Positioning the US to Play a Leading Role in and Benefit from a Successful ITER Research Program

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Your charge includes a presumption of US Participation in ITER
This talk is about how to prepare to make it successful

"The study of burning plasmas, in which self-heating from fusion reactions dominates plasma behavior, is at the frontier of magnetic fusion energy science. The next major step in magnetic fusion research should be a burning plasma program, which is essential to the science focus and energy goal of fusion research… ITER offers an opportunity for the study of burning plasma physics in conventional and advanced tokamak configurations for long durations with steady state as the ultimate goal, and would contribute to the development and integration of plasma and fusion technology"

2002 Snowmass meeting press release; later endorsed by FESAC

- The ITER construction project must produce a scientific instrument that can achieve specific technical goals
  - Q=10 for hundreds of seconds
  - Q=5 in steady-state-capable scenarios for thousands of seconds
  - Provide a unique laboratory to study the physics and technology of burning plasmas and provide a significant part of the basis to proceed to a DEMO
- The results will inform US efforts toward a fusion energy DEMO
- There is still work to be done
  - The US FES program has the assets in place to prepare for a successful ITER program – we are world-leading in many areas
  - The most important need is run time
    - Planned upgrades can make us more effective

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Activities are needed in three broad areas

Efforts in three areas must be prioritized to make ITER a success both in meeting its technical objectives and in moving forward the US Domestic Fusion program:

Make ITER succeed

1. **Inform ITER design decisions**
   The US is a strong contributor, and in some areas a clear leader, in ongoing research supporting ITER's design during construction. These activities are supported by ongoing US tokamak research, but rely on the availability of adequate resources and run-time.
2. **Prepare for leading roles in the ITER research program**
   The US is among the leaders in ongoing fusion science research that will prepare scientists to play leading roles in scientific exploitation of ITER, and US tokamak capabilities are world-leading in increasing fidelity to expected burning plasma conditions.
3. **Prepare the US to make use of the results of the ITER research program**
   A successful ITER research program along with progress in fusion nuclear science will provide much of the needed basis to proceed to a fusion DEMO. To position the US to benefit from ITER and proceed toward energy development requires continued strong domestic programs in tokamak physics, materials, and fusion nuclear science.

Position the US to benefit from the ITER Research Program

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1: Inform ITER design decisions

The ITER design is sufficiently advanced that construction is underway, but there are numerous technical issues that must be addressed to reduce risk when ITER operates

- ✓ Develop and qualify disruption prediction, avoidance, and mitigation techniques
- ✓ Prepare a physics basis for ELM control and ELM-free operating scenarios that can be extrapolated to ITER
- ✓ Extend current plasma control techniques to be effective in the burning plasma environment
- ✓ Develop standards for acceptable error fields and techniques to measure and correct them
- Qualify candidate heating and current drive upgrades for ITER steady-state scenarios
- *Be prepared to take up other issues as they arise during construction*

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Work to address these issues is ongoing, but will require continued effort in the coming years

✓ US is a leader

2: Prepare for leading roles in a successful ITER research program

Plasmas produced in ITER will differ in important ways from those we can produce today. Improved understanding of how to extrapolate from current research will be important for reducing risk in the ITER research program.

- ✓ Advance the capability to simulate ITER plasmas using validated models
  - *Need to simulate each condition before attempting in ITER*
- ✓ Understand energetic particles and energetic particle driven instabilities
  - *Today's fast ions are a proxy for alpha particles in ITER*
- ✓ Develop plasma-based solutions for controlling heat flux on ITER's divertor
  - *Geometric variation (within constraints of ITER design) and divertor seeding for detachment*
- ✓ Develop and qualify ITER inductive and noninductive operating scenarios
  - *Scenarios must integrate core and edge solutions including high-Z materials and without large ELMs*
- Develop techniques to understand and mitigate damage to tungsten surfaces from helium plasmas in the non-nuclear phase and helium ash in the DT phase

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We must develop and maintain a high quality scientific workforce who can represent the US program within the ITER Team

✓ US is a leader

3: Prepare the US to make use of the results of the ITER research program

- Maintain strong domestic programs in tokamak physics, materials, technology and fusion nuclear science throughout and in parallel with ITER research program
- The consequences of allowing the domestic program to shrink significantly in favor of ITER would be crippling to the post-ITER development of fusion as an energy source

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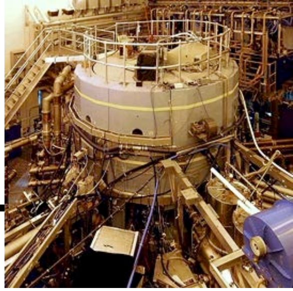
US facilities are already well positioned to prepare for ITER

C-Mod



	Present	Planned upgrades
Boundary	• Record heat flux with ITER B_{pol} and λ_Q • Metal PFCs • Unique SOL and surface diagnostics	• Advanced W divertor
Equilibrium and transient control	• MGI, runaways, asymmetries • ELM-free operation with I-mode	
H&CD capabilities	• Unique tests at ITER B, n_e • High power density ICRF • Understand and mitigate high Z sources • LHCD informs ITER upgrade for SS	• New ICRF and LHCD antennas
Transport, EP, Diagnostics	• Heat, high Z particle & momentum flux and turbulence studies, with electron-dominant heating, no core torque or fueling.	• Extended turbulence, x-ray diagnostics.

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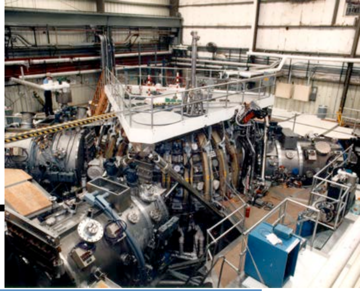
All three major US facilities have extensive diagnostic suites and work closely with the theory and modeling community emphasizing the development of physics understanding leading to the validated models needed for ITER.

US facilities are already well positioned to prepare for ITER

DIII-D



	Present	Planned upgrades
Boundary	• Extensive diagnostics (DTS,…) • Geometry variation	• Diagnostics
Equilibrium and transient control	• DIII-D Plasma Control System in widespread use • Disruptions: Testing both leading ITER DMS actuators, RE control, active avoidance • ELM control: RMP, pellet pacing • ELM avoidance: QH-mode	• Additional ECH off-axis & balanced NBI • 3D coils
H&CD capabilities	• On- and off-axis NBI; co-/counter-NBI • ECH for direct electron heating and OACD • *ITER baseline/hybrid/SS qualification under increasingly relevant conditions*	• Additional ECH & balanced NBI
Transport, EP, Diagnostics	• Too many actuators and measurements to list…	…more in development

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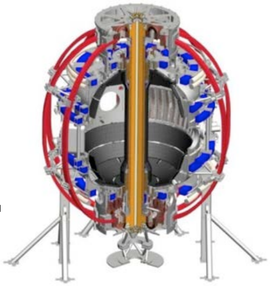
US facilities are already well positioned to prepare for ITER

NSTX-U



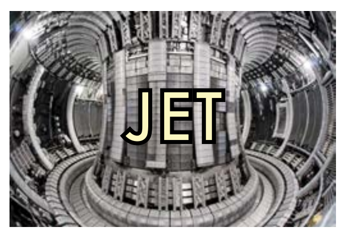
	Present	Planned upgrades
Boundary	• Detachment threshold studies • Laser blow-off for high-Z impurity transport • Divertor magnetic configuration variation	• W divertor tiles • Full metal 1st wall • Divertor cryo-pump
Equilibrium and transient control	• Advanced disruption warning + MGI • ELM pacing with granule injector, 3D fields	• Off-midplane 3D field coils
H&CD capabilities	• Understand fast-wave edge losses, optimize coupling and core heating • High power NBI (on- and off-axis)	
Transport, EP, Diagnostics	• Access non-linear Alfvén Eigenmodes, vary distribution with full diagnostics + modeling • Thermal, momentum, particle transport vs. beta and collisionality • MSE-LIF: q(r) and p(r) w/o heating beam	• Electromagnetic turbulence diagnostics

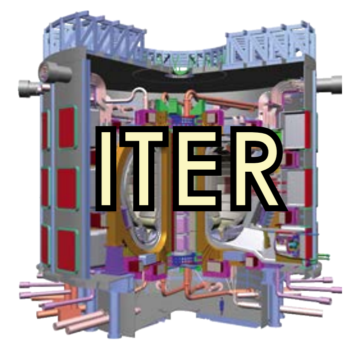
All three major US facilities have extensive diagnostic suites and work closely with the theory and modeling community emphasizing the development of physics understanding leading to the validated models needed for ITER.

International collaborations will have the largest impact and benefit when leveraged from a position of strength provided by our domestic research program

… Includes ITER

- US is a major participant in ITPA due in large part to technical contributions from our tokamaks
- Research leading toward and beyond ITER should take advantage of the complementary nature of US facilities and those of our international partners
  - Example: long-pulse superconducting tokamaks can work together with more flexible, but shorter-pulse, US devices to develop and qualify long pulse operating scenarios
- In some cases, international facilities can provide opportunities to extend research beyond US capabilities
  - Example: DT experiments in JET





Not a one-way progression from US to foreign devices – collaborations can and should go in both directions!

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Current research is already addressing these areas

What are we asking you to endorse:

- The assets we have in hand are already world-leading in many ways that provide critical information for ITER
- Preparing for a successful ITER depends most strongly on our continuing to assign high priority to the needed research within the present programs
  - Run-time, upgrades, people,…
- Many of the initiatives being proposed to the panel will provide valuable new capabilities that enhance our probability of success
  - Tokamak upgrades for improved fidelity to ITER conditions
  - Computational capabilities for more advanced modeling and simulation
  - Technology developments both to contribute to ITER and to learn from ITER
- Continue to leverage our unique capabilities by partnering with international experiments with complementary capabilities

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