United States
Burning Plasma Organization

U.S. Burning Plasma Organization: Supporting US Scientific Contributions to ITER

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USBPO Council Chair
on behalf of USBPO

Fusion Power Associates
Thirty-year Anniversary Meeting and Symposium
Fusion Energy: Status and Prospects.
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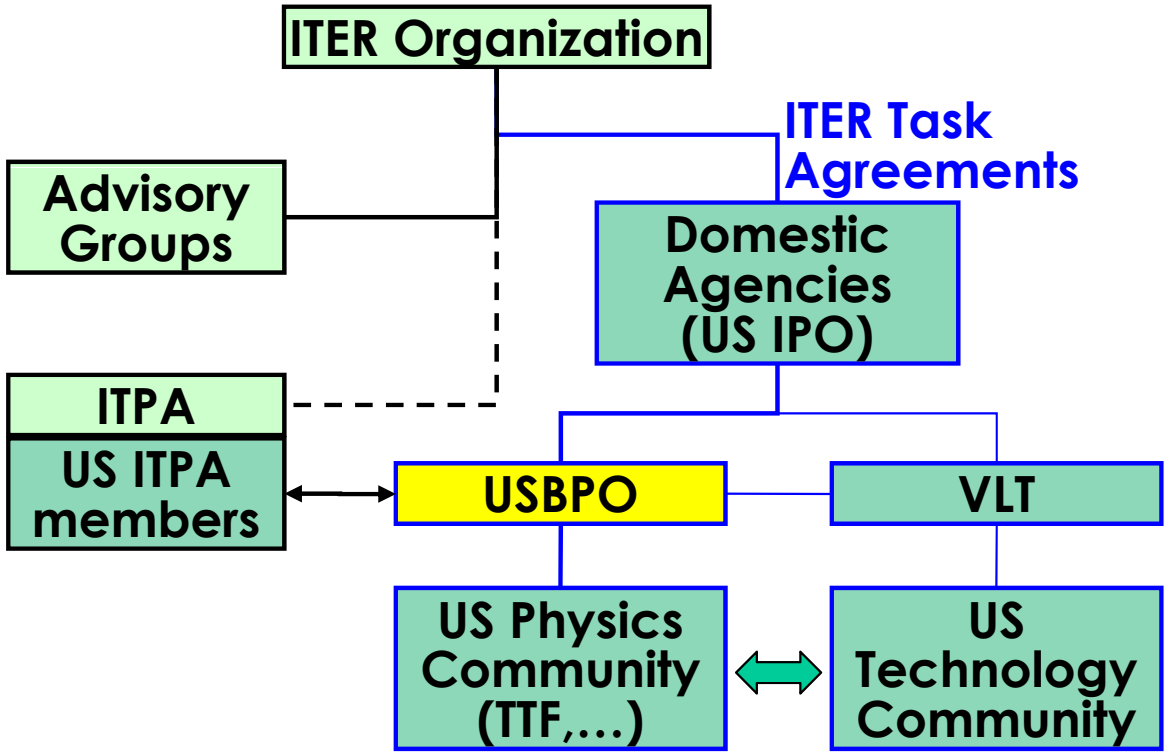
Outline

- Introduction: Role and organization of USBPO
- High priority ITER Research Needs
- Examples of recent US contributions *(few of many!)*
- Planning for US Participation in ITER: 2009 report by USBPO Panel.
- Other USBPO roles and activities

Role of US Burning Plasma Organization in ITER support

- As the Domestic Agency, US ITER Project Office is the main link to ITER Organization. Primarily responsible for providing US technical contributions (ie our 9% of project). See previous talk.
- US fusion program also supports many other ITER needs, answering science questions which will affect ITER design, operation and ultimate success
  - Not limited to 'our' contributions; US expertise and effort greatly exceed 9%!
- **USBPO mission is to coordinate US Burning Plasma related research, to advance science understanding and ensure the greatest benefit from ITER.**



USBPO Director, Jim Van Dam, also serves as US IPO Chief Scientist, assuring strong connection and communication between the two entities.

The US Burning Plasma Organization; Topical Groups cover a broad range of expertise.

Jim Van Dam (Director)
Chuck Greenfield (Deputy Director)
Nermin Uckan (Assistant Director for ITER Liaison)

Council:
Amanda Hubbard (Chair)
Mike Zarnstorff (Vice Chair)
+10 members at large +
ITER Chief Techologist

Executive Committee members in red

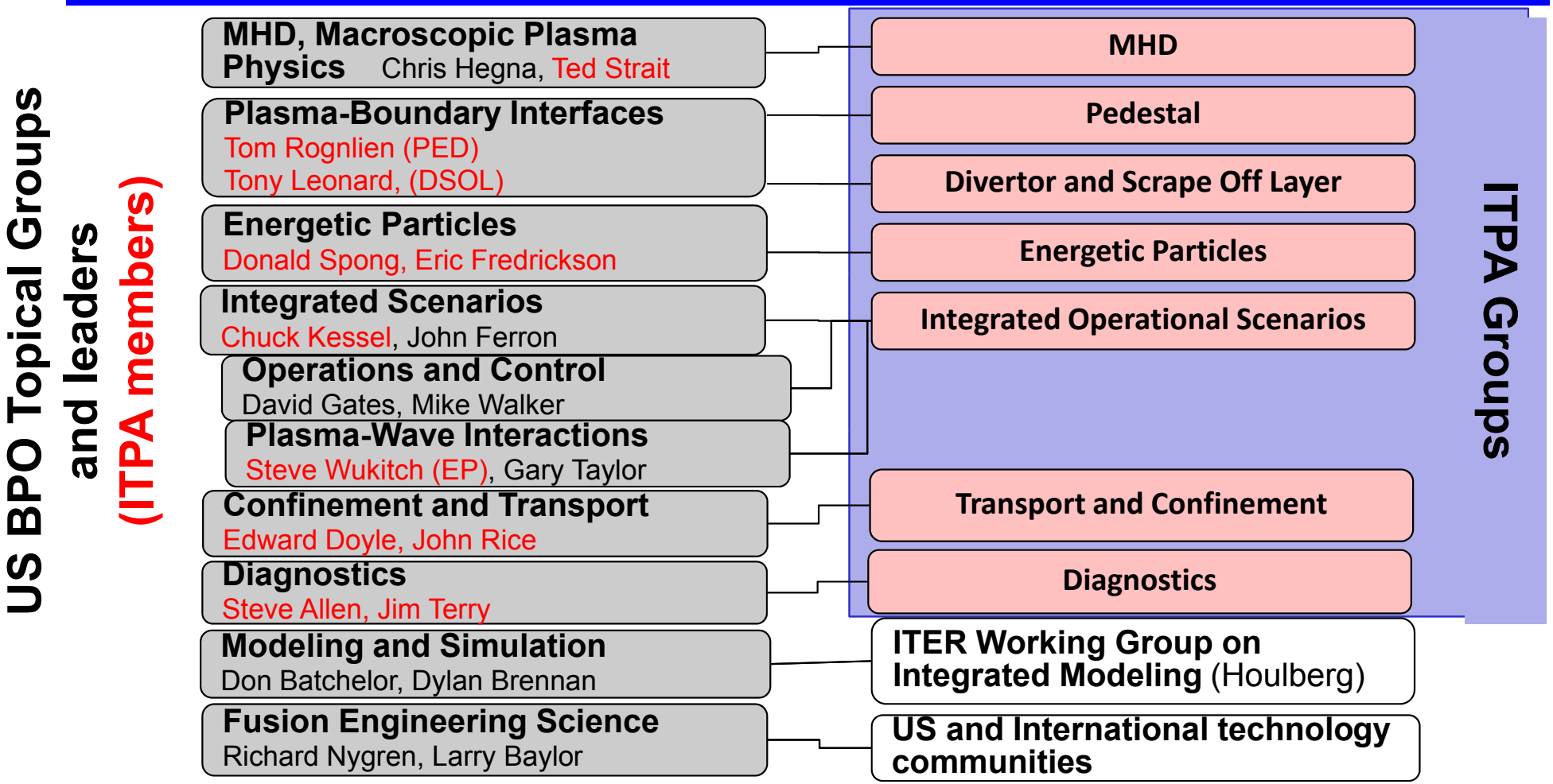
Research Committee made up of Leaders and Deputies of 10 Topical Groups

- MHD, Macroscopic Plasma Physics
- Integrated Scenarios
- Plasma-Boundary Interfaces
- Operations and Control
- Fusion Engineering Science
- Modeling and Simulation
- Diagnostics
- Confinement and Transport
- Plasma-Wave Interactions
- Energetic Particles

MEMBERS
(currently 331)

Membership in USBPO is open to any fusion researcher who joins one or more topical groups.

USBPO TGs have strong links to ITPA and ITER Working Groups



- ITPA is now under ITER auspices; USBPO nominates US representatives to ITPA TGs and to ITER WGs (eg Research plan, Modelling, TBM)
- Serves to **inform** and **involve** many US researchers, well beyond the limited number of official members; **We seek to enhance these links.**

Several channels for ITER Research Priorities and requests

- **ITPA High Priority Research Tasks** – set by topical groups and ITPA Coordinating committee, on an annual basis.
  - USBPO is represented on CC, disseminates to membership. Voluntary international efforts, typically on 1-2 year time scale.
- **ITER Physics Work Programme** – prepared by IO.
- **ITER Research Plan Working Group** has identified a number of issues which affect planning. Has US members, who communicate needs. Setting up a USBPO Task Group to assist.
- **ITER Task Agreements** – specific work needed on short time scale, paid for by ITER (eg, design and analysis, scenario simulations).
  - Calls sent to USIPO. USBPO distributes, helps assess proposals.
- **Special urgent requests** – eg, Tests of TBM ripple effects, recent call for efforts on ELM mitigation and avoidance.

Much overlap among these requests. Key role for USBPO in coordinating, contacting appropriate US experts to do the research.
Actual work is done by US facilities and other fusion research groups!

US has been highly successful in bidding for recent ITER Tasks

- US researchers submitted proposals for most (13/16) tasks solicited by the ITER Organization in past year.

- Awarded about 50%, reflecting strong and broad expertise:
  - Study of Error Fields using Ideal Perturbed Equilibrium Code
  - Study of Control of Plasma Current, Position and Shape
  - Self Consistent Simulations of Plasma Scenarios
  - Benchmarking and update of TSC codes and simulations of ITER disruptions/VDEs scenarios
  - Task on the Error Fields Measurements without plasma
  - Task on the Error Fields Measurements using plasma response
  - Task for Self-consistent Transport Simulations of Plasma Scenarios with Fixed-Boundary Equilibria
  - Task for Edge magnetic field structure for ELM control in ITER and associated power/particle fluxes to plasma-facing components

Examples of current ITER R&D needs relating to Research Plan

Taken from D. Campbell presentation leading off special session on "US Research in Support of ITER" at APS 2009, organized by USBPO

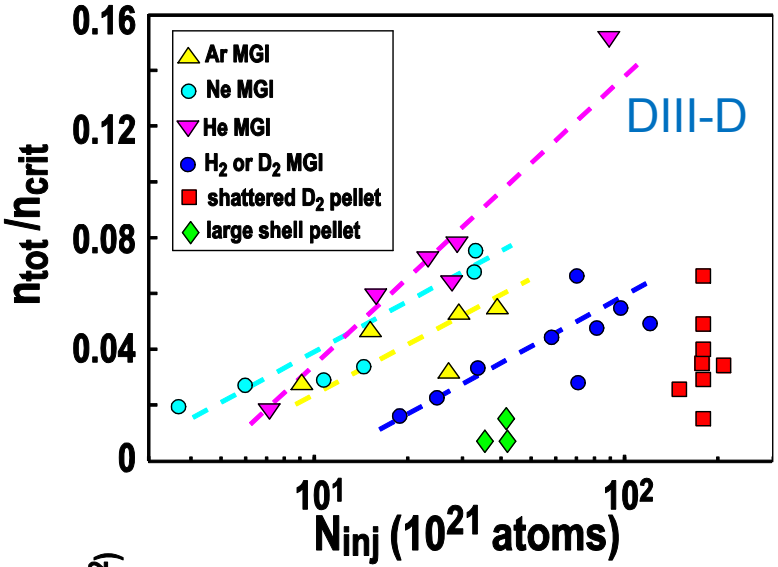
- **Top 12 risks associated with plasma operation and their potential consequences have been identified; mitigation strategies (and implications) have been developed, eg:**
  - Disruption mitigation has limited effectiveness
  - H-mode power threshold at high end of uncertainty range
  - ELM mitigation schemes of limited effectiveness or require extensive R&D in programme
  - Vertical stability control limited by excessive noise (or failure of in-vessel coils)
  - Lack of reliable high power heating during non-active phase of programme
  - Acceptable "divertor" performance with tungsten PFCs proves difficult to establish over required range of plasma parameters

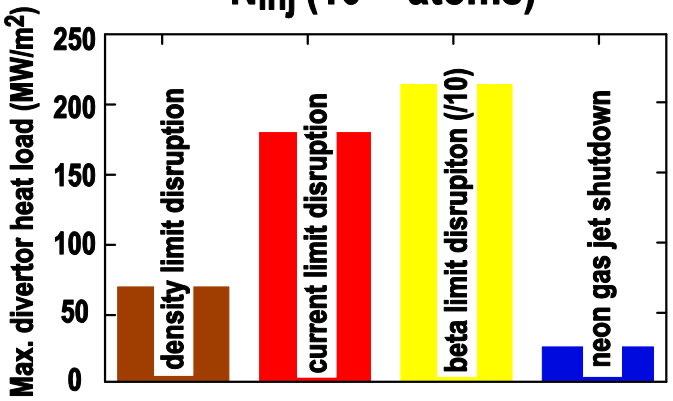
I will show *examples* of recent US work in these areas, from several groups. Much more is going on, covering nearly all high priority ITER topics.

Disruption Mitigation

- **Issue:** Need highly reliable means of mitigating disruptions (fast I_p quench) to avoid machine damage by IxB forces, thermal heat loads, and runaway electrons. *What is the best means? What are ITER requirements?*

- **DIII-D** is assessing multiple techniques – Massive Gas Injection, shattered pellets, shell pellets. (Hollman, APS 09)
- **C-Mod** is testing MGI with mixed gases, using Lower Hybrid Current Drive to generate fast electron "seed". Runaways are created, but rapidly lost during thermal quench. (Whyte, APS 09)
- Both experiments show good mitigation of heat loads, vessel currents and resulting forces with MGI.

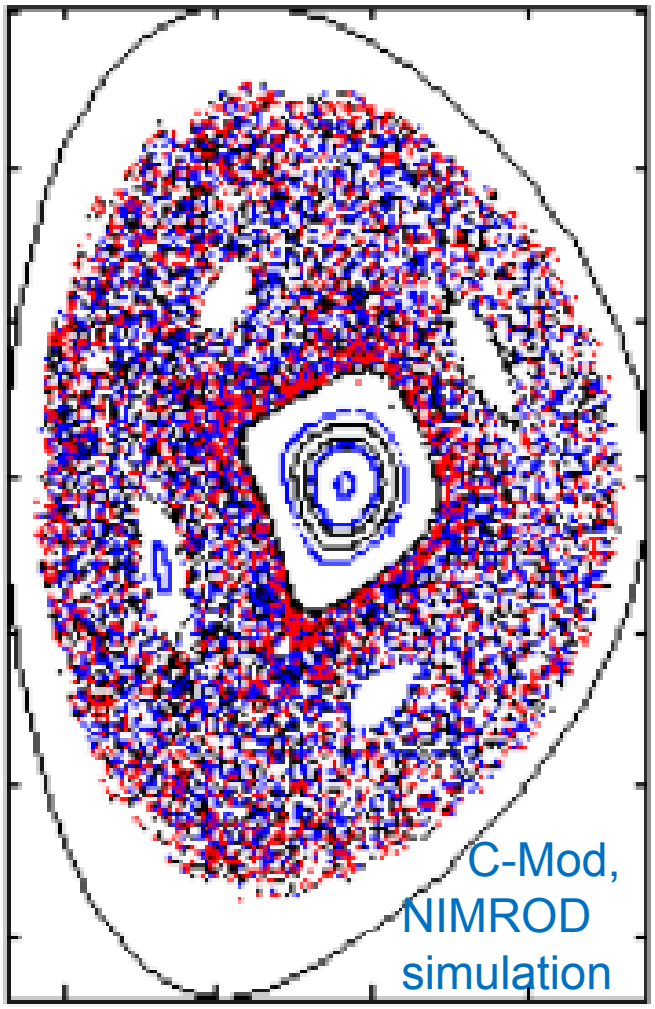




Disruption Mitigation: New insights from experiments, modeling

- A key open issue is what density is needed to suppress high energy runaway 'avalanche'.
  - Suppression' purely by collisions would require a "critical density" n_{crit} which is difficult to reach on ITER, and would impose a large gas load on pumping system.

- 3-D resistive MHD modeling of MGI in both C-Mod and DIII-D finds that stochastic fields triggered by edge cooling cause rapid loss of both thermal and non-thermal (runaway) particles, consistent with experiments. (V. Izzo, UCSD, APS09).

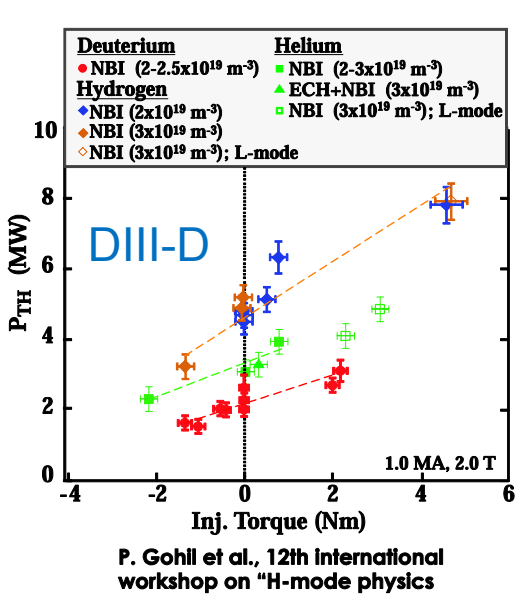


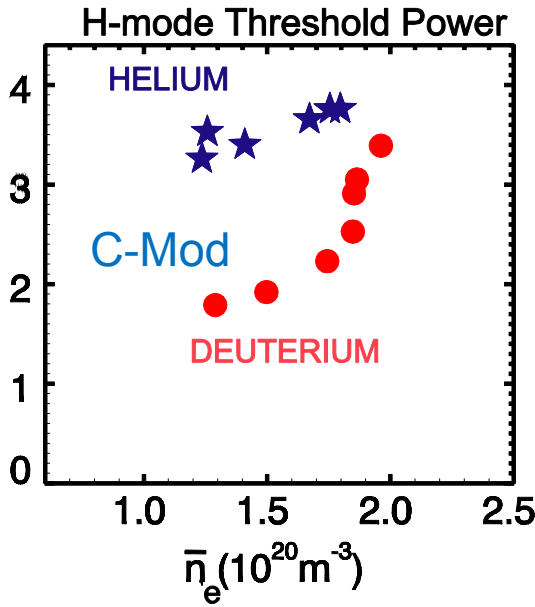
The additional loss mechanism implies it may not be necessary to attain the Connor-Hastie-Rosenbluth collisional limit to suppress runaways.

L-H Power Threshold

- **Issue:** ITER plans to operate in "High-confinement mode" with an edge transport barrier. Highly desirable to achieve this in pre-nuclear phase (H or He) to test physics and hardware. *What is power threshold? Will regime be accessible? Is it similar to D, T?*

- 2009 ITPA experiments in C-Mod, DIII-D and NSTX (and EU tokamaks) in response to ITER requests.
- L-H power thresholds are significantly higher in Helium than D in C-Mod (20% to 80%) and DIII-D (30-50%). Still higher in Hydrogen.
- Smaller difference (up to 20%) between He, D found on NSTX.



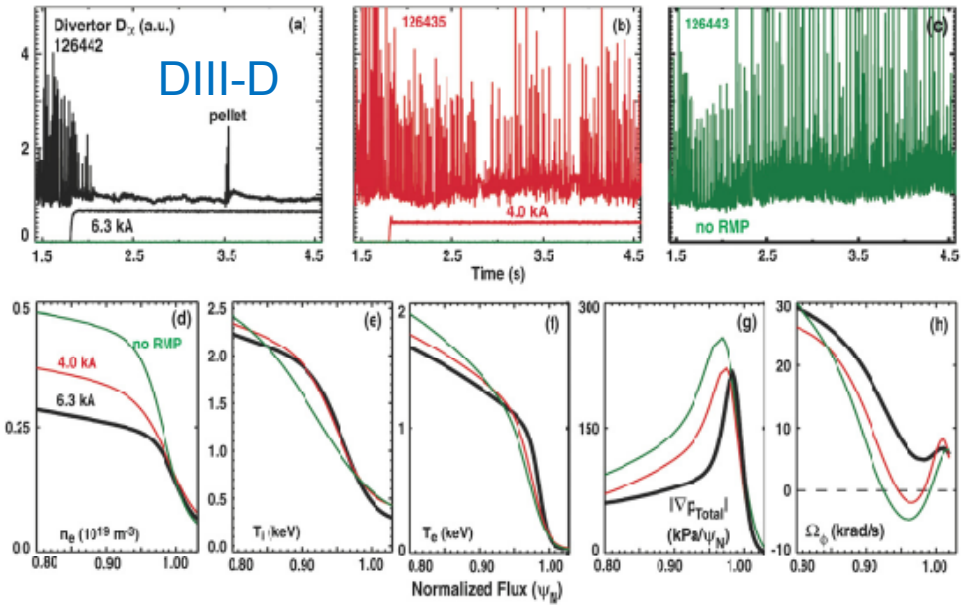


Given variation in L-H thresholds, prudent for ITER to plan for higher power thresholds for H-modes in the pre-nuclear phase. ITPA will be further studying physics mechanisms, and H-mode, ELM regimes in Helium.

ELM Mitigation and Avoidance

- **Issue:** Most H-modes exhibit periodic relaxations or "ELMs". Heat pulses on ITER could damage divertor. Need to control ELMs by active means, such as external "RMP" coils or pellets, or use regimes with benign relaxation mechanisms. *Urgent ITER R&D request sent recently to all DAs – but US program was already very active!*

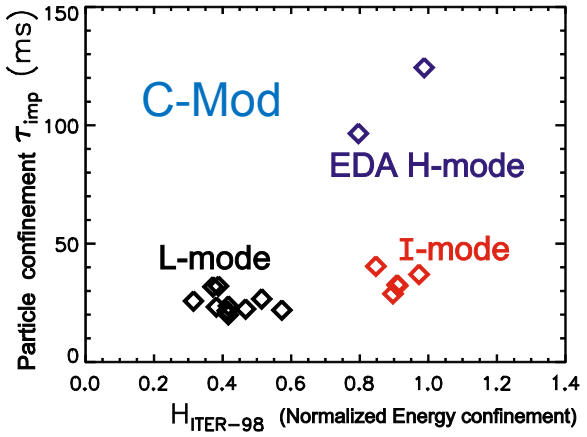
- **Mitigation:** DIII-D Tokamak has pioneered the use of RMP coils to suppress ELMs.
  - Results form the basis for the main proposed control method on ITER.
  - US is leading the ITER RMP coil design effort.
- Current physics issues include ELM suppression criteria, effect of RMP on particle and energy confinement.



Evans, Nucl. Fusion **48** (2008)

Multiple regimes *without* large ELMs are also being studied

Issue: Edge thermal transport barrier is needed for high energy confinement. BUT, If edge particle barriers are *too* strong, impurities build up. Ideally, want a continuous, benign, relaxation mechanism. Several such regimes have been found in US (and other) tokamaks. *Will they extrapolate to ITER conditions?*

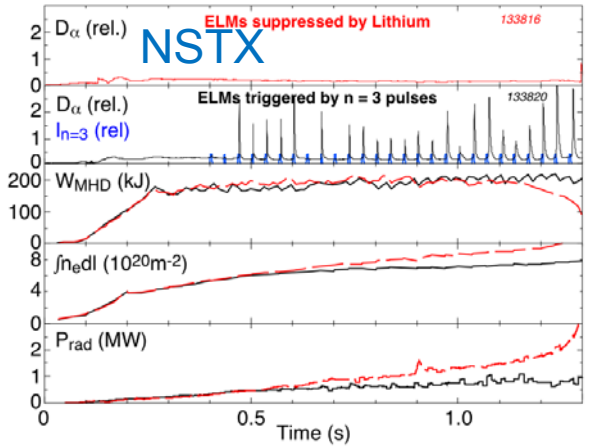


C-Mod:

- Enhanced D_α H-mode, without ELMs.
- "Improved L-mode" with energy barrier but no particle barrier. (Marmar, APS 09)

NSTX:

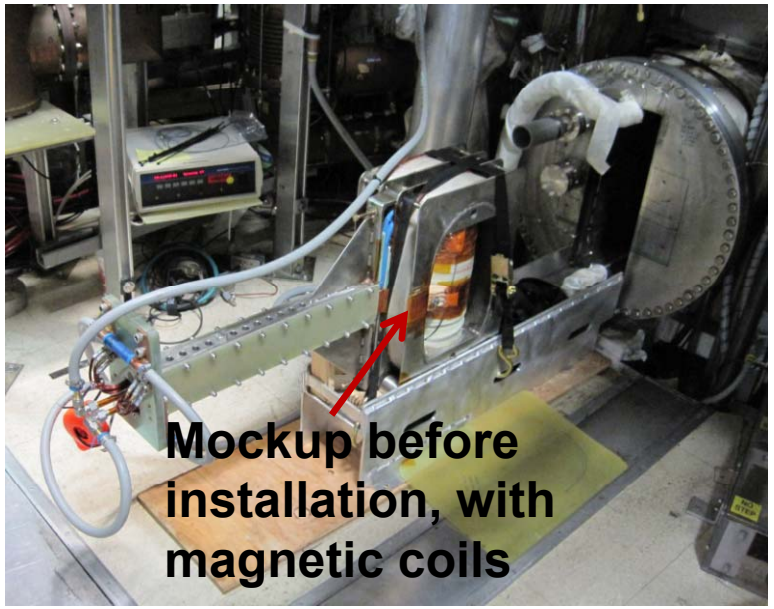
- Small ELM regimes.
- ELMs suppressed with Li walls. Controlled ELMs triggered with pulsed 3-D fields' and vertical shifts. (Maingi, PRL 09)



DIII-D: Quiescent H-mode, without ELMs. Recently extended to co-NBI and low-torque regimes, higher pedestal pressure. (Burrell 09)

ITER Test Blanket Module Error Field experiments in DIII-D

- **Issue:** ITER plans to test 6 tritium breeding Test Blanket Modules, ~1 tonne ferromagnetic steel in each. Will cause a localized error field exceeding those in present tokamaks. *What will be effects on plasma? (confinement, rotation, fast particles, ELMs etc)*



- While some effects (eg on alpha particles) can be calculated, most need to be measured – **ITER requested experiments!**
- DIII-D fabricated and installed a 'mockup' to approximate the error field of 2 TBMs in one port. (Project supported by ARRA funds).
- Just completed 2 weeks (11/9-20) of dedicated experiments, run by a highly international team, including IO and 5 ITER parties! Analysis is underway, should set limits on allowable ripple.

USBPO is also engaged in longer-term strategic planning

- USBPO Council responsibilities include long-term strategic planning of burning plasma research. Council Panel, led by Earl Marmar, recently completed a report on "Planning for US Participation in ITER". **http://burningplasma.org**/ref/bpo_iter_research_20090903.pdf

Addresses three questions:

1. *What is the US research agenda for ITER?*
2. *How will ITER promote progress toward making fusion a reliable and affordable source of power, and how should this progress be assessed?*
3. *How does ITER relate to other elements of the US Fusion Energy Sciences program?*

for each of six scientific Themes:

A) plasma macrostability; B) waves and energetic particles; C) multi-scale transport; D) plasma boundary interfaces; E) fusion engineering science; and F) integrated burning plasma science.

- 2009 report extends and updates 2006 EPAct report led by Ray Fonck, which was reviewed by CRISPP in 2008.
- Should be useful for explaining US BP program to Congress, others.

Other USBPO roles and activities

- **Communication to fusion community.**
  - Monthly e-news, with 475 subscribers, provides updates on ITER, ITPA and other activities (eg, summaries of STAC, ITPA meetings).
  - Web page: http://**burningplasma.org**/home.html and 'forum'.
  - Organizing APS sessions on BP-related research.
- **Informing US representatives to ITER entities** such as STAC.
  - Organizes pre-briefings with US experts.
- **Assisting ITER Design, Review activities:**
  - eg 2008 Design Review, STAC issues ~25-35% US effort , 2009 VV review
- **Coordination of joint activities**
  - BPO Director is represented on ITPA coordinating committee, and at IEA joint activities planning meetings, also in US Fusion Facilities Coordination Committee
- **Education and outreach:**
  - eg, Will host 4th ITER Int. Summer School, May-June 2010 at U. Texas.

U.S. BPO: Supporting US Scientific Contributions to ITER

- US Burning Plasma Organization continues to serve to enhance US scientific involvement in, and contributions to, ITER.
- Strong, increasing, links to ITPA topical groups.
- US contributing strongly on a wide range of high priority research needs, both through facility programs and specific tasks.
- Strategic planning aims to ensure the greatest benefit from a burning plasma experiment.
- Feedback has been highly positive - ITER Organization has commented on the responsiveness of the US community, and USBPO is providing a model for other ITER parties.