U.S. BURNING PLASMA ORGANIZATION

eNews

November 10, 2011 (Issue 60)

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 (Dylan Brennan) Assistant Editor (Rita Wilkinson). Thank you for your interest in Burning Plasma research in the U.S.!

Director's Corner by C. M. Greenfield

USBPO Activities at the APS-DPP Annual Meeting in Salt Lake City

This year the USBPO has again organized a contributed oral session (NO4) "Research in Support of ITER." It will be held on Wednesday, November 16, 9:30 a.m.–12:30 p.m., in Ballroom E, with yours truly as session chair.

By the way, another contributed oral session (TO4: "ITER and MFE Physics") also has several ITER-related talks. It will be held on Thursday morning, 9:30 a.m.–12:30 p.m., in Ballroom E. Also, a poster session with ITER-related contributions is GP9, to be held Tuesday morning.

On Tuesday evening, 7:30-9:30 p.m., there will be a USBPO Town Meeting on ITER Status. The meeting will be chaired by Michael Bell, Vice Chair of the USBPO Council, and will feature:

- Joseph Snipes, Senior Scientific Officer, Plasma Operations Group Leader, Directorate of Plasma Operation, of the ITER Organization, will describe the latest developments with ITER and also discuss control systems.
- David Rasmussen, WBS Team Leader for Pellet Injector, ECH & ICH Systems at the US ITER Project Office, will describe the status of heating systems for ITER.
- Réjean Boivin, international leader of the ITPA Diagnostics Topical Group and diagnostics head for DIII-D at General Atomics, will describe the status of diagnostics for ITER and open areas for burning plasma diagnostic development.
- I (Chuck Greenfield) will review US contributions and scientific opportunities for ITER R&D.

Following the final presentation, we will open the meeting for discussion.

ITER Advisory Committee Meetings

The Science and Technology Advisory Committee (STAC) of the ITER Council held its eleventh meeting recently, October 10-12, in Cadarache, France. The delegation from the US consisted of Rob Goldston, Stan Milora, Tony Taylor, and Jim Van Dam. Prior to this meeting, the US Burning Plasma Organization continued its tradition of organizing a community briefing for the STAC members. In the coming months, the BPO will work to address some of the remaining unresolved scientific issues.

The Council at its June 2011 meeting (IC-8) formulated a set of five charges for STAC-11 to address:

1. Assess technical aspects of the DG's plan to improve schedule, including the impact of the earthquake in Japan. This should include all technical aspects of new proposals including cold coil testing and vacuum pumping, and the project's strategy for the Central Solenoid and the TF Coils to be developed taking into account the results of the Task Force on Coil Issues, especially the plan for conductor qualification.
2. Assess the technical aspects of the project's proposals on possible scope deferrals and deletion aiming at more effective cost reduction and cost-profile refinement.
3. Review the progress and status of other STAC actions, including continued assessment of the ADI items from the scientific and technical perspective, in-vessel coils, neutron shielding (including adequacy from the perspective of nuclear heating of the TF coils), and progress on Neutral Beam Injection (NBI) against the previously presented plan.
4. Review a report by the IO on safety analysis of the superconducting coils particularly related to quench control and impact of coil failure.
5. Review a report by the IO on the general strategy on remote handling design and implementation.

Top management and senior scientific leaders from the ITER Organization presented a series of talks to the STAC concerning the five charges and additional items of business. The STAC members divided into groups to write draft sections of the report. The STAC then discussed the entire report in plenary session, before briefing ITER management at the end of the third day of the meeting. The final version of the report was completed the following week via email.

The Management Advisory Committee (MAC) held its twelfth meeting on October 17-18. Items discussed included project schedule performance, schedule strategy, the IO annual work plan for 2012, guidelines for evaluating Additional Direct Investment credit, draft strategy for deferrals, cost strategy, management of intellectual property, IO partnership with Monaco, and management assessment.

Both the STAC-11 and MAC-12 reports will be submitted to the ITER Council at its upcoming IC-9 to be held in Cadarache, November 17-18, 2011. The ITER Newsline contains an article about both committee meetings.

An Opportunity at ITER

As many of you know, Wayne Houlberg has been ITER's Chief Scientific Officer for Integrated Modeling. Wayne is now preparing to retire, and the ITER Organization has begun the search for his replacement. I urge US scientists to consider this opportunity. If you are interested, please contact the ITER Organization directly. The position is posted at on the ITER web site. Look for Senior Scientific Officer POP-009. **Applications will be accepted until 13 November**. I know the entire US Burning Plasma community will join me in wishing Wayne the best in his retirement, and thanking him for his service to ITER and the community during the last few years.

ITER Developments

The ITER Organization has placed a set of construction photo galleries on their website. The photograph below, taken from that website, shows the Tokamak Isolation Pit as it appeared last month.

Looking south over the Tokamak Complex Seismic Isolation Pit in September 2011.
Photo: Altivue/ITER Organization.

Upcoming Meetings of ITPA Topical Groups

Most of the ITPA topical groups have already had their "fall" meetings, with one left to go. The Divertor and SOL group will meet in Jülich, Germany, during the second week of January, 2012.

USBPO Topical Group Highlights

(Editor's Note: The BPO Plasma-Wave Interactions Topical Group works to facilitate U.S. efforts to understand radio frequency plasma heating and current drive in existing and future magnetic fusion devices via experiments and simulations [leaders are Gary Taylor (PPPL) and David Green (ORNL)]. This month's highlight describes an effort to model and understand a new diagnostic for the electric field near an antenna used to launch electromagnetic radiation to heat the plasma. Understanding this near field physics could lead to breakthroughs in the power coupling to the plasma, which is currently limited by power deposition by the antenna in the region surrounding the antenna itself.)

Spectroscopic Measurements of Dynamic Electric Fields in the RF and Microwave Range of Frequencies

Elijah Martin and Steven Shannon *(NC State University),* ***Christopher Klepper, Ralph Isler, and John Caughman*** *(ORNL)*

A major challenge facing magnetic confinement fusion and the success of ITER is the implementation of reliable heating/current drive systems. Typically heating/current drive is realized through the following schemes: electron cyclotron resonance (ECR), lower hybrid (LH) resonance, and ion cyclotron resonance (ICR). All three schemes launch electromagnetic radiation from a waveguide/antenna into the core of the thermonuclear plasma. Through a resonance interaction the electromagnetic energy is directly dissipated in the form of electron/ion kinetic energy. The resonance frequency associated with reactor-like plasma parameters ranges from tens of MHz to hundreds of GHz depending on the heating/current drive scheme.

In order for the electromagnetic wave to undergo resonant absorption with the plasma it must propagate from the waveguide/antenna across the low-density scrape off layer (SOL). Due to its close proximity to the SOL, there is a complex interaction between the near-field of the waveguide/antenna structure and the local plasma. Parasitic electric field is established by the associated nonlinear interactions and power is locally deposited in the waveguide/antenna near-field region through collisional and collisionless phenomena. Local power deposition in the waveguide/antenna near-field region severely limits the power throughput of the heating/current drive scheme and can cause catastrophic damage to the waveguide/antenna structure and other plasma facing components. To continuously and efficiently launch the required megawatts of power across the SOL, control of the waveguide/antenna near-field must be achieved through a thorough understanding of the underlying physics. The diagnostic being developed at ORNL will be capable, for the first time, of experimentally determining the electric field topology and dynamic needed to propel our theoretical understanding of near-field physics.

The diagnostic is based on time averaged and phase resolved optical emission spectroscopy of the Balmer series transitions of hydrogen/deuterium and select transitions of helium. The parameters associated with the dynamic electric field [1] are determined by fitting the experimentally measured time averaged line profile to the theoretical time averaged line profile given by the first order perturbation theory(1).

$$\overline{E}(t) = \overline{E}_o + \sum_{n=1}^{N} \overline{E}_n \cos\left(n\omega t + \phi_n\right) \quad [1]$$

The phenomena governing the shape of the time averaged line profile is the dynamic Stark effect. The dynamic Stark effect(2) is a multiphoton process in which photons associated with the atomic transitions are emitted/absorbed with photon(s) associated with the dynamic electric field [1]. To illustrate this phenomenon Figure 1 depicts both the discrete and continuous time averaged line profile associated with the H_α transition, in the presence of a 5 kV/cm monochromatic electric field with a frequency of 20 GHz. The discrete line profile is given in the absence of broadening mechanisms such as natural, Doppler, and instrument broadening. Notice the spacing between the discrete transitions is exactly 20 GHz illustrating the multiphoton nature of the dynamic Stark effect.

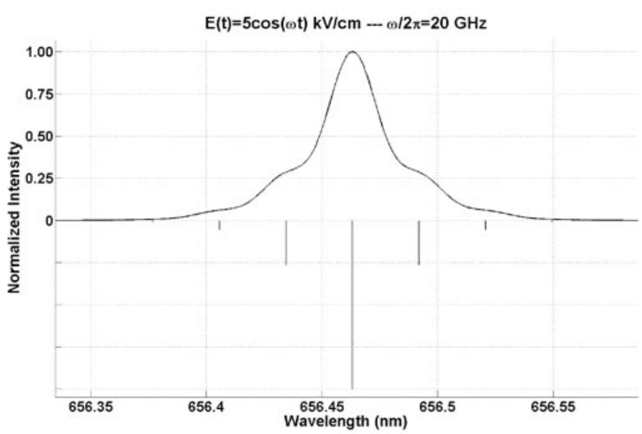

Figure 1. Discrete and continuous time averaged line profile associated with the H_α ($n = 3 \rightarrow 2$) transition, in the presence of a 5 kV/cm monochromatic electric field with a frequency of 20 GHz. The continuous line profile is given by convoluting the discrete line profile with a Gaussian function with FWHM

To calculate the line profile the time dependent Schrodinger equation [2] must be solved.

$$i\hbar \frac{\partial \Phi}{\partial t} = \left[H^o + \frac{\mu_B}{\hbar} \overline{B} \cdot \left[\overline{J} + \overline{S} \right] + e\overline{E}_o \cdot \overline{r} \right] \Phi + \sum_{n=1}^{N} \frac{e\overline{E}_n \cdot \overline{r}}{2} \left[e^{i\left(n\omega t + \phi_n\right)} + e^{-i\left(n\omega t + \phi_n\right)} \right] \Phi \quad [2]$$

Due to the periodic nature of the time dependent Schrodinger equation, Floquet's theorem[3] and a Fourier series expansion can be utilized to find an exact solution within the first order perturbation theory framework[4]. The time averaged line profile is then calculated assuming electric dipole induced spontaneous emission of a photon[4,5]. This requires solving the time dependent Schrodinger equation, in the limit[6] of [3], connecting the upper state to the lower state utilizing the solution of [2] as the basis set.

$$\Delta \approx \frac{A_{ki}}{\omega} << 1 \qquad [3]$$

Where A_{ki} is the transition probability (i→k) per unit time. For the transitions of interest the validity criteria of [3] is easily satisfied for electric field realized by the ECR and LH schemes. To explore the validity of the procedure described above in calculating the time averaged line profile for the ICR scheme, where [3] is on the order of unity, we perform the time averaged line profile calculation utilizing the following limit.

$$\Delta \approx \frac{A_{ki}}{\omega} >> 1 \qquad [4]$$

This describes the quasistatic approximation in which the quantum states respond instantaneously to the dynamic electric field. The Schrodinger equation given by [2] can be solved by discretizing the dynamic electric field in time and solving the set of time independent equations. The time independent line profile is then calculated in a similar manner stated above[5]. The time averaged line profile is calculated by averaging the time independent line profiles with the respective weight associated with discretizing the dynamic electric field. Figure 2 depicts the time averaged line profile calculated utilizing the Floquet method, [3], and the quasistatic method, [4]. Note the time averaged line profile calculated utilizing the quasistatic method is independent of the frequency associated with the dynamic electric field.

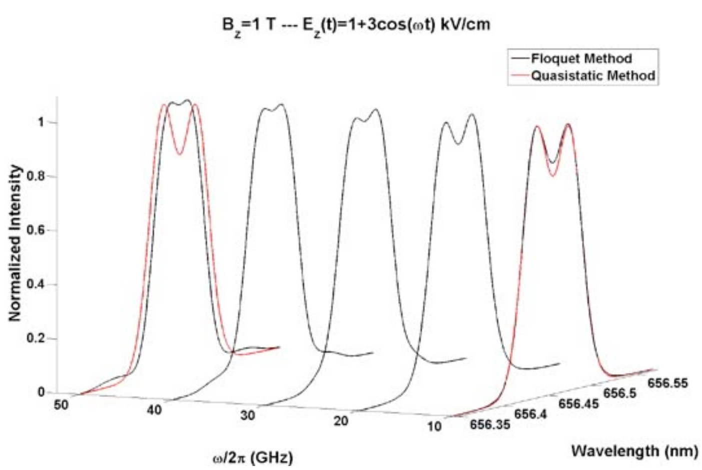

Figure 2. Continuous time averaged line profile associated with the H_α ($n = 3 \rightarrow 2$) transition, in the presence of a 1 T magnetic field, a 1 kV/cm static electric field, and a 3 kV/cm monochromatic electric field with the indicated frequency. The instrument function was Gaussian with FWHM of 0.25A, a typical instrument function.

Figure 2 illustrates the following conclusion: the time averaged line profile calculated utilizing the Floquet method converges to that calculated utilizing the quasistatic method. The convergence of the Floquet and the quasistatic methods is purely based on the fact that the spacing between multiphoton transitions is equal to integer multiples of the dynamic electric field frequency – thus as the frequency is decreased the methods begin to converge as the broadening mechanisms begin to 'smear-out' the discrete line structure. The frequency at which this convergence is acceptable is a function of the broadening mechanisms, the magnetic and electric field intensity and topology, the electric field dynamic, and the transition being considered. The above result indicates that either the Floquet or quasistatic methods can be implemented to calculate the time averaged line profile associated with electric field realized by the ICR scheme.

To verify our theoretical calculations and capability to extract the dynamic electric field parameters [1] from the time averaged line profile a small scale laboratory experiment at ORNL has been constructed. The experimental setup, given by Figure 3, consists of an RF electrode driven at 13.56 MHz immersed in plasma generated by a 2.45 GHz ECR source. The time averaged line profile associated with optical emission originating solely from the RF sheath is measured with a high resolution spectroscopic system.

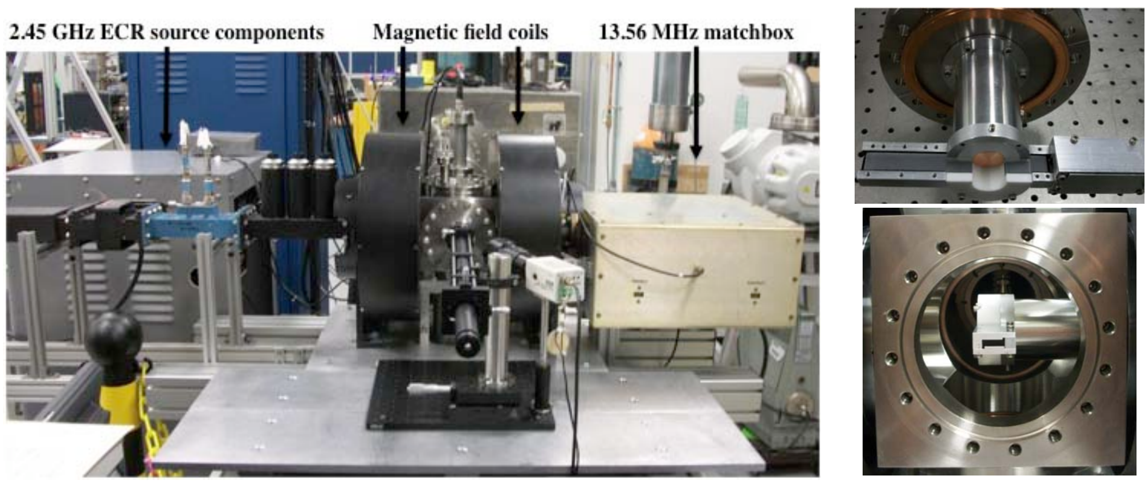

Figure 3a: Overview of experimental setup. **Figure 3b:** 13.56 MHz RF feedthrough/electrode. **Figure 3c:** Optical assembly allowing direct optical access to emission originating in the RF sheath.

Figure 4 depicts examples of experimentally measured time averaged line profiles, σ and π polarization, associated with the H_β transition and the 2^3P-5^3D He-I transition as a function of distance from the 13.56 MHz RF biased electrode.

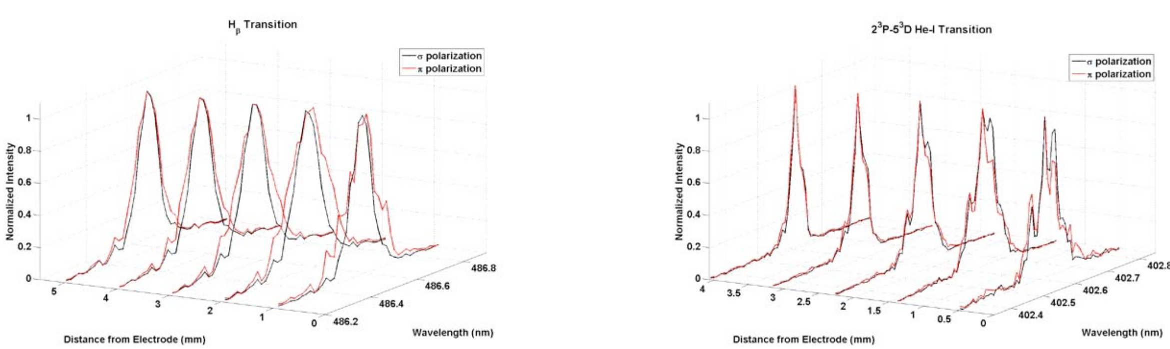

Figure 4. Experimental time averaged line profile associated with the H_β ($n = 4 \rightarrow 2$) transition and the 2^3P-5^3D He-I transition. Discharge conditions were equivalent.

We are currently developing a robust fitting algorithm to extract the dynamic electric field parameters from the experimentally measured time averaged line profiles. The algorithm is based on optimizing the fit associated with the theoretical, given by either the Floquet or quasistatic method, and experimental time averaged line profile. Due to the large number of degrees of freedom associated with the fit, [1], multiple transitions and various polarizations, σ and π, may need to be considered for a unique solution. The extracted dynamic electric field will be compared with a numerical calculation of the dynamic electric field(7,8) to verify the diagnostic.

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ITPA Reports

Summary of the 7th Meeting of the ITPA Energetic Particles Topical Group

D. Spong *(Oak Ridge National Laboratory)*

The 7th Meeting of the ITPA Energetic Particle Topical Group was held at the University of Texas, Austin, Texas, September 12 – 13, 2011 following the 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, which was held in Austin during the preceding week. The technical part of the meeting was organized by ITPA-EP chair Kouji Shinohara (JAEA) with assistance from Sergei Putvinski (ITER) and Boris Breizman (UT-Austin). 23 presentations were given with about 30 participants present; they are posted at the ITER ITPA web site under 7th Energetic Particle Physics TG Meeting. This meeting was divided into reports on continuing efforts in areas such as joint experiments and joint modeling/benchmarking (carried over from previous ITPA-EP meetings) along with talks on new physics, diagnostics and experimental results. Each area is summarized below.

Joint Experiments: The joint ITPA experimental tasks in energetic particle physics are: EP-2 (Fast ion loss and redistribution from localized Alfvén instabilities), EP-3 (Interaction between fast ions and turbulence), EP-4 (Effect of dynamical friction at resonance on nonlinear Alfvén mode evolution), EP-5 [TBM (test blanket module) induced fast ion losses with internal MHD (magnetohydrodynamic) activity and RWM (resistive wall mode) control fields], and EP-6 (Fast-ion losses due to edge perturbations). Recent activity in each task is summarized below with the task leaders indicated.

EP-2 (S. Pinches - JET): Continued improvement in diagnostic capabilities, such as fast ion D-alpha diagnostics (FIDA), velocity/pitch-angle resolved fast ion loss detectors (FILD), beam emission spectroscopy (BES), and reflectometry and electron cyclotron imaging (ECEI) have allowed a more systematic approach in correlating AE (Alfvén eigenmode instability) activity with fast ion redistribution and transport. NSTX typically observes cascades of multiple Alfvén modes that are correlated with fast losses and enhanced thermal transport. DIII-D and ASDEX are obtaining good 2D mode structure measurements of RSAE modes in reversed shear discharges and analyzing related fast ion losses. Tornado modes (simultaneous multiple n TAEs) on JET are being modeled with the HAGIS code, leading to successful simulation of the observed gamma-ray intensity measurements from which fast ion redistribution can be inferred. New diagnostic capabilities are being added to MAST.

EP-3 (M. Albergante - EPFL): The interaction between energetic particles (EP) and core plasma turbulence was further investigated on DIII-D and ASDEX. DIII-D found larger anomalies in EP transport at small E_{fast}/T_e , which would be indicative of such mechanisms. ASDEX found larger anomalies for low triangularity, possibly due to larger electromagnetic fluctuations. Results for lower temperature plasmas were also presented from LAPD and TORPEX. The next step will be to understand finite β effects and to develop a good benchmark case (free from AE modes) for modeling.

EP-4 (S. Sharapov - JET): Collisional drag modifies the nonlinear AE evolution especially for modes near marginal stability. This was investigated on MAST and analyzed using the BOT code for various models of hole/clump formation. Further such experiments are planned for MAST and LHD.

EP-5 (G. Kramer - PPPL, presented by D. Pace - ORISE): The modeling and results from the DIII-D 2009 TBM simulation experiments were reviewed. The main topics for EP studies were the location and level of the NBI losses to the tiles near the TBM and the enhanced losses of DD produced 1 MeV tritons. A second round of experiments will be conducted in Oct. 2011 with improved diagnostics [IR (infra-red) camera for wall heat loads and a new neutron detector for better triton burn-up measurements].

EP-6 (M. Garcia-Munoz - IPP): The effect of different types of edge perturbations (edge localized mode activity and RMP coils) on fast ion confinement has been studied in DIII-D, ASDEX and JT-60U. There are several issues of interest: (a) enhanced fast ion losses due to ELM/RMPs, (b) effects of fast ions on ELM stability and pedestal transport and (c) ELM diagnostic information available from fast ion loss characteristics. Non-negligible effects were found in all of these areas. Modeling of fast ion confinement with RWMs (resistive wall modes) has been done with the SPIRAL, ASCOT, and F3D-OFMC codes; EP effects on ELM stability are being analyzed with the TAEFL code.

D. Pace also gave a presentation on C-Mod capabilities for energetic particle studies. C-Mod can produce ICH (ion cyclotron heating) tails with fast ion pressures comparable to the total pressure and has well-resolved neutral particle analyzer arrays, fast ion charge exchange and fast ion loss detectors.

S. Pinches led a discussion on the next steps for joint experiments. Possible new topics were identified, including stability issues for runaway electrons, sawtooth-driven transport, expt./theory comparison for marginal stability and detailed identification of low frequency (Alfvén-acoustic) modes.

Joint Modeling/Benchmarking: From the previous meetings a linear stability n = 6 TAE benchmark case had been developed by A. Könies (IPP). A number of codes (HMGC, GYGLES, CKA-EUTERPE, CAS3D-K, LIGKA, MEGA, VENUS, TAEFL and AE3D-K) have now been applied to this case and are giving similar results for the mode structure and growth rate dependence on energy; the variation with energy is a useful test for the treatment of finite orbit width effects. A number of talks (S. Briguglio - ENEA, A. Könies - IPP, D. Spong - ORNL, Y. Todo - NIFS) described on-going refinements in these models. Initial nonlinear regime results for this case were also presented from the HMGC code, which studied resonance structures and saturation mechanisms. Further work on the nonlinear evolution for this case will be carried out by the other codes and will be the topic of a joint paper for the next IAEA FEC.

In addition to this existing case, several new directions for joint modeling were discussed; these include: a JET DT case (S. Sharapov), prediction of ITER stability boundaries (P. Lauber - IPP) and simulation of NBI losses from ELM coil perturbations (T. Kurki-Suonio - AALTO).

Other topics that were reported on in this session included: destabilization of electron fishbones by energetic electrons (S. Briguglio, XHMGC code), damping mechanisms (Y. Todo, MEGA code), and AE instabilities in ITER steady state reversed shear case (D. Spong, TAEFL code).

Fast Ion Confinement Studies: Fast ion confinement has been analyzed using Monte Carlo methods, which follow many fast ion particle trajectories all the way to the wall and calculate loss rates and power loadings. T. Kurki-Suonio (ASCOT code) and K. Shinohara (F3D-OFMC code) reported on new developments in this area. ASCOT was upgraded to include magnetic islands due to neoclassical tearing instabilities and applied to beam ion redistribution in ASDEX and ITER. For ITER it was found that beam current drive is not affected much by the islands due to their non-alignment with the current drive region. F3D-OFMC reported results on the effect of ELM coils on fast ion confinement in the ITER 15MA scenario. Larger incremental losses were observed for beam ions than for alpha particles. Heat load increases were present in the divertor region, but the level (< 0.3MW/m^2) should be manageable.

Alfvén stability: Two talks focused on JET DT operation. D. Testa (EPFL, presented by M. Albergante) revisited supra-classical ion heating that was observed in the 1997 DTE1 campaign in discharges that had high fusion yield. Subsequent analyses and modeling (GENE code) has indicated that increasing alpha particle density can suppress turbulence [e.g., ITG (ion temperature gradient) modes] that propagates in the ion drift direction; this ITG stabilization has been identified as a likely cause for the ion temperature increase. S. Sharapov discussed the possibility of a new DT campaign on JET that could provide alpha-excited AE's in a low-Q regime. This was based on TRANSP analysis of the best deuterium discharge with an ITB (ion transport barrier) (#40214). The idea is to excite AE's in the beam afterglow phase when the net AE drive becomes positive; LHCD can now also be used to modify the q-profile in ways that should further increase the drive.

G.-Y. Fu (PPPL) presented M3D-K simulation of beam driven AE's in DIII-D plasmas using realistic beam distribution functions. Two types of instability were found: an RSAE (reversed shear Alfvén eigenmode) and a lower frequency EPM (energetic particle mode).

M. Lesur analyzed momentum exchange between waves and particles in the Berk-Breizman bump-on-tail instability model. He found that the resulting structures could be characterized by a quantity known as phasestrophy, which is the phase-space density auto-correlation. These structures can drive the waves in a nonlinear way and account for sub-marginal instabilities.

Diagnostics: A. Fasoli (EPFL) summarized AE diagnostics and control of AE instabilities as described in the final report of the WG4 (Working Group 4). This will involve developing appropriate diagnostics and control actuators for ITER based on physics studies of AE modes. This includes: identifying the modes, their location and profile changes that could remove the drive or increase damping.

F. Meo described the current status of fast ion collective scattering on ITER. This technique can resolve fast ion fluctuations and distinguish between trapped and passing ions. Two systems are proposed for ITER: a low field side back-scattering (LFS-BS) system with RF launcher and receiver located in the equatorial port on the low field side, and a high field side forward-scattering (HFS-FS) system with RF launcher in the mid-plane port on the low field side and receiver mounted in the high field side inner wall between two blanket modules. Currently, only the LFS-BS has been approved. This implies near parallel fast ions with energies > 3 MeV cannot be measured (the LFS system can primarily only measure energetic trapped ions). The ITPA-EP group unanimously endorsed adding the HFS-FS diagnostic to the ITER diagnostic set.

Runaway Electrons/Disruptions: Z. Chen (HUST/KSTAR) discussed experiments on KSTAR to measure the generation efficiency of runaway electron currents during disruptions. The runaway currents were observed to reach up to 80% of the pre-disruptive currents. KSTAR will continue these studies with the goal of providing a disruption database for ITER.

J. Riemann (IPP) presented 2D modeling of runaway energy amplification in vertical disruptions. The model assumed a circular cross section runaway current intersecting with vessel walls; it took into account poloidal/solenoidal coils, resistive diffusion and energy transfer onto different plasma-facing surfaces. For ITER it indicated that the runaway energy multiplication could be a factor of ~10, leading to ~100MJ of runaway energy. The additional drive came from current ramp-down induced electric fields as the runaways are scraped off.

In closing, it was announced that the spring ITPA-EP meeting will be held at NIFS in Japan as a joint meeting with the MHD stability TG on March 5 – 9, 2012. It was also decided that S. Sharapov would serve as the new deputy chair of the ITPA-EP.

Summary Report of the 7th Meeting of the MHD Stability ITPA Topical Group

A. Sen *(IPR, India),* ***E. Strait*** *(GA), and* ***Y. Gribov*** *(ITER)*

The ITPA Topical Group (TG) on MHD Stability held its seventh meeting in Padova, Italy during October 4-7, 2011, hosted by Consorzio RFX. The scientific program of the meeting was devoted to addressing key magnetohydrodynamic (MHD) stability topics for ITER such as disruptions, error field correction, resistive wall mode (RWM) stability, neoclassical tearing mode (NTM) stability, sawtooth control, 3D physics effects etc. A major focus of the meeting was on disruption control and disruption mitigation issues**.**

The next meeting of the TG will be held in Toki, Japan in conjunction with the 16th US-Japan Workshop on active MHD control (proposed for March 5-9, 2012) and will be hosted by the National Institute for Fusion Science (NIFS), Toki, Japan. The next following meeting will be held in San Diego, USA (tentatively scheduled for Oct. 15-17, 2012) and will be hosted by General Atomics.

3D Physics

The importance of 3D effects on tokamak stability and plasma control was highlighted in a number of theoretical/modeling and experimental presentations. Topics of discussion included the effects of non-axisymmetric passive structures (ports, blanket modules, etc.) on the stability of the resistive wall modes in ITER; the existence of stationary helical states in tokamaks (e.g., snakes); experiments and nonlinear simulations of the interaction between a sawtooth and an external (2,1) kink mode; and the plasma response to resonant magnetic perturbations in stellarators and tokamaks. Plasma response to resonant magnetic perturbations (RMPs) and predictions on screening, braking and transport effects associated with suppressed islands were compared for various theoretical/simulation models. Finally the importance and utility of 3D tools, developed over the years in stellarator research, for tokamak applications (including ITER) was highlighted with specific reference to rapid reconstruction of experimental equilibria for enabling interactive monitoring and control of plasma confinement.

Error Fields

An ITER Organization (IO) presentation summarized the present status of error field calculations for ITER using both the “3-mode” and the “overlap” error field criteria and concluded that error fields expected in ITER should be reduced by about a factor of 4. Further studies are in progress to improve the estimates and to optimize strategies for their reduction. The working group WG-9 has developed a new scaling for error field thresholds in torque-free H-modes. Near-term analysis in this group will focus on analysis of the error correction capabilities of ITER’s error field control coils (EFCC) and edge localized mode (ELM) coils.

Experimental results from NSTX showed the importance of plasma amplification of error fields in high β plasmas as well as the role of rotation in determining the error field (EF) threshold. The principle of error field assessment through application of an externally driven mode rotation was successfully demonstrated on Extrap-2R device using an n=10 rotating kink mode.

Resistive Wall Mode Stability and Control

The principal areas of concern and investigation associated with RWM stability and control continue to be towards obtaining a better estimate of passive stabilization effects, and validation of various active control schemes by comparison with experiments.

Theoretical modeling studies have shown that in tokamaks kinetic stabilization is mainly due to mode resonance with the precession frequency of trapped particles whereas in reversed field pinches (RFPs) it arises mainly due to mode resonance with the transit frequency of passing particles. Joint experiment MDC-2 is engaged in benchmarking and experimental validation of kinetic RWM stability models, including a joint NSTX/DIII-D experiment.

NSTX reported significant success in producing high β_N plasmas with low l_i by using a new RWM state space controller. Some recent RWM experiments carried out on the RFX-mod device (operated in the low q(a) tokamak mode) explored the efficacy of different control strategies and the physics of resonant field amplification. Working group WG-7 has near-term goals of validation of RWM feedback stabilization models with existing experimental data, and assessment of the capability of ITER's ELM coils for RWM stabilization.

Neoclassical Tearing Mode Stability and Control

A status report on the development of a real time control system for electron cyclotron current drive (ECCD) control of NTMs on ITER was presented. The basic elements of this control system rely on utilizing the presence of a growing mode to align the mirrors followed by "active tracking" of the resonant surface when the mode is suppressed. Some of the main issues related to the control system that need further study are the necessity of having real time poloidal mode analysis to distinguish between an (m/n=2/1) mode and sawteeth (m/n=1), and a simultaneous real time equilibrium reconstruction capability (MSE EFIT and TORAY) for active tracking. The IO has requested an assessment of the relative merits/demerits of CW operation of ECCD (larger energy consumption) vs. modulated operation (leading to fatigue of the electron cyclotron (EC) system).

Several joint experiments are concerned with NTM stability and control. Data collection on NTM aspect ratio effects is essentially complete for MDC-4, and analysis is in progress. In MDC-5, several devices have demonstrated sawtooth pacing for NTM avoidance, using modulated ECCD. In MDC-8, NTM stabilization experiments using real-time steering of ECCD mirrors are anticipated at several facilities. Recent results in MDC-14 indicate that plasma rotation may affect NTM stability through the triggering physics as well as through the underlying plasma stability. Much of the near-term effort in these joint experiments will be focused on input to ITER requirements for real-time control of NTMs and sawteeth.

Disruption Modeling and Experiments

An IO presentation highlighted some of the important disruption related design issues for ITER, particularly in the areas of disruption induced electromagnetic loads and position control of runaway electron beams. Data from some present day tokamaks indicate a complicated temporal evolution of a current quench (e.g., initially slow and then fast) that can cause an overlapping of large halo and eddy currents. Large forces experienced by some of the in-vessel components due to resonance between their natural frequencies and halo current rotation are another major concern for ITER. Preliminary analysis performed with the DINA code demonstrated very limited capability of ITER in-vessel coils for vertical position control of the disruption generated runaway electron beam. The TG was requested to provide physics and design guidelines on some of these issues with the help of additional experimental data and modeling efforts.

Recent progress on modeling of halo currents and vertical disruption events (VDEs) was presented by several groups. A new working group WG-10 has recently begun assessment of halo current models.

There has been significant progress recently on the disruption database (joint experiment MDC-15). Input of initial halo current data is essentially complete. An initial set of variables has been defined for massive impurity injection experiments, and data are being submitted. A new web-based interface to the database has been created, with password access for working group members.

Disruption Avoidance and Control

In joint experiment MDC-17, disruption avoidance by electron cyclotron heating (ECH) has been demonstrated in Asdex-Upgrade (AUG). Disruption avoidance by ECCD was demonstrated in DIII-D, using RMP fields to steer a locked mode the proper toroidal phase for suppression. Further ECH/ECCD experiments with real-time mirror control are expected in AUG, DIII-D, and FTU in 2012. Future work will include the assessment of the power requirements for disruption avoidance by localized ECH and ECCD. The scope of this joint experiment on disruption avoidance is being expanded to include requirements for real-time detection of disruption thresholds and soft-stop strategies.

A conceptual disruption avoidance/control scheme based on feedback control of internal/infernal modes and near ideal MHD modes was presented. The scheme envisages the use of non-magnetic sensors (e.g., electron cyclotron emission (ECE) diagnostics) for sensing the mode and the radial injection of a modulated ECH beam to generate an instantaneous "non-thermal pressure" to act on the mode and suppress it.

Disruption Mitigation

As one of the major outstanding issues for ITER operation, disruption mitigation received primary attention at this meeting with a number of experimental, theoretical and modeling papers devoted to this topic. An overview presentation, summarizing the present status of disruption mitigation research and the challenges that remain, provided a background perspective on the topic and a framework for future work to be done. Keeping in mind the objectives and design constraints of a disruption mitigation system (DMS) for ITER, the presentation reviewed the principal features of various massive material injection (MMI) systems and their attendant physics and technology issues to meet the demands of reduction of heat loads and forces on the vessel and prevention/control of runaway electrons. A detailed written report, based on the presentation, is currently under preparation and it is planned to make it available to the TG members as well as to the IO and Science and Technology Advisory Committee (STAC) members of ITER.

Of all the MMI schemes, the one based on massive gas injection is the most developed to date and is being actively studied both experimentally and theoretically. New experimental results from JET show that massive gas injection (MGI) substantially reduces the amplitude and duration of plasma current (I_p) asymmetry. AUG experiments find a higher fuelling efficiency (by a factor of 2) for gas injection done from the high field side compared to injection from the low field side. Several facilities have installed new valves for tests of high-field side injection, private flux injection, and multiple-valve injection.

Joint experiment MDC-1 will continue to assess the mass injection requirements for heat load and halo current mitigation, and the prospects for runaway avalanche suppression by MMI. Working group WG-8 is in the process of evaluating radiation asymmetries and local heat loads during MGI, based on existing single-valve experiments. The disruption database (MDC-15) has recently added variables related to MGI, and is ready to accept data on this topic.

In the area of runaway electron (RE) control and suppression experiments, Tore Supra and T-10 devices have successfully tested a rupture disc type gas injection system. It was found that the high-pressure gas jet propagates faster through current quench plasmas and slower through high temperature plasmas. The gas jet can trigger a secondary instability in a slow current quench as evidenced in T-10, but Tore Supra results were inconclusive. RE control experiments on DIII-D were successful in ensuring the vertical position and vertical stability of the RE beam; there appear to be no fundamental obstacles to a full RE current rampdown. Recent experimental data on fast RE current mitigation using a variety of injected gases also provide the first basis for comparison of runaway dissipation by gas vs. reverse electric field. In the coming year, joint experiment MDC-16 will focus on testing the predicted critical electric field for avalanche production of runaways.

Progress in theoretical modeling/simulation of RE dynamics was shown by comparing NIMROD results on RE confinement in diverted Ar pellet discharges to experimental RE plateau current. The RE current vs. RE loss rate was seen to obey the trend predicted by the simplest model of Ar distribution over the plasma volume. There is also good agreement between simulations of MGI done for C-Mod and DIII-D configurations and corresponding experimental results.

Axisymmetric Control

A new joint experiment on axisymmetric control (MDC-18) will extend previous experimental analysis and modeling of vertical position control. The new work will address models of plasma response and plasma disturbances, validation of these models, and the design of higher-order controllers. Axisymmetric control of runaway electron currents will be included. An IO presentation emphasized an urgent need for further analysis of the scaling of dZ/dt noise, for input to controller design and estimates of coil heating, and MDC-18 will address this issue.

An IO presentation discussed a proposal to reduce the Lorentz loads on the central solenoid conductors, including a faster current ramp and early x-point formation. The implications for axisymmetric control MHD stability should be studied with numerical simulations and scaled experiments.

Active joint experiments:

MDC-1	Disruption mitigation by massive gas injection
MDC-2	Joint experiments on resistive wall mode physics
MDC-4	Neoclassical tearing mode physics – aspect ratio comparison
MDC-5	Comparison of sawtooth control methods for neoclassical tearing mode suppression
MDC-8	Current drive prevention/stabilization of NTMs
MDC-14	Rotation effects on neoclassical tearing modes
MDC-15	Disruption database development
MDC-16	Runaway electron generation, confinement, and loss
MDC-17	Active disruption avoidance
MDC-18	Evaluation of axisymmetric control aspects for ITER (Proposed)

Active working groups:

WG-7	Resistive Wall Mode feedback control
WG-8	Radiation asymmetry during massive gas injection
WG-9	Requirements for error field control
WG-10	Halo current modeling

Announcements

Submit BPO-related announcements for next month's eNews to Dylan Brennan.

Upcoming Burning Plasma Events

2011 Events

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

Nov 20-22, 2011
16th Workshop on MHD Stability Control
San Diego, California USA

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

2012 Events

Jan 16-19, 2011
ITPA Divertor and SOL (PSI Selection Committee) Topical Group Meeting
Jüelich, GERMANY

Apr 2-4, 2012
ITPA Pedestal and Edge Physics Meeting
Hefei, China

Oct 8-13, 2012
24th IAEA Fusion Energy Conference
San Diego, CA

Directories of Other Plasma Events

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

Please contact the administrator with additions and corrections.