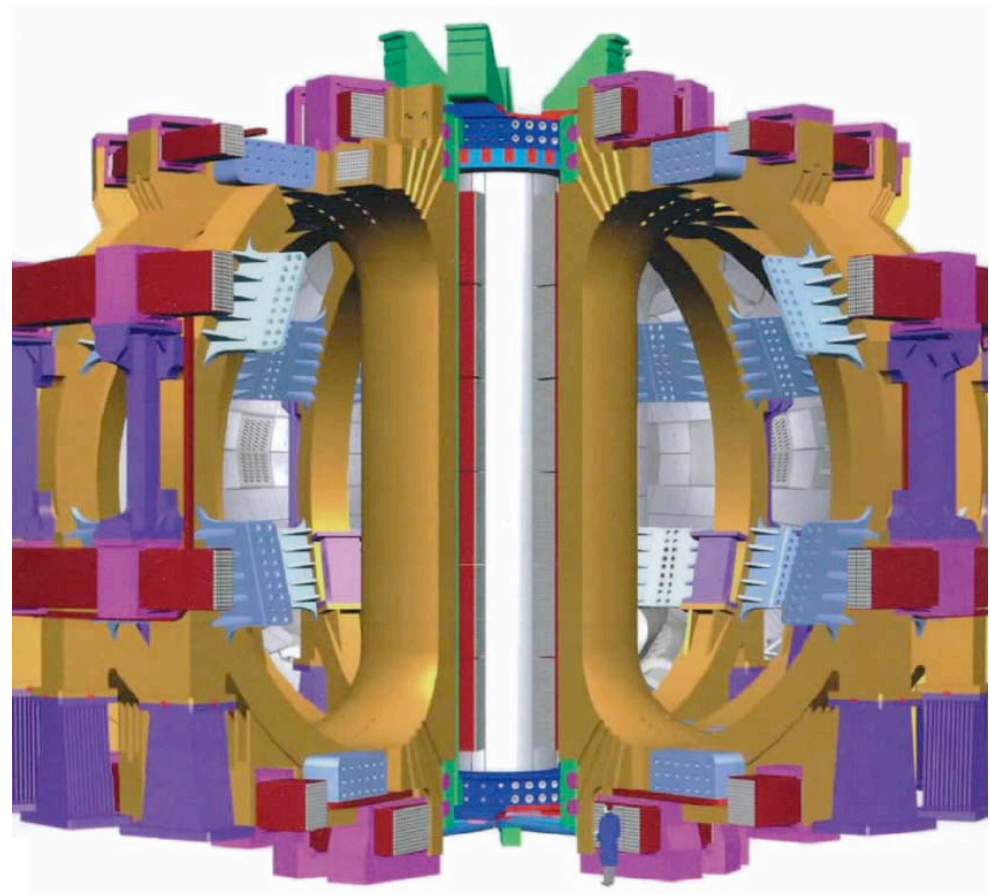


ITER Physics Initiatives & ITER Research Plan

James W. Van Dam
Chief Scientist, U.S. ITER Project
Director, US Burning Plasma Organization

U.S. ITER Technical Advisory Committee
April 14-15, 2009
Oak Ridge, Tennessee



TAC charge (part 3):
ITER research initiatives

- *Is the U.S. ITER Project building appropriate links to the fusion base programs in ITER-relevant technology and physics/research?*



Recent ITER task solicitations

- New task agreements (March 2009)
 1. Task on the study of control of plasma current, position, and shape
 2. Task on self-consistent simulations of plasma scenarios
 3. Task on the study of plasma start-up
 4. Task on the study of error fields using the Ideal Perturbed Equilibrium Code
 5. Preparation of design database with the updated disruption code DINA
 6. Task on magnetic reconstruction of the plasma boundary
 7. Task on error field measurements in ITER without plasma
 8. Task on simulations of toroidal field ripple and TBM effects on energetic particle losses in ITER
 9. Task on analysis of Resistive Wall Mode control by in-vessel (RMP) coils
 10. Task on error fields measurement in ITER using plasma response
- Procedural logistics
 - Circulated to USBPO and US ITPA membership, plus major facility groups and “target” scientists
 - To be set up as work agreements between ITER and USIPO

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US participation in ITER STAC meetings



- Science and Technology Advisory Committee
 - US participants: R. Goldston (member), S. Milora (member), E. Oktay (expert), T. Taylor (expert), J. Van Dam (expert)
 - Actively contribute to the STAC reports
- STAC meetings to date:
 - STAC-1 (Sept 5-6, 2007) → Design Review concluded (8 WGs)
 - STAC-2 (Nov 5-7, 2007) → “13 STAC Issues”
 - STAC-3 (Apr 7-9, 2008)
 - STAC-4 (May 19-21, 2008) → *ITER Research Plan (v1)*
 - STAC-5 (Oct 20-22, 2008)
 - Briefing for US STAC members on Oct 7, 2008 (5 hours, 20 experts)
 - **STAC-6 (May 25-27, 2009)** → *ITER Research Plan (v2)*
 - Briefing for US STAC members scheduled on May 4

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US actively contributes through ITPA – 1



Topical Group	U.S. Members
Transport and Confinement (TC)	Stan Kaye (U.S. Coordinator) [1] ← George McKee (U.S. Deputy Coordinator) Andris Dimits Ed Doyle Dave Mikkelson Craig Petty John Rice
Divertor and SOL	Bruce Lipschultz (U.S. Coordinator) [1] ← Tony Leonard (U.S. Deputy Coordinator) Russ Doerner Mathias Groth Charles Skinner Peter Stangeby Dennis Whyte
MHD Stability	Ted Strait (U.S. Coordinator) [2] ← Bob Granetz (U.S. Deputy Coordinator) Valerie Izzo Steve Jardin Steve Sabbagh Francois Waelbroeck John Wesley
Pedestal	Phil Snyder (U.S. Coordinator) Rajesh Maingi (U.S. Deputy Coordinator) C. S. Chang Max Fenstermacher Jerry Hughes Alexei Pankin Tom Rognlien

US actively contributes through ITPA – 2



Energetic Particles	Raffi Nazikian (U.S. Coordinator) Boris Breizman (U.S. Deputy Coordinator) Johan Carlsson Eric Fredrickson Bill Heidbrink Don Spong Steve Wukitch
Diagnostics	Rejean Boivin (U.S. Coordinator) [1] ← Jim Terry (U.S. Deputy Coordinator) Steve Allen David Brower Don Hillis Dave Johnson Brent Stratton
Integrated Operation Scenarios	Chuck Kessel (U.S. Coordinator) Tim Luce (U.S. Deputy Coordinator) Paul Bonoli David Gates Amanda Hubbard Masanori Murakami Ron Prater

Four of the U.S. members also function as either the international leader [1] or the deputy leader [2] of various topical groups, as indicated (←).

IEA/ITPA Joint Experiments Meeting



- 7th Annual Meeting held to decide joint experiments
 - Hosted by MIT, Dec.11-13, 2008
 - Extra day added to review the ITER list of urgent R&D issues
- Agenda
 - Each ITPA Topical Group reviewed progress on past cross-machine experiments and proposed plans for new activities
 - Expanded from “Joint Experiments” to “Joint Activities” (in order to fold in theory/modeling)
 - ITER representatives assessed proposed experiments/activities for relevance and value in addressing ITER issues
 - Presentations posted at <http://www.psfc.mit.edu/iealtw69/index.html>

US scientists participate in ITPA Topical Group meetings



Fall 2008 Topical Group meetings

Topical Group	Date	Place	Comments
DivSOL	15-18 Sept. 2008	Nagasaki (Japan)	Following ICPP Conference. Host: Prof. T. Tanabe & Prof. M. Sakamoto (Kyushu Univ.)
Pedestal	20-22 Oct. 2008	Milan (Italy)	Following IAEA Fusion Energy Conference. Jointly hosted by Institute of Plasma Physics of CNR and the University of Milano-Bicocca Host: Dr. Paola Mantica
Confinement and Transport			
MHD Stability	20-22 Oct. 2008	CRPP (Lausanne)	Following IAEA Fusion Energy Conference. Host: Dr. Ambrogio Fasoli
Energetic Particle			
Integrated Operation			
Diagnostics	17-21 Nov. 2008	IPR, Ghandinagar (India)	After one day ITER Diagnostics Mtg.
IEA/ITPA Joint Experiment Planning Mtg	11-13 Dec. 2008 (2.5 days)	MIT (USA)	1.5 days of R&D planning + 1.0 day of joint expt planning

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US scientists participate in ITPA Topical Group meetings



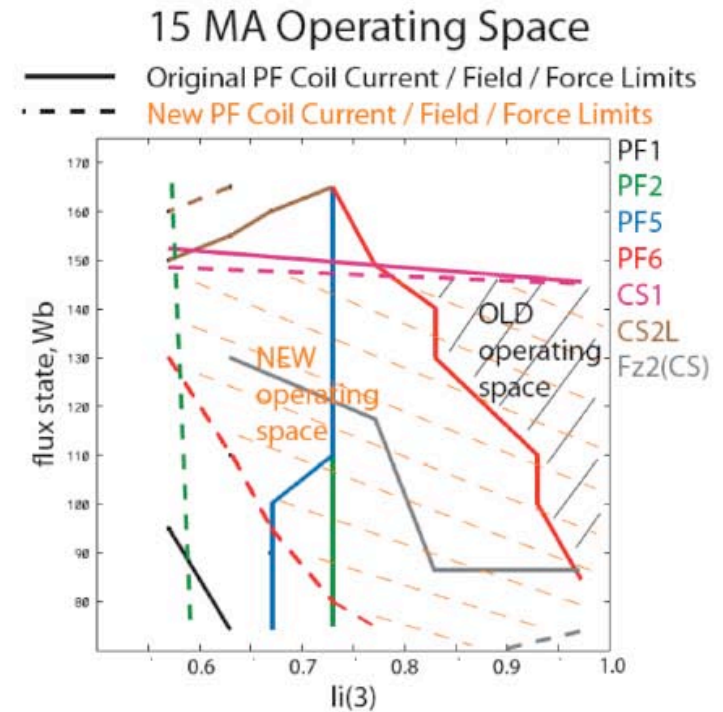
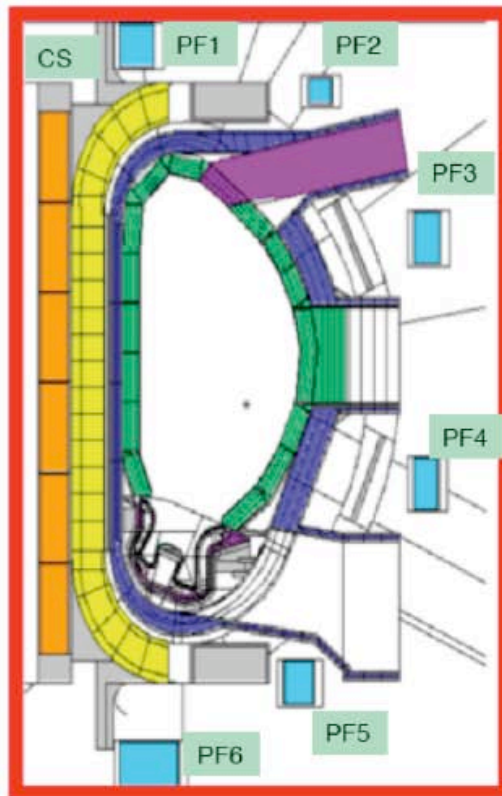
Spring 2009 Topical Group meetings

Topical Group	Date	Place
Transport and Confinement	31 March–2 April 2009	Naka (Japan)
Integrated Operation Scenarios	31 March–3 April 2009	Naka (Japan)
Pedestal and Edge Physics	20-22 April 2009	Cadarache (France)
MHD	21-24 April 2009	Daejon (Korea)
Energetic Particles	21-24 April 2009	Daejon (Korea)
SOL and Divertor	5-8 May 2009	Utrecht Amsterdam (Netherlands)
Diagnostics	20-24 April 2009	St. Petersburg (Russia)
ITPA Coordinating Committee	15-16 July 2009	Cadarache (France)

Examples of US work for ITER urgent R&D issues (taken from Hawryluk 2008 IAEA talk)



Performance of ITER PF System Was Evaluated



C. E. Kessel *et al.* IT/2-3

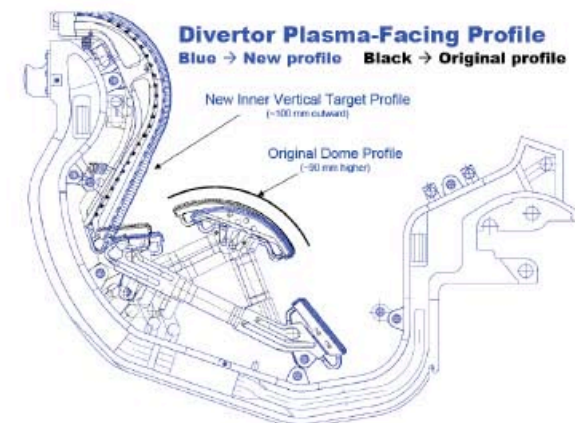
- Analysis showed that operating space was not adequate for H-modes with large pedestals.

Examples of US work for ITER urgent R&D issues (taken from Hawryluk 2008 IAEA talk)



Design Changes Enable Low Inductance (H-mode) operation

- Increase the current and field capability of the PF conductor;
- Increase the number of turns in PF2 and PF6;
- Increase the limit on the central solenoid vertical separation forces (from 75 MN to 120 MN);
- Relocate PF6 toward the plasma by 9 cm and radially by 7 cm;
- Sub-cool PF6 to about 3.8 K; and
- Modify the divertor slots and dome geometry
- Current analysis is focusing on analyzing the effect of plasma disturbances on the operating range and a
- Detailed assessment of rampdown phase of the discharge including the H to L transition.



C. E. Kessel *et al.* IT/2-3.

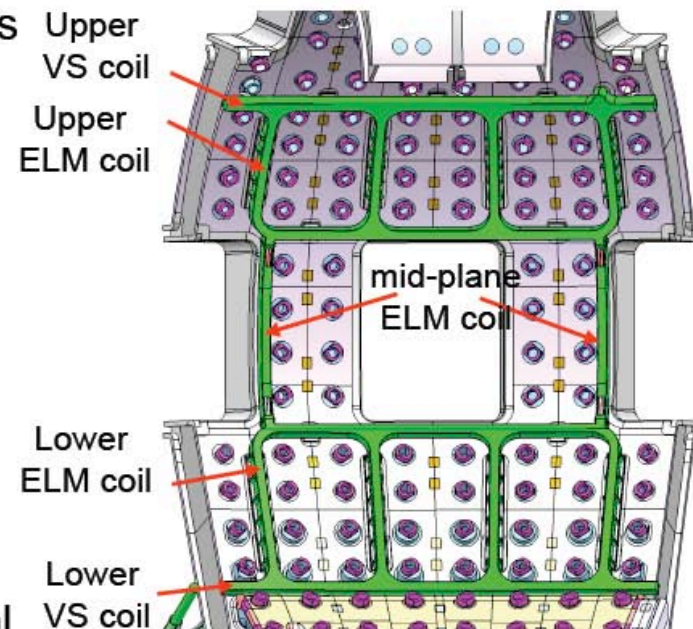
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Examples of US work for ITER urgent R&D issues (taken from Hawryluk 2008 IAEA talk)



Vertical Position Control Must Be Robust and Reliable in ITER

- Loss of vertical plasma position control in ITER will cause large thermal loads on PFCs
- Vertical Disruption Events (VDE) generate the highest electromagnetic loads.
- Experiments on C-Mod, DIII-D, JET, NSTX, and TCV have provided a criteria for evaluating the vertical stability control:
 - $\Delta z/a > 0.05$ for reliable vertical stability
 - $\Delta z/a > 0.1$ for robust vertical stability
- Original system capable of $\Delta z/a \sim 0.02$.
- Evaluating design of internal coils for vertical stability, ELM and RWM control.
 - Capable of $\Delta z/a > 0.05$



A. Portone *et al.* IT/2-4Ra; D. Humphreys *et al.* IT/2-4Rb.

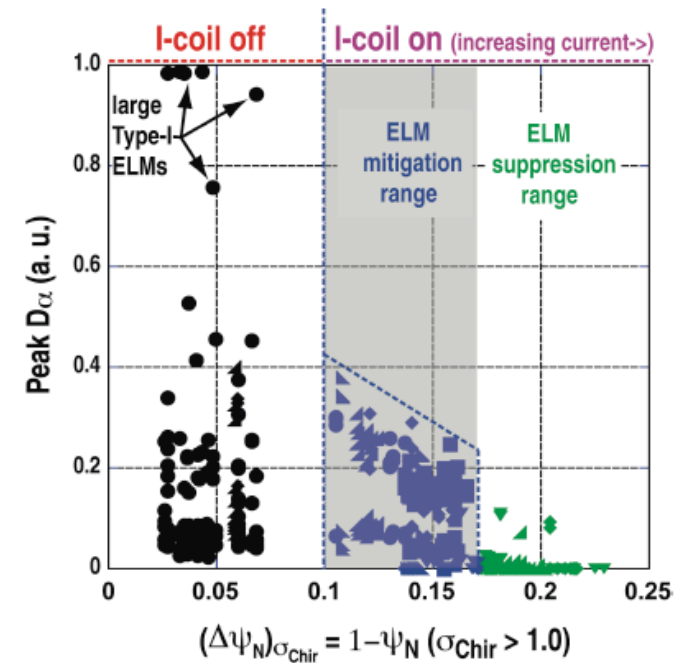
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Examples of US work for ITER urgent R&D issues (taken from Hawryluk 2008 IAEA talk)



Resonant Magnetic Perturbations Suppressed ELMs in DIII-D

- Suppressed ELMs with $n=3$ RMPs, with small aperture off-mid-plane coils
 - Obtained $H_{IPB98(y,2)}=1$
 - $3.2 < q_{95} < 3.8$
 - Density decreased
- Incorporated into the design of the in-vessel coils based on DIII-D results and theoretical considerations.
- Understanding of the underlying physics is still emerging.
 - Criteria for field line alignment and mode spectrum
 - Role of edge pumping
 - Effectiveness of core pellet fueling



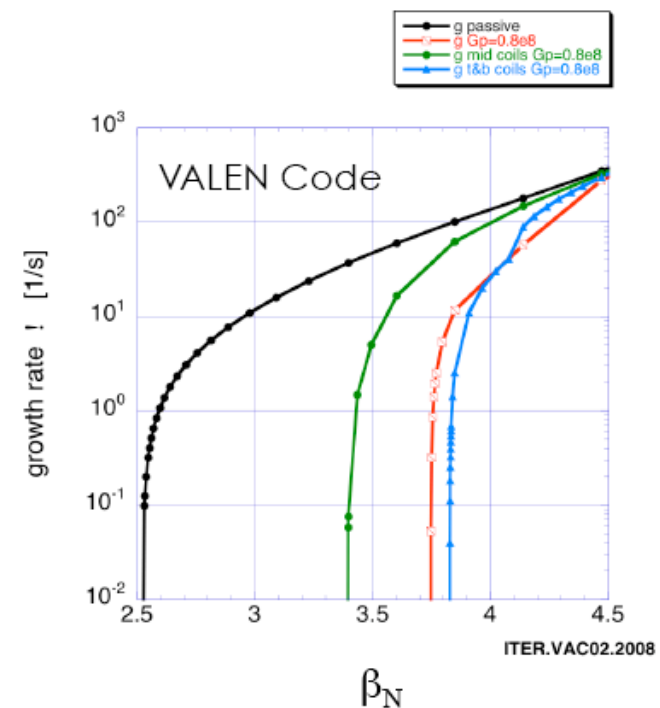
M.E. Fenstermacher *et al.* (2008)

Examples of US work for ITER urgent R&D issues (taken from Hawryluk 2008 IAEA talk)



Control of Resistive Wall Modes (RWM) Enables Steady-state Operating Scenarios

- “Steady-state” operation in ITER entails $\beta_N > 3$, which can result in a RWM.
 - Even if rotation can stabilize the RWM, can be excited by finite amplitude error fields or other MHD activity.
- Active feedback control on DIII-D and NSTX have shown that it is possible to stabilize RWM even at low rotation.
- In-vessel coils are predicted to stabilize RWM to $\beta_N < 3.8$.
 - Coil current requirements are modest.
- Further analysis and benchmarking of codes is in progress.



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Examples of US work for ITER urgent R&D issues (taken from Hawryluk 2008 IAEA talk)



Massive Gas Injection Has Been Used for Disruption Mitigation on Present Experiments

- Resulted in short current decay time, reduced halo currents and radiative loss of plasma and poloidal magnetic energy.
 - Detection of VDEs should be reliable, and mitigation possible, due to long ITER timescales.
 - Necessary part of PFC/FW protection strategy.
- Avalanche generation of runaway electrons is predicted if density is less than Connor-Hastie-Rosenbluth density.
 - Avalanche mechanism is predicted to be more important in ITER due to the higher plasma current.
 - Collisional damping requires a gas influx of $500 \text{ kPa}\cdot\text{m}^3$ assuming a 20% fueling efficiency
 - Large impact on vacuum and tritium systems
- Workshop was held in July and identified research areas including:
 - Are the runaways well confined, requiring collisional damping?
 - Should gas, liquid or pellets be used?

D. G. Whyte *et al.* IT/P6-18

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Enhancing US involvement in addressing R&D needs



- Consultation:
 - Teleconference meetings of “council of chief scientists” with ITER
 - Two held so far: Sept 2008 and Dec 2008
 - Periodic consultations with US program leaders and OFES to be arranged
 - USBPO participates in Fusion Facilities Coordinating Committee meetings (most recent = 20 Nov 2008 meeting + 10 Apr 2009 videoconference)
- Special USBPO task group efforts
 - Heating & current drive mix (C. Kessel)
 - Test Blanket Module science (N. Uckan)
 - PFCs/PSI (D. Whyte et al.)
 - “Tutorial” on PFCs presented to FESAC by Whyte (Nov 2008)
 - Experiments and modeling on surface modification, mixed materials, T retention (VLT)
 - Radiation patterns with disruptions (D. Whyte)
- Other activities
 - Verification & Validation task group published original contributions
 - *Validation in fusion research: Towards guidelines and best practices*, Phys. Plasmas **15**, 062503 (2008)]
 - USBPO *ITER Diagnostics Needs White Paper* presented to FESAC (Nov 2008)

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US involved in TBM Program Committee



- ITER Council (Nov 2008) approved including Test Blanket Module program in framework of ITER Agreement
- TBM Program Committee set up to oversee this activity
 - First meeting held March 25-26, 2009 in Aix-en-Provence
 - Chair is Dr. Satoshi Konishi (JA)
 - US attendees: Jeff Hoy (member), Mohamed Abdou (expert), Mike Hechler (expert), and Larry Leiken (DOE legal expert on intellectual property matters)
 - Rob Goldston (expert) will attend future TBM Program Committee meetings
 - Next TBM-PC meeting to be held Apr 29 (Barcelona)
- TBM Workshop is planned for Dec 2009
 - Review guidelines for TF ripple, amount of ferromagnetic content, and impact on physics operation

US involved in ITER Integrated Modeling



- ITER established Integrated Modeling Expert Group
 - Preview had been given by W. Houlberg (IMEG leader) in a talk at special ITER Town Meeting held by USBPO at 2008 TTF Meeting
 - IMEG to include representatives from all ITER Members
 - US participants are D. Batchelor and L. Lao
- IMEG will coordinate development of comprehensive suite of integrated modeling capabilities and associated infrastructure by establishing:
 - Core modeling requirements that cover a spectrum of applications
 - Documentation, verification, and validation standards for core elements
 - Installation and acceptance testing procedures for core elements
 - Regression testing procedures for core elements
 - ITER hardware (e.g., grid and HPC) and software needs
 - Guidelines for the remote access environment
- IMEG first annual meeting to be June 22-26, 2009, in Cadarache

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TAC charge (part 4): ITER Research Plan

- *Does the evolving ITER Research Plan adequately address the vision for ITER research and present a plan suitable for action?*
- *How could it be improved?*
- *How can the U.S. improve its participation in the development of the Research Plan?*

Development of the ITER Research Plan



- Version 1:
 - Task 1 (Project development plan) of ITER Design Review WG #1 (Design Requirements & Physics Objectives) morphed into an IRP Working Group led by IO, with 3 participants from each Member
 - From the US: M. Bell, E. Synakowski, M. Wade
 - IRP WG began work May 2007
 - *ITER Research Plan (version 1)* document was presented at STAC-4 meeting (May 2008)
- Version 2:
 - STAC-5 (Oct 2008) was charged to
 - “Review the evolving ITER Research Plan, in particular considering its consistency with the commissioning plan, with the major R&D needs identified, and with the TBM testing programme”
 - IRP v2 is scheduled to be presented at STAC-6 (May 2009)

Priorities for further IRP development



- Specific goals for Version 2 are to include:
 - Operational planning constraints based on RAMI (reliability, availability, maintainability, and inspectability) analysis
 - TBM program
 - Heating and current drive commissioning program
 - Physics Work Programme for 2009-2011
 - Options for accelerating the arrival of the research program at DT operation
 - Plasma scenarios for experimental operation
 - Upgrade options and how they might fit into the research time schedule

US involvement in second phase of development of ITER Research Plan



- Conference call with IO of chief scientists from ITER Members
 - Organized by D. Campbell (IO) on Dec. 18, 2008
 - Discussed the anticipated Phase 2 activities, as described in the IO action plan document (IO-DA Nov 2008; dated Dec. 8)
- US participation in Working Group was augmented (Jan 2009)
 - Previous US members to continue: M. Bell, E. Synakowski, and M. Wade
 - Two more US members were added: S. Wolfe and S. Milora
- Second phase activities of the IRP Working Group
 - Several conference calls (from Feb 2009) and two in-person meetings so far (Mar 12 and Apr 15-17, both in Cadarache)
- US updates
 - Conference call (Mar 9): US participants with USIPO, OFES & USBPO
 - Report by US participants to USBPO Research Committee (Apr 6)

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IRP Working Group subdivision



- Allocation of responsibilities for upgrades to ITER Research Plan

Integration: Operations, TBM, H&CD Commissioning	Integration: Physics Work Programme	DT Acceleration	Plasma Scenarios	Burning Plasma Experiments	Upgrade Options and R&D
<u>S. Milora (US)</u> D. Van Houtte (IO) L. Giancarli (IO) D. Campbell (IO) A. Tanga (IO)	D. Campbell (IO)	Y. Takase (JA) <u>M. Bell (US)</u> B. Wan (CN)) R. Pitts (IO) A. Polevoi (IO)	S. Ide (JA) <u>M. Wade (US)</u> Y. K. Oh (KO) Y. Gribov (IO) J. Snipes (IO)	N. Oyama (JA) <u>S. Wolfe (US)</u> W. C. Kim (KO) W. Houlberg (IO) V. Mukhovatov (IO)	O. Kaneko (JA) <u>E. Synakowski (US)</u> H. G. Jhang (KO) A. Loarte (IO) M. Shimada (IO) A. Tanga (IO) A. Costley (IO)



US interaction with EU task forces

- Lower hybrid
 - New EU task force called “LH4IT”
 - USBPO sponsored internet seminar (Feb 23, 2009) by A. Becoulet and T. Hoang (LH4IT leaders) about developments with a possible lower hybrid current drive system for ITER
- Tungsten divertors
 - EU task force on W divertors for ITER sponsored 2-day meeting in Cadarache (Feb 17-18, 2009)
 - Evaluate status of knowledge and risks with switching start-up of high-heat flux region of ITER divertor to tungsten from carbon
 - Perhaps reach DT phase faster and more economically?
 - From US, B. Lipschultz attended (on invitation) to report about high-Z wall experience on C-Mod and ITPA SOL/divertor plans
 - Follow-up meeting planned in Madrid (Apr 29-30) to discuss drafts of “work plans” on how to address W issues during next 2-3 years

More about Burning Plasmas

Update about how US participation in ITER is being communicated to fusion community



- APS-DPP Annual Meeting (Nov. 17-21, 2008)
 - Contributed-oral session “Research in Support of ITER”
 - 14 ten-minute talks, including several from international groups
 - “Town Meeting on ITER” on Tuesday evening with 3 talks
 - D. J. Campbell: *Scientific Status of ITER*
 - C. Baker: *Programmatic Status of ITER*
 - J. W. Van Dam: *US Contributions to ITER*
- Other presentations
 - ICPP (Sept 2008); FESAC (Nov 2008); FPA (Dec 2008)
- USBPO Annual Progress Report
 - Most recent report (dated March 31, 2009) was posted online
- USBPO monthly eNews
 - Currently distributed to 450 subscribers — cf. 300 USBPO regular members (50 institutions) + 14 associate members

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National Academies review was published



- National Research Council reviewed the Energy Policy Act Report
 - EAct Report had been written by USBPO in 2006
 - NRC “Committee to Review US ITER Science Participation Planning Process” (CRISPPP) reviewed this report favorably
- Briefing for Dr. Pat Dehmer (SC Deputy Director)
 - Held October 6, 2008, at DOE Germantown
 - CRISPPP Report was summarized by M. Zarnstorff (CRISPPP member)
 - NRC representatives, OFES program managers, and USBPO director participated in the briefing
- Final publication version of the report
 - Recently available at National Academies Press online bookstore
 - http://www.nap.edu/catalog.php?record_id=12449



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USBPO members are involved in ReNeW



- Research Needs Workshop for magnetic confinement
 - Five Theme areas, each having 4-7 panels, with ~ 6 participants per panel
 - Theme 1 = Achieving and Understanding the Burning Plasma State in ITER
 - FESAC *Gaps, Issues, & Opportunities Report* (Greenwald panel) was written with assumption that ITER would be a success; Theme 1 is charged to analyze the research work needed to ensure that ITER will indeed be a success
 - USBPO director is Theme 1 leader
 - Themes 1 (BP for ITER) & 2 (High Performance Steady State) joint Theme Workshop was held Mar 23-27, 2009, in San Diego
 - Themes 3 (Plasma-Material Interface) & 4 (Harnessing Fusion) also closely relevant to ITER
 - Overall ReNeW Workshop to be held June 8-12, 2009, in Bethesda, MD
- Contributions of USBPO members to ReNeW
 - USBPO is hosting the ReNeW web site
 - Personnel involvement:
 - Of the 22 members of the USBPO Research Committee, 16 are involved in ReNeW (= 2 theme leaders, 3 panel leaders, and 11 panel members)
 - Of the 12 members of the USBPO Council, 10 are involved (= 4 theme leaders, 3 panel leaders, and 3 panel members)

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