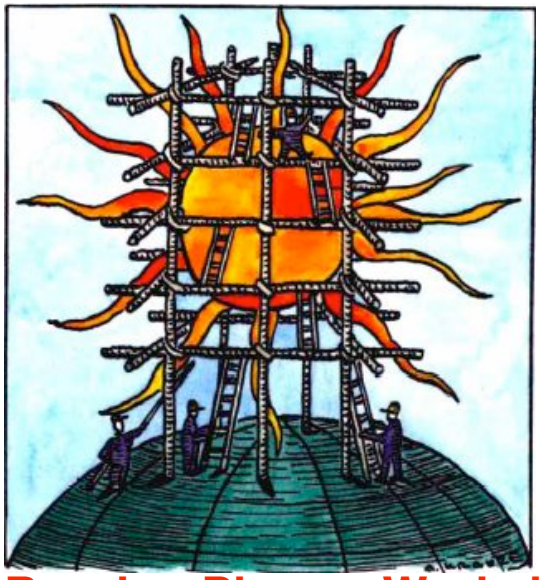
Burning Plasma Technologies

Stan Milora, ORNL
Director, Virtual Laboratory for Technology



U.S. Burning Plasma Workshop
Oak Ridge
December 7-9, 2005

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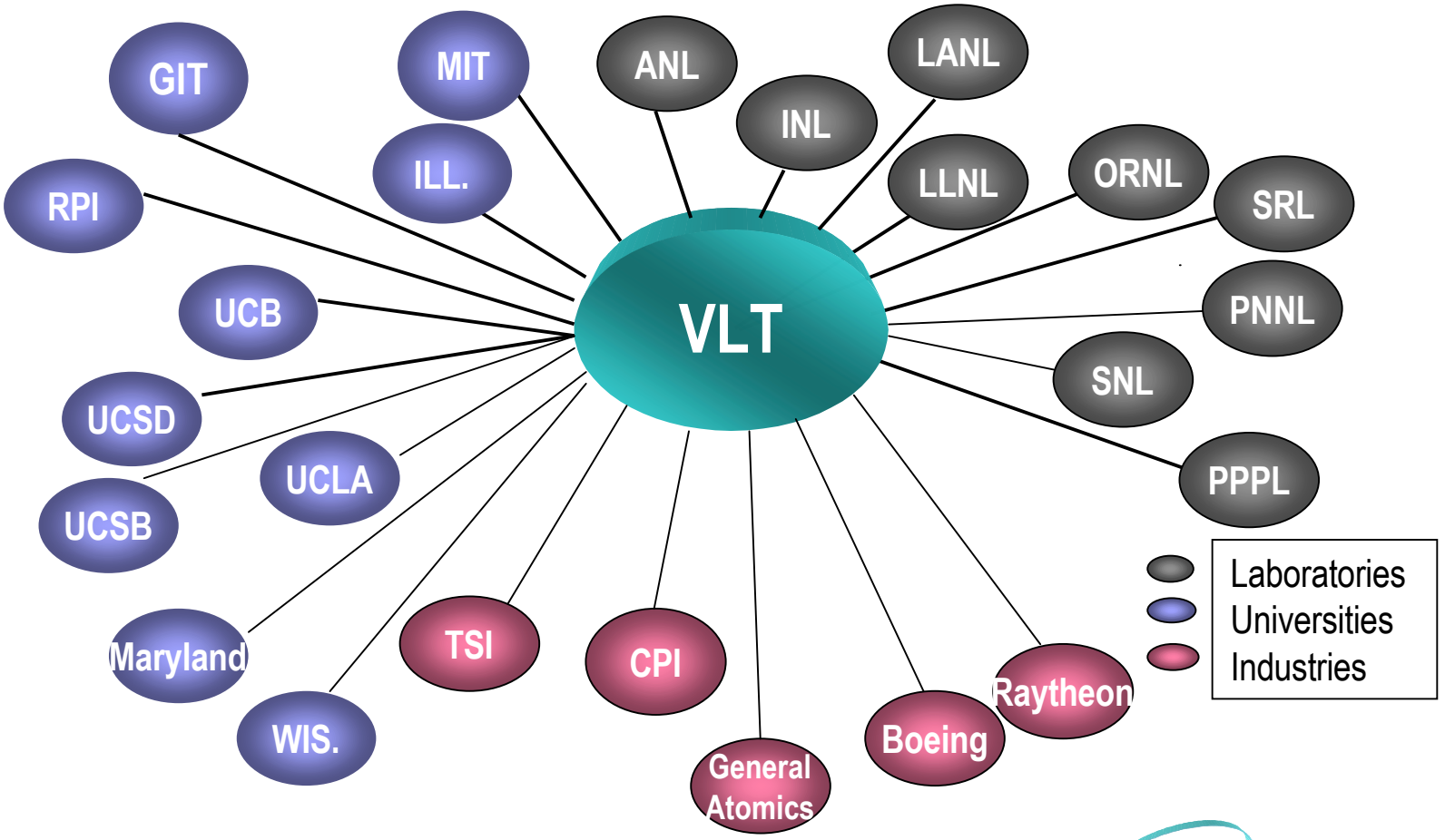
For Fusion Energy Science

The Technology Program is a multi-institutional national resource



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VLT Research Mission

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.

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The VLT is the repository of burning plasma technology expertise.

Deputy Director	**D.Petti, INL**
Program Element	**Element Leader**
Magnets	**J. Minervini - MIT**
PFC	**M. Ulrickson - SNL**
Chamber	**M. Abdou - UCLA**
ICH	**D. Swain - ORNL**
ECH	**R. Temkin - MIT**
Fueling	**S. Combs - ORNL**
Tritium Processing	**S. Willms – LANL**
Safety & Tritium Research	**D. Petti - INL**
Materials	**S. Zinkle - ORNL**
NSO/FIRE	**D. Meade - PPPL**
ARIES	**F. Najmabadi - UCSD**
Socio-Economic	**J. Schmidt - PPPL**

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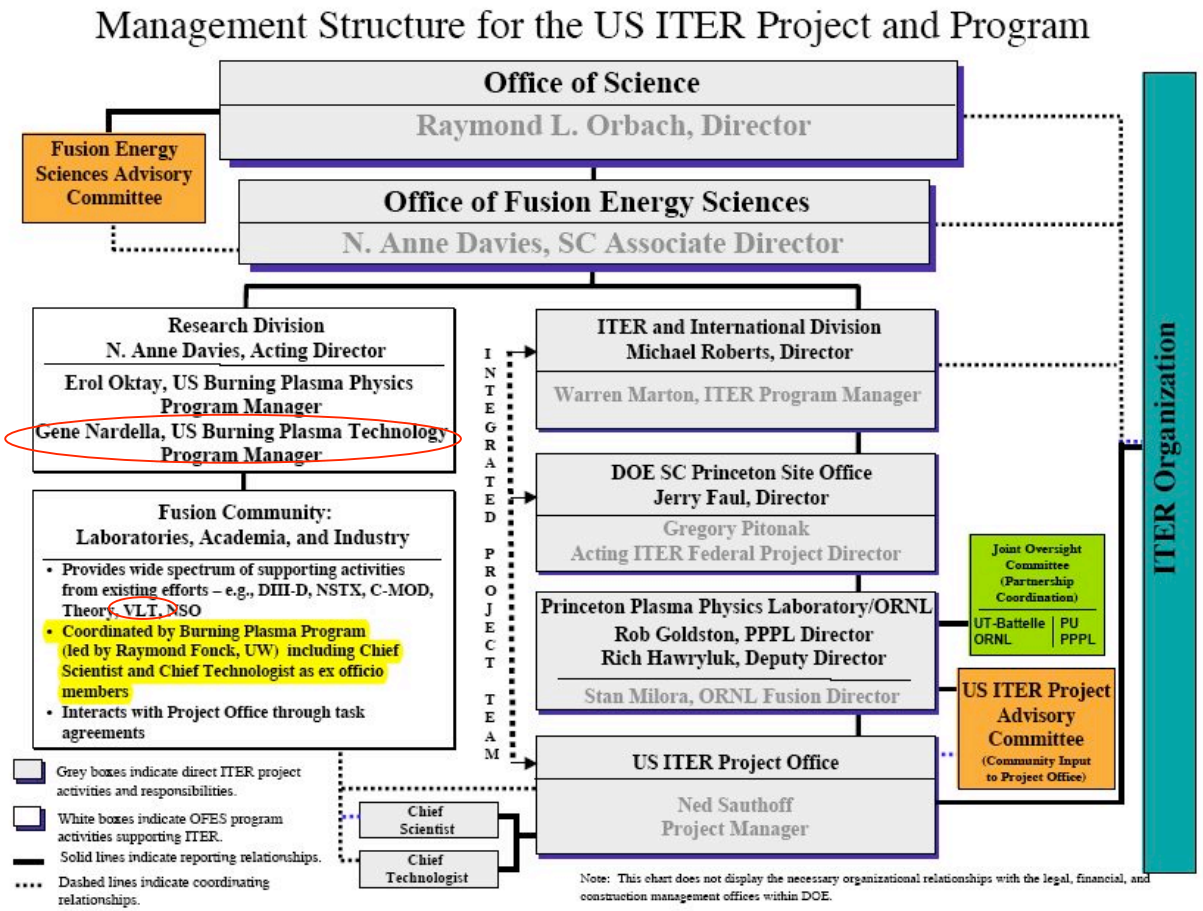
The VLT in the greater scheme of things



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

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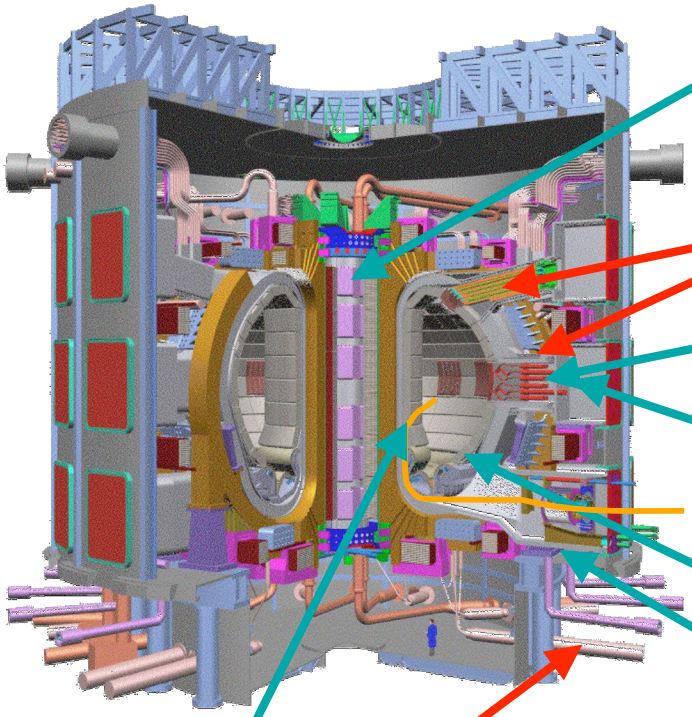
VLT participants lead the planning and R&D activities for six of the U. S. provisional "in kind" hardware contributions



4 of 7 Central Solenoid Modules

Steady-state power supplies

15% of port-based diagnostic packages

44% of ICRH antenna + all transmission lines, RF-sources, and power supplies

Start-up gyrotrons, all transmission lines and power supplies

Blanket/Shield 10%

Test Blanket

Roughing pumps, standard components

Tokamak exhaust processing system

Pellet injector

Cooling for divertor, vacuum vessel, …

Cross cutting activities: Materials science, nuclear analysis, safety

For Fusion Energy Science

"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/m^3), plasma heating (up to 20 MW/m^2), 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

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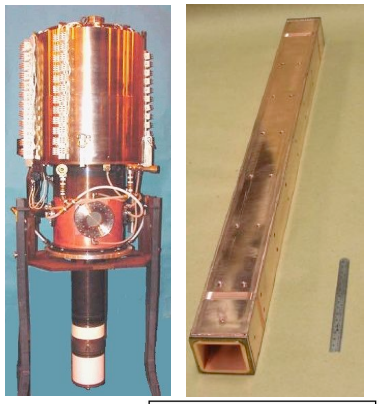
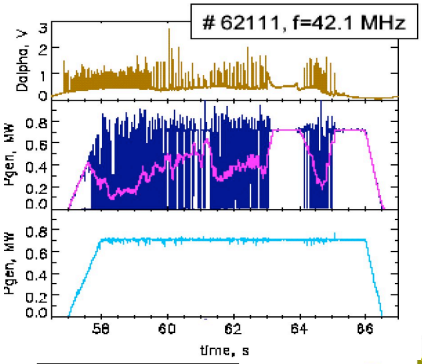
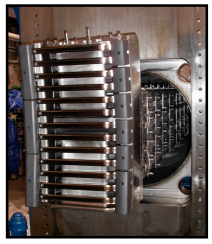
What's new in burning plasma technology since Snowmass

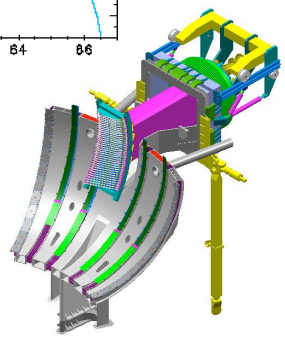
- **ECH**: Operation of CPI 140 GHz Gyrotron at 0.9 MW for 30 minutes at Greifswald / W7-X
  - New Joule record at total efficiency 41.7 %
  - Need 1 MW at 120 GHz and 1000 sec and 50% for ITER start up Gyrotrons
  - Square corrugated waveguide allows for remote (external to vacuum vessel) steering

- **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/m^2 in ELMY H-mode ITER-like antenna to be tested on JET (vacuum tests of lower power mockup show potential for > 9MW/m^2)



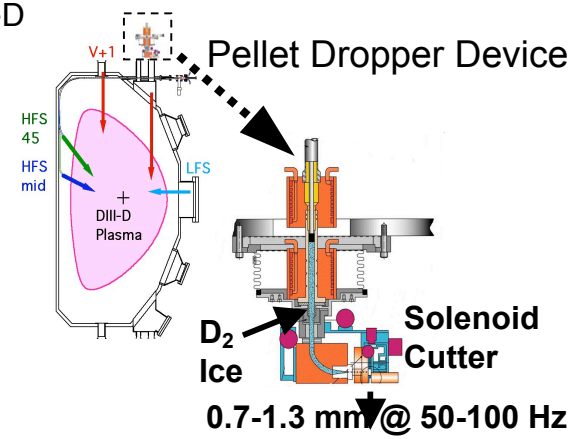




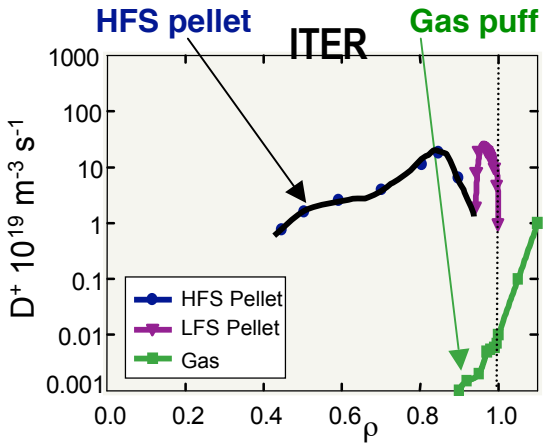


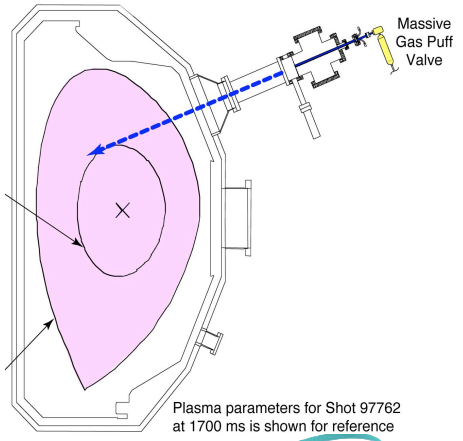
What's new in burning plasma technology since Snowmass

- **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





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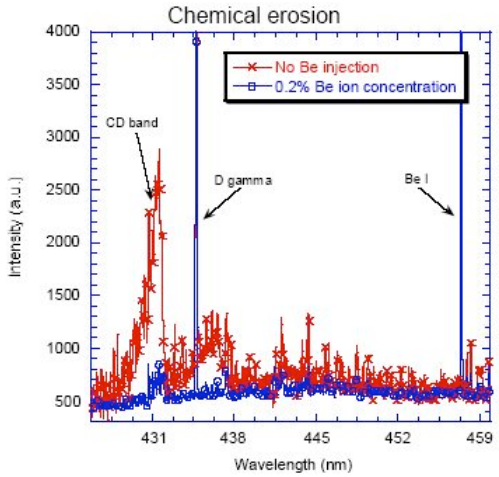
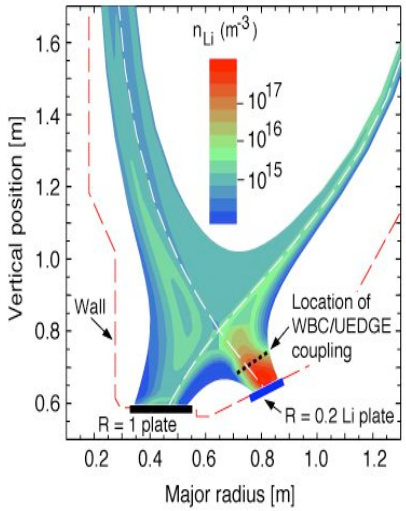
What's new in burning plasma technology since Snowmass

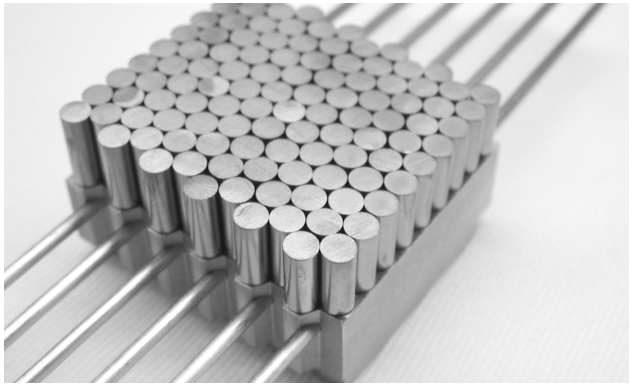
- Experiments and theory addressing PMI issues relevant to ITER
  - Erosion, re-deposition, co-deposition etc.
    - DIII-D (DIMES experiments)
    - PISCES and other plasma edge simulators (W, Be, C mixed materials)
  - Mixed material erosion/re-deposition analysis in ITER
    - Package Omega suite of codes
  - PFC/PMI community initiative on "All metal ITER" to address T co-deposition



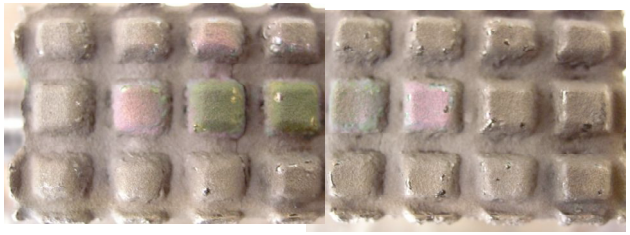


What's new in burning plasma technology since Snowmass

- 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



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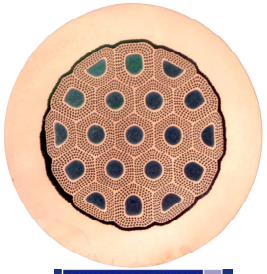
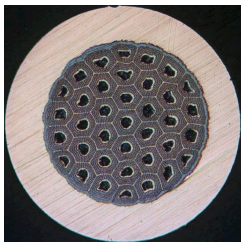
What's new in burning plasma technology since Snowmass

- 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





Outkumpu Advanced Superconductors

SUPERCONDUCTING SYSTEMS, INC.

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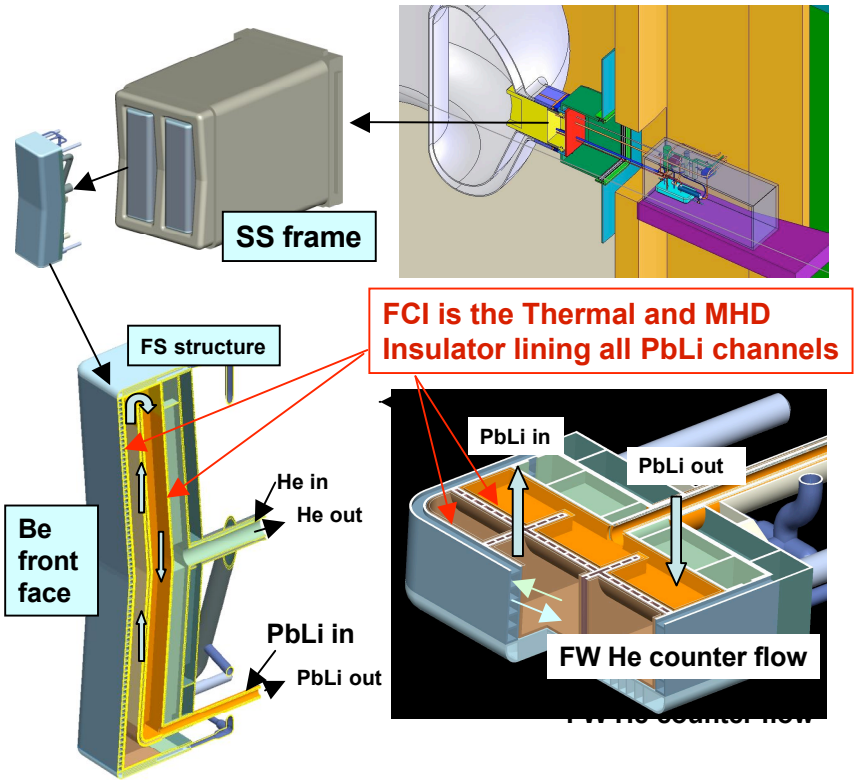
What's new in burning plasma technology since Snowmass

- **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

US DCLL TBM module



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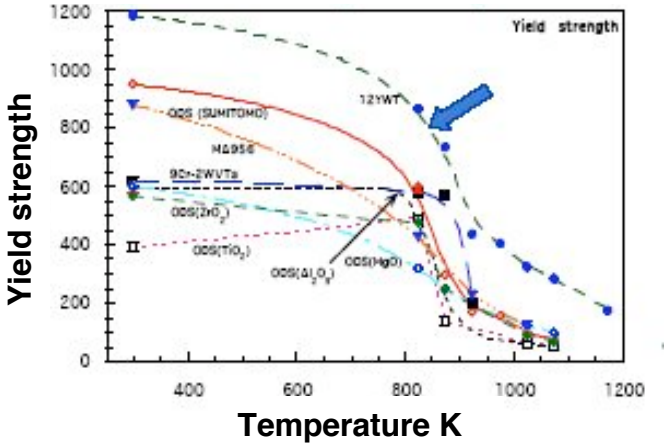
What's new in burning plasma technology since Snowmass

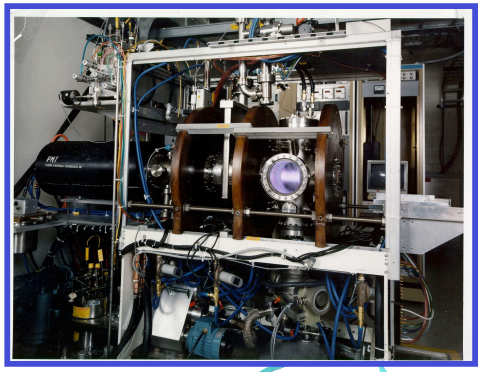
- **Materials research**
  - New low activation ferritic steels developed with superior properties (yield strength and thermal creep time to failure)
    - Potential fo rincreasing upper operating temperature for iron based alloys by ~200 degrees C.
  - HFIR fission reactor irradiation of candidate ICH 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



Tritium Plasma Experiment



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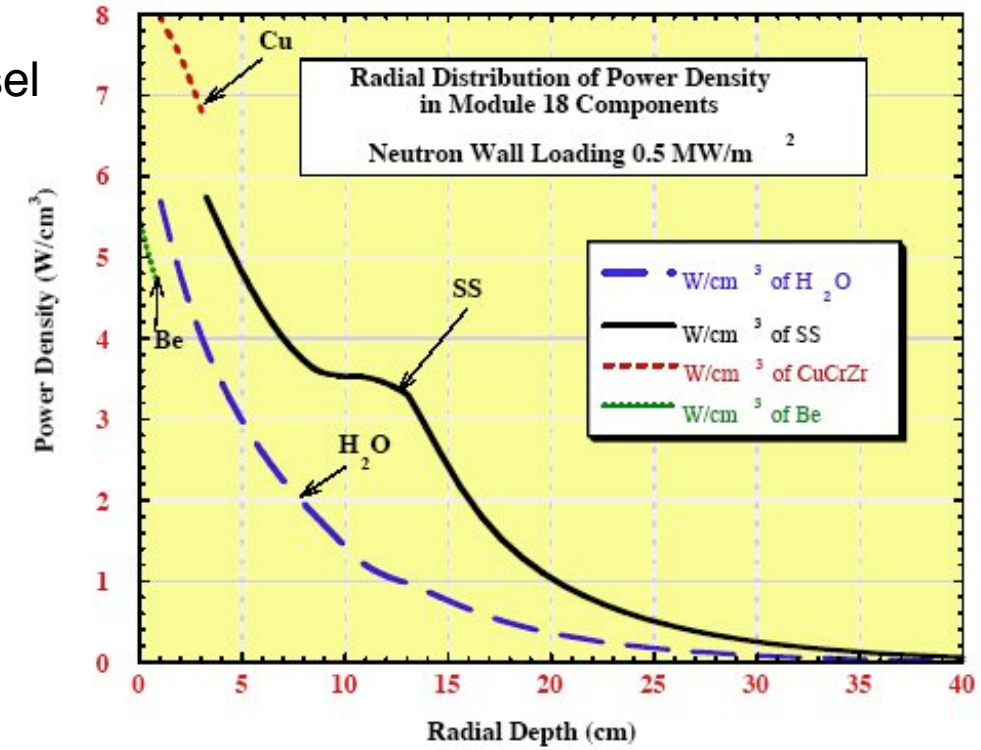
- **Neutronics**: analyses of nuclear heating of in vessel components has begun
  - 1-D calculations of first wall and blanket have been performed
  - Coupling of CAD drawings to MCNP



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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. DIIID, 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

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Research thrusts for VLT materials program.

	ITER Base machine	R&D needed for ITER to be successful	ITER as test bed (TBM, etc)	Next generation technology (for current and future machines)	Longer Term R&D
ITER structural materials	X	X			
ITER insulator and plasma diagnostics	X	X	X		X
F/M steels for ITER TBM and beyond			X	X	X
SiC composites for ITER TBM and beyhond			X	X	X
Cross-cutting theory and modeling			X	X	X
Chemical compatibility			X	X	X
Higher performance materials R&D			X	X	X
Liquid breeder materials (MHD insulator)			X		X

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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

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