Office of Fusion Energy Sciences
Program Overview

University Fusion Association Meeting
Philadelphia, Pennsylvania

Dr. Stephen Eckstrand
Research Division
Office of Fusion Energy Sciences
October 30, 2006

www.science.doe.gov/ofes
U.S. Fusion Energy Sciences Program Mission

Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels a star, thereby enabling a landmark scientific achievement--bringing fusion power to the U.S. electric grid by the middle of this century.

• Establish the scientific and technological feasibility of fusion energy through the study of burning plasmas.
• Develop a fundamental understanding of plasma behavior sufficient to provide a reliable predictive capability for fusion energy systems.
• Determine the most promising approaches and configurations to confining hot plasmas for practical fusion energy systems.
• Develop the new materials, components, and technologies necessary to make fusion energy a reality.
FY 2006 Has Been a Year of Remarkable Progress

• Major progress on ITER agreement
  – Representatives from the seven ITER parties initialed the agreement in May
  – Kaname Ikeda named the Director General Nominee, and Norbert Holtcamp named the Principal Deputy Director General Nominee

• Significant scientific progress

• Improving budget outlook as a result of the American Competitiveness Initiative
Fusion Energy Sciences Priorities

• Fully support ITER Construction

• Continue to develop burning plasma physics and technology and prepare for ITER operation

• Take advantage of opportunities for collaboration on unique international facilities

• Conduct research to define facilities beyond ITER

• Continue stewardship of plasma science
The ITER Signing will Mark a New Era for the World Fusion Program

- ITER will be the world’s first experiment capable of sustaining burning plasmas
  - Most plasma heating provided by the internal fusion process
  - Goals: 500 MW produced for 500 seconds, Power gain of 10

- Seven ITER parties represent over half of the world’s population
  - China, European Union, India, Japan, Russia, South Korea, and United States

- ITER Agreement establishes a 35 year program of construction, operation, deactivation and decommissioning
  - Operations begin ~2015

- Well-integrated with world-wide fusion development program
  - Will provide experimental results and validated suite of codes for design of demonstration power plant
U. S. ITER Progress in FY 2006

U.S. ITER Project Accomplishments

• Completion of appointments of key management staff of the USIPO including Work Breakdown Structure (WBS) Managers responsible for the U.S. procurement allocations

• Revision of project documentation (preliminary cost, schedule ranges, acquisition strategy, etc.) in preparation for project cost reviews

• Planning, interaction and coordination with the International ITER Organization on all project activities including the upcoming international design review, nomination of potential seconded staff urgently needed by the ITER Organization, determination and discussion about fulfillment of the FY2006/FY2007 task assignments

• Planning for and aggressive participation in specific seven-partner international technical and operational Working Group meetings (through Fall).

• Completed first cash contributions made to the ITER organization on August 31, 2006, transferring $528,918 dollars or 409,000 euros.
2006 U.S. “in-kind contribution” scopes

- 7 Central Solenoid windings
- 8% of Toroidal Field conductor
- 15% of port-based diagnostics
- all Ion Cycl. transmission lines
- all Electron Cyclotron Transmission Lines
- Blanket/Shield 20%
- Roughing pumps, standard components
- Steady-state power supplies
- Tokamak exhaust processing system
- pellet injector
- 75% Cooling for divertor, vacuum vessel, ...
ITER Funding Profile Budget
(dollars in thousands – in as spent dollars)

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Total Estimated Costs</th>
<th>Other Project Costs</th>
<th>Total Project Costs</th>
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<tr>
<td>2006</td>
<td>15,866</td>
<td>3,449</td>
<td>19,315</td>
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<td>2007</td>
<td>37,000</td>
<td>23,000</td>
<td>60,000</td>
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<td>2008</td>
<td>149,500</td>
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<td>2009</td>
<td>208,500</td>
<td>6,000</td>
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<tr>
<td>2010</td>
<td>208,500</td>
<td>821</td>
<td>209,321</td>
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<td>2011</td>
<td>181,964</td>
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<tr>
<td>2012</td>
<td>130,000</td>
<td>0</td>
<td>130,000</td>
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<tr>
<td>2013</td>
<td>116,900</td>
<td>0</td>
<td>116,900</td>
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<tr>
<td>2014*</td>
<td>30,000</td>
<td>0</td>
<td>30,000</td>
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<td>TOTAL</td>
<td>1,078,230</td>
<td>43,770</td>
<td>1,122,000</td>
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</table>

*The estimated TPC is based on project completion in 2014. The international ITER Organization recently announced a schedule indicating a 2015 project completion and first plasma in 2016. The international and domestic project schedule will be more firm at CD-2, and the estimate remains preliminary until the baseline is established at CD-2.
Roles of U.S. organizations in ITER

- **OFES** in the Office of Science of the U.S. Department of Energy is the funding and management entity for the US ITER activities.

- **The U.S. ITER Project Office (USIPO)** at ORNL manages the U.S. Contributions to ITER (hardware, personnel and cash)
  - Ned Sauthoff of ORNL is the USIPO Director

- **The U.S. Burning Plasma Organization (USBPO)** coordinates the physics and technology R&D programs in the OFES Program to prepare for and participate in the ITER scientific program
  - Ray Fonck of Univ. of Wisconsin is the USBPO Director and serves as the Chief Scientist for USIPO

- **The Virtual Laboratory for Technology** manages the diverse and distributed collection of technology R&D activities
  - Stan Milora of ORNL is the VLT Director and serves as the Chief Technologist for USIPO

- **USIPO, USBPO, and VLT** work together for the success of US contributions to ITER
U.S. ITER Project Office
(U.S. Domestic Agency)

US ITER Advisory Board

US ITER Technical Advisory Committee

U.S. ITER Project
N. Sauthoff
Project Manager
- Deputy Project Manager
- Engineering Manager
- Procurement Manager
- Project Controls Manager
- ESH&Q Manager

C. Strawbridge
B. Nelson
J. Geouque
S. Herron
TBD

Project Office
C. Strawbridge

Magnet Systems
- J. Miller
  WBS Team Leader

Cooling Water Systems
- J. Berry
  WBS Team Leader

Electric Power Systems
- C. Neumeyer
  WBS Team Leader

Diagnostics
- D. Johnson
  WBS Team Leader

Support to the ITER International Team
- J. Hill
  WBS Team Leader

Blanket Shielding Systems, Port Limiter Systems
- M. Hechler
  WBS Team Leader

Vacuum Pumping & Fueling, ICH Systems, ECH
- D. Rasmussen
  WBS Team Leader

Tritium Plant Exhaust Processing
- D. Green
  WBS Team Leader

Project Support
- S. Herron
  WBS Team Leader

Chief Scientist
(Director of US Burning Plasma Organization)
Provides scientific support from the OFES base program

Chief Technologist
(Director of Virtual Laboratory for Technology)
Provides technology support from the OFES base program
U.S. Burning Plasma Organization
Comprised of 3 Elements

Entry: Join Topical Groups of Interest

[Implementation: Working Groups]
U.S. BPO: Help Apply Community Activities & Expertise to BP-Relevant Issues

**USBPO Campaigns, Tasks (E.G.)**

- Diagnostics
- Pedestal
- Tritium Retention
- Disruption Mitigation
- RWM
- BP Planning
- Alternates’ Implications
- ETC…

Problems to Address….

**Knowledge Base & Capabilities**

- Burning Plasma Regime
  - Long-Pulse
  - Alpha Particles
  - Self-Heated Exothermic
- Large Scale
- Strong Couplings
- Plasma and Engineering Science Topical Areas
  - Macroscopic Stability
  - Wave-Plasma Interactions
  - Transport & Confinement
  - Energetic Particles
  - Plasma-Boundary Interfaces
  - Integrated Scenarios
  - Technology
  - Diagnostics
  - Simulation & Modeling
  - Operations, Control
USBPO Recent Activities

• Held U.S. Burning Plasma Workshop at ORNL in December 2005

• Prepared a plan for Congress on
  - Planning for U.S. Fusion Community Participation in ITER

• Developed ITER Physics Tasks and ITER Design Issue Cards

• USBPO has close interaction with the U.S. members of ITPA
US Burning Plasma Organization
Directorate (http://burningplasma.org)

- Director: Prof. Ray Fonck, U of Wisc;
- Deputy Director: Dr. Tony Taylor, GA

- Research Committee:

  Steve Allen --------- LLNL  Jon Menard --------- PPPL
  Don Batchelor ------ ORNL  Raffi Nazikian ------- PPPL
  Rejean Boivin ------ GA  Richard Nygren ------- SNL
  Ed Doyle -------- UCLA  Cynthia Phillips ------- PPPL
  Ray Fonck -------- USBPO  Tom Rognlien ------- LLNL
  Dave Gates ------- PPPL  Tony Taylor ------- USBPO
  Chuck Greenfield ---- GA  Jim Terry --------- MIT
  Chris Hegna ------- UWISC  Paul Terry ------- UWISC
  Bill Heidbrink ------ UCI  Nermin Uckan ------- ORNL
  Dave Humphreys ---- GA  Dennis Whyte ------- UWISC
  Chuck Kessel ------- PPPL  Steve Wukitch ------ MIT
  Jon Kinsey -------- GA
US Burning Plasma Organization Council
(Community Governance)

– Chair: Prof. Jim Van Dam, U of Texas
– Co-Chair: Dr. Amanda Hubbard, MIT

– Council members;

Steven L. Allen ___ LLNL ___ allens@fusion.gat.com
Steve Cowley ___ UCLA ___ cowley@physics.ucla.edu
Raymond Fonck ___ UWisc ___ fonck@burningplasma.org
Richard J. Hawryluk ___ PPPL ___ rstawryluk@pppl.gov
Amanda Hubbard ___ MIT ___ hubbard@psfc.mit.edu
Earl Marmar ___ MIT ___ marmar@psfc.mit.edu
Stanley L. Milora ___ ORNL ___ milorasl@ornl.gov
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George Tynan ___ UCSD ___ gtyman@ucsd.edu
James Van Dam ___ UTexas ___ vandam@physics.utexas.edu
Michael Zarnstorff ___ PPPL ___ mzarnstorff@pppl.gov
Today’s Fusion Tokamaks Are Making Important Contributions to ITER

**DIII-D** completed system upgrades and modifications in 2006 and began research in ITER-relevant low rotation regimes using balanced (co- and counter-current) neutral beam injection. Demonstrated that the threshold for rotational stabilization of the RWM using this method of slowing rotation is much lower than previously attained with magnetic braking techniques.

**Alcator C-Mod** researchers successfully coupled ~850 kilowatts of RF power at the lower hybrid frequency to a 1 MA plasma and sustained nearly all of the current for one profile relaxation time. These results are in agreement with theoretical calculations and imply that lower hybrid power could be used for current profile control in ITER.

**NSTX** scientists used a set of six non-axisymmetric feedback coils and improved equilibrium coils to carry out studies of error field reduction, plasma rotation control, and active resistive wall mode control in high performance plasmas. They were able to control the resistive wall mode successfully at high normalized pressure at ITER relevant rotation for a plasma skin time.

**Joint ITPA experiments** on DIII-D, C-MOD, NSTX, the European tokamaks JET and ASDEX-UG, and the Japanese tokamak JT-60U are investigating the scaling of energy confinement time with plasma pressure in ITER relevant plasmas.
Education at the Fusion Science Centers

The Center for Extreme States of Matter and Fast Ignition Physics 2005 summer school in high energy density physics at the University of California at Berkeley

• 96 undergraduate and graduate students, post docs attended six days of lectures
• 96 undergraduate and graduate students, post docs, and research scientists attended a wide range of lectures on high energy density plasma physics

The Center for Multiscale Plasma Dynamics and The Center for Magnetic Self-Organization 2006 winter school on the Physics of Magnetic Reconnection at UCLA

• Over 50 graduate students and post docs attended six days of lectures
• Second winter school on Plasma Turbulence and Transport: Commonalities between Lab, Space and Astrophysics in January 2007

Two dimensional PIC simulation of electron generation and transport in fast ignition.
Fusion Energy Sciences Funding
(FY 2007 $ in Millions)
## FY 2008 Fusion Energy Sciences OMB Budget Request

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<thead>
<tr>
<th></th>
<th>FY 2006</th>
<th>FY 2007</th>
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<tr>
<td></td>
<td>July</td>
<td>Cong</td>
</tr>
<tr>
<td>Science</td>
<td>148.4</td>
<td>154.2</td>
</tr>
<tr>
<td>Facility Operations</td>
<td>104.5</td>
<td>121.6</td>
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<tr>
<td>Enabling R&amp;D</td>
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<td>43.2</td>
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<td><strong>OFES Total</strong></td>
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<td><strong>319.0</strong></td>
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<td>DIII-D</td>
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<td>C-Mod</td>
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<td>22.8</td>
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<tr>
<td>NSTX</td>
<td>34.2</td>
<td>35.1</td>
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<tr>
<td>NCSX</td>
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<td>16.6</td>
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<tr>
<td>ITER</td>
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<tr>
<td>Non-ITER</td>
<td>256.1</td>
<td>259.0</td>
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# Fusion Energy Sciences

($ in thousands)

## Science

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<th>Science</th>
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<td>DIII-D Research</td>
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<td>NSTX Research</td>
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<td>Experimental Plasma Research</td>
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<td>MST Research</td>
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<td>NCSX Research</td>
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<td>Theory</td>
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<td>Advanced Computing/SciDAC</td>
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<td>General Plasma Science</td>
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## Enabling R&D

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## Total Fusion Energy Sciences

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<td>Alcator C-Mod</td>
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<td>NSTX</td>
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<td>ITER (Preparations, OPC &amp; MIE)</td>
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## Facility Operation

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<td>Alcator C-Mod</td>
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<tr>
<td>NSTX</td>
<td>18,681</td>
<td>18,422</td>
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<td>NCSX</td>
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<td><strong>7/14/11</strong></td>
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<tr>
<td>GPP, GPE, Other</td>
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<td>ITER Preparations</td>
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<td><strong>Facility Operations Total</strong></td>
<td><strong>104,460</strong></td>
<td><strong>121,555</strong></td>
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Fusion Energy Sciences Budget
($ in Millions)

FES FY 2006 July Fin Plan Distribution

- Tokamak: $85.4
- Theory: $24.9
- Enabling R&D: $24.3
- Alternates: $95.3
- SciDAC: $4.2
- GPS: $14.2
- Other: $7.8

Total: $280.7 M

FES FY 2007 Congressional Budget

- Tokamak: $88.4
- Theory: $23.9
- Enabling R&D: $20.2
- Alternates: $90.6
- SciDAC: $7.0
- GPS: $14.0
- Other: $14.9

Total: $319.0 M
Fusion Energy Sciences Funding Distribution

FY 2007 Request
$319.0M

Institution Types

- Laboratory: 55.0%
- Industry: 19.3%
- Universities: 23.2%
- Other*: 2.4%

Functions

- ITER Direct: 18.8%
- Facility Operations+: 26.5%
- Technology: 6.3%
- SBIR/STTR: 2.3%
- Science: 46.1%

*NSF/NIST/NAS/AF/Undesignated funds
+Includes NCSX Project
ITER MIE Funding for FY07

Distribution of Funding
Total of $60.0M in FY07

- **Design/R&D/Mgmt** $47.5M
  - Magnet
  - First wall shields
  - Cooling water systems
  - Roughing pump
  - Pellet injector
  - Exhaust Processing
  - ICH transmission line
  - ECH transmission line
  - Diagnostics
  - Project management

- **ITER Organization (IO)**
  - Employees and Secondees $6.0M

- **Cash to IO** $5.0M

- **Hardware Commitments** $1.5M
  - Toroidal field coil conductor
  - Diagnostic Components

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FY 2007 Performance Targets

Science

- In FY 2007, FES will measure and identify magnetic modes on NSTX that are driven by energetic ions traveling faster than the speed of magnetic perturbations (Alfvén speed); such modes are expected in burning plasmas such as ITER.

- In FY 2007, improve the simulation resolution of linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal modes used to 15.

Facility Operations

- Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.

- Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%.
Ten Year Goals for Fusion Energy Sciences*

- **Predictive Capability for Burning Plasma**: Progress toward developing a predictive capability for key aspects of burning plasmas using advances in theory and simulation benchmarked against a comprehensive experimental database of stability, transport, wave-particle interaction, and edge effects (2015)

- **Configuration Optimization**: Progress toward demonstrating enhanced fundamental understanding of magnetic confinement and improved basis for future burning plasma experiments through research on magnetic confinement configuration optimization (2015)

- **High Energy Density Plasma Physics**: Progress toward developing the fundamental understanding and predictability of high energy density plasma physics (2015)

*FESAC is evaluating progress against these present goals, but these goals may be changed based on a long-range planning activity to be carried out under the leadership of the new Associate Director for Fusion Energy Sciences*
Letter to FESAC Concerning the Charge to Examine Program Evolution

- Original Charge February 27, 2006
  - Examine program evolution over the coming decade
  - Identify goals, scope, deliverables, schedules, and time frames
  - Report due February 2007

- Letter From Dr. Orbach to FESAC Chair dated July 18, 2006
  - Imminent signing of ITER agreement will affect fusion research for many years
  - “… it is extremely important that the new Associate Director for the Fusion Energy Sciences (FES) program have the opportunity to provide input on all … aspects of this activity…”
  - “… we need to have a planning horizon that coincides with a significant part of [the ITER lifetime]. Therefore, I would suggest that the planning horizon be 20-25 rather than the ten-year period as asked for in the original charge letter.”
  - “With regard to the other aspects of this planning activity … I would like to wait until the new AD comes on board … before providing any other input. …I would strongly suggest that you delay any decision on the format of community input, such as a Snowmass-type meeting until further guidance is received,”
OFES Management Transitions

- Anne Davies (Associate Director for Fusion), John Willis (Director of Research Division), Michael Roberts (Director of ITER and International Division), and Warren Marton (U.S. ITER Program Manager) have retired during the past 18 months.

- A new Associate Director is expected to be on board in December.

- Dr. Jim Decker will remain Acting Associate Director until the new AD is officially on board.

- Gene Nardella and Steve Eckstrand are sharing (2 month rotation) the position of the Acting Director of Research Division.

- Erol Oktay is the Acting Director of ITER and International Division.

- Jeff Hoy has been selected as the U.S. ITER Program Manager.