

A world map where the landmasses are dark and the city lights are glowing in a golden-yellow color, set against a dark blue background.

International Collaborations

Presented by

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Budget Planning Meeting

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<http://www.ofes.fusion.doe.gov>

Outline

- Objectives
- Elements
- Budgets
- Some Highlights/Plans
- Issues and Opportunities

Goals of International Collaboration

- A strong domestic fusion program and an effective international collaboration program are both needed for the US magnetic fusion to be successful.
- The magnetic fusion International Collaboration program seeks to complement and leverage off the domestic program and to take advantage of unique international opportunities to carry out research in critical areas.
- Results and experience will build a framework for future international collaboration on ITER.

International Collaboration and Contributions to ITER Physics are becoming more important.

- The International Tokamak Physics Activity (ITPA) identifies key issues and facilitates coordination through topical groups
- The IEA-Tokamak agreements facilitates personnel/hardware exchanges and joint activities (68) in ITPA key areas. (50 joint experiments, 13 joint analysis, 4 under development, 1 closed)
- Bilateral exchanges and IAEA meetings provide additional programmatic exchanges and workshops.
- A likely decision to proceed with ITER will focus international collaboration:
 - Strengthen research on key areas for ITER design and operations
 - Develop the ITER research paradigm
 - Build ITER research program through international topical groups

International Collaboration is Carried Out Through Three Primary Program Areas

- The OFES Science budget includes a line for International Collaborations (about \$5 M in FY 05 and FY 06).
- Major facilities (DIII-D, C-MOD, and NSTX) support related collaborations through their program funds – ITPA, personnel exchanges, workshops...
- Diagnostics Program supports some collaborative activities on JET, AUG, and TEXTOR, and several theory grantees participate in Collaborations.

Current Emphasis for International Collaborations

• High Performance (toward BP): JET, JT-60U	\$2.29 M
• Long-pulse Tokamaks: Tore Supra, KSTAR, EAST	\$1.98 M
• Stellarator Physics: LHD, CHS, W7-AS, TJ-II	\$0.45 M
• Niche Opportunities: AUG, TEXTOR	\$0.15 M
Total	\$4.86 M

- Also look at breakout vs ITPA Topical Working Groups or Priorities Panel.

International Collaboration Budgets (by International Facility)

Facility (US Coordinator)	FY 2004 actual	FY 2005 Jan 05 Fin Plan	FY 2006 Pres 2/3/05
JET (Nazikian)	2,001	2,003	1,685
JET Diag (Nazikian)	1,172	950	430
JT-60U (Nazikian)	191	191	175
Tore Supra (Mioduszewski)	272	272	200
AUG (Marmar)	84	84	75
TEXTOR (Hillis)	84	84	75
KSTAR (Wesley)	488	509	1,600
LHD (Lyon)	250	250	175
China (Chan)	-	200	175
TJ-II (Lyon)	260	320	270
	4,802	4,863	4,860

International Collaboration Budgets

(by Domestic Institution)

	FY 2004 actual	FY 2005 Jan 05 Fin Plan	FY 2006 Pres 2/3/05
ORNL (JET, TS, K*, TEXTOR, AUG)	1,479	1,478	1,214
PPPL (JET, K*, JT-60U, W-7AS)	2,614	2,676	2,065
MIT (JET, K*)	173	173	186
GA (KSTAR, EAST, JET)	314	314	725
LLNL(K*)	22	22	20
Universities (Colo. U, Columbia, UC-Davis, Wisc)	200	200	650
	4,802	4,863	4,860

Note: some adjustments to be made in KSTAR distribution.

JET is a Unique Facility for International Collaboration on Burning Plasma Issues

- The JET program is clearly focused on addressing ITER specific scientific and technical issues.
- JET is the only facility that can operate near reactor relevant collisionality and ρ^* before the start up of ITER
- JET is the only facility capable of operating in DT before the start up of ITER
- The US should strongly participate in the JET program as an integral part of the US burning plasma program and in preparation for ITER.

However, the FY06 budget guidance reduces the ability of the US to exploit our investments in the JET collaboration.

US High Power Prototype Antenna R&D for JET



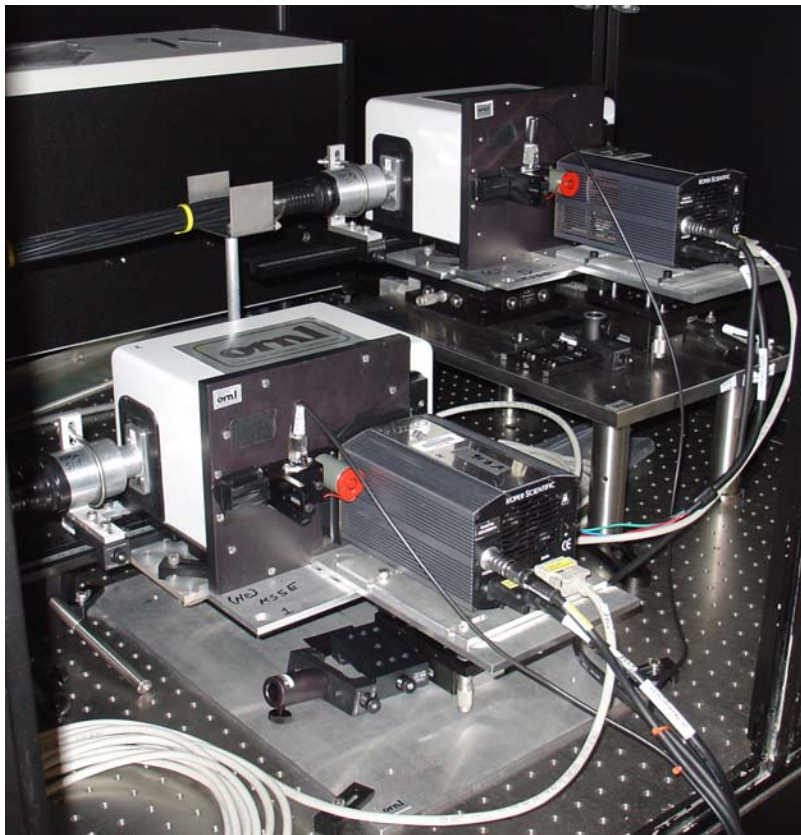
The HPP tests identified design improvements for the JET ITER-like antenna.

Changes are being made to the JET ITER-like antenna, and it will be installed in CY06.

JET is very pleased with the US effort and has requested that the collaboration continue.

CXRS Helium Ash Diagnostic for JET-EP

Spectrometer Hardware installed at JET



ORNL CXRS Upgrade & He Ash Diagnostic for JET-DT Experiments

- ORNL has built and installed CXRS He Ash Spectroscopy System for JET DT and upgraded existing JET CXRS System
 - Provide increased sensitivity for detection of He produced in DT reaction
 - Increase number of radial spatial chords to 40 for investigating ITB changes in radial profile
 - improved time resolution
 - hardware installation completed - March 2005
 - ready for first plasma - Sept. 2005
- Address Helium transport and exhaust issues for future Burning Plasma Experiments
 - **JET is the only near term DT experiment**
- Improved profile measurements of T_i , V_{rot} , and impurity densities
- Joint effort by ORNL & PPPL

Incremental funding request for continued support of ORNL post doc

JET Plans

- JET will restart physics experiments in November 2005 with significant enhancements contributed by the US :
 - He CXR (α ash transport in DT) ORNL
 - Lost alpha detector PPPL
 - Thomson Scattering (for ITB studies) GA
 - HPP ICRF Launcher ORNL, PPPL
 - Moderate n active MHD antennas (for TAE studies) MIT
- In addition, the EU is upgrading the JET divertor to high- δ and increasing neutral beam power. In CY06 a high power ITER-like FW antenna will also be installed on JET, with strong input from the US.
- JET is preparing a major proposal for an ITER-like wall (Be PFCs, W divertor baffles and W or C targets). Would be installed in 2008 with experiments to start in 2009. Presently in the discussion stage.

JT-60U and AUG Highlights

- JT-60U activities for FY 2005 - 2006 include:
 - continued data analysis of TAEs and ITB physics
 - negative ion neutral beam development

\$175 k

- Asdex-UG activities focuses on divertor modeling
 - Application and development of b2-EIRENE to DIII-D, JET, and ITER, especially for ELMs
 - develop an extrapolable model for ELM effects on particle transport (e.g., helium in ITER).
 - assess the relative strengths and weaknesses of the existing divertor modeling codes
 - b2-EIRENE has been improved to include effects of micron-scale dust particles on the divertor target.

Future Work: (FY2006-FY2007)

- develop an integrated model for ELM behavior, both for impurity enrichment (including helium) and to develop successful ELM heat flux mitigation scenarios.

Many additional collaborations (17), funded out of individual programs.

\$200¹³ k

Tore Supra Highlights

Unique Features

- long pulse (~ 360s) with high power density ($< 5 \text{ MWm}^{-2}$) on carbon with H₂O cooled Cu
- will increase steady state LH power to 8 MW, and ECRH to 3 MW.
- "short pulse" ICRH capability (8 MW for 30s) will be maintained.

Tests to Validate Edge Modeling of Carbon Transport

coupled codes CASTEM / BBQ / ITC => the carbon originating from the actively cooled plasma-facing components (CASTEM, a 3D finite elements code developed by CEA), through the SOL (using the ORNL BBQ code, describing 3D multi-species Monte Carlo impurity transport) and into the core (with ITC, a new, efficient radial impurity transport).

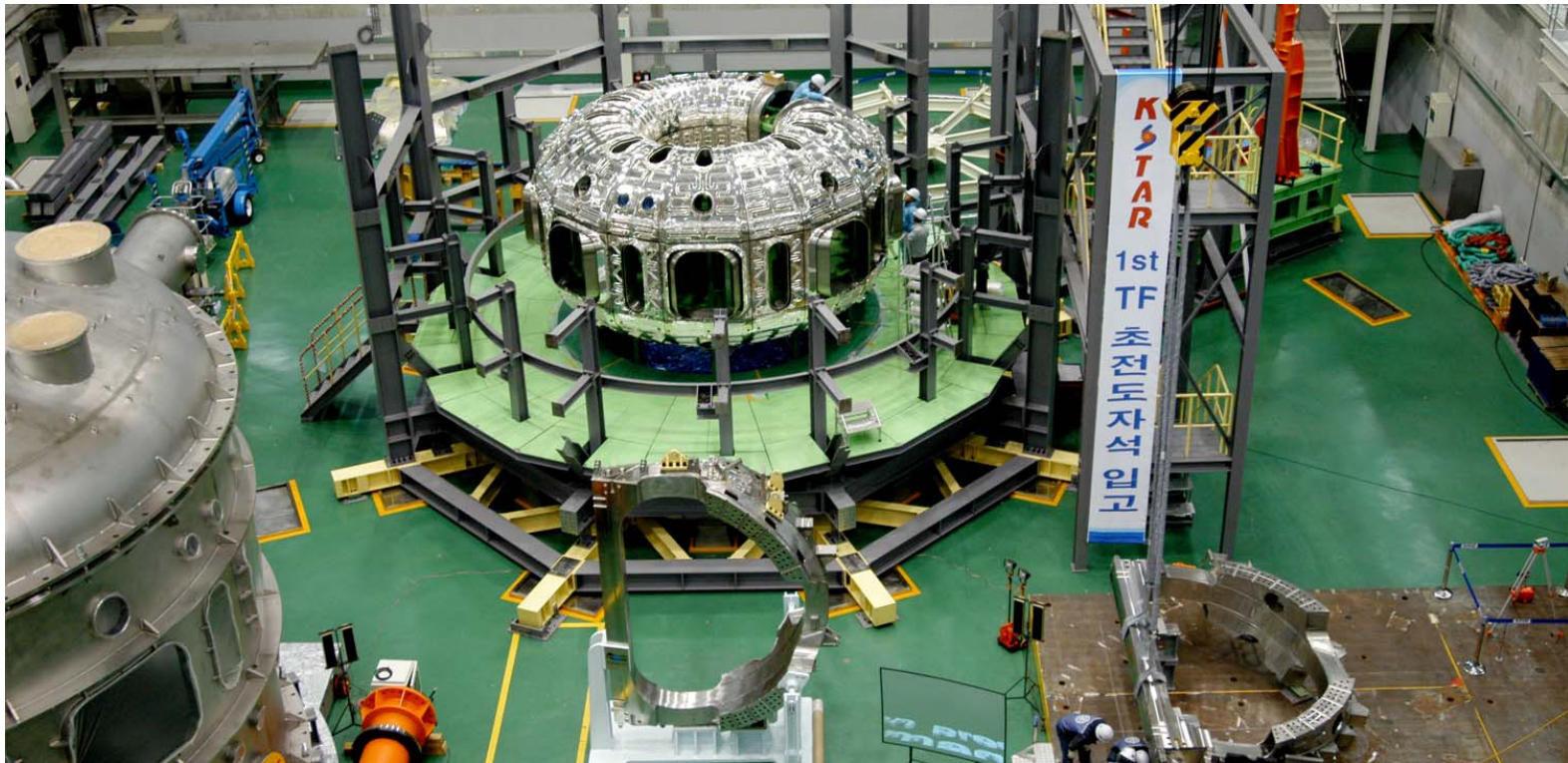
D retention in long discharges

TS sees a fundamental difference between several days operation with "short" pulses, i.e., each $< 15 \text{ s}$; and several days operation with "long" pulses.

- Can recover virtually all the D between shots and overnight with short pulse operation,
- But "permanent" retention rate of ~ 50% for long discharge operation.
- Is this due to diffusion into the bulk or co-deposition?

KSTAR Highlights

- **KSTAR will be an all-superconducting tokamak (Nb_3Sn TF and PF coils)**, with a major radius of 1.8 m, a plasma current of 2 MA and a toroidal field of 3.5 T. Initial operation by the end of 2007. “Steady-state” plasma operation sustained by non-inductive current drive for periods of up to 300 s is anticipated by 2015; pulse duration capability during the “basic” operation phase —scheduled for 2008–2013 — will be 20 s. KSTAR size, operation capabilities and mission objectives for this period will be comparable to those of the present DIII–D.
- **Construction is now is 82% complete**, 12 of 16 TF coils are finished and tokamak assembly has started:



KSTAR Highlights

A US-Korea Workshop held at GA in May 2004 identified **elements for an expanded US collaboration** with KSTAR, focused on progress towards **experiments commencing in CY2008**. The first-year FY06 embodiment of this expanded collaboration comprises \$1.6 M of US-funded activities.

FY06 International Collaboration to Prepare for KSTAR Operation (President's budget 2/3/05):

Institution	Task(s)	FY06 (\$K)	Total Institution (\$K)
PPPL	AT scenario definition studies	50	340*
	Thomson scattering system design	150	
	LHCD launcher and component design	150	
	FusionGrid collaboratory	50	
GA	Interface engineering for other diagnostics	140	550*
	Plasma control system development	150	
	EC launcher and component design	150	
	FusionGrid collaboratory	150	
ORNL	Inside pellet launch guide tube design	70	215*
	CHERS diagnostic design	110	
MIT	FusionGrid collaboratory	50	25*
Columbia U	RWM control concept validation	110	125*
U Wisconsin	BES diagnostic system design	50	50*
UC Davis	MRI/ECE diagnostic system design	110	125*
Nova Photonics	MSE diagnostic system design	110	150*
Total	Preparation for initial plasma operation	1,600	1,600

Experimental Advanced Superconducting Tokamak (EAST) at ASIPP-Hefei, China - Highlights

EAST has NbTi superconducting TF and PF coils. All TF coils are fabricated, the last is undergoing cold test now. The last CS coils will be cold tested in early April. Assembly (shown below) includes: 7 TF coils, 2 large PF coils and 1 divertor coil.



Schedule

July-Aug

Cool down and energize coils

Sep-Nov

Weld vac vess, install a limiter

Around end of 2005

First Plasma

Parameters

$B = 3.5 - 4 \text{ T}$, $I_p = 1 - 1.5 \text{ MA}$

$R = 1.7 \text{ m}$, $a = 0.4 \text{ m}$

$\kappa = 1.2 - 2$, $\delta = 0.2 - 0.5$, DN, SN

ICRH=3-6 MW, ECRH=0.5-1.5MW

LHCD = 3.5 - 8 MW

Pulse length 1000s active cooling

The University of Texas Collaboration with the Institute of Plasma Physics, Chinese Academy of Sciences



- ◆ **US Participants: P. E. Phillips, W. L. Rowan, Huang He, and K. W. Gentle**
- ◆ **The goal of the collaboration is to develop diagnostics for and conduct experiments on EAST. In both areas, preparatory work has already started on HT-7.**
- ◆ **Accomplishments**
 - **Installation of a 16 channel ECE radiometer on HT-7 and identification of upgrades for EAST**
 - **Successful transfer and operation of a diagnostic neutral beam**
 - **Design of a CXRS system for HT-7 and identification of upgrades for EAST. Assembly is in progress**
 - **Design and installation of beam diagnostics for monitoring the DNB performance**
 - **Participated in the installation of MDSPlus for improved remote access to data**

DIII-D EAST Collaboration is a New Paradigm

GA(DIII-D) => ASIPP(EAST)	ASIPP(EAST) => GA(DIII-D)
Train ASIPP staff on DIII-D controls	3 ASIPP ops staff to DIII-D
DIII-D control system for EAST	3 engineers to DIII-D divertor design
GA assists in EAST divertor design	Fabricate parts for DIII-D lower divertor
GA leads design of EAST cryopumps	Fabricate parts to refurbish 8 DIII-D NB sources
Provide two new ion sources	Provide main HV transformers
Assist ASIPP in RWM coil design	Possible fabrication of NBI pole shields

FY05		FY06		FY06(I)		FY07	
FTE	\$K	FTE	\$K	FTE	\$K	FTE	\$K
0.3	200	0.3	175	0.1	25	0.3	200



* For fabrication of the two NB ion sources for EAST with parts provided by EAST

TEXTOR Program FY2005-2006

- **Dynamic Ergodic Divertor operation will be exploited during FY05-06**
 - Explore resonant layers at plasma edge by varying field strength to produce large ergodic zones or large laminar zones
 - Utilize the 16 DED coils to generate different modes
 - $m/n = 3/1$ (deeply penetrating) and $m/n = 6/2$ during FY05 and FY06
 - Study influence of perturbation fields on the stabilization of external kink modes
 - Effects of the DED on plasma-wall interaction, especially heat deposition, particle recycling, and impurity screening
- **Electron Cyclotron Emission Imaging (ECEI)**
 - measures density and temperature fluctuations
 - 2D imaging system is now in routine operation
 - 128 channels for Te fluctuations
 - Provides movies of sawtooth precursor and crash
- **TEXTOR will operate throughout CY2005**
 - 3 weeks of ops followed by 1 week of maintenance
 - 6 week summer break in July-August 2005

D. Hillis, J. Hogan, P. Mioduszewski (ORNL), R. Moyer (UCSD), T. Evans (DIII-D)

N. Luhmann, C. Domier (U.C. - Davis), E. Mazzucato, H. Park PPPL \$75k

LHD/CHS Stellarator Collaboration

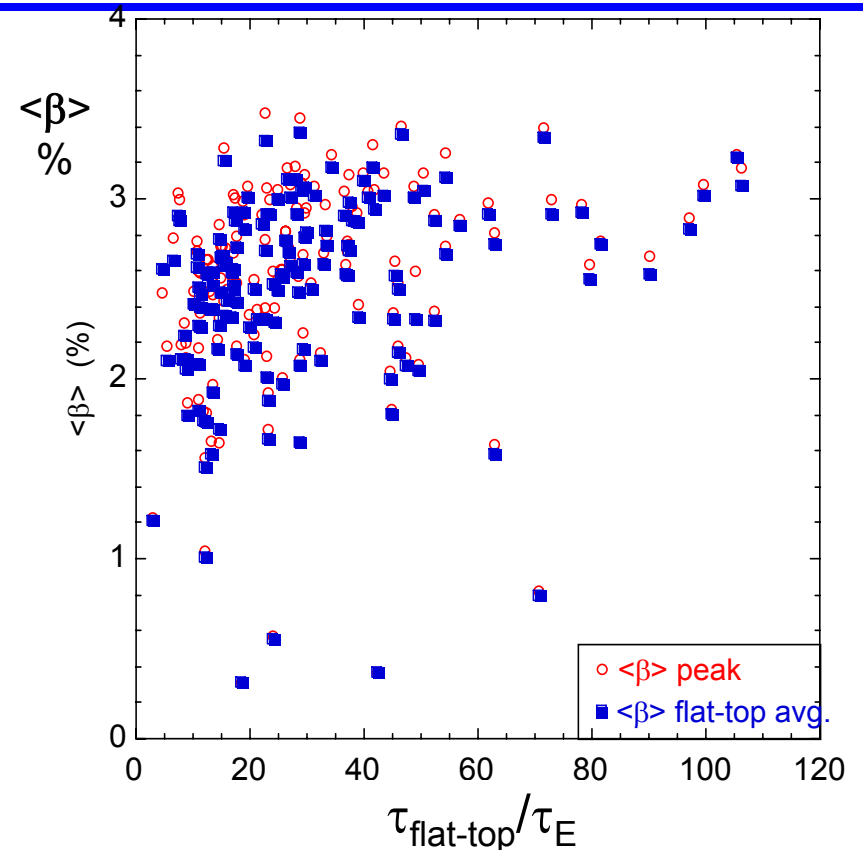
- Status: $\langle\beta\rangle = 4.3\%$, $T_i(\text{Ar}) = 14 \text{ keV}$, $T_e = 10 \text{ keV}$ max values, NAS
1/2-hour pulse length with 3 cm/3 min axis sweeping, energy input $\approx 1.3 \text{ GJ}$
- US activities and budgets
 - energetic neutral particle analysis, theory and code development (ORNL)
FY 2005 -- \$253k; FY 2006 -- \$253k (includes ORNL Exp'l Pgm funds)
 - role of magnetic stochasticity in limiting performance at high beta.(PPPL)
FY 2005 -- \$250k; FY 2006 -- \$175k
- Purpose:
 - studies of confinement improvement, high-beta equilibrium and stability, long-pulse operation and divertors is important for US compact stellarator program and comparison with tokamaks
- Issues:
 - CHS experiment will shutdown in a year -- potential for people and hardware collaborations in US compact stellarator program

TJ-II Stellarator Collaboration (Spain)

- Status: operating with ECH and NBI
 - studying magnetic topology and confinement, equilibrium and stability, neoclassical and momentum transport
- US activities and budgets
 - improving NBI, pellet injection, EBW heating, code development and theory (ORNL)
FY 2005 -- \$225k; FY 2006 -- \$175k
 - 2-D edge turbulence imaging (PPPL)
FY 2005 -- \$75k; FY 2006 -- \$75k
- Purpose:
 - understanding effect of magnetic topology (helical axis and low-aspect-ratio bean-shaped plasma) on equilibrium and confinement for benchmarking compact stellarator calculations
- Issues:
 - raising injection energy from 30 kV to 40 kV for higher power
 - growth in tasks vs. funding reduction

W 7-AS (Germany) Stellarator Collaboration

- Status: experiment shutdown in 2002
 - ongoing data analysis
- US activities
 - Achieved FY04 milestone to “Explore the relation between MHD equilibrium and high beta performance in the W7-AS device”
 - paper and oral presentation given at the Nov. 2004 IAEA meeting
 - paper at EPS 2005



- Purpose:
 - studies of confinement improvement, high-beta equilibrium and stability, effect of plasma current, and divertors important for US compact stellarator program

- Issues:

Lyon — wealth of W7-AS data, but no budget for additional data analysis

International Collaboration has Expanded Substantially Through the International Tokamak Physics Activity (ITPA)

- **ITPA includes ITER Parties - CH, EU, JA, RF, KO, US**
- About 100 U.S. scientists are involved in ITPA topical groups
 - Erol Oktay, Ned Sauthoff and Ron Stambaugh are the US members of the ITPA Coordinating Committee.
 - R. Stambaugh- Chair of ITPA Coordinating Committee,
- **ITPA focus is on seven topical areas**
 - Identifies High Priority Research (HPR) topics in burning plasma physics, emphasizing tokamak plasmas;
 - Activities include experiments, data analysis, theory & modeling;
 - Broader than ITER physics issues (STs and stellarators participate)
- **IEA tokamak agreements implement ITPA HPR topics** through Joint Experiments on tokamaks world-wide
 - **Substantial increase in collaborations** among: ASDEX-UG, DIII-D, C-MOD, JET, JT-60U, MAST, NSTX, TEXTOR, TORE-SUPRA

The US is Well Represented in the International Tokamak Physics Activity (ITPA)

Topical Physics Groups	US Coordinator	International Chair/Co-Chair
Coordinating Committee	Sauth/Oktay	Stambaugh(US) / Shimada(IT)
Transport physics	Doyle	Doyle(US) / Mukhovatov(IT)
Edge pedestal physics	Leonard	Kamada(JA) / Leonard(US)
MHD (includes Fast Particles)	Strait	Hender(EU) / Gribov(IT)
Confinem't DB and Modeling	Houlberg	Houlberg(US) / Polevoi(IT)
Diagnostics	Johnson	Donne(EU) / Costley(IT)
Scrape-off Layer and Divertor	Lipschultz	Asakura(JA) / Lipschultz(US)
Steady State Ops	Luce	Sips(EU) / Ide(JA)

Note: IT members are from EU, JA and RF

- Update of the Tokamak Physics Basis is a major activity - scheduled for July 2005
- ITPA web page <http://itpa.ipp.mpg.de/>

US Theory Contributions to Int'l Collaboration

- Many Important contributions are being made by the theory base program.
- The US is a leader in fast particle theory/simulation, diagnostics and experiments (several IAEA 2004 talks)
 - Alfvén Cascades on JET, JT-60U - US interpretation
 - Grand Cascades => diagnostic for q_{\min} in ITB creation
 - Non-linear fishbones
 - Induced transport - intermittent losses, diffusive transport
 - Integrated simulations are being planned
- Transport studies: electron dominated transport (eg., Tore Supra-Texas @ IAEA) and many more.
- The Fusion Simulation Project (FSP) will be a major contribution by the US to the international effort, and will be an important tool to prepare for US participation in ITER research.

Opportunities in International Collaboration

- Exploit our previous investments in JET as an avenue to high performance, Burning Plasma Physics and ITER R&D.
- Fully engage in the ITPA - paradigm for the future
- Coordinate with Needs of US ITER project
- Prepare for Emerging Opportunities
 - KSTAR
 - EAST
 - JET ITER-Like Wall Proposal

Concluding Comments

- The US is making a significant impact on other international programs, and “We are bringing home the data.”
- “Do it domestically if we can, if we can’t, then do it internationally” has been our selection criteria, and has been effective in the past.
- In the future, some international activities will be needed to develop our infrastructure for international research, especially preparation for ITER.
- Considerable hardware investments have been made by the US in 2003-2005 to address ITER-relevant issues, but FY 2006 budget guidance will limit our ability to exploit these investments.
- Continue to work on improving coordination of international and domestic activities.