U.S. Burning Plasma Organization: MFE Research in Support of Burning Plasmas

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Deputy Director, USBPO

Fusion Power Associates
34th Annual Meeting and Symposium
Fusion Energy: Visions of the future.
December 11, 2013, Washington, DC
Strong need for US research in support of burning plasmas!

• ITER is now under construction, but is much more than a construction project.
  • While much of the design is complete, critical issues remain and decisions are being made now, on the basis of worldwide magnetic fusion research.

• Current and ongoing research also inform the experimental planning for ITER, both the early operation (eg, high confinement regimes in reduced field, non-nuclear phase) and scenarios to meet ITER’s goals (Q=10, and steady state).

• Also need to build teams to exploit ITER physics. Ultimately, the parties which get the most out of their investment will be the ones which have the strongest research teams in the period before ITER operates.
Examples: Two big decisions made Nov 2013 by ITER Council

#1 New divertor strategy

- IO proposed in 2011 to eliminate first CFC/W divertor and begin operations with a full-W variant which should survive to the end of the first DT campaign.
  - Main issue is that Carbon, used by most tokamaks, will likely retain too much tritium to be licensed in DT phase.

  - IO proposal in 2011 to limit first CFC/W divertor and begin operations with a full-W variant which should survive to the end of the first DT campaign.

  - Multi-year study by several ITPA groups, and engineers, informed ITER Science and Technology Advisory Committee (STAC) recommendation.

  - Bottom line: There will be issues with W divertor. But, ITER will need to address them in any case, not made markedly worse by facing earlier. The change will affect the research plan. Do need ongoing R&D on boundary physics, and operation with metal walls!

A. Hubbard, USBPO. Dec 2013 FPA meeting
#2: Install in-vessel coils to control Edge Localized Modes and vertical movements

**Issues are**

1) **Edge Localized Modes** cause pulses of heat to divertor, which would erode it – need to stabilize them.

2) **Vertical instability** could lead to very damaging disruptions.

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**Design Overview**

<table>
<thead>
<tr>
<th>27 ELM (Edge Localized Mode)</th>
<th>2 VS (Vertical Stability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide Resonant Magnetic Perturbations at 5 Hz; Consider RWM in future</td>
<td>Stabilize 15 MA plasma up to $Z_0 = 16.5$ cm</td>
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- Again, there has been a recent multi-year effort to establish confidence that RMP coils should work, and are robust & redundant enough – very challenging engineering. US has been a leader, especially in RMP ELM stabilization, first demonstrated on DIII-D. But, physics issues remain – other devices finding different results.

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E. Daly, ex-ITER
APS town meeting 2013
USBPO role is to support ITER via US MFE program

- **US ITER Project Office**
  - US Domestic Agency for ITER
  - Provides hardware & technical contributions

- **USBPO**
  - Coordinates US burning plasma research, to advance scientific understanding & ensure greatest benefit from ITER
  - USBPO Director, Chuck Greenfield, is also the US ITER Project Office Chief Scientist, and on ITER STAC.

- He is also on the ITPA Coordinating Committee, which is meeting this week in St. Paul Iez Durance.

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A. Hubbard, USBPO. Dec 2013 FPA meeting
USBPO Mission and activities

USBPO Mission
Advance the scientific understanding of burning plasmas and ensure the greatest benefit from burning plasma experiments by coordinating relevant U.S. fusion research with broad community participation

Activities can be divided into three main elements:

1. **Communication.** Ensuring that a broad community of interested and qualified researchers is well informed about and engaged in solving current burning plasma issues.

2. **Coordination.** When it is beneficial, coordinate and help prioritize US research on selected issues. Actual research is done by FES-funded laboratories.

3. **Preparation.** Prepare for operational phase of ITER, by encouraging broad, open participation and eventually helping form well qualified teams so US will maximize scientific benefit.

A. Hubbard, USBPO. Dec 2013 FPA meeting
Working to strengthen links between USBPO topical groups and ITPA, other groups

USBPO Topical Groups:
- MHD, Macroscopic Plasma Physics
- Pedestal and Divertor/SOL
- Energetic Particles
- Confinement and Transport
- Diagnostics
- Integrated Scenarios
- Plasma-Wave Interactions
- Operations and Control
- Modeling and Simulation
- Fusion Engineering Science

ITPA Topical Groups:
- MHD
- Pedestal
- Divertor and Scrape Off Layer
- Energetic Particles
- Transport and Confinement
- Diagnostics
- Integrated Operational Scenarios

- ITER Plasma Control Group
- Fusion Simulation Project
- ITER Modeling Expert Group
- US & Int’l technology communities Virtual Laboratory for Technology

A. Hubbard, USBPO. Dec 2013 FPA meeting
Enhanced communication between ITPA and USBPO community

The issue:

• **ITPA (International Tokamak Physics Activity)** groups have members from all ITER parties, meet twice a year in different countries.
  – Each party limited to 7 members. Most are from large facilities.
  – While US allows other experts to attend, travel costs in practice limit participation. Access to ITER-hosted website is now restricted.

• **USBPO membership** is open to all interested in any topical group.
  – Currently 377 members, from many institutions of all types and sizes.

• Several means being used for regular communication:
  – **E-News.** Monthly newsletter (to 588 subscribers) includes short summaries of upcoming topics in advance of ITPA meetings, and highlights afterwards.
  – **E-Mails to BPO Topical Group lists.** Can provide more detailed information such as ITPA agendas and meeting summaries.
  – **Forum.** Post similar content for future reference, broader access.
  – **Web seminars.** Online presentations to BPO community, with open discussion.

A. Hubbard, USBPO. Dec 2013  FPA meeting, 8
Web seminars are proving most popular and effective

- Based on participation and community feedback, web seminars are an effective tool.
  - Made possible by ESnet tools (ReadyTalk, H323) provided by DOE.
- Reestablished more regular series in 2013, some on ITPA and others on broader ITER topics. Recent examples:
  - June 12: Energetic Particle Physics ITPA, Eric Frederickson (PPPL).
  - September 25: Challenges and R&D needs for combined thermal and magnetic energy mitigation in ITER, John Wesley (GA).
  - Dec 9: Transport and Confinement ITPA, George McKee (U. Wisc) and Gary Staebler (GA).
- Participation varies, and cannot be exactly counted, but is large – Typically > 30 Ready Talk connections + ~3 large groups on H323, 60+ participants.
  - Notably, we always get many participants from small groups, beyond the large fusion labs. Universities report that students are engaged.
- Expect to expand seminar series in 2014 – many topics being suggested.
Example of Coordination: Disruption Task Group

- In many cases, ITPA communication and facility program planning processes provide sufficient coordination—then BPO stays out of the way.
- In some cases, a task group is set up to broaden participation, focus attention. A current example is Disruption Mitigation.
- Disruptions (sudden loss of plasma current and energy) have potential for serious damage to a fusion-scale device such as ITER!

C. Greenfield, APS 2013

A. Hubbard, USBPO. Dec 2013 FPA meeting
Example of Coordination: Disruption Task Group

- Disruptions must be avoided where possible, if not, “mitigated”: take action before or during a current quench to reduce forces, spread out heat.
- Disruption Mitigation System is a new US responsibility, not in baseline. Many key decisions needed before design reviews in next 2-4 years.
  - What type of system (gas, pellets?)
  - How many locations needed?
- While specifying is a shared responsibility for whole ITER/ITPA team, US has a key interest in making the best decisions, soon!
- Task group led by Bob Granetz (MIT), John Wesley (GA), members from across US. Started with 2012 workshop. PPPL held 2013 theory workshop.
- Feedback from STAC is that disruption mitigation is likely to be a high ITER priority in 2014.

Wesley, BPO seminar

A. Hubbard, USBPO. Dec 2013 FPA meeting
Progress on quantifying quench time, peaking and asymmetries.

- In 2013, focussed mainly on mitigation of thermal and mechanical loads by massive gas injection.
- Quench time must be not too slow (excessive heat & forces) – or too fast (excessive torque). Studying variations with type, quantity of gas on DIII-D.
- Experiments have shown poloidal and toroidal peaking, which varies a lot and can be worse with multiple jets.
- Recent C-Mod analysis and modeling show this unexpected result is due to MHD instabilities, reduces if mode rotates. Can this be controlled for ITER?

G. Olynk, MIT Ph.D. thesis
Many critical issues remaining, especially runaway electrons

- **Bad news:** Runaway electrons during ITER disruption pose potential for very serious damage – in worst case melting W divertor, or Be first wall.

- **Good news:** ITPA study shows density needed to stop REs is 5-10x lower than theory predicts.

- **Open issues:** What is the additional mechanism quenching runaways? How will limit scale to ITER? Can ITER reliably meet this limit, at the same time as other mitigation requirements? Need improved theory as well as more experiments!

R. Pitts, ITER APS 2013

R. Granetz, APS 2013

Example: fast RE loss: $t_{\text{loss}} = 100 \, \mu s$ $W_{\text{RE}} = 20 \, \text{MJ}$, $E_{\text{RE}} = 12.5 \, \text{MeV}$

A. Hubbard, USBPO. Dec 2013 FPA meeting
Preparation: Task Group on ‘Modes of Participation on ITER’

• As ITER project rightly focusses on construction, we also need to consider how the experiment is going to operate. Surprisingly little has been decided about the operating phase.
• While this may seem premature, key decisions are being made, NOW, about CODAC which will affect what is feasible later.
  *Eg, How are experiments proposed and decided? Access to data by whole team? Remote participation?*
• Impetus for task group was combination of our own interests as US researchers, and requests for input from the ITER Organization.
• Task group led by Rajesh Maingi (PPPL), Mike Walker(GA), 8 other members from across MFE program.
• To date:
  – Gave ITER input on practices on US experiment workflow, from proposal to publication, and examples of data analysis (June 2013).
  – Gave ITER *draft* input on how US envisages experimental operation on ITER, as input to CODAC design reviews (Sept).
• Coming months: Broaden scope (eg, *How will, US organize itself?*) and community input (web site, web seminar). Produce final report.

A. Hubbard, USBPO. Dec 2013 FPA meeting
MFE research in support of burning plasmas is – and needs to be – very active.

Results were highlighted in a recent contributed session at APS-DPP “Research in support of ITER”

USBPO got ~ 28 submissions for 15 slots. Much more relevant research in other presentations.

All talks now posted on USBPO web site. http://burningplasma.org

Broad range of topics including:

- Integrated modeling: S. Pinches, ITER Org.
- Disruptions: C. Greenfield, GA for J. Wesley and R. Granetz, MIT for G. Olynk
- ITER Diagnostics: Brent Stratton, PPPL
- ICRF and with Metallic PFCs: S. Wukitch, MIT
- Scenarios: J. Schweinzer, IPP Garching, J. Ko, NFRI Korea, F. Poli, PPPL
- ELM Mitigation: L. Baylor, ORNL, N. Ferraro, GA
- Divertor physics and integration: T. Petrie, GA, J. Lore, ORNL
- Plasma Control: J. Snipes, ITER, D. Humphreys, GA, D. Shiraki, Columbia

Will show a few examples, time permitting
ELM Control – RMP models are being improved with plasma responses

Nate Ferraro, GA

• “Improved” ELM suppression criteria, with and without plasma response are being compared to DIII-D ELM suppression experiments.

• Used to predict suppression in ITER scenarios.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Threshold</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>Vacuum IOW</td>
<td>12.7%</td>
<td>63%</td>
</tr>
<tr>
<td>Plasma IOW</td>
<td>6.4%</td>
<td>70%</td>
</tr>
<tr>
<td>Vacuum $\sigma_{ped}$</td>
<td>1.55</td>
<td>89%</td>
</tr>
<tr>
<td>Plasma $\sigma_{ped}$</td>
<td>0.90</td>
<td>73%</td>
</tr>
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Integrated modeling looking ahead to H&CD upgrades for ITER steady state

F Poli, PPPL

20 MW of coupled LH can enhance the plasma performance toward the ITER goals

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<tr>
<th></th>
<th>Baseline</th>
<th>LH upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/n_G</td>
<td>1.0</td>
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</tr>
<tr>
<td>q_95</td>
<td>8.1</td>
<td>5.6</td>
</tr>
<tr>
<td>I_{NI}</td>
<td>6.4</td>
<td>8.2 MA</td>
</tr>
<tr>
<td>Q</td>
<td>1.7</td>
<td>2.9</td>
</tr>
<tr>
<td>β_N</td>
<td>1.77</td>
<td>1.78</td>
</tr>
<tr>
<td>H_{98}</td>
<td>1.38</td>
<td>1.42</td>
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Francesca Poli 55th APS-PP meeting, Denver CO, nov 2013 07/08

A. Hubbard, USBPO. Dec 2013 FPA meeting
Impurity seeding experiments modelled in 3-D MC3-EIRENE

- ITER question: *How many gas valves will we need for seeding to uniformly reduce divertor heat load?*
- C-Mod ran experiments with toroidally localized divertor gas injection, arrays of diagnostics.

J. Lore (ORNL), modeling C-Mod experiments by M. Reinke (MIT)
Impurity seeding experiments modelled in 3-D MC3-EIRENE

- ITER question: *How many gas valves will we need for seeding to uniformly reduce divertor heat load?*
- C-Mod ran experiments with toroidally localized divertor gas injection, arrays of diagnostics.
- New ORNL modeling reproduces many of the trends with puff location—some will require new physics.

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Control research involves new physics and mathematics

D. Humphreys, GA

Eg CURRENT PROFILE CONTROL

- Actuators and Scheme:
  - ECH, NBI, density, loop voltage?
  - Multipoint q-profile control
  - Share EC system with MHD control

- Status/Research Gaps:
  - Some experiments done
  - ITER specific candidate not identified and demonstrated
  - Need robust actuator sharing scheme
  - Need integrated goals: scenario/kinetic and stability control

JET q-Profile Control

D. Moreau, CEA

- q-profile regulated using LHCD, NBI, ICRH
USBPO: MFE Research in Support of Burning Plasmas

• ITER is providing a strong focus in the US MFE program on the issues which need to be resolved to achieve burning plasmas.
  – Most of these are relevant to any fusion-scale facility (eg a Fusion Nuclear Science Facility). DEMO will have same and greater needs. Hence any ‘vision for the future’ requires solving BP issues.

• USBPO plays a role in supporting this research.
  – Communicating issues and progress to the US community.
  – Coordinating research where helpful.
  – Preparing for effective participation on, and benefit from, ITER.

• The actual research is conducted by US research groups, and depends on continued DOE support.
  – Has been declining in recent years as number of facilities, run weeks and supported researchers at all institutions decreases.
  – Strong MFE program is vital if US is to help ITER succeed, and “ensure the greatest benefit from burning plasma experiments”

A. Hubbard, USBPO. Dec 2013 FPA meeting
For more info or to join

- Web site  www.burningplasma.org

- There you can sign up:
  - To become a member, researchers join one or more topical groups of interest.
  - Those outside US can become ‘associate members’
  - Anyone can receive monthly e-News.