The US Burning Plasma Organization Activities

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Fusion Power Associates
Annual Meeting and Symposium

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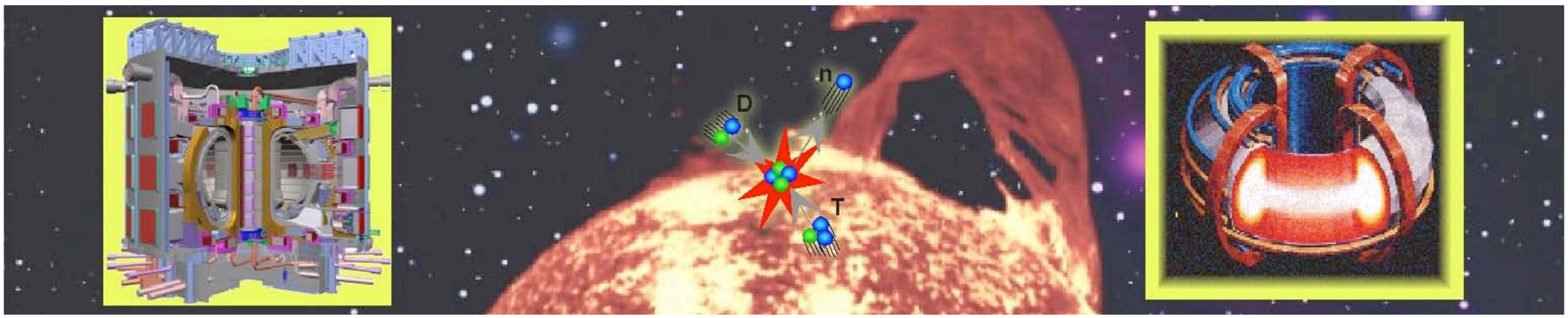
The US fusion community is engaged in preparations for a "burning plasma world"

- US Burning Plasma Organization (BPO) created to organize the community to prepare for, carry out, and benefit from burning plasma (ITER) research
  - Mission: advance the scientific understanding of burning plasmas and ensure the greatest benefit from a burning plasma experiment by coordinating relevant US fusion research with broad community participation
    - Broad participation: 278 registered (regular) members from 49 US institutions represent a cross section of the community
    - Focus on magnetically confined plasmas
- Strategic planning
  - 2006 USBPO response to Energy Policy Act of 2005
    - Follow-up (2007/08) will take into account ITER research plan
  - Other exercises: Plasma 2010, FESAC Greenwald panel
- BPO/US fusion community has been a major participant in the ITER design review – provided 21% of the (world-wide) effort
- Non-ITER-specific research continues to build the scientific basis needed for a successful burning plasma experiment

BPO Website http://burningplasma.org



- *e-News*
- *USBPO Home:*
  - Mission & Goals
  - Charter & Bylaws
  - Organization
  - Event Calendar
  - Forum
- *ITER*
- *ITPA*
- *BP Reference:*
  - Upcoming events
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  - Fusion Links
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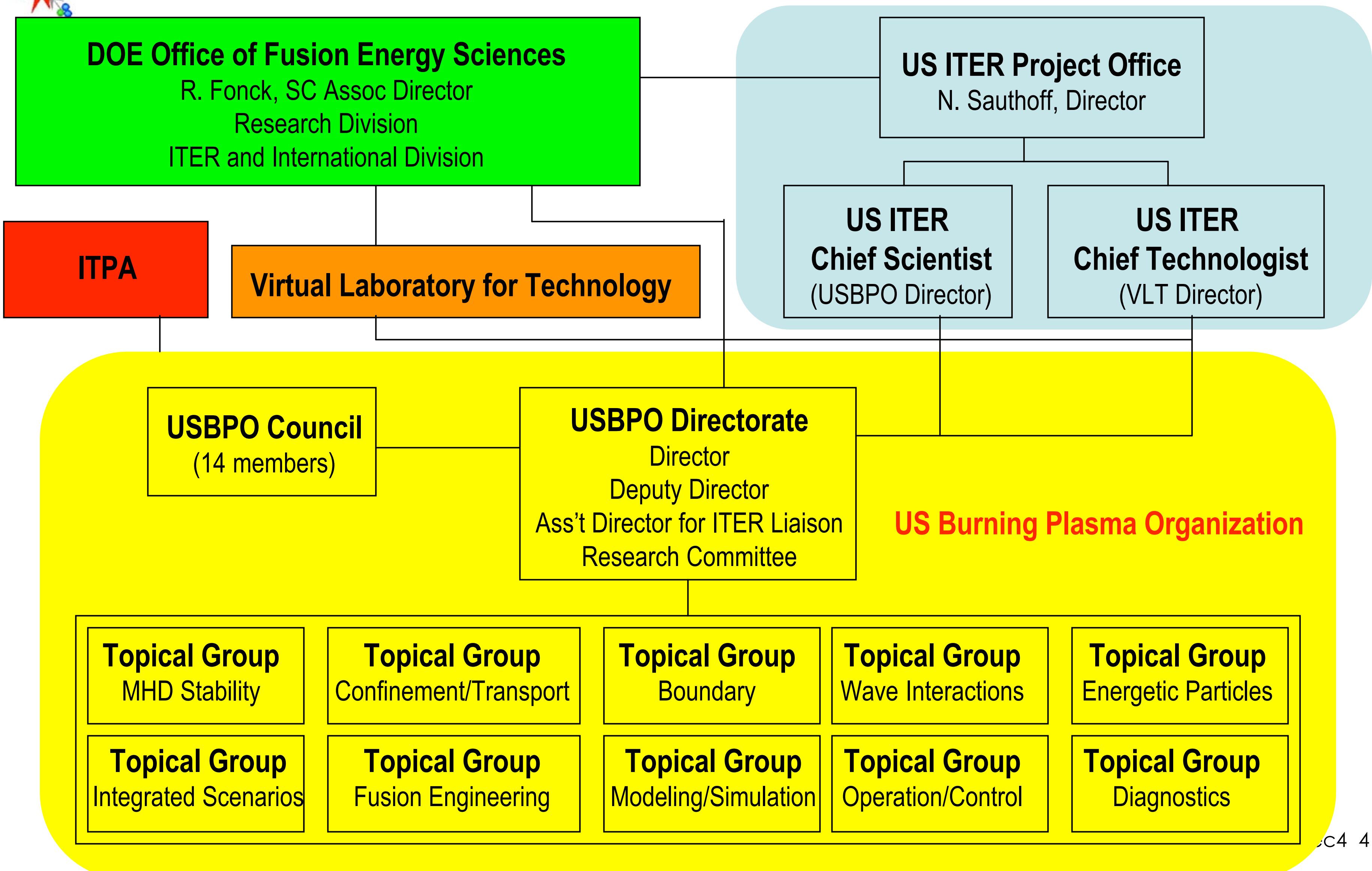
- *Sign Up*:
  - Topical Groups
  - e-Newsletter

Coordinating the US Burning Plasma effort

USBPO



BPO research is carried out in 10 Topical Groups

Topical Group	Leader	Deputy Leader
MHD, Macroscopic Plasma Physics	Jon Menard (PPPL)	Chris Hegna (UW)
Confinement and Transport	Paul Terry (UW)	Ed Doyle (UCLA)
Boundary	Dennis Whyte (MIT)	Tom Rognlien (LLNL)
Plasma-Wave Interactions	Cynthia Phillips (PPPL)	Steve Wukitch (MIT)
Energetic Particles	Raffi Nazikian (PPPL)	[tbd]
Integrated Scenarios	Chuck Kessel (PPPL)	Tim Luce (GA)
Fusion Engineering Science	Nermin Uckan (ORNL)	Richard Nygren (SNL)
Modeling and Simulation	Don Batchelor (ORNL)	Jon Kinsey (Lehigh)
Operations and Control	Dave Humphreys (GA)	Dave Gates (PPPL)
Diagnostics	Rejean Boivin (GA)	Jim Terry (MIT) Steve Allen (LLNL)

… on the Energy Policy Act of 2005

- **2006 charge to USBPO:**
  …The EPAct requires the Secretary of Energy to develop a Plan, in consultation with the Fusion Energy Sciences Advisory Committee (FESAC), for the participation of United States scientists in ITER that includes:
  i. The U.S. research agenda for ITER;
  ii. Methods to evaluate whether ITER is promoting progress toward making fusion a reliable and affordable source of power; and
  iii. Description of how work at ITER will relate to other elements of US fusion program.

  The EPA also requires that the Secretary shall request a review of the plan by the National Academy of Sciences.
- **Initial EPAct report completed by USBPO in June, 2006**
  - **Based on NRC Burning Plasma report**

Findings of the 2006 USBPO study

USBPO

i. The U.S. Research Agenda for ITER

- ***ITER will make major contributions to the U.S. research agenda for burning plasma studies in six major scientific themes, or campaigns*** *[integrated BP science, stability, waves & energetic particles, transport phys, plasma-boundary interfaces, fusion eng science].*
- ***Achieving the long-term scientific goals in ITER requires well-defined, long-term R&D activities in each of the priority science areas. These efforts span from the present design support stage to the final high-power, long-pulse technology test stage of ITER operation.***

ii. Methods to evaluate whether ITER is promoting progress toward making fusion a reliable and affordable source of power

- ***Progress on critical scientific and technology issues needed to design future fusion energy power plants will be evaluated with metrics based on increased scientific understanding and on performance in the burning plasma regime.***
- ***The research plan toward the fusion goal should be periodically assessed and modified by internal and external reviews.***

iii. Description of how work at ITER will relate to other elements of US fusion program

- ***A program of configuration optimization, enabling technology, and predictive simulation, supplementing ITER, ensures that the U.S. will have an adequate knowledge base for developing an attractive fusion power source beyond ITER.***

Strategic planning continue…

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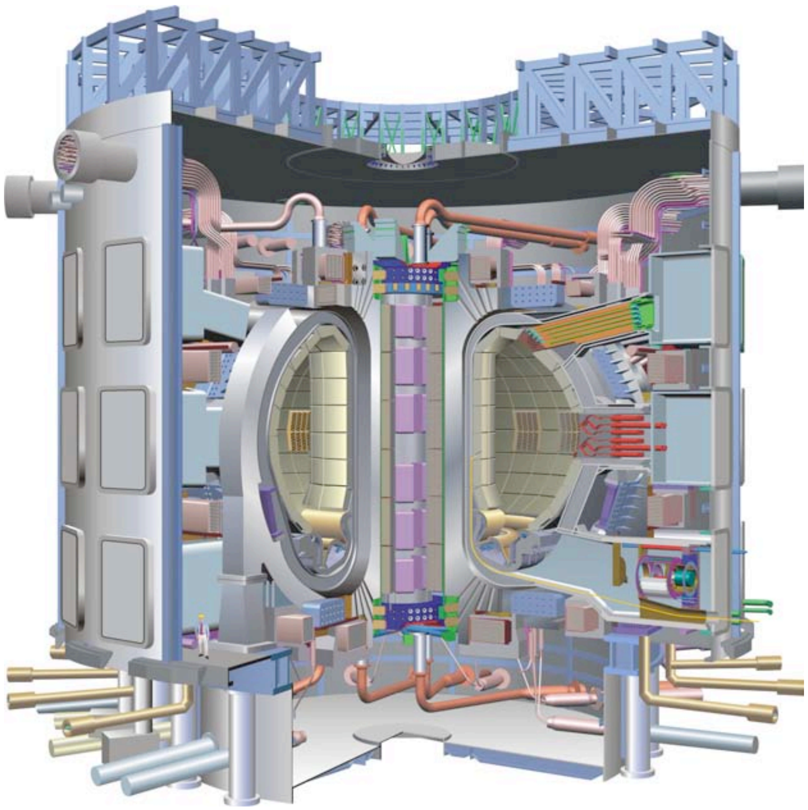
- **USBPO committee formed to update the BPO EPAct 2006 report (**Chair: E. Marmar; members: S. Allen, M. Bell, P. Bonoli, S. Knowlton, F. Najmabadi, H. Neilson, M. Peng, P. Snyder, T. Strait, G. Tynan, N. Uckan**)**
  - **Will be informed by**
    - **ITER design review results**
    - **ITER research plan**
    - **Plasma 2010 report**
  - **Committee will "map back" from long-term goals to identify near-term research needs**
  - **Also needs to look further ahead into the future**
- **FESAC panel, led by M. Greenwald, explored what other program elements are needed to be ready to move on to DEMO after ITER**
- **US National Academies is to review planning for U.S. fusion community participation in the ITER Program**

Not waiting for a plan, BPO has been responding to ITER needs and interfacing with ITPA and VLT

USBPO

- ITER is a major focus throughout the Fusion Energy Sciences program
  - Physics community organized by the BPO
    - BPO also interfaces with the US ITPA participants
  - Technology community organized by the VLT
- While reacting to immediate needs, BPO
  - Identifying BP research needs
  - Heavily contributing to ITER design review process
  - Developing BP research plan



USBPO participation in the ITER Design Review began before there *was* a design review

- **June, 2006: USBPO Research Committee assembled a list of 79 ITER research topics with community input**
- **August, 2006: From these 79 topics, 14 were selected for submission as “Issue Cards”**
  - **Submitted through the US ITER Project Office (IPO)**

ITER Issue Cards submitted by USBPO *(August, 2006)*

1. Active coil system for ELM suppression and RWM stabilization
2. Limitations to startup flexibility for advanced scenarios
3. ELM mitigation scenario
4. ITER CODAC architecture design
5. ITER disruption mitigation system design and physics understanding
6. Requirements for stabilization of (3,2) and (2,1) NTMs
7. ICRF antenna performance and coupling
8. Heating and current drive mix on ITER and impact on achievable scenarios
9. Review measurement requirements related to US diagnostic packages
10. ICRF heating and current drive scenarios
11. Tritium retention and H/D/T control
12. Feasibility of lost and confined fast ion diagnostic systems for ITER
13. Pedestal and L-H transition
14. Locked-modes and error field correction specification

ITER Design Review process

USBPO

- Design Review to
  - Create a new Baseline Design 2007
  - Establish ITER design decisions in detail on a broad basis, so Parties take ownership
  - Broaden knowledge basis into the Parties (for successful procurement of ITER components in-kind
- Coordinator: G. Janeschitz
  - Issue Cards: 200 existing(prior to 2007) + 250 new
- Chronology (2007):
  - March: List of US experts, effort estimates, and priorities for WG1 tasks; discussed with US program leaders; sent by USIPO to Design Review WGs and ITER IO
  - March: ITER IO guidance about PT resource allocations for design review
  - May: WG1 subtask leaders contact US and international experts for work
  - June: OFES Guidance Letter in response to OMB decision
  - July: Revised list of US experts/effort/tasks provided to USIPO, which initiated paperwork with US institutions for work packages

Design Review performed by eight working groups

USBPO

WG#	WG Name	Chair	IO Representative
WG 1	Design Requirements & Physics Objectives (DR&PO)	P. Thomas (US: R. Hawryluk, R. Stambaugh)	D. Campbell
WG 2	Safety & Licensing/Security	J.-P. Perves	J.-P. Girard
WG 3	Site & Buildings	C. Strawbridge	J. Sovka
WG 4	Magnets	M. Huguet	N. Mitchel
WG 5	Vacuum Vessel & Interfaces	Songtao Wu	K. Ioki
WG 6	Heating & Current Drive	J. Jacquinot	A. Tanga
WG 7	Tritium Plant	D. Murdoch	M. Glugla
WG 8	In-vessel components	I. Mazul	M. Pick/C. Lowry

- **WGs 1-to-8 include approximately 150 members**
- **Work packages have been agreed with the Parties, thus adding ~160 more persons**
- **Require extra PT resources of ~82.4 PPY from 7 Parties in 2007**
  - **17.4 PPY from US = 21%**

USBPO primarily supported WG1: Design Requirements & Physics Objectives

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Task	Title	Leaders (+IO)	IO	CN	EU	JP	KO	IN	RF	US	Sub-totals	Issue Cards
1	Project development plan	Campbell (IO)	3	3	3	3	3	3	3	3	24	
2	Sensitivity studies	Stambaugh	6		11	4				13	34	1
3	Ripple requirements	Thomas			5	5			2	2	14	4
3a	Ripple from TBMs	Thomas			1						1	
4	Disruption, VDE	Sen			2	2		2		2	8	7
5	Choice of PFC	Lackner	1	1	5		1	1		5	14	22+19
6	Tritium breeding blanket	Lackner			1						1	3
7	Startup scenarios	Saibene	2		24			12	24	12	74	6
8	RWM/ELM control coils	Hawryluk			10	1				18	29	8
9	Gas loads (ELM, disrupt)	Hawryluk	1		1					2	4	5
10a	Reliability (definition)	Chiocchio, Kaye	1		2						3	3
10b	Reliability (execution)	Chiocchio, Kaye	12		6					6	24	
11	Maintenance (cryostat)	GS Lee	5				1				6	1
12	Heating & current drive	Stambaugh	10			5				3	18	11
	Totals (# persons)		41	4	71	20	5	18	29	66	254	88

Many USBPO issue cards represented in Design Review and covered in DCRs

1. Active coil system for ELM suppression and RWM stabilization
2. Limitations to startup flexibility for advanced scenarios
3. ELM mitigation scenario
4. ITER CODAC architecture design
5. ITER disruption mitigation system design and physics understanding
6. Requirements for stabilization of (3,2) and (2,1) NTMs
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Some technical issues for ITER design

[details to be covered by Rich Hawryluk on Wednesday]

- Heat loads:
  - Control coils for Edge Localized Modes (ELMs) and Resistive Wall Modes (RWMs)
  - Disruption mitigation
- Definition of “First Plasma”
- Heating mix
- Ripple and Test Blanket Modules (TBMs)
- Choice of plasma-facing components (PFCs); tritium retention
- Plasma start-up; vertical stability

Few examples from USBPO contributions included for reference

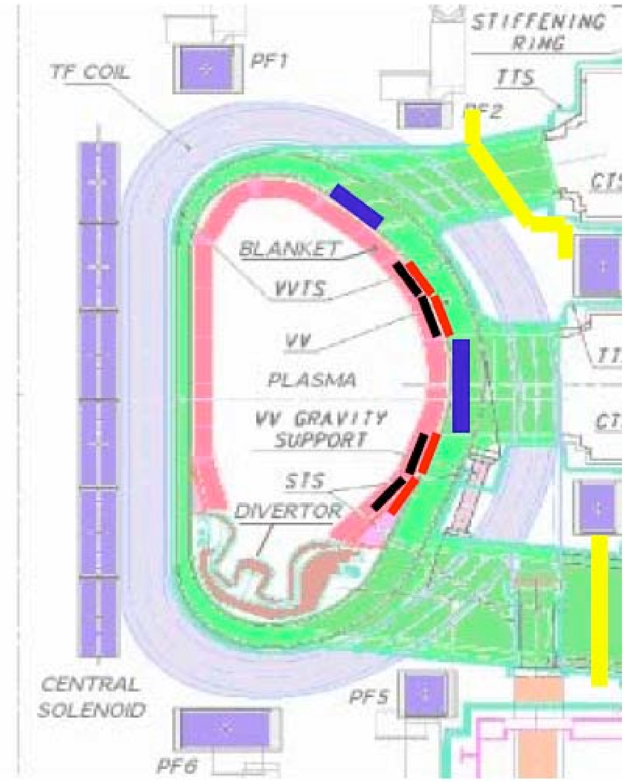
[to be covered by Rich Hawryluk on Wednesday]

Internal coils for control of ELM and RWM events

- US has special expertise in these areas
  - USBPO participants from Columbia, GA, LLNL, and PPPL
  - Work with EU & IO on engineering design, and ITPA on ELM requirements
  - Several DCRs under study
- ELM control: ELMs can deposit a potentially damaging repetitive heat load on the divertor plates.
  - Control techniques use resonant magnetic perturbations (RMP) or pellets
- RWM control: The conventional H-mode scenario in ITER will operate below the no-wall limit for n=1 kink modes. Wall stabilization, or an active control system that can mimic it, will be needed to reach the higher pressures needed for steady-state scenarios
  - Active control needed to offset effects of low expected rotation and off-normal events (e.g. ELMs)
- Error field correction coils (EFCC):
  - EFCC likely not suited for RMP and RWM, due to high current and voltage (and power) requirements

See R. Hawryluk on Wednesday

Various coil options for RMP and RWM



1. Coils around blanket modules
2. Coils at blanket/wall interface
3. Upper+mid-plane port-plug coils
4. 36 external coils outside TF

- **Two coil options are being investigated to obtain a cost estimate:**
  - **Coils at blanket/wall interface**
  - **Port-plug coils**

See R. Hawryluk on Wednesday

Pellet pacing for ELM control

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- Alternative control technique
  - For <1 MJ ELMs, estimate 40 Hz for ITER; size of pellets determined by whether ELMs need to penetrate half-way or to the top of the pedestal
  - Maximum throughput in vacuum system = 120 Pa-m3/s
  - Benchmarking exercise on pellet codes needed to improve estimate
- In addition, core fueling is required
  - Previous estimates were ~ 80 Ps-m3/s; is this additive? self-consistent?
  - Hence recommend increasing total pumping-fueling to ~200 Pa-m3/s
- Uncertainties: depth of pellet penetration, mass retention, particle transport coefficients
  - Increased gas load --> size of pumping system and tritium processing affects the size of the building; also possible regulatory issues

See R. Hawryluk on Wednesday

Massive gas injection for disruption mitigation

- Disruptions cause high transient mechanical and thermal loads
- US scientists developed requirements for disruption mitigation
  - Uncertainties: Are the runaways well confined? Current quench rates? Fraction of injected gas assimilated into plasma? Optimal gas or gas mixture? Should pellets be used? Will disruption mitigation be used prior to or after thermal quench?
- Programmatic issue: Is 2-3 hour recovery time acceptable?
  - Number of times per day that disruption mitigation will be used?
  - While ITER will disrupt, will the emphasis be on identifying operating modes with low probability of disruption (albeit at decreased fusion power)?

See R. Hawryluk on Wednesday

A broad spectrum of the US community has been involved in the ITER Design Review

& ITER-specific research

- Involvement through USBPO, ITPA, VLT, and USIPO
- Work of technical experts performed through Design Review USIPO contracts and/or base program support
- WG1: ~100 (±) technical experts, from >10 institutions
- Plus, ~24 official US participants on the 8 Working Groups
- Enormous effort, on a short (& urgent) time scale
  - Made possible by the willingness of US programs/institutions to make qualified technical experts available for Design Review work
- Also significant amount of ITER-specific research by FES (experiment, theory, simulation) community

… on ITER-specific research by FES community

A few examples follow ….

SciDac Simulations Show Potential of High Harmonic Fast Wave Heating for ITER

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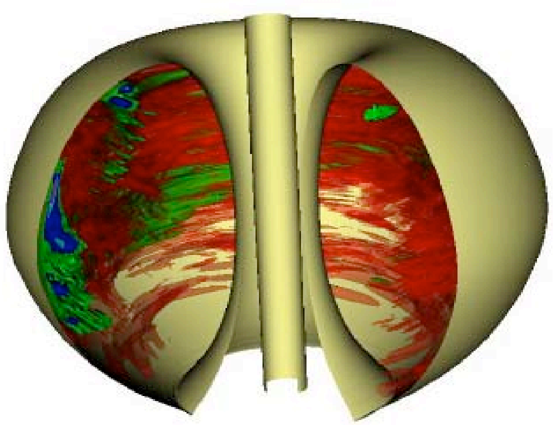
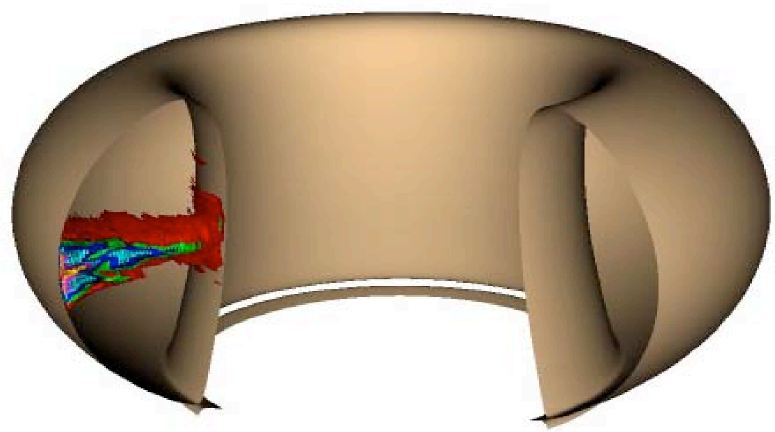
- **Simulations for NSTX summed over 81 toroidal modes show only edge heating in agreement with experiment**
- **Simulations for ITER summed over 169 toroidal modes are favorably showing improved coupling and core heating**
- **The AORSA 3D RF code run on Jaguar at ORNL using 2,048 processors for 8 hours**

NSTX



ITER Scenario 2



Simulations performed by the FES SciDAC Center for Simulations of Wave-Plasma Interactions

The AORSA 3D RF code run on Jaguar at ORNL using 2,048 processors for 8 hours

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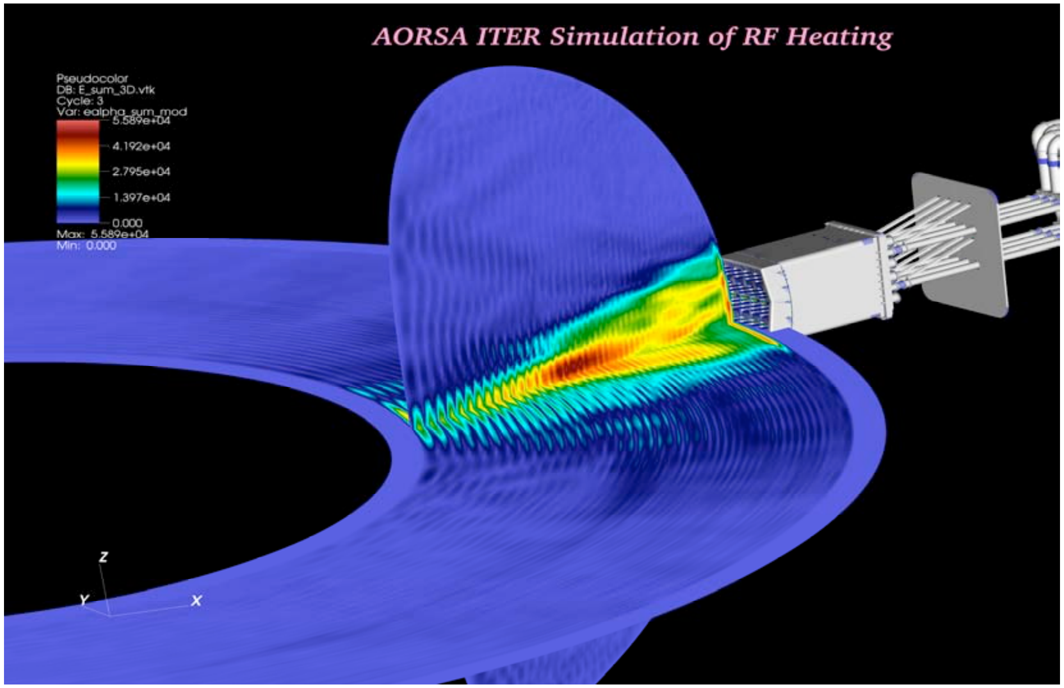
- Visualization of 3D - RF field from simulations provides a valuable tool in understanding the process of absorption.
- RF waves launched from the antenna propagate inward and efficiently absorbed in ITER plasma core within a single pass.



Simulations performed by the FES SciDAC Center for Simulations of Wave-Plasma Interaction [figure by Sean Ahearn of ORNL]

A free boundary ITER VMEC equilibrium model has been developed - assess finite β effects on ripple

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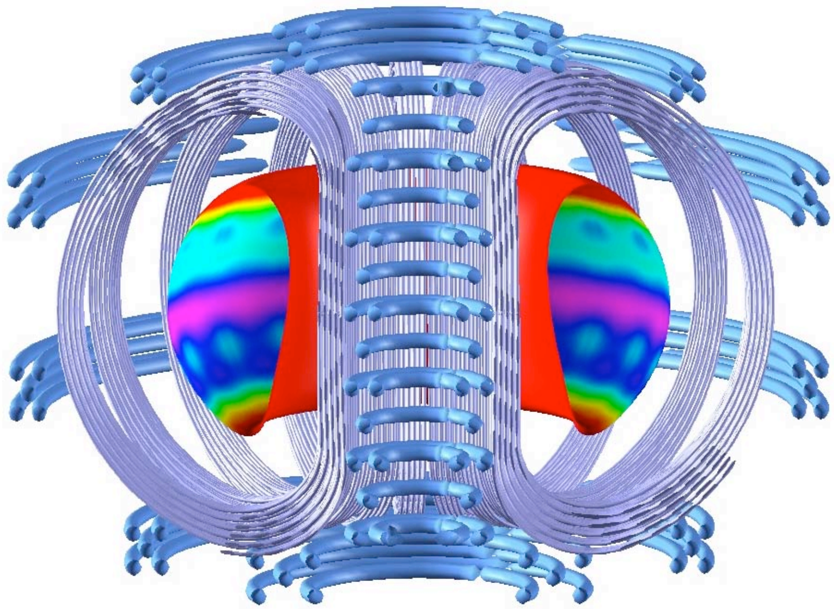
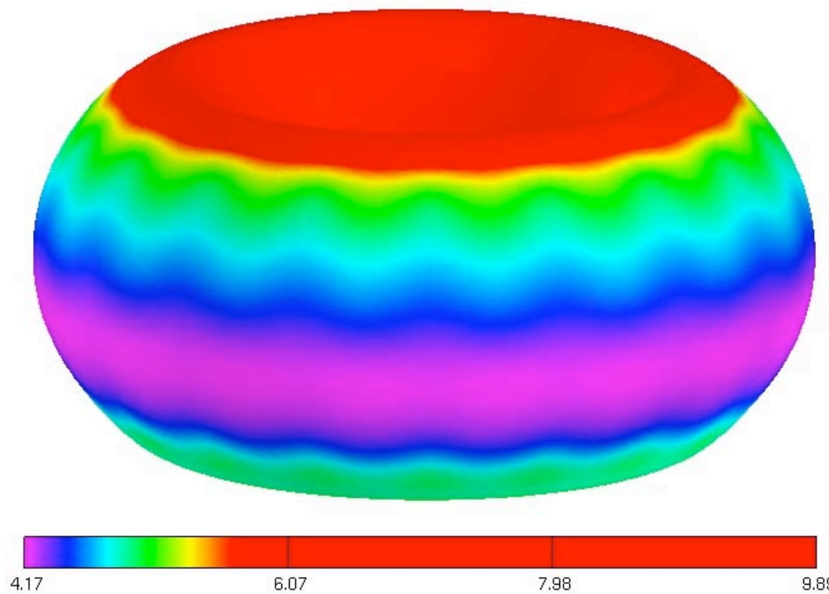
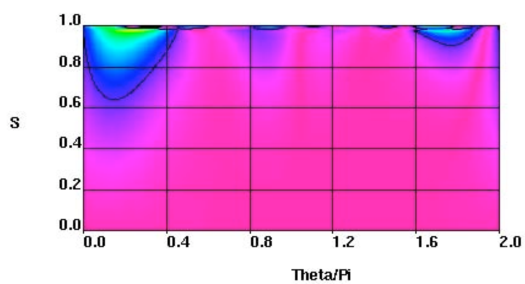
Multi-filament coil model

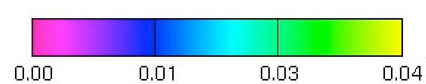


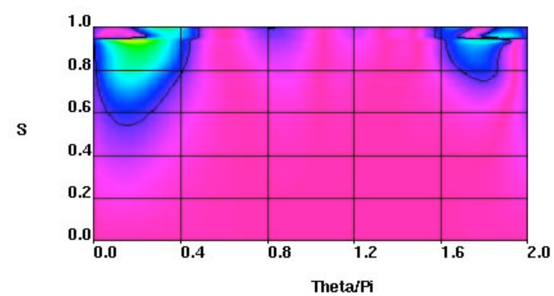
Ripple contours on outer flux surface



Ripple contours $[B_{n=18}(\theta,s)]$ at $\langle\beta\rangle = 0$







Controlling instability at the plasma edge, and relating turbulence to confinement properties

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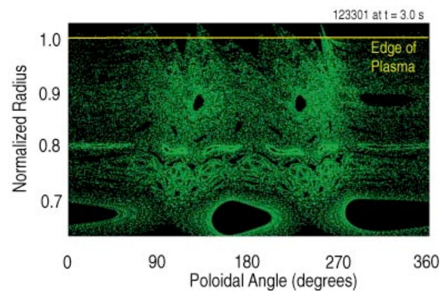
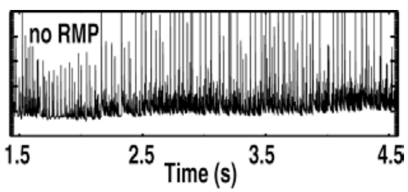
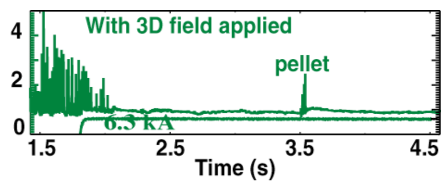
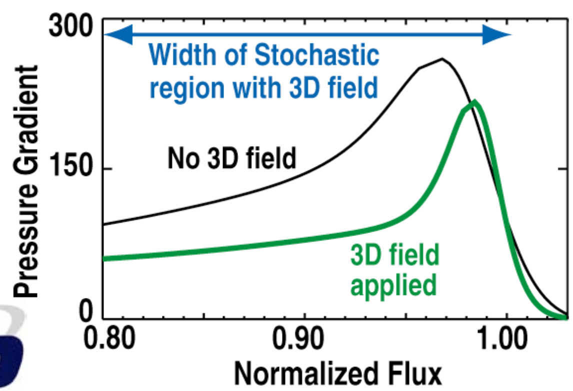
Critical Edge Instability Controlled by Purposefully Degrading Magnetic Surfaces

Applying 3D fields produces Stochastic region leading to stabilization of edge instabilities



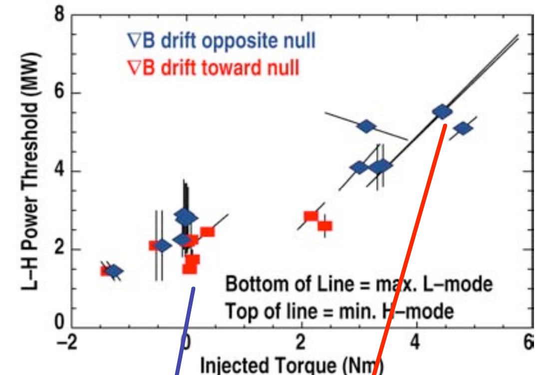




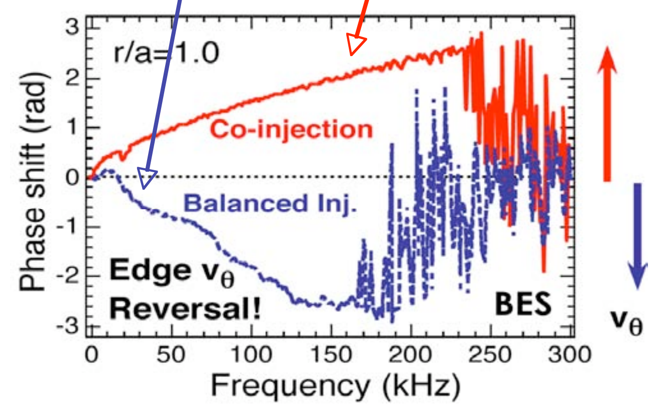


Controlling Flow Shear via Directed Torque

Threshold for access to high confinement dependent on torque input



Measurements show correlation between reduced threshold and turbulence characteristics



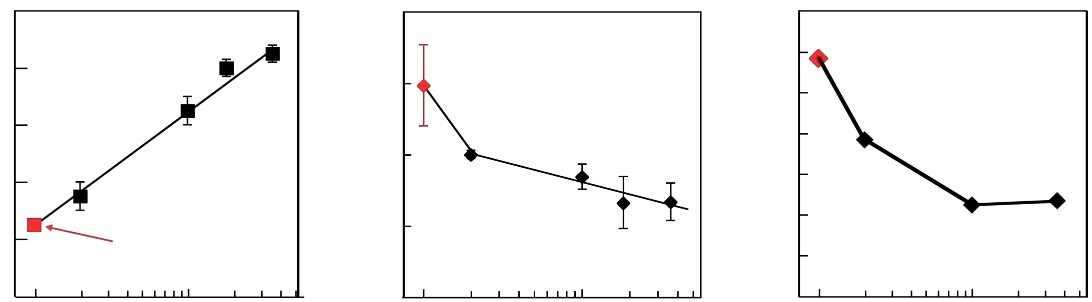
DIII-D NATIONAL FUSION FACILITY

Understanding an effective disruption mitigation technique

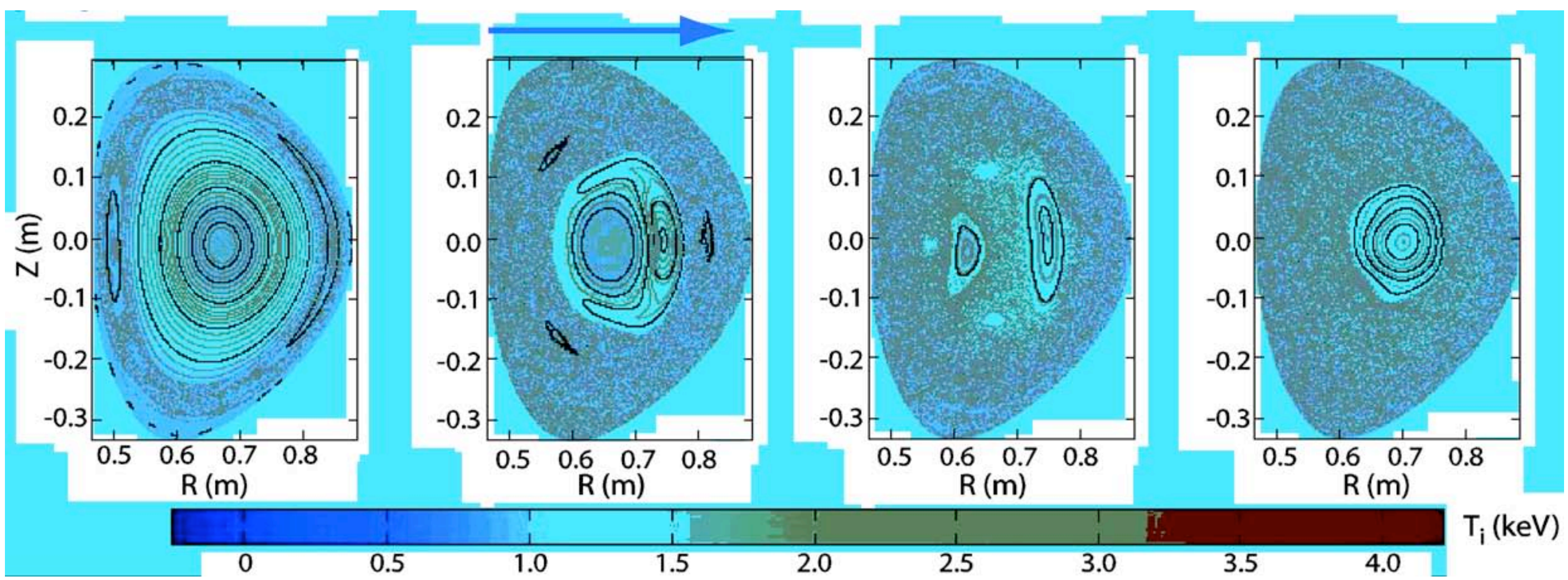
USBPO

Injection of massive gas puff dissipates energy through radiation:

3-D MHD Numerical Model (NIMROD + Radiation Package) gives quantitative agreement with detailed experimental results.



Fully 3-D simulation shows rapid destruction of flux surfaces:



Alcator C-Mod

Other recent activities & upcoming events

USBPO

- APS-DPP
  - Town Meeting on ITER Design Review (Tuesday evening): Janeschitz, Hawryluk, Stambaugh
  - First Microns of the First Wall mini-conference (w/Edge Coordinating Committee & BPO support)
  - Invited/contributed/tutorial talks:1(tutorial); 1(review); 8(invited); 10(oral); 58(poster); 22(mini-conf); 3(town meeting)
- ITER Design Review
  - In close collaboration with VLT and USIPO
    - STAC-1 (Aug07) background materials & video-conf briefings
    - STAC-2 (Oct-Nov07) background materials & video-conf briefings
- BPO Council
  - Created a new category of membership - Associate Member - for scientists whose home institutions are outside the US
- NRC [Dec 14-15]
  - BPO is preparing to meet with the National Research Council committee that has been set up to review the 2006 Energy Policy Act Report, concerning US plans for participating in the research program of ITER

BPO preparing for burning plasma research

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- Strategic planning has been ongoing, but is largely on hold while
  - The community is otherwise engaged with the ITER Design Review
  - The ITER research plan is being prepared
- A great deal of effort has gone into supporting the ITER Design Review
  - Broad participation across the community, organized by the USBPO
  - US contributions (21%) exceeded the US share of ITER (9%)
- In parallel with the ITER design review, BPO continue to work on broader burning plasma issues