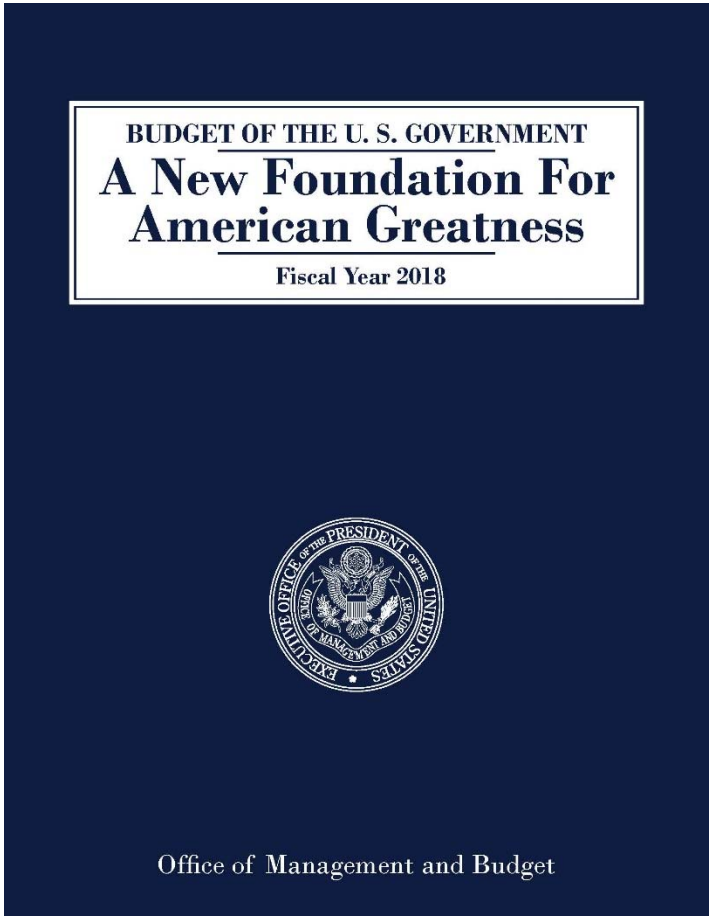
# U.S. Fusion Program Overview

**James W. Van Dam**
**Acting Associate Director**
**Office of Science**
**Fusion Energy Sciences**

U.S. DEPARTMENT OF ENERGY
Office of Science

**Fusion Power Associates**
**Annual Meeting & Symposium**
**December 6-7, 2017**

# 1. Budget Updates




https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/budget/fy2018/budget.pdf

# Current status

- **FY 2018**
  - Under a Continuing Resolution until **December 8, 2017**
    - *Bill H.R. 601 funds all programs at the FY 2017 enacted level less a 0.6791% across-the-board cut*
  - Funding actions for grants and cooperative agreements are being processed, following a priority order based on the starting date of their FY 2018 budget periods
  - Labs (and some large cooperative agreements) are being funded incrementally
  - Under the CR, ITER is being funded incrementally
  - *[Placeholder for any budget updates]*

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# Highlights from the House and Senate marks for FY 2018 budget

- **From the Senate Energy and Water Development mark [July 2017]**
  - The Committee recommends **$232,000,000** for Fusion Energy Sciences.
  - The Committee recommends **no funding for the U.S. contribution to ITER**.
  - The Committee remains concerned about the **timeline of facility repair and recovery actions for NSTX-U** and directs the Department to assess science drivers for the NSTX–U to support future planning and reconfiguration for the Fusion Energy Sciences program; DOE must provide a briefing to the Committees on Appropriations of both Houses of Congress upon completion.
  - The Committee recommends **prioritization of research and operations for DIII-D and supports continued research on HEDP**.
- **From the House Energy and Water Development mark [July 2017]**
  - The Committee recommends **$395,000,000** for Fusion Energy Sciences, $15,000,000 above fiscal year 2017 enacted and $85,060,000 above the budget request.
  - Recognizes that "**University-led research helps further U.S. research in fusion energy and trains the next generation of scientists**" and directs DOE to summarize the fusion energy sciences program's current collaborations with universities and report back to the Committee
  - Specific marks for two programs (HEDLP & SciDAC)
  - The Committee recommends **$63,000,000** for the U.S. contribution to the ITER project

# 2. Programmatic Updates & Highlights

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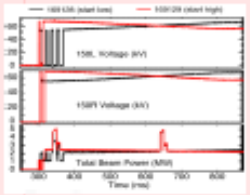
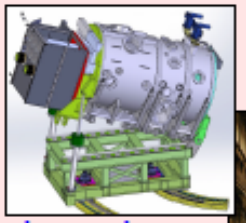
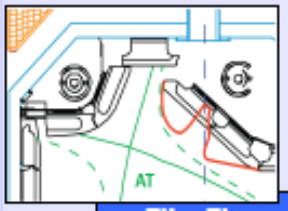
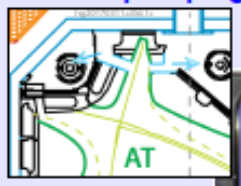
# DIII-D program and facility enhancements aim at addressing key scientific issues for fusion energy

| DIII-D Program Elements | FY17 | FY18 | FY19 | FY20-21 |
|---|---|---|---|---|
| **Prepare Burning Plasma Scenarios** | | | | |
| Transient Control (ELMs) | | | | |
| Transient Control (Disruptions) | | | | |
| Transport (pedestal, Te/Ti, rotation) | Super-SPA supply (ASIPP) | Increased electron Heating/current drive | Super-SPA #2 | |
| **Determine Path to Steady State** | | | | |
| High β Operation | | | | |
| Fast Ion Transport | | | | |
| Current Profile Control | Real-time NBI voltage modulation | | Increased co-cntr, off-axis current drive | HFS-LHCD; New helicon system |
| **Develop PMI-Boundary Solutions** | | | | |
| Model Validation | | | | |
| Divertor Configuration Changes | Upper divertor closure; Tile Thermal Upgrade | | | |
| PMI Studies and Material Evaluation | | | | SAS with pumping; Surface Station |




DIII-D NATIONAL FUSION FACILITY SAN DIEGO

**Capable, mature facility enables collaborations with international programs across global magnetic fusion energy community**

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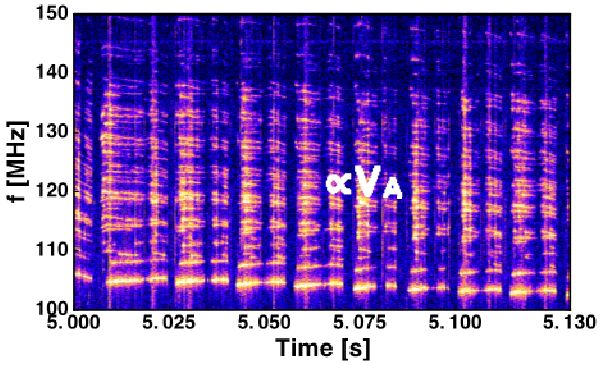
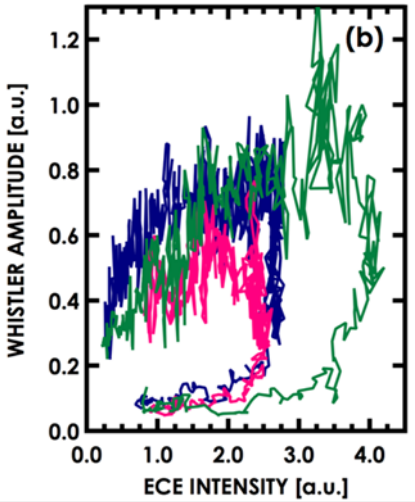
# Frontier science campaign on DIII-D

- In FY 2017, FES supported a new initiative to carry out experiments on DIII-D focusing on frontier plasma science, with input solicited from the university community to identify experiments not directly related to fusion energy issues
- Four experiments were performed:
  - Interaction of Alfvén/whistler fluctuations and runaway electrons
  - Self-consistent chaos in magnetic field dynamics
  - Self-organization of kink-unstable flux ropes; and
  - Impact of magnetic perturbations on turbulence
- The initiative was very successful and resulted in a post-deadline invited paper in the 2017 APS-DPP meeting
- Plans are underway to continue this initiative in FY 2018, contingent upon budget authority




Whistler frequency bands showing intermittency from sawtooth and whistler scattering




Predator-prey limit cycles between whistler wave amplitude and electron cyclotron emission – related to scattering of runaways

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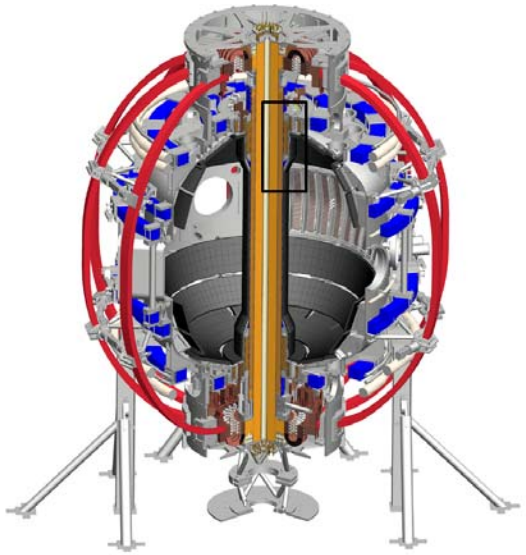
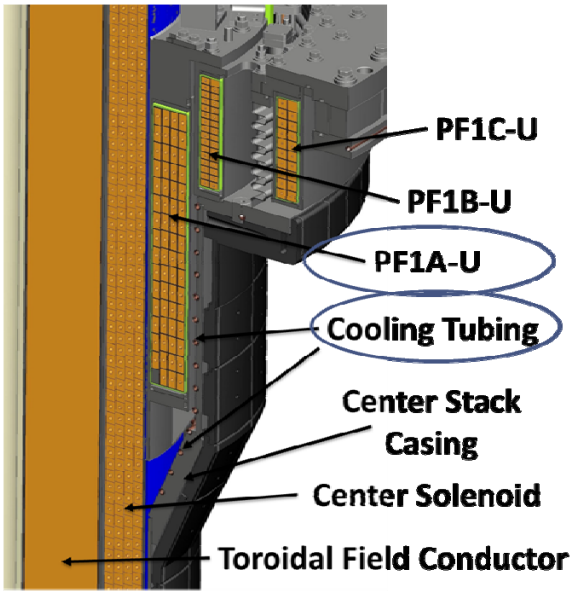
# NSTX-U status

- **Research operation of NSTX-U:**
  - Plasma operations commenced after the completion of the NSTX Upgrade project.
  - However, after ten weeks of experimental operation, a series of hardware failures rendered the machine inoperable, stopping operations prematurely in 2016.
- **In response, FES directed PPPL to:**
  - Conduct an independent investigation of all policy and procedural causes of the NSTX-U project difficulties
  - Identify all design, construction, and operational deficiencies with the NSTX-U facility.
- **These activities led to the development by PPPL of a corrective action plan and proposed recovery activities to effect the necessary repairs to NSTX-U**
  - During FY 2017, 12 Design Verification and Validation Reviews, Extent of Condition Review, Extent of Cause Review, etc., were carried out
  - PPPL is now completing preliminary and final design reviews of all necessary device repairs





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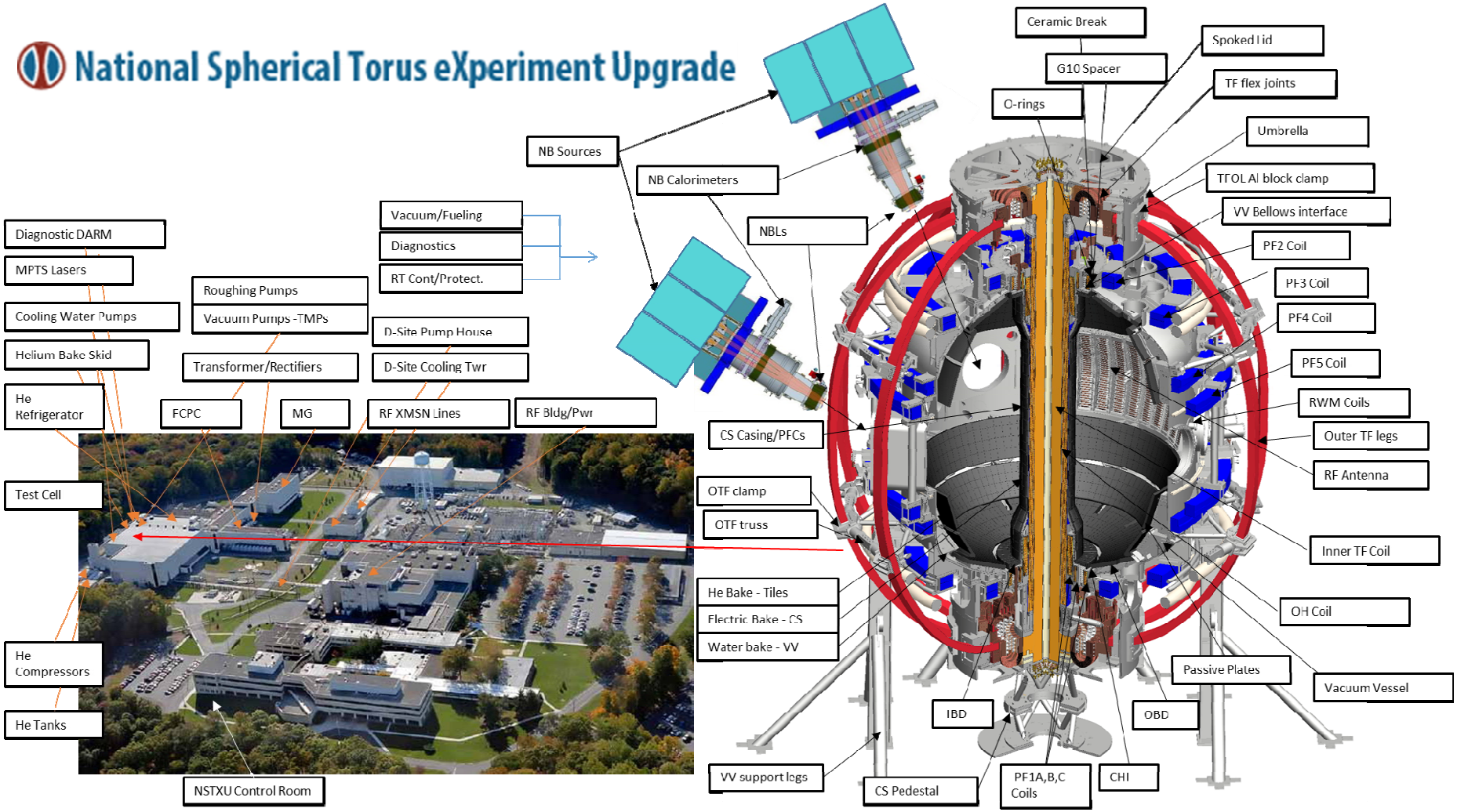
# Extensive "Extent of Condition" assessment

National Spherical Torus eXperiment Upgrade



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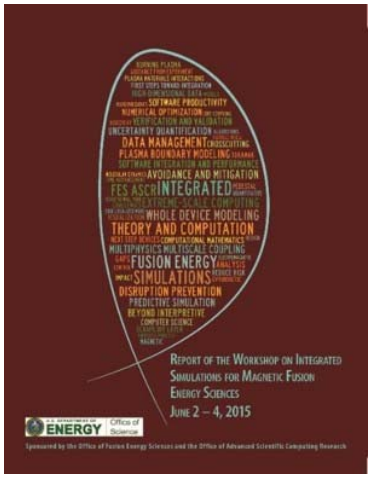
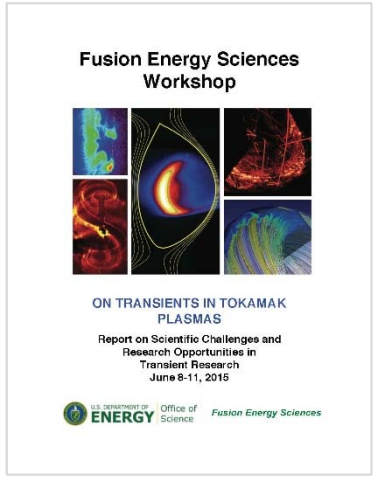
# A new SciDAC portfolio addresses priorities identified in community workshops

- The FES SciDAC portfolio was recompeted in FY 2017
  - FES and ASCR jointly invested $24M in FY 2017 to support **seven** multi-institutional and interdisciplinary SciDAC partnerships
  - An **eighth** project is being supported by FES, starting in FY 2018
  - 11 universities, 8 DOE national laboratories, and 5 private industry institutions (including small businesses) in 13 states are involved
- The research activities of the eight partnerships will be coordinated to accelerate progress toward Whole-Device Modeling
- The new portfolio strengthens the U.S. domestic fusion program, advances U.S. world-leadership and competitiveness in fusion simulations, and addresses research opportunities identified in recent community workshops

**27 PF Titan @ OLCF**




**2015 community workshops on Integrated Simulations for Magnetic Fusion Energy Sciences and Transients in Tokamak Plasmas**

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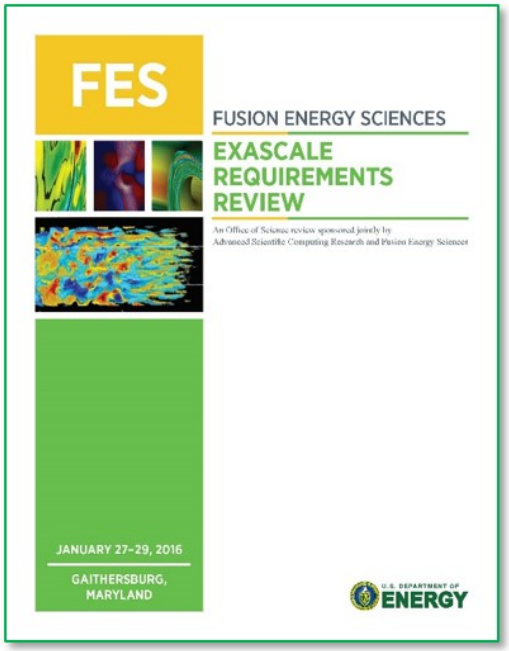
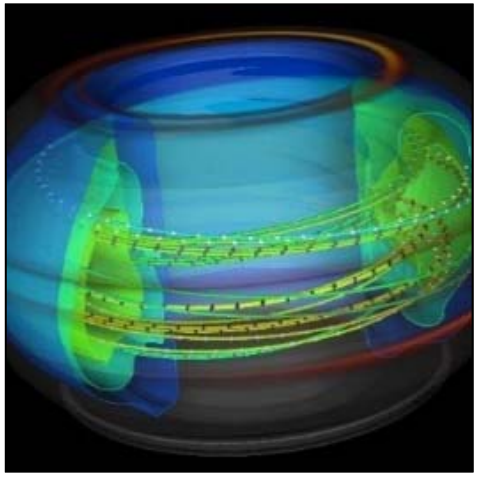
# Fusion presence in Exascale activities

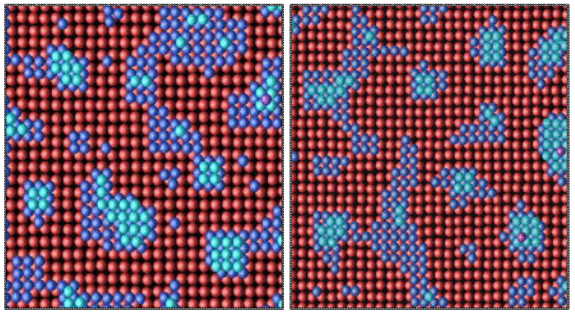
- The upcoming Exascale era will enable transformative advances in predictive power for fusion systems, based on fundamental science and high-performance computing
- Community studies identified priorities and challenges
- Two fusion-relevant multi-institutional efforts are part of the DOE Exascale Computing Project (ECP)
- University participation is through subcontracts with the DOE Labs



**High-Fidelity Whole-Device Modeling of Magnetically Confined Fusion Plasma**
(led by PPPL)

ECP EXASCALE COMPUTING PROJECT



**Molecular Dynamics at the Exascale: Spanning the Accuracy, Length and Time Scales for Critical Problems in Materials Science**
(led by LANL; addresses needs of BES, FES, and NE)

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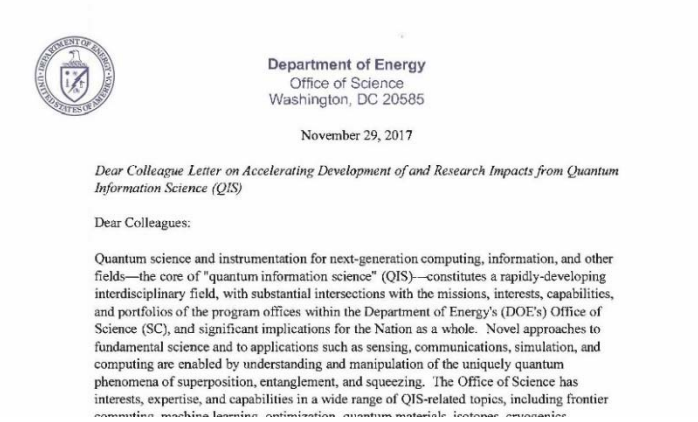
# Quantum Information Science (QIS)

- **QIS**—which includes quantum science and instrumentation for next-generation computing, information, and other fields—has been identified as an important cross-cutting topic with potential impact across all SC program offices
- A "Dear Colleague Letter" was issued recently by SC, encouraging the submission of innovative research ideas in QIS

- In **early 2018**, FES will be working with the community to determine:
  - The potential of fusion and plasma science to contribute to the development of QIS
  - The potential of QIS to provide transformative advances in the science areas supported by FES


https://science.energy.gov/



Department of Energy
Office of Science
Washington, DC 20585

November 29, 2017

*Dear Colleague Letter on Accelerating Development of and Research Impacts from Quantum Information Science (QIS)*

Dear Colleagues:

Quantum science and instrumentation for next-generation computing, information, and other fields—the core of "quantum information science" (QIS)—constitutes a rapidly-developing interdisciplinary field, with substantial intersections with the missions, interests, capabilities, and portfolios of the program offices within the Department of Energy's (DOE's) Office of Science (SC), and significant implications for the Nation as a whole. Novel approaches to fundamental science and to applications such as sensing, communications, simulation, and computing are enabled by understanding and manipulation of the uniquely quantum phenomena of superposition, entanglement, and squeezing. The Office of Science has interests, expertise, and capabilities in a wide range of QIS-related topics, including frontier

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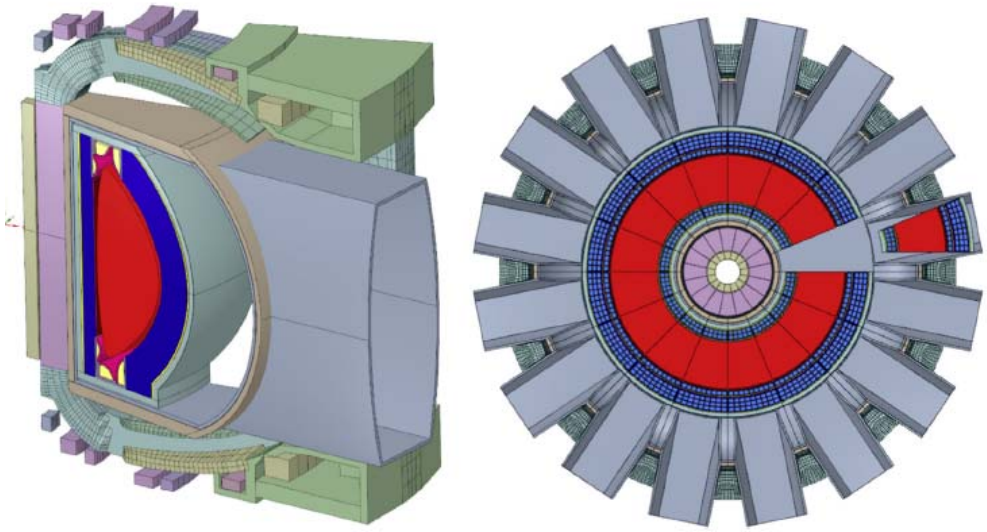
# Fusion Energy Systems Studies team: FNSF study

- The national Fusion Energy Systems Studies (FESS) team finalized its three-year project examining the Fusion Nuclear Science Facility (FNSF).
- This included examination of the FNSF mission and requirements, and identification of required R&D to support this facility's design, construction, and operation.
- Details will be available soon in a thirteen-paper special issue of *Fusion Engineering and Design* journal.



**CAD layout of the FNSF primary fusion core components and top view showing sector removal**

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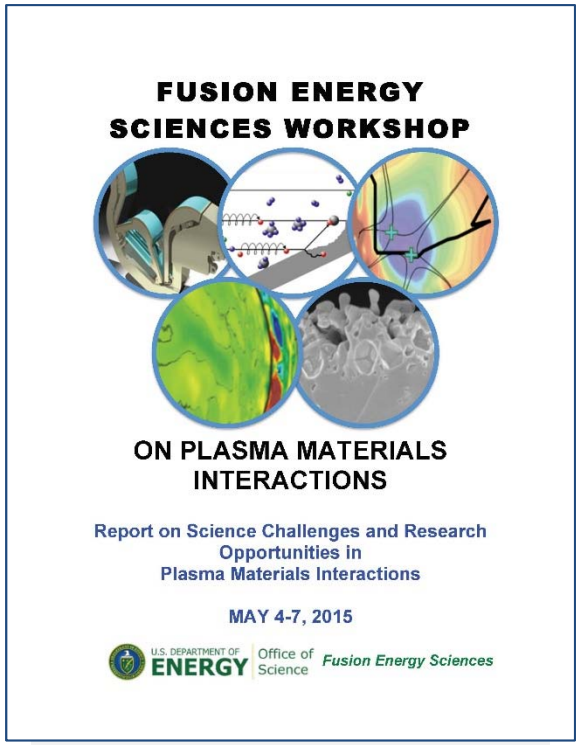
# Fusion Energy Systems Studies team: liquid metal PFCs integrated tokamak study

- **Liquid metals** PFCs are attracting increasing attention due to their potential advantages over solid PFC options, as highlighted in the 2015 PMI community workshop report.
- FES has commissioned the **Fusion Energy Systems Study (FESS)** team to examine this class of PFCs from a systems-level perspective in order to identify the most promising concepts and provide feedback on high-priority, high-leverage R&D on the path towards demonstrated viability.
- This two-year study, initiated in February of 2017, includes participation of **six national laboratories** and **five universities**.




**2015 community workshop on PMI**


PPPL PRINCETON PLASMA PHYSICS LABORATORY
INL Idaho National Laboratory
UC San Diego
Savannah River National Laboratory
UCLA
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON
PSFC
OAK RIDGE National Laboratory
Los Alamos NATIONAL LABORATORY
ILLINOIS

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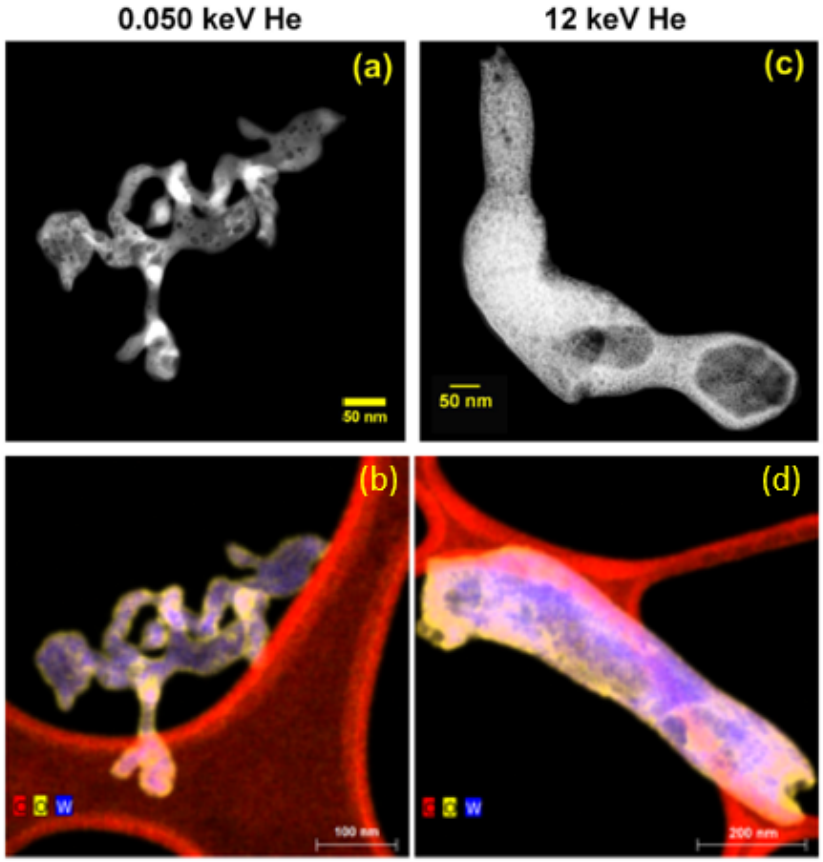
# Fusion Materials: Understanding the growth and structure of tungsten fuzz

- Scanning and transmission electron microscopy were used in conjunction with electron nano-crystallography to illuminate differences in tendril morphologies and bubble distributions in 50 eV and 12 keV helium-exposed tungsten.
- Tungsten exposed to both high and low energy helium bombardment showed qualitatively similar nano-tendril formation, but with different grain size and bubble distributions
- Determination of growth structures under these different plasma-exposure conditions will provide baseline information for modeling and help future materials engineering efforts to mitigate plasma-induced degradation.




STEM (a & c) and X-ray mapping (b & d) images comparing nano-tendril structure and elemental composition under varying growth conditions

OAK RIDGE National Laboratory

K. Wang, R.P. Doerner, M.J. Baldwin, F.W. Meyer, M.E. Bannister, A. Darbal, R. Stroud , C.M. Parish, Morphologies of tungsten nanotendrils grown under helium exposure, Scientific Reports, 7 (2017) 42315

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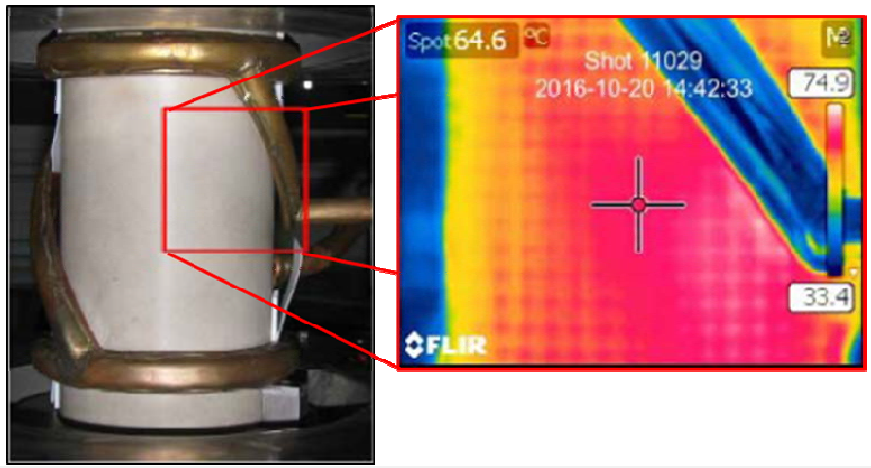
# Fusion Materials: Steady-state RF plasma generator development

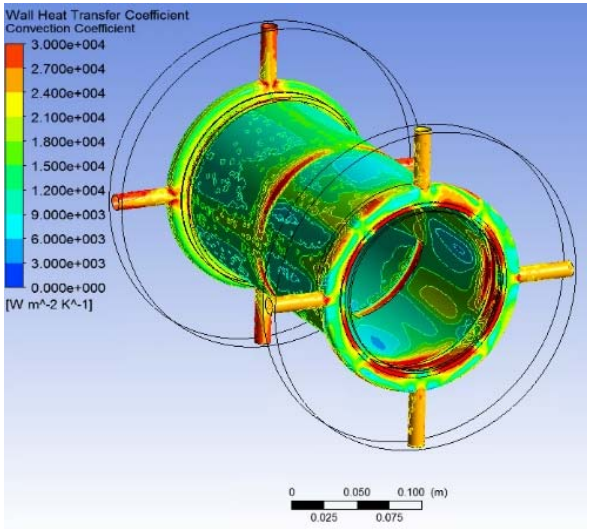
- USCD and ORNL are working in concert to develop a steady-state, high-power radio-frequency helicon plasma source to further PMI science.
- A prototype source based off this effort is currently being fabricated for testing in the CSDX plasma device located at the PISCES laboratory.
- Successful demonstration of this new source concept will open the pathway to the production of steady-state, divertor-like plasmas for reactor-relevant PMI and diverter plasma physics studies.

OAK RIDGE National Laboratory

UC San Diego




**RF source temperature distribution during short-pulse operation**




**Liquid-cooled RF source design**

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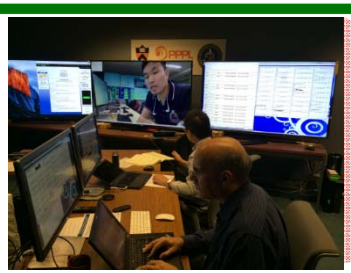
# U.S. remote control rooms enhance utilization of international & domestic research facilities






- U.S. teams at **GA** completed a week of experiments in FY 2017 during EAST third shift and can lead experiments at KSTAR
- **PPPL** and collaborators can lead experiments on KSTAR & connect to W7-X, DIII-D
- Remote control room at **MiT** is being designed, with assembly to commence in Spring FY 2018

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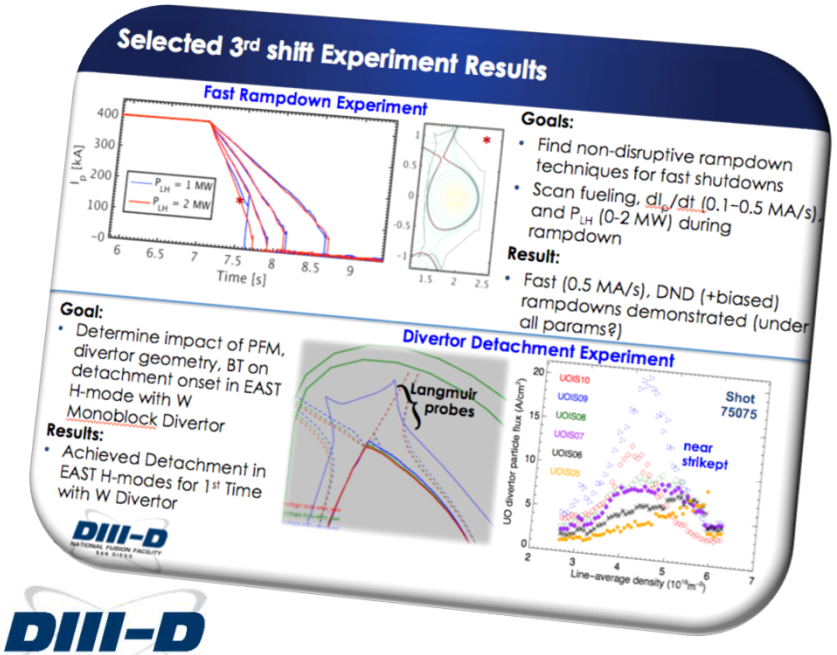
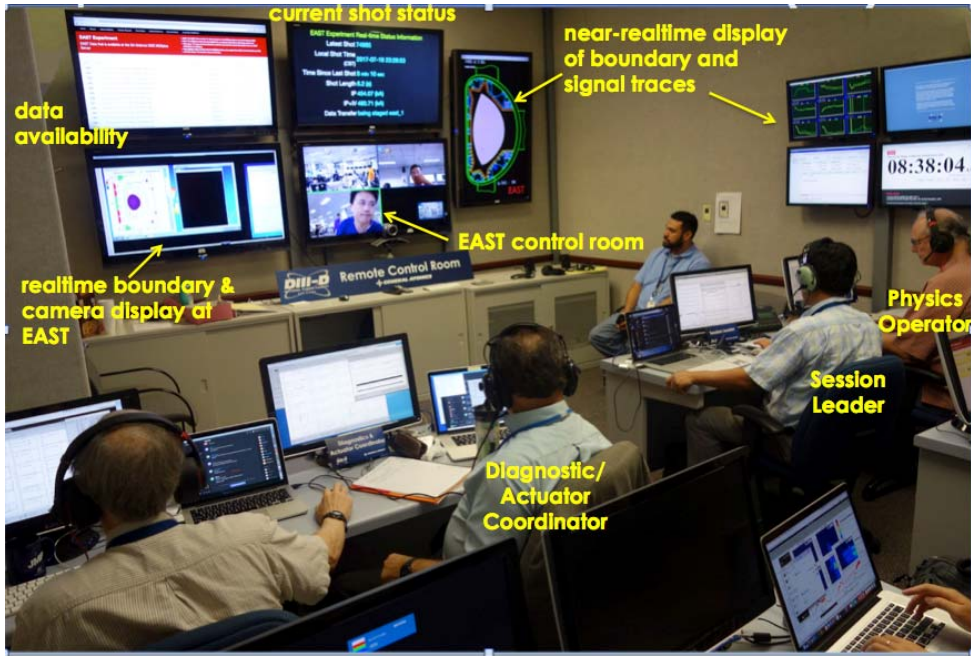
# Effective remote experiments demonstrated during EAST 3rd shift operation

**Scientific Achievements in 2017:**

- Remote technology challenges addressed (audio, data transfer)
- Four expt's carried out over 5 shifts (1 wk)
- New EAST capabilities demonstrated
  - Divertor detachment
  - Fast ramp-down without disruption




**Future Plans:**

- 2018: 2-3 weeks of 3rd shift ops
- 2019: 4-6 weeks of 3rd shift ops

**Issue:**

- ASIPP staff coverage for 11 pm–5 am shift
- Coordination of 3rd shift experiments & resources with daytime campaign

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

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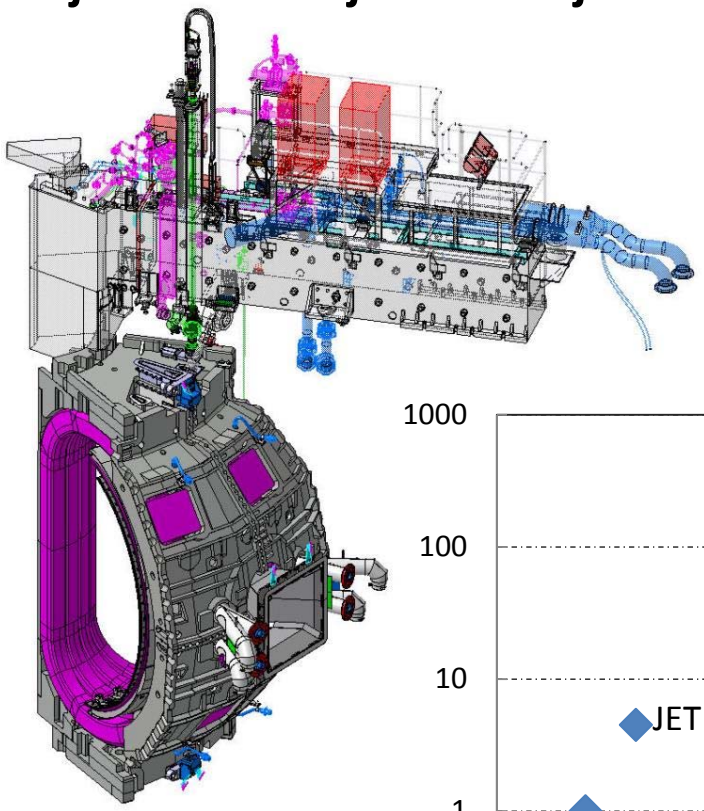
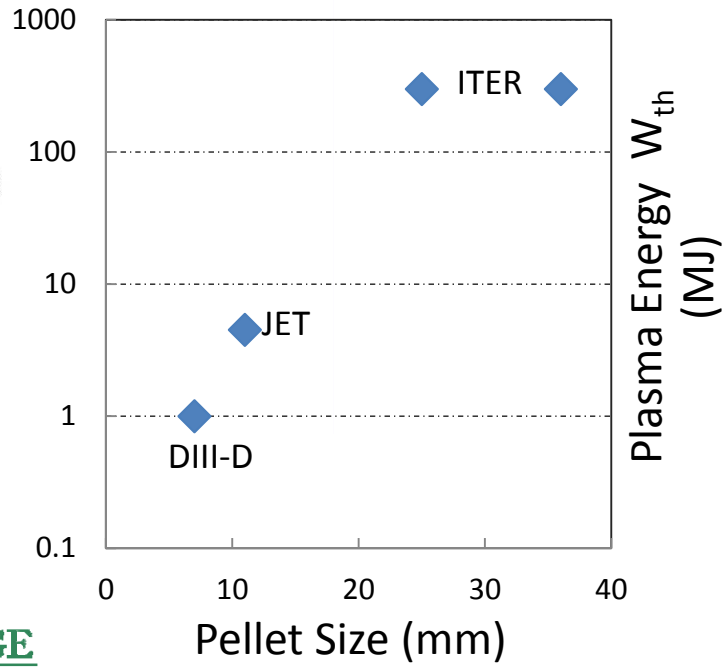
# Collaboration on JET shattered pellet injector informs ITER disruption mitigation requirements

## JET SPI has ITER-like 3-barrel injector and injection trajectory






## Status of U.S. Contributions

- D pellet injector from ORNL tested successfully
- Mechanical punch designed to dislodge high-Z pellets in the largest barrel works in the two smaller barrels, requires further development
- Cold zone for the large barrel may be reduced to achieve desired performance
- Ship to JET in November; install and check out systems by May 2018

***Large collaborative effort involves JET/EUROfusion, ORNL, USIPO, ITER Org, EC, and US DOE***

JET
OAK RIDGE National Laboratory

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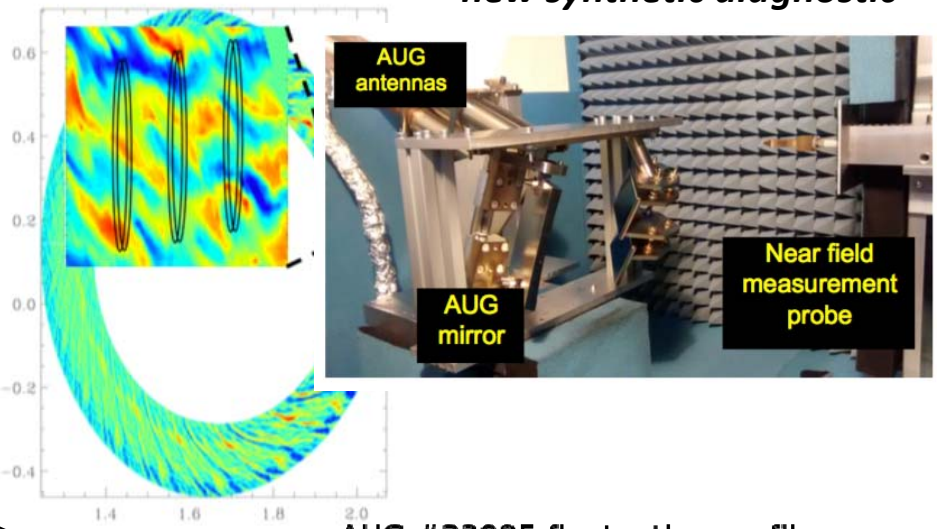
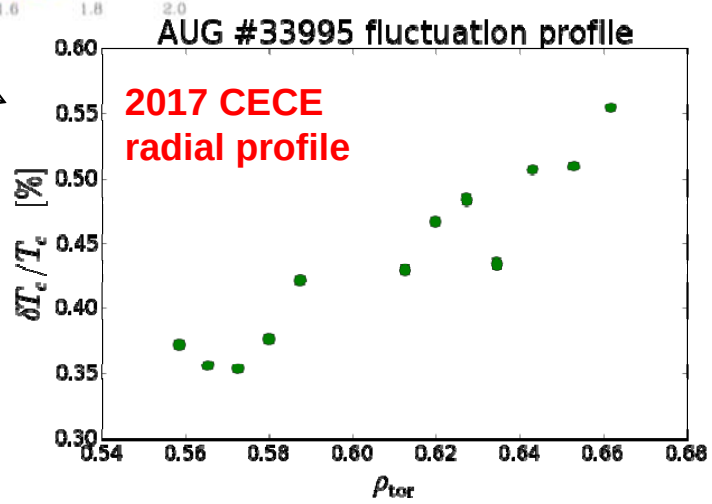
# New 30-channel CECE system at ASDEX-Upgrade commissioned in 2017

- Measurements of $\delta T_e/T_e$ profiles and frequency spectra in 2016 campaign (Freethy, RSI 2016)
- Transport-relevant fluctuations used to validate non-linear gyrokinetic (GENE) simulations (Freethy, EPS 2017)
- In 2017 – Greater flexibility and increased number of channels to allow finer $\delta T_e/T_e$ radial profiles (below) and radial correlation lengths
- CECE also coupled to reflectometer gives n-T cross-phase measurement: This is a strong constraint on turbulence simulations

**GENE simulation of perpendicular $T_e$ fluctuations + new antenna pattern measurements = *new synthetic diagnostic***



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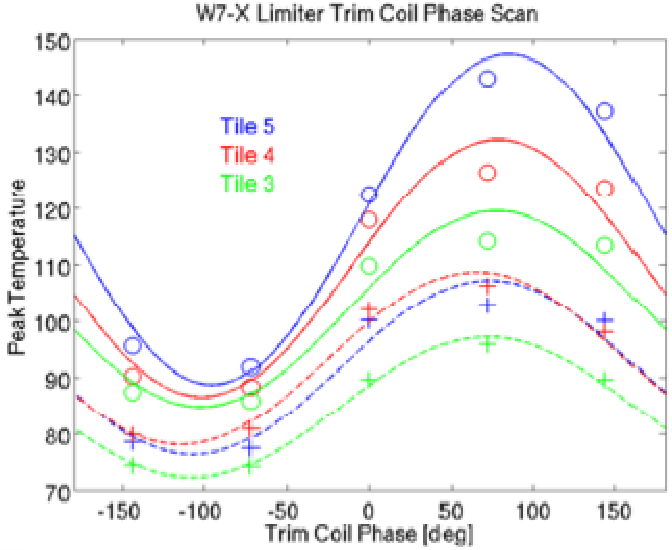
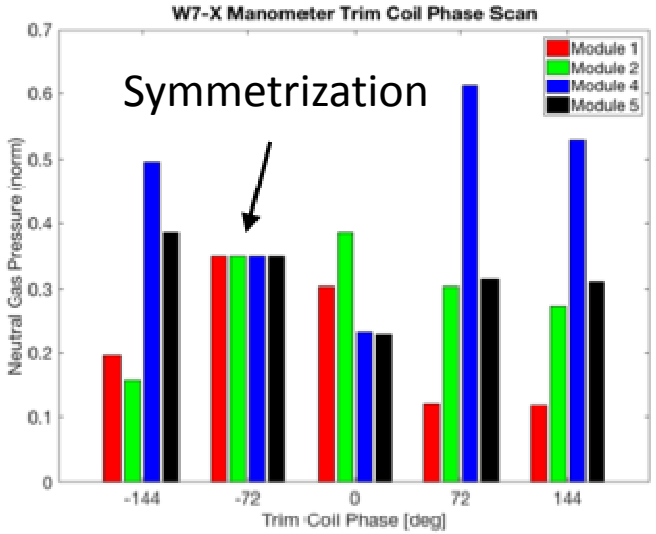
# US-provided magnetic field trim coils on W7-X are used to balance divertor heat load

- Heat load balance among the 10 divertors is sensitive to field errors
- First tests of heat load control with trim coils (carried out in OP1.1 limiter plasmas) demonstrates that the diagnostic/control approach is feasible




Limiter heat loads as measured by LANL infrared camera. Compensation phase agrees with phase measured by flux surface mapping.




Neutral pressure measurements showing pressure symmetry at error field compensation phase.


- M. Otte et al., PPCF 58, 064003 (2016)
- S. Lazerson et al., Nuclear Fusion (2016)
- T. S. Pedersen et al., Nature Comm. (2016)
- S. Lazerson et al., Nuclear Fusion (2017)
- S. Bozhekov et al., Nuclear Fusion (2017)

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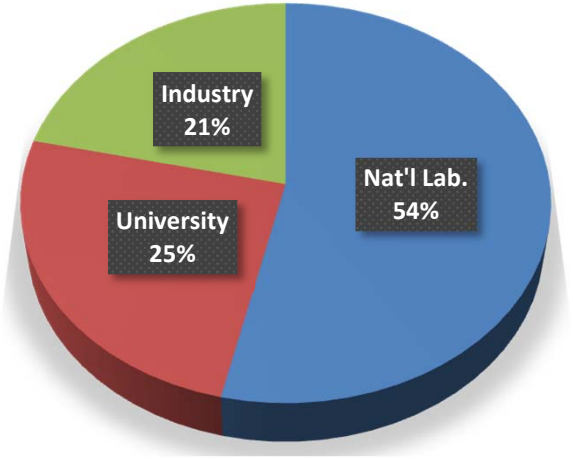
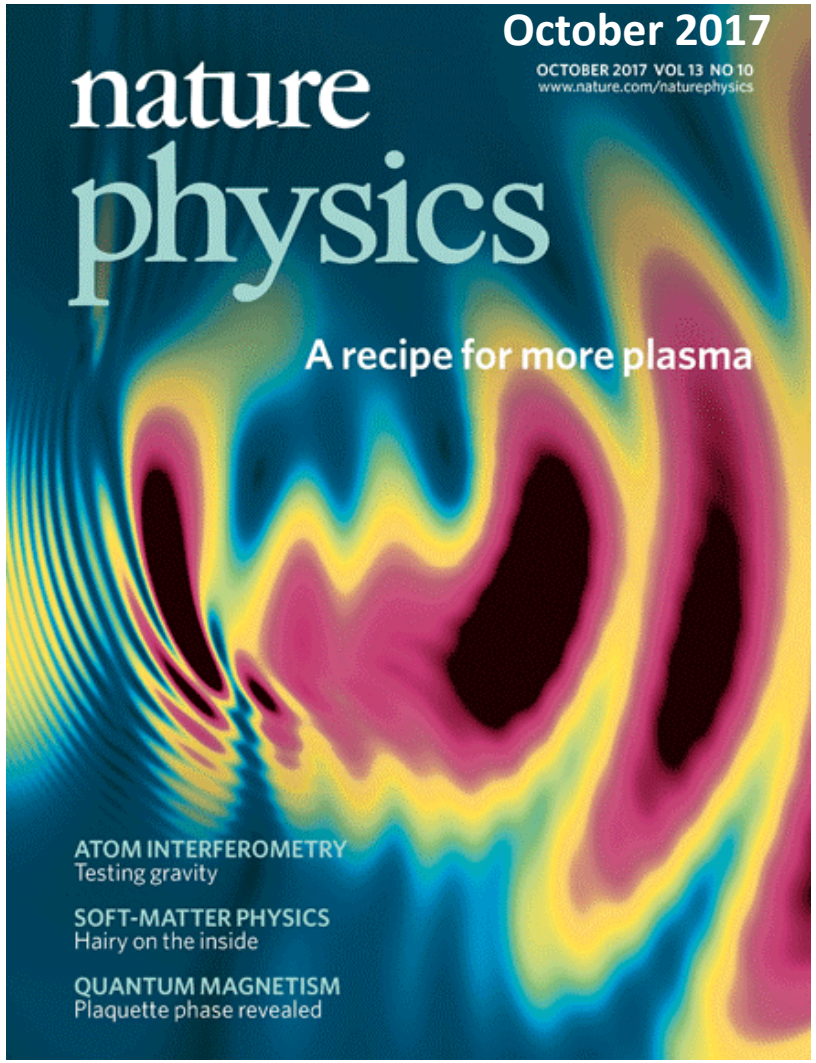
# U.S. collaborations on JET span the full range of R&D activities pursued by FES

- U.S. and EU facilities (TFTR and JET) performed first DT fusion experiments, preliminary to ITER project
- U.S. and EU continue to push fusion science forward, as evidenced by many high-impact publications
- U.S.-UK Science & Technology Agreement was signed Nov 21, 2017




**~30 U.S. activities on JET sorted by institution type**



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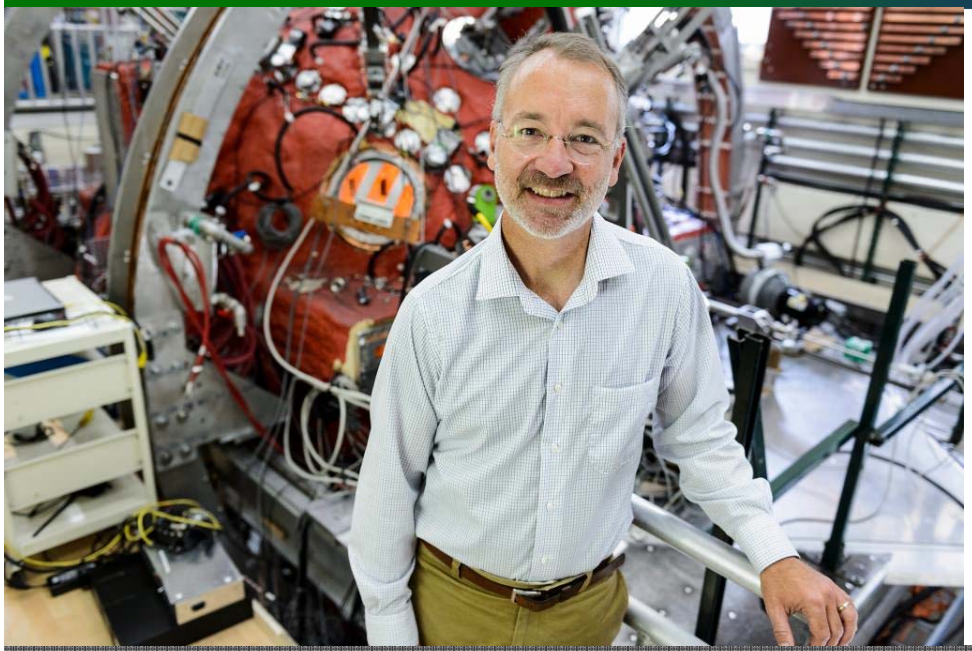
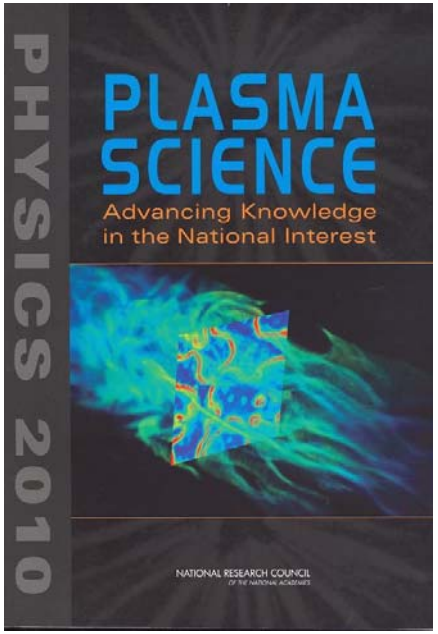
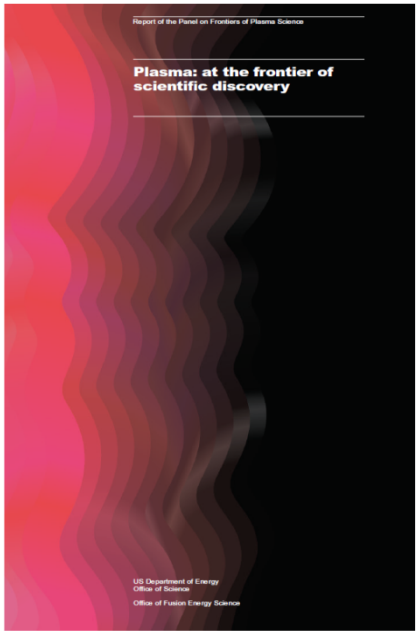
# A new intermediate-scale facility was awarded by FES for the first time in nearly two decades






The DOE Office of Fusion Energy Sciences has awarded $12.5 million FY17 funds over five years to the University of Wisconsin–Madison to develop an intermediate-scale, integrated, collaborative plasma science user facility that will expand the frontiers of plasma astrophysics. Two existing experiments, the Big Red Plasma Ball and the Madison Symmetric Torus, are combined into the new Wisconsin Plasma Physics Laboratory (WiPPL). The new project will join the expertise of more than two dozen UW–Madison scientists and technicians with outside plasma scientists, who will gain access to the facility and establish new collaboration.

"Several areas of basic plasma science would benefit from new intermediate-scale facilities."(2010 Decadal Study)

"There is a need for creation and exploration of new regimes in the laboratory." (2016 PSF Report)

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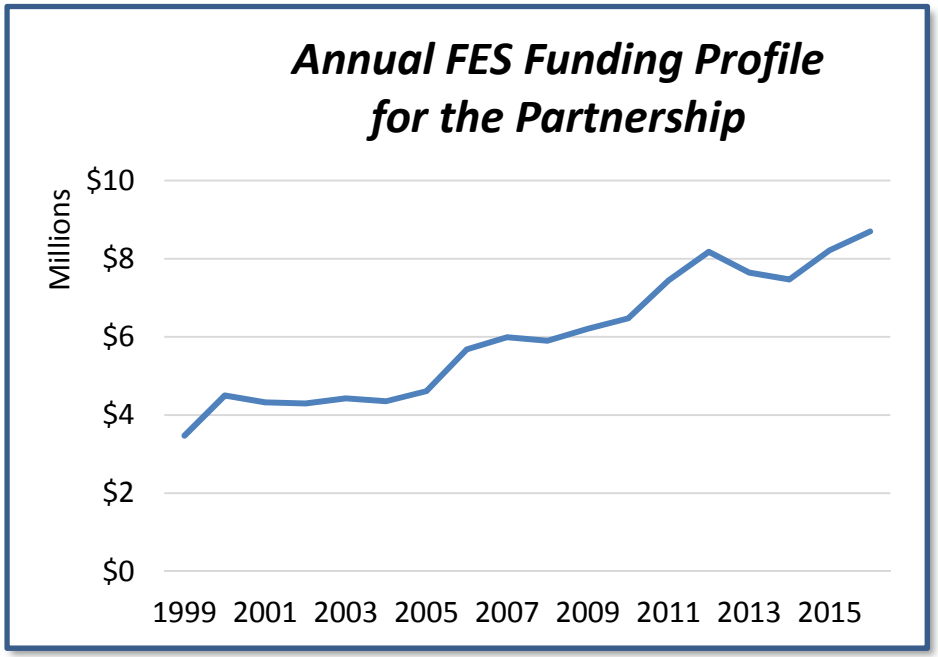
# 2017 workshop celebrated 20 years of NSF-DOE Partnership in basic plasma science


***Attendees at workshop (Jan 9-11, 2017)***




- The NSF/DOE Partnership is one of the longest-running interagency joint programs in the federal government.
- Main objective of original Memo of Understanding (1996) was to "provide enhanced opportunities for university-based research in fundamental processes in plasma science and engineering."
- DOE funding increased from $3.5M in 1999, to $8.7M in 2016. DOE provided additional funding in 2016 of $6.7M, which increased the award success rate to 28%.

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# MEC-enabled science at SLAC

You are here: SC Home » Programs » **FES Home**

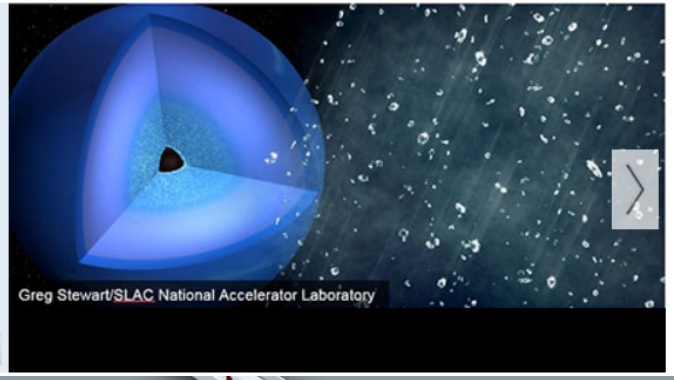
## Fusion Energy Sciences (FES)

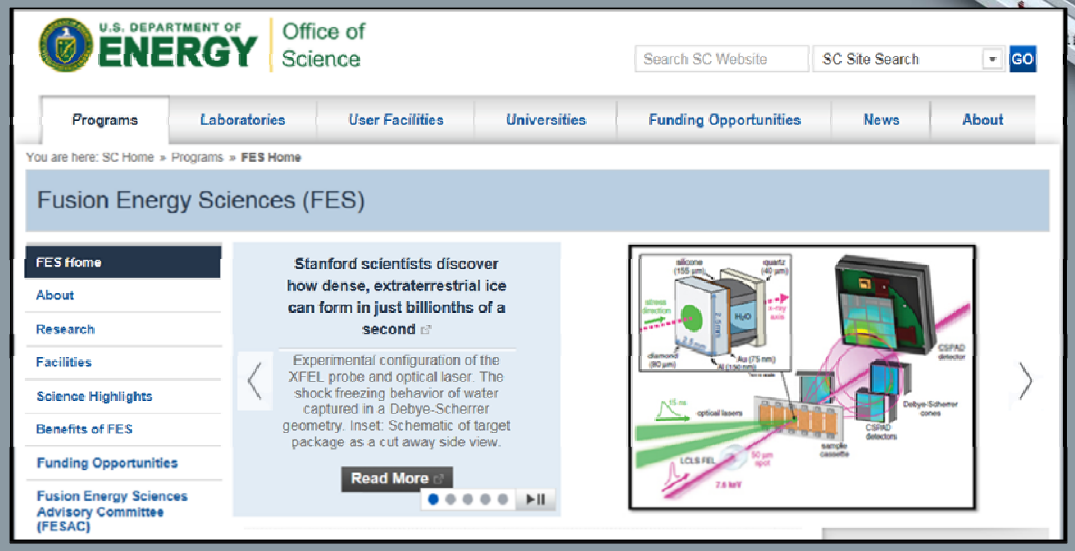
- **FES Home**
- About
- Research
- Facilities
- Science Highlights
- Benefits of FES
- Funding Opportunities
- Fusion Energy Sciences Advisory Committee

**Scientists Create 'Diamond Rain' That Forms in the Interior of Icy Giant Planets**

SLAC's X-ray laser and Matter in Extreme Conditions instrument allow researchers to examine the exotic precipitation in real time as it materializes in the laboratory.

Read More







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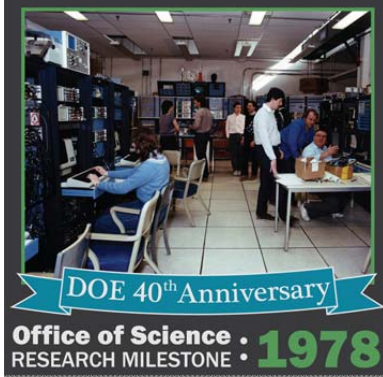
# DOE celebrates 40th anniversary

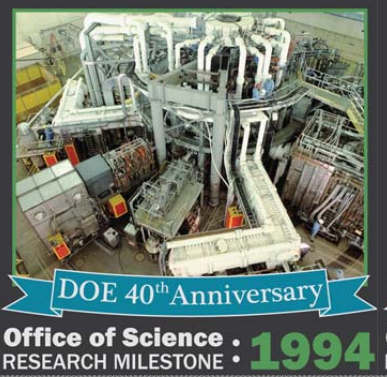




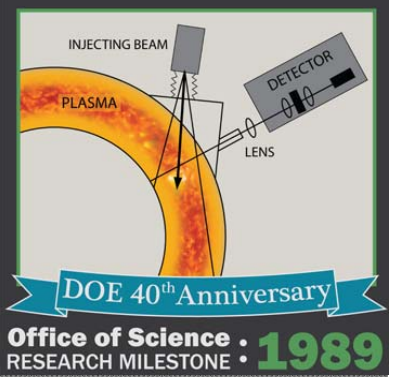

N.J. Fisch, PRL 41(13), 873 (1978)
Confining a tokamak plasma with rf-driven currents


G.B. Andresen et al., *Nature* 468, 673 (2010)
Trapped antihydrogen


R.J. Groebner et al., PRL 64, 3015 (1990)
Role of edge electric field and poloidal rotation in the L-H transition




J.D. Strachan et al., PRL 72, 3526 (1994)
Fusion power production from TFTR plasmas fueled with deuterium and tritium




F.M. Levinton et al., PRL 63, 2060 (1989)
Magnetic field pitch-angle measurements in the PBX-M tokamak using the motional Stark effect

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# Current community input / workshops

**In FY 2017, the community had several opportunities to provide input to various planning activities:**

- **FESAC subcommittee** to identify the most promising **transformative enabling capabilities** for the U.S. to pursue that could promote efficient advance towards fusion energy, building on burning plasma science and technology
  - Report will be available soon and will be discussed at **the next FESAC meeting (Feb 1-2, 2018)**
- **National Academy of Sciences (NAS) Burning Plasma Study**:
  - Two community workshops on magnetic fusion research strategic directions in order to provide input to NAS:
    - July 24-28, at the University of Wisconsin-Madison
    - December 11-15, at The University of Texas at Austin
  - Meetings organized by NAS:
    - June 5-6, 2017, at Washington, DC
    - August 29-31, 2017, at Irvine, CA
    - December 15-16, 2017 at Austin, TX (following the community workshop)
    - February 26-28, 2018, in San Diego, CA

**In FY 2018, the 2020 Plasma Science Decadal Survey will be launched**

- Charge and Statement of Task have been finalized
- NAS submitted a proposal to FES, which is under review
- The Decadal Survey will be carried out over 24 months

# 3. ITER Updates

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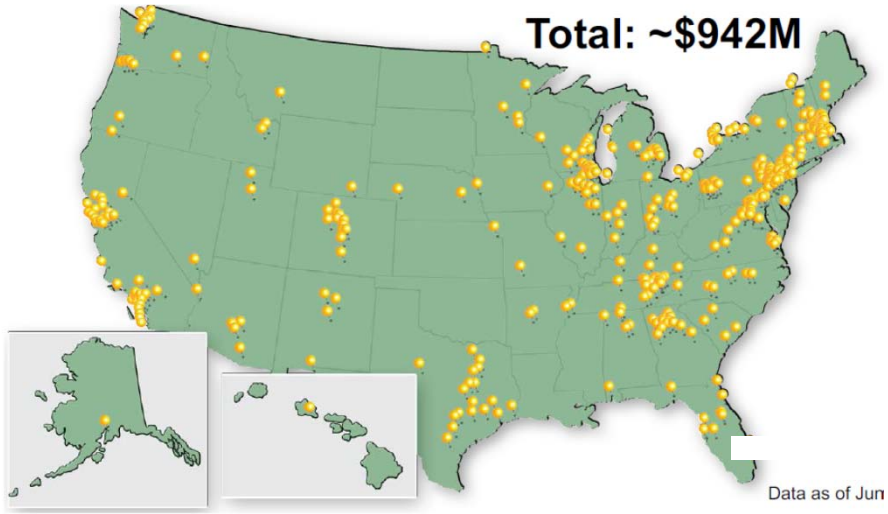
# Progress of U.S. ITER project

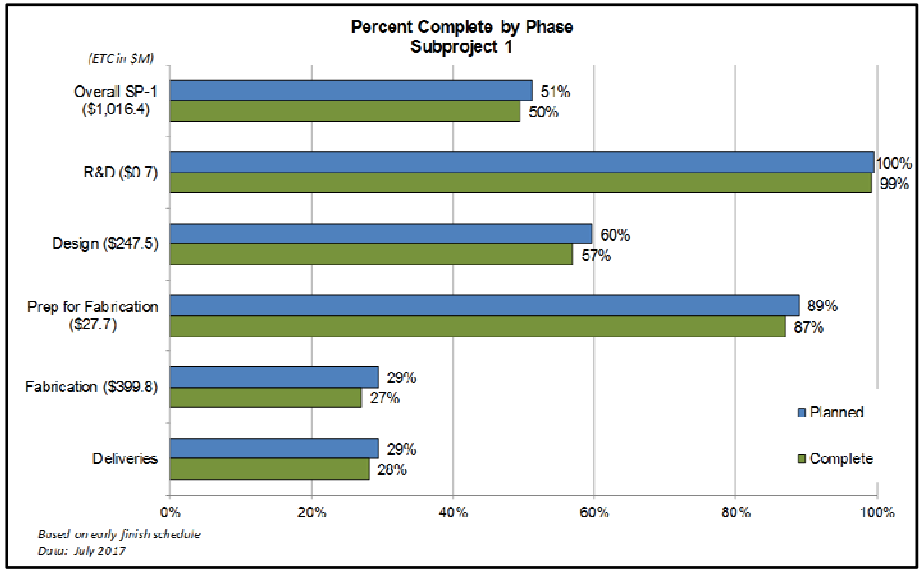
**80% of fabrication awards for U.S. ITER project remain in the U.S.**

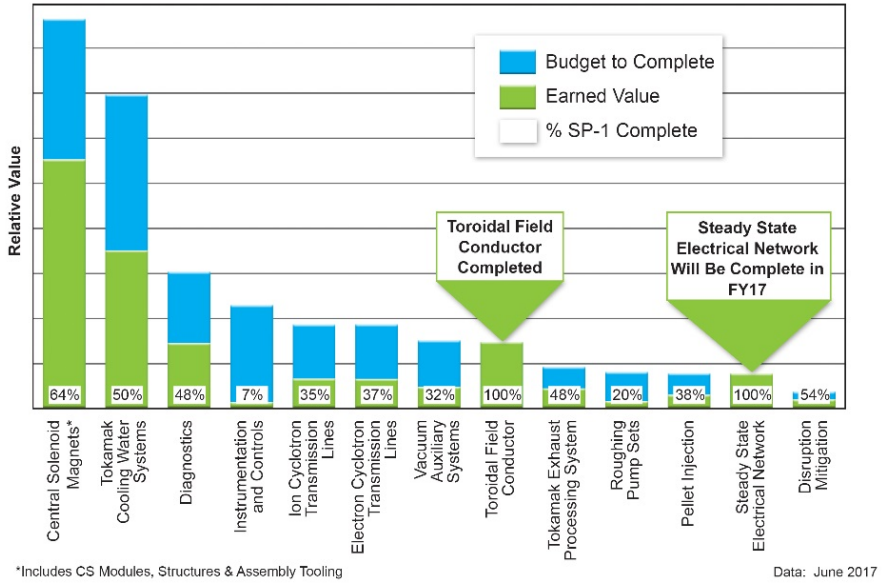
- 600+ contracts to U.S. industry, universities, and national laboratories in 44 states
- 500+ direct jobs, 1100+ indirect jobs per year




Data as of June 30, 2017

**U.S. ITER Subproject-1 (First Plasma) is 50% done**



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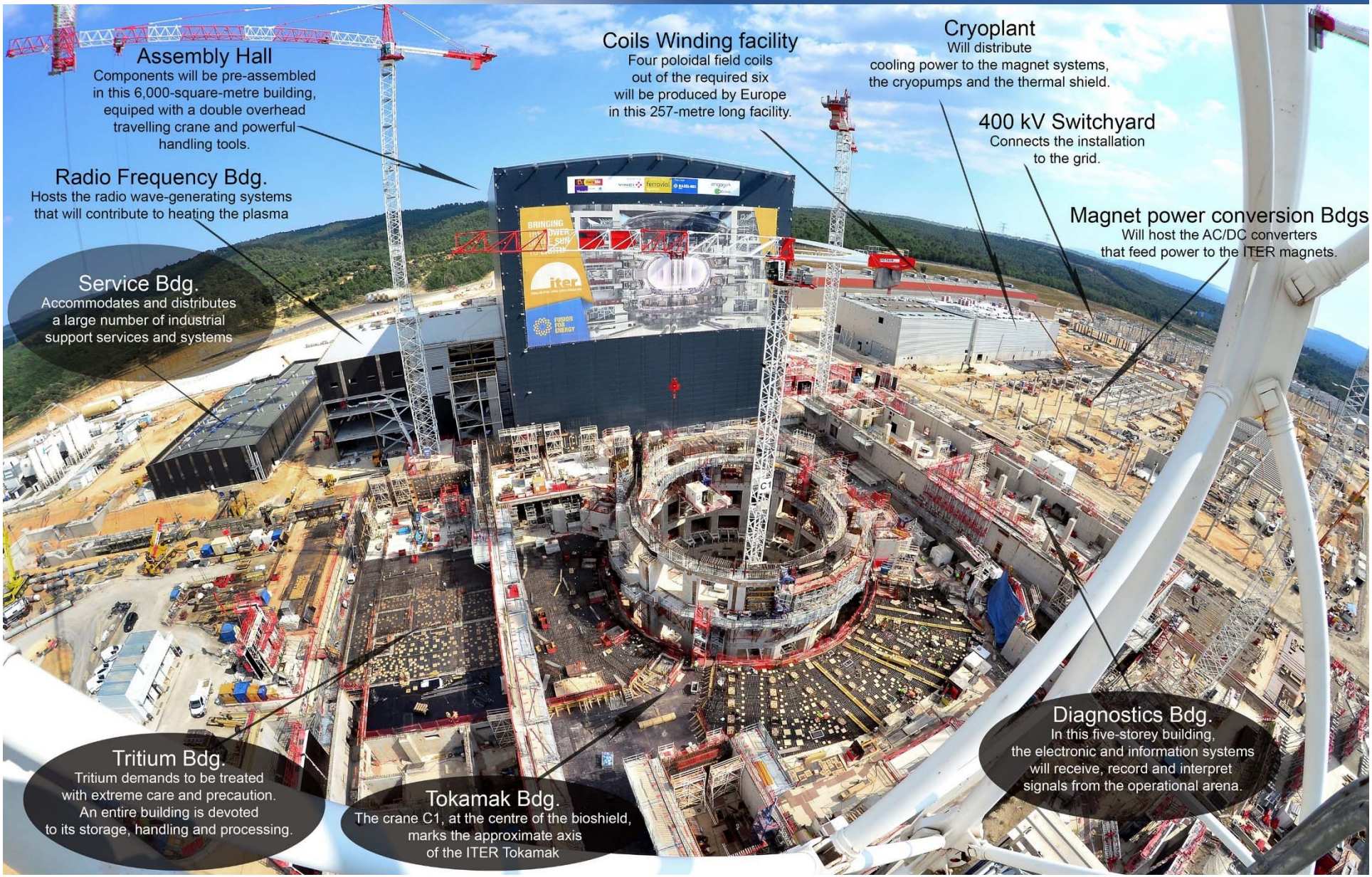
# Current status of ITER complex



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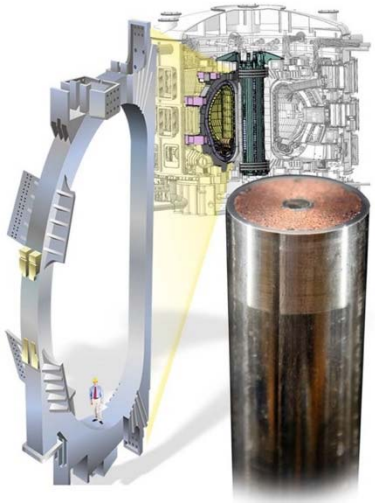
# Examples of U.S. hardware for ITER

*Piping fabrication in the U.S. for the Tokamak Cooling Water System at Schulz Xtruded Products in Robinsonville, MS*

*Central Solenoid Module 1 after completing heat treatment at General Atomics Poway, CA facility*

*U.S. completed Central Solenoid Assembly Structure*



*U.S. Toroidal Field Conductor fabrication completed and shipped to EU winding facility*

*U.S. completed delivery of Steady State Electrical Network to the ITER site*

# 4. People

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# DOE leadership updates

Mr. **Dan Brouillette** was sworn in as the Deputy Secretary of the U.S. Department of Energy on August 7, 2017

Mr. **Paul Dabbar** was sworn in as Undersecretary for Science on November 7, 2017

Dr. **J. Stephen Binkley** continues as the Deputy Director for Science Programs, Office of Science

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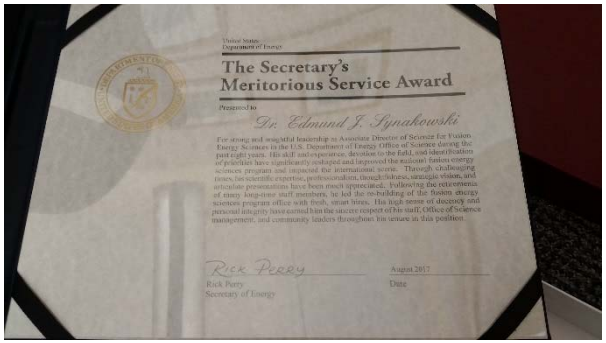
# FES personnel changes

- **Ed Synakowski**, FES Associate Director since 2009, left federal service in August 2017 to join the University of Wyoming as the VP for Research & Economic Development
- **Jim Van Dam** is the Acting Associate Director for FES
- **John Mandrekas** is the Acting FES Research Division Director


## Other transitions:

Sean Finnegan left FES to join NNSA

Long-time FES program managers Steve Eckstrand, Al Opdenaker, and Francis Thio retired