Burning Plasma Technologies

Stan Milora, ORNL
Director, Virtual Laboratory for Technology

U.S. Burning Plasma Workshop
Oak Ridge
December 7-9, 2005
The Technology Program is a multi-institutional national resource
To contribute to the national science and technology base by 1) developing the enabling technology for existing and next-step experimental devices, by 2) exploring and understanding key materials and technology feasibility issues for attractive fusion power sources, by 3) conducting advanced design studies that integrate the wealth of our understanding to guide R&D priorities and by developing design solutions for next-step and future devices.
The VLT is the repository of burning plasma technology expertise.

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<th>Program Element</th>
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<td>Magnets</td>
<td>J. Minervini - MIT</td>
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<td>PFC</td>
<td>M. Ulrickson - SNL</td>
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<td>Chamber</td>
<td>M. Abdou - UCLA</td>
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<td>ICH</td>
<td>D. Swain - ORNL</td>
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<td>ECH</td>
<td>R. Temkin - MIT</td>
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<td>Fueling</td>
<td>S. Combs - ORNL</td>
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<td>Tritium Processing</td>
<td>S. Willms – LANL</td>
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<td>Safety &amp; Tritium Research</td>
<td>D. Petti - INL</td>
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<td>Materials</td>
<td>S. Zinkle - ORNL</td>
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<td>NSO/FIRE</td>
<td>D. Meade - PPPL</td>
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<td>ARIES</td>
<td>F. Najmabadi - UCSD</td>
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<td>Socio-Economic</td>
<td>J. Schmidt - PPPL</td>
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Deputy Director: D. Petti, INL
The VLT in the greater scheme of things

Management Structure for the US ITER Project and Program

Office of Science
Raymond L. Orbach, Director

Office of Fusion Energy Sciences
N. Anne Davies, SC Associate Director

Fusion Energy Sciences Advisory Committee

Research Division
N. Anne Davies, Acting Director
Erol Oktay, US Burning Plasma Physics Program Manager
Gene Nardella, US Burning Plasma Technology Program Manager

Fusion Community: Laboratories, Academia, and Industry

- Provides wide spectrum of supporting activities from existing efforts – e.g., DIII-D, NSTX, C-MOD, Theory VLT, NUD
- Coordinated by Burning Plasma Program (led by Raymond Fonck, UW) including Chief Scientist and Chief Technologist at ex-officio
- Interacts with Project Office through task agreements

ITER and International Division
Michael Roberts, Director
Warren Marton, ITER Program Manager

DOE SC Princeton Site Office
Jerry Faul, Director
Gregory Pitonak, Acting ITER Federal Project Director

Princeton Plasma Physics Laboratory/ORNL
Rob Coldston, PPPL Director
Rich Havrilyuk, Deputy Director
Stan Milora, ORNL Fusion Director

US ITER Project Office
Ned Sauthoff, Project Manager

Note: This chart does not display the necessary organizational relationships with the legal, financial, and construction management offices within DOE.
The technology community (VLT) became involved in ITER at an early stage

- 2003 planning activities for possible construction contributions
  - Major contributions UFA organized ITER Forum
- 2004 and 2005
  - Participation in U. S. IPO planning (cost estimation) activities
  - Emphasis on R&D that also fulfills burning plasma device (ITER) needs during construction
  - Program priorities adjusted to reflect the need to make ITER a success and to exploit burning plasma device as a test bed in the longer term
    - Cross cutting research (materials, safety, neutronics) focused on burning plasma (ITER) issues
    - Some liquid surface PFC research redirected to Test Blanket and solid surface PFC relevant work
- About 60% of VLT activity is currently devoted to burning plasma technology research and development
VLT participants lead the planning and R&D activities for six of the U. S. provisional “in kind” hardware contributions.

- 4 of 7 Central Solenoid Modules
  - Steady-state power supplies
- 44% of ICRH antenna + all transmission lines, RF-sources, and power supplies
- Start-up gyrotrons, all transmission lines and power supplies
- Blanket/Shield 10%
- Cooling for divertor, vacuum vessel, …
- Roughing pumps, standard components
- Tokamak exhaust processing system
- Pellet injector
- Cross cutting activities: Materials science, nuclear analysis, safety

Test Blanket
“A Burning Plasma will provide significant opportunities to advance development of technologies for follow-on devices (DEMO) needed for commercial power production.”

- DEMO relevant magnet technology: all superconducting, advanced superconductor materials, structural support techniques and insulation
- Tens of megawatt rf heating and current drive technologies operating reliably in intense radiation environment and for long pulse.
- High throughput (1000X) steady state fueling and real time exhaust gas processing systems.
- Actively cooled PFCs and first wall that withstand neutron damage, nuclear heating (1 MW/m³), plasma heating (up to 20 MW/m²), erosion while minimizing tritium retention.
- Test blankets for tritium breeding and high temperature heat extraction.
- Neutron irradiation effects on insulators, optical materials, Cu heat-sink materials and joining technologies and diagnostics.
- Demonstration of safety and environmental advantages of fusion at reactor levels of tritium inventory, neutron flux, energy sources
What’s new in burning plasma technology since Snowmass

• **ECH**: Operation of CPI 140 GHz Gyrotron at 0.9 MW for 30 minutes at Greifswald / W7-X
  - New Joule record at total efficiency 41.7%
  - Need 1 MW at 120 GHz and 1000 sec and 50% for ITER start up Gyrotrons
  - Square corrugated waveguide allows for remote (external to vacuum vessel) steering

• **ICH**: New high power load - tolerant antenna systems control reflected power due to ELMs
  - No false transmitter trips ⇒ greater effective rf power density through launcher
  - 8 MW/m² in ELMY H-mode ITER-like antenna to be tested on JET (vacuum tests of lower power mockup show potential for > 9MW/m²)
What’s new in burning plasma technology since Snowmass

- **Fueling:** New tools for density control, disruption and ELM mitigation
  - DIII-D experiments show efficacy of HFS pellet launch, agreement with model
  - DIII-D LFS launch effective for ELM triggering
    - High frequency ELM pacing system planned for DIII-D
  - Massive gas injection reduces disruption halo currents and their effects on DIII-D and C-Mod
What’s new in burning plasma technology since Snowmass

- Experiments and theory addressing PMI issues relevant to ITER
  - Erosion, re-deposition, co-deposition etc.
    - DIII-D (DIMES experiments)
    - PISCES and other plasma edge simulators (W, Be, C mixed materials)
  - Mixed material erosion/re-deposition analysis in ITER
    - Package Omega suite of codes
  - PFC/PMI community initiative on “All metal ITER” to address T co-deposition
What’s new in burning plasma technology since Snowmass

- Solid surface plasma facing component research
  - Collaboration with C-Mod to develop W rod (and lamellae) on Inconel Divertor Tiles
    - Relevant to all metal ITER (for reducing tritium co-deposition)
  - Development and testing including ELM simulation of Be clad Cu heat sink options for ITER first wall
What’s new in burning plasma technology since Snowmass

• Magnet research has focused on ITER central solenoid technology issues
  – Development of high performance superconducting strand
  – Jacket alloy with reduced SAGBO sensitivity
  – Characterization and mitigation of effect of bending stresses on conductor performance
  – New quench detection sensors
What’s new in burning plasma technology since Snowmass

- **Chamber technology R&D** has focused on tritium test blanket options for potential ITER application
  - 1) US led dual coolant lead-lithium (DCLL) concept for high temperature potential
  - 2) Helium cooled ceramic breeder (HCCB) “unit cells” in EU test blanket module
What’s new in burning plasma technology since Snowmass

• **Materials research**
  - New low activation ferritic steels developed with superior properties (yield strength and thermal creep time to failure)
    - Potential for increasing upper operating temperature for iron based alloys by ~200 degrees C.
  - HFIR fission reactor irradiation of candidate ICH antenna insulators at $10^{18}-10^{20}$ n/cm$^2$

• **Safety and tritium research**
  - Tritium plasma experiment (TPE) online
    - Will study T uptake, retention and possible release in ITER relevant materials
  - Updated and upgraded Melcor (ITER safety analysis) 1-D Navier Stokes code

12% Cr Nanocomposited Ferritic Steel
What’s new in burning plasma technology since Snowmass

- **Neutronics**: analyses of nuclear heating of in vessel components has begun
  - 1-D calculations of first wall and blanket have been performed
  - Coupling of CAD drawings to MCNP
The 10 VLT technical areas have developed planned research thrusts for several modes of participation in burning plasma research

- Supporting U.S. contributions to ITER (e.g. dual use technology, maintaining facilities necessary for testing ITER hardware, etc.)
- Supporting areas that are outside of our ITER contributions, but that still support making ITER a successful and valuable experiment. (e.g. tritium in mixed materials, all metal tokamaks, safety and licensing, etc.)
- Utilization of ITER as a test bed for technology (e.g. Test Blanket Modules, H&CD, Fueling, PFCs etc.)
- Developing the next generation of technology that can be used to improve/expand performance on both our current (e.g. DIII-D, CMOD, NSTX, JET, ICCs, etc.) and future (e.g. LTX, NCSX, KSTAR, ITER, etc.) machines including international devices
- Detailed plans for all ten technical areas on VLT website:
  - http://vlt.ucsd.edu/presentations.html
## Research thrusts for VLT materials program.

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<tr>
<th></th>
<th>ITER Base machine</th>
<th>R&amp;D needed for ITER to be successful</th>
<th>ITER as test bed (TBM, etc)</th>
<th>Next generation technology (for current and future machines)</th>
<th>Longer Term R&amp;D</th>
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<tr>
<td>ITER structural materials</td>
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<td>ITER insulator and plasma diagnostics</td>
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<td>F/M steels for ITER TBM and beyond</td>
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<td>SiC composites for ITER TBM and beyond</td>
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<td>Cross-cutting theory and modeling</td>
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<td>Chemical compatibility</td>
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<td>Higher performance materials R&amp;D</td>
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<td>Liquid breeder materials (MHD insulator)</td>
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Representatives of the VLT with relevant expertise will participate in several breakout sessions.

- Larry Baylor (Boundary/Integrated Scenarios/Macroscopic Stability)
  - Fueling and related topics such as disruption mitigation and ELM pacing
- Jeff Brooks (Boundary)
  - PMI/PFC issues including modeling
- Keith Leonard (Diagnostics and Control)
  - Materials issues
- Dave Rasmussen (Integrated Scenarios/Boundary)
  - Ion cyclotron and electron cyclotron heating and current drive
- Phil Sharpe (Boundary/Energetic Particles)
  - Safety and tritium issues
- Mike Ulrickson (Macroscopic Stability/ Boundary)
  - RWM stabilization and PFCs