

The U. S. Technology Program and ITER

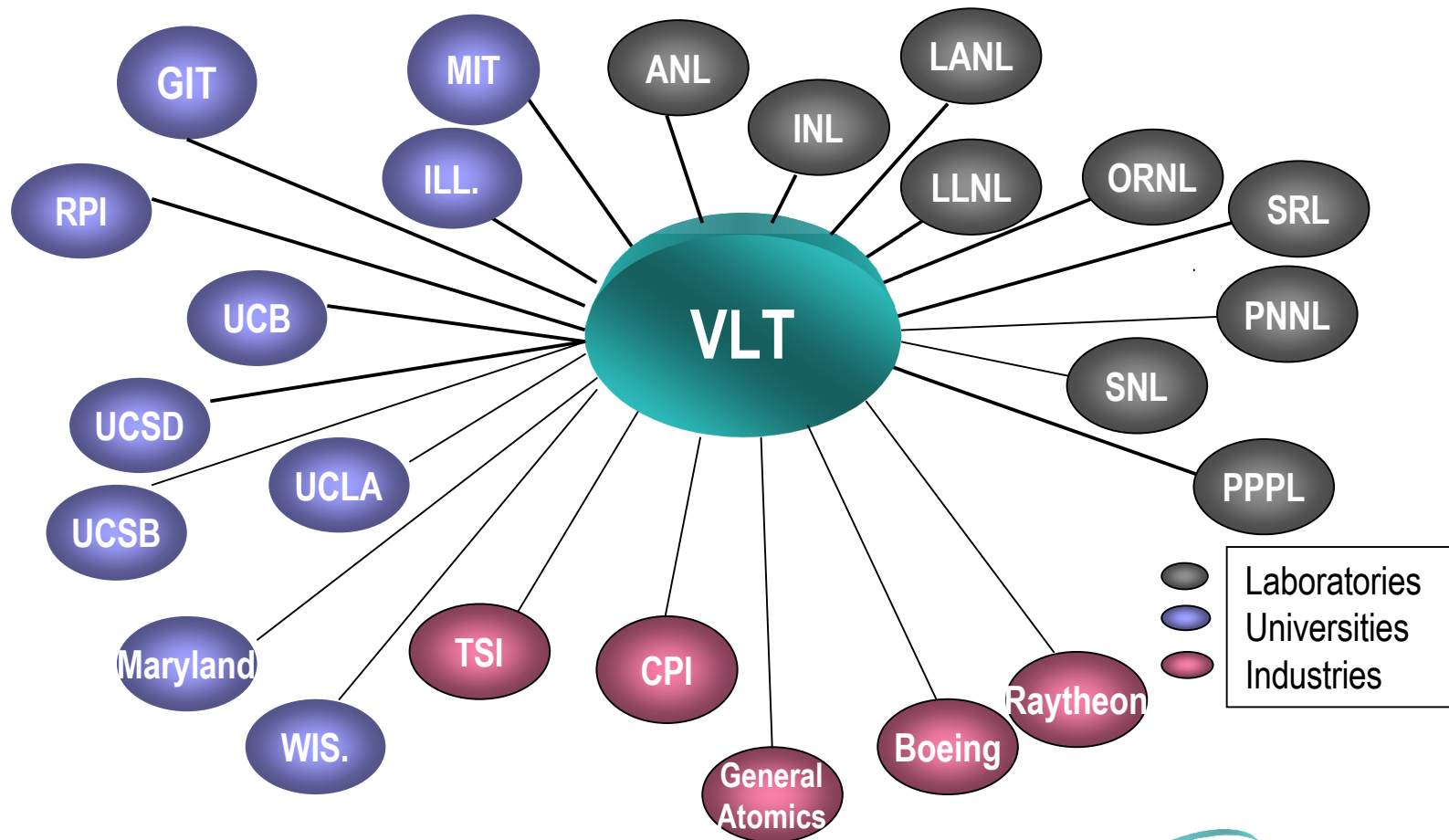
Stan Milora, ORNL
Director, Virtual Laboratory for Technology
Chief Technologist, U. S. ITER Project Office

**Fusion Power Associates Annual Meeting and
Symposium: Pathways to the Future**

September 27-28, 2006
Washington, DC



The Technology Program is a multi-institutional national resource



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.

The VLT is the steward of burning plasma technology.

Deputy Director

D.Petti, INL

Program Element

Element Leader

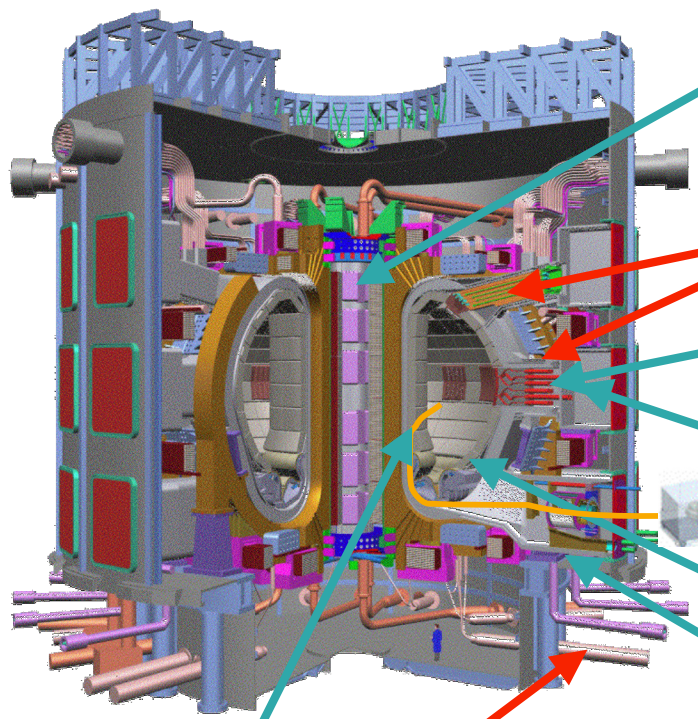
**Magnets
PFC
Chamber
ICH
ECH
Fueling
Tritium Processing
Safety & Tritium Research
Materials
NSO/FIRE
ARIES
Socio-Economic**

**J. Minervini - MIT
R. Nygren - SNL
M. Abdou - UCLA
D. Swain - ORNL
R. Temkin - MIT
S. Combs - ORNL
S. Willms - LANL
D. Petti - INL
R. Kurtz - PNNL
TBD
F. Najmabadi - UCSD
L. Grisham - PPPL**

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 led the planning activities and participate in R&D and design for 7 of the U. S. hardware packages



7 Central solenoid windings
8% of TF conductor

Steady-state power supplies

15% of port-based diagnostic packages

All Ion Cyclotron transmission lines (20MW)

All ECH transmission lines (24MW)

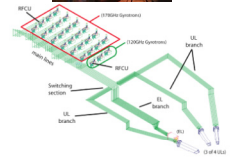
Blanket/shield 20%; limiters **Test Blanket**

Roughing pumps, standard components

Tokamak exhaust processing system

Pellet injector

75% cooling for divertor, vacuum vessel, ...



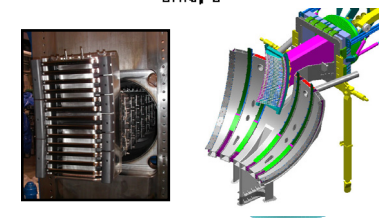
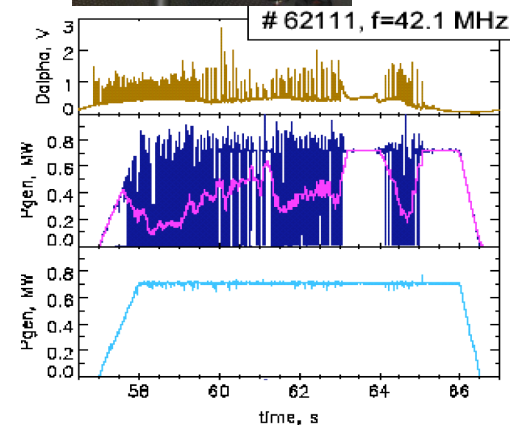
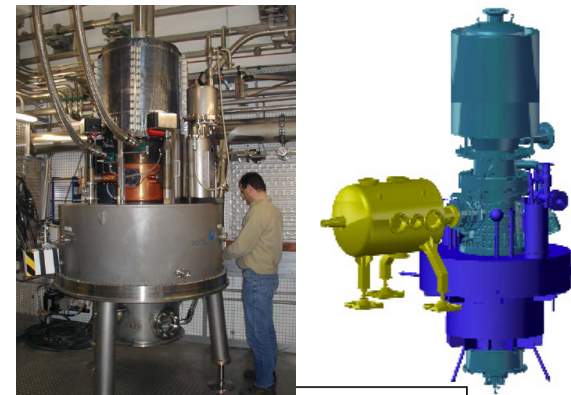
Cross cutting activities: Materials science, nuclear analysis, safety

“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

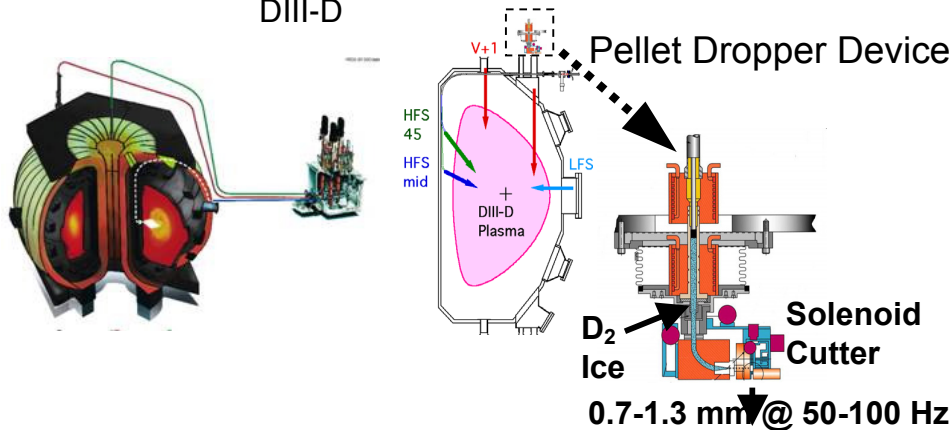
Electron Cyclotron and Ion Cyclotron heating and current drive

- **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 and 170 GHz and 1000 sec and 50% for ITER Gyrotrons
 - Development and testing of 1000 second mode control and low loss waveguide components for ITER project
- **ICH:** New high power load - tolerant antenna systems control reflected power due to ELMs
 - No false transmitter trips \Rightarrow 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)
 - Long pulse (1000 sec) high power tuning, matching and transmission line components for ITER project

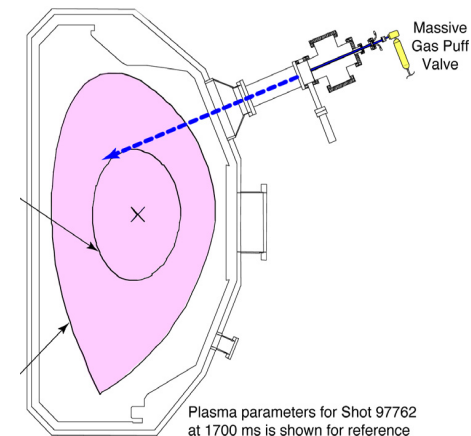
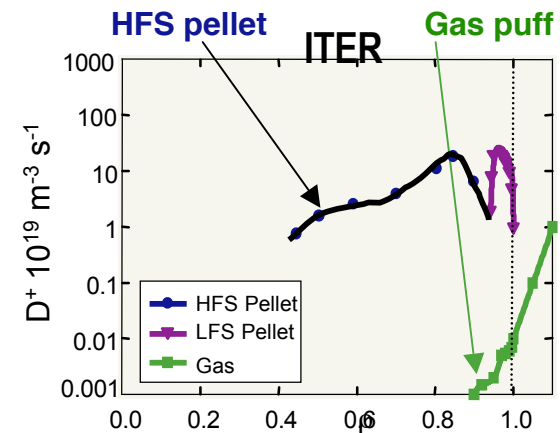


Pellet Fueling and related technologies (ELM pacing and disruption mitigation)

- **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

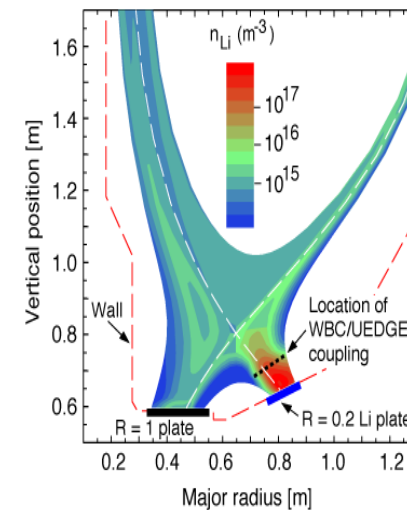
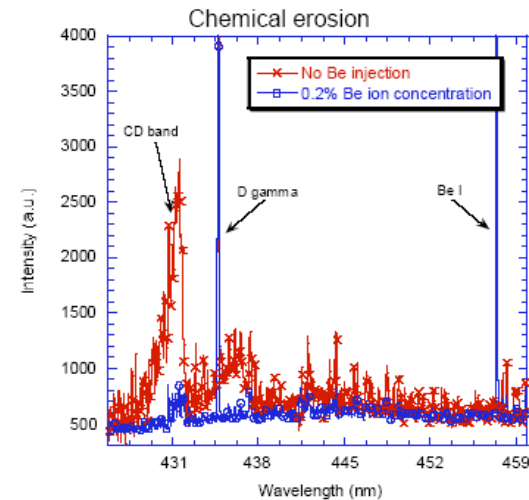


- Massive gas injection reduces disruption halo currents and their effects on DIII-D and C-Mod
- High throughput, long pulse T pellet feed, accelerator and pumping systems for ITER



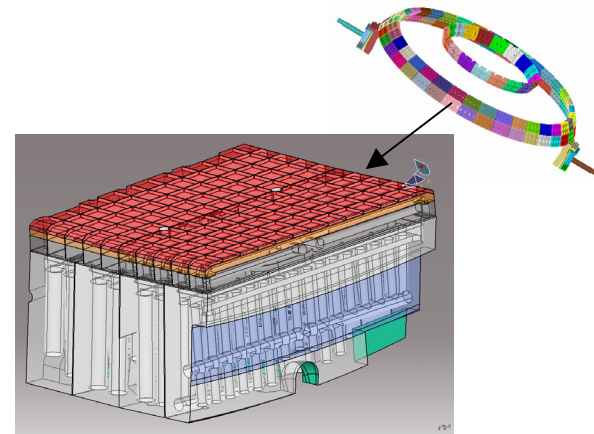
Plasma Materials Interaction experiments and modeling

- Experiments and theory addressing PMI issues relevant to ITER
 - Erosion, re-deposition, co-deposition, ELMs.
 - DIII-D (DIMES experiments)
 - PISCES and other plasma edge simulators (W, Be, C mixed materials and ELMs)
 - 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

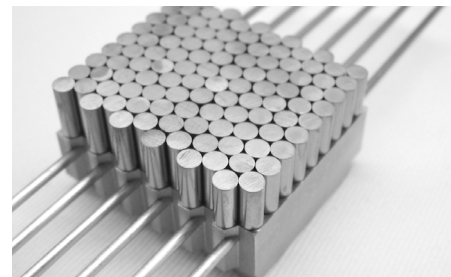


Plasma Facing Component research and development

- ITER first wall/shield R&D
 - Detailed design, thermal/fluid analysis of FW shield block
 - Development and testing including ELM simulation of Be clad Cu heat sink options for ITER first wall
 - Qualification of joining of Be/Cu/316LN for ITER first wall panels
 - Manufacturing studies for optimum shield block manufacturing
 - Forging/machining, HIPing, casting
 - Casting preferred because of cost
 - Qualification tests (thermal cycling etc.)
- Solid and liquid 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 in carbonaceous films)

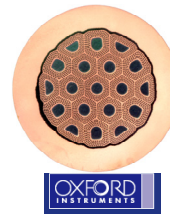


– shield block



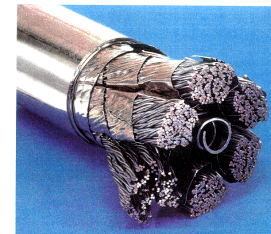
Magnet research and development

- Research focused on ITER conductor issues
 - Industrial qualification of high performance (1000 A/mm^2) Nb_3Sn superconducting strand
 - Conductor fabrication
 - Characterization and mitigation of effect of bending stresses on conductor performance
- Advanced superconductor development
 - e.g. MgB_2 has the potential for huge cost savings vs Nb based or Ag stabilized superconductors. (\$s for MgB_2 vs \$70/lb Nb).

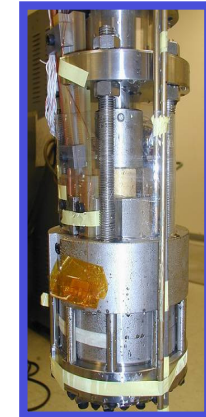
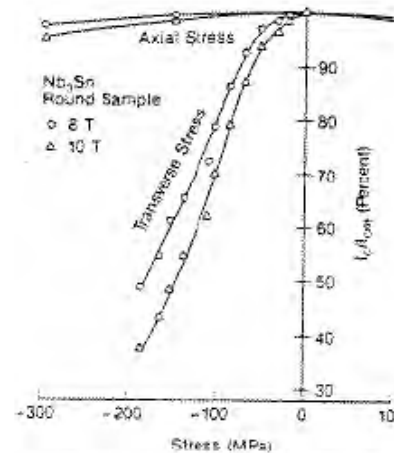


OXFORD
INSTRUMENTS

ITER TF superconducting strand qualification



ITER TF conductor

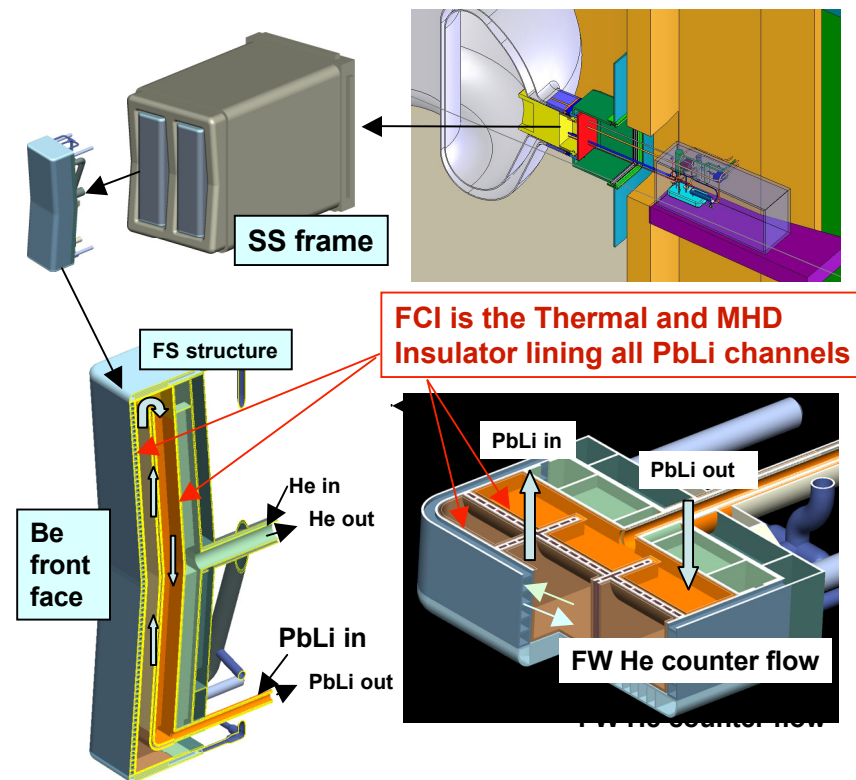


Transverse compression in a multi-strand cable

Chamber Technology efforts in support of a U. S. ITER Test Blanket Program

- Testing of blanket modules in special ports is one of the principal objectives of ITER. TBM is a key element in ITER utilization.
- Chamber technology R&D and planning 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
- The TBM team has been engaged during the past year in developing the strategy, technical plan, and cost estimates for US participation in ITER TBM.
 - The plan was favorably reviewed in August

US DCLL TBM module



Materials Science

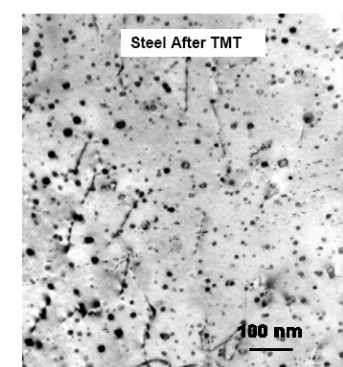
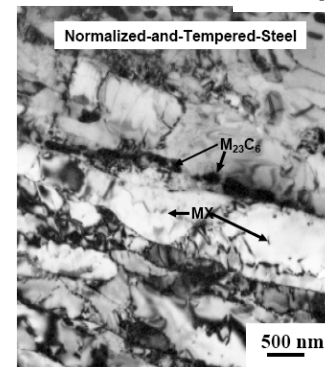
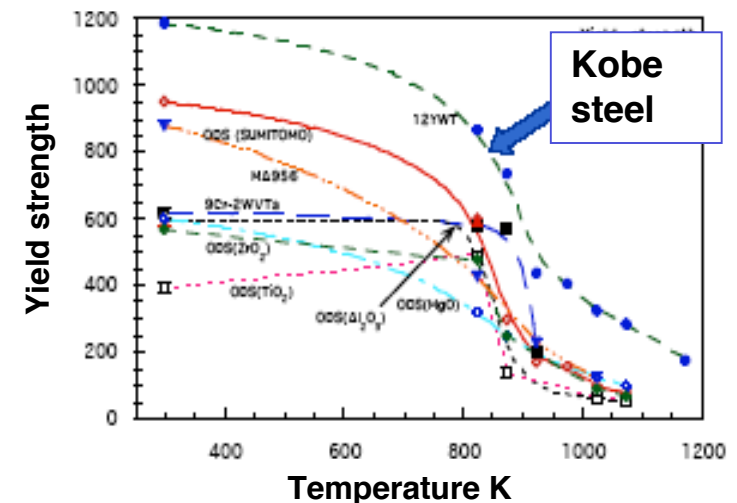
- **Materials research**

- New low activation oxide dispersion strengthend (ODS) ferritic steels developed with superior properties (yield strength and creep resistance)
 - Potential for increasing upper operating temperature for iron based alloys by ~200 degrees C.
- Innovative thermo-mechanical treatment produces steels as good as the best ODS and better than the best low activation ferritic steel

- **ITER support**

- HFIR fission reactor irradiation of candidate ICH antenna insulators at 10^{18} - 10^{20} n/cm²
- Casting and irradiation studies to qualify cast 316 LN for use in U.S. shield block and Be/Cu/SS joining techniques.

12% Cr Nanocomposited Ferritic Steel



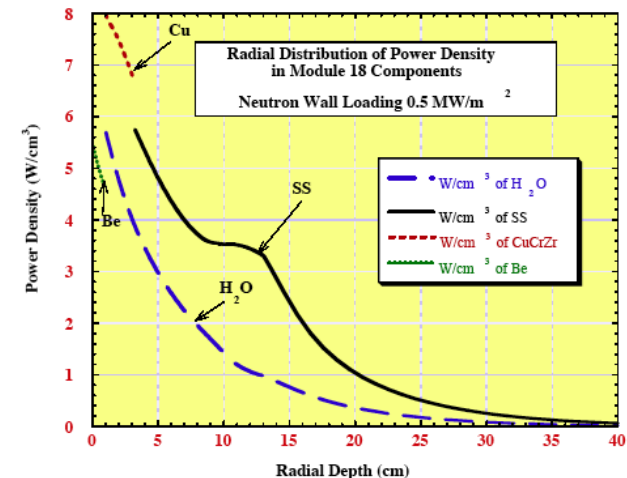
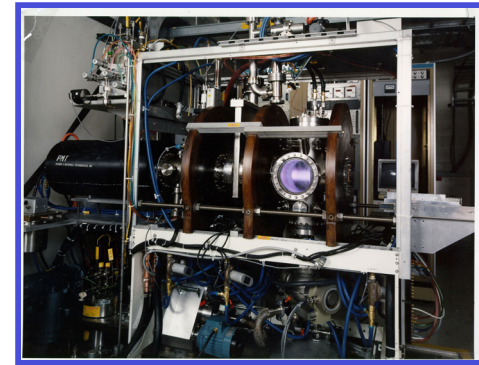
9Cr-1Mo before

After thermo-mechanical treatment

Tritium, Safety, and Neutronics Analysis

- **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)
 - Working with French regulators to expedite ITER construction licensing approval.
 - Scale up of throughput and processing time for exhaust gas processing for the ITER project
- **Neutronics**: analyses of nuclear heating of ITER in-vessel components has begun
 - 1-D calculations of first wall and blanket have been performed
 - Coupling of CAD drawings to MCNP
 - Implementation of ATILLA code

Tritium Plasma Experiment



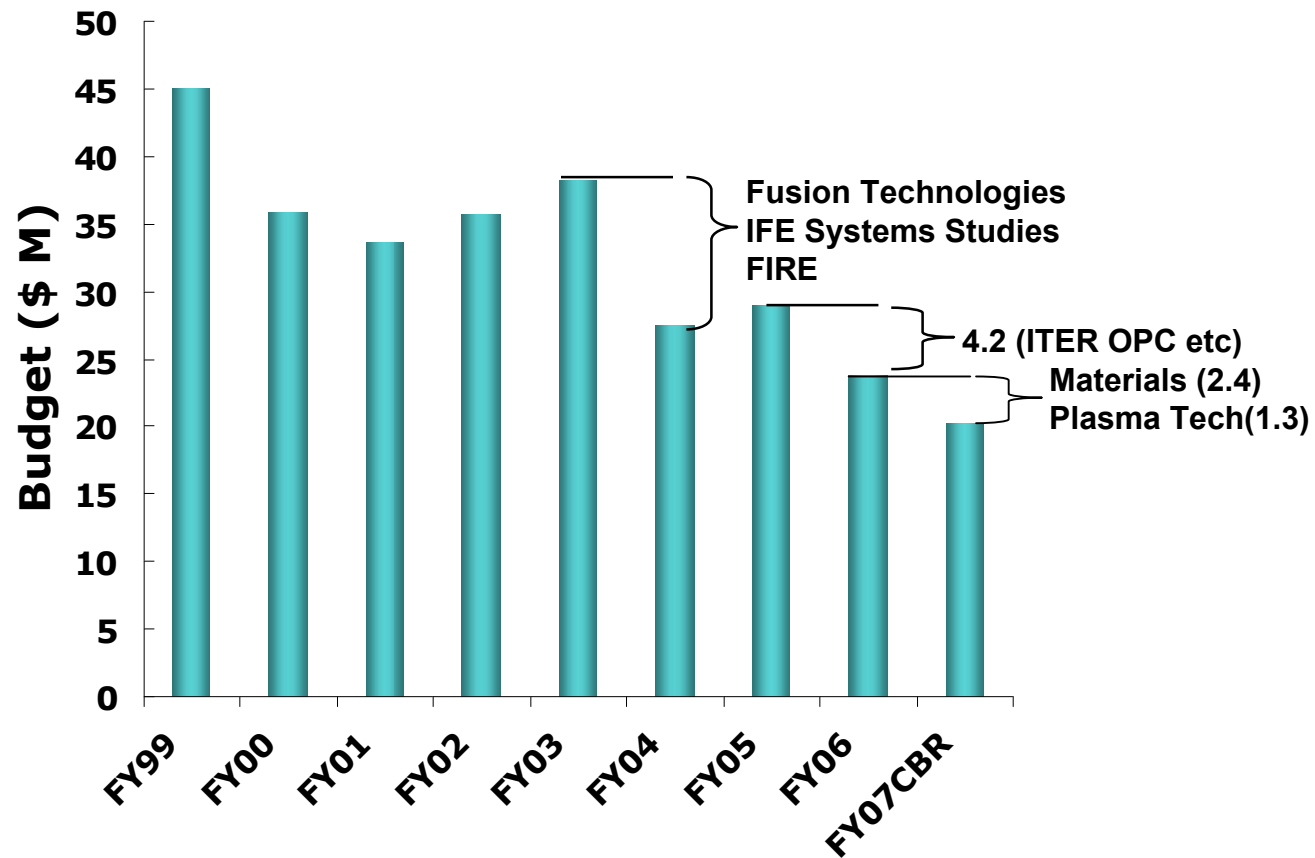
The VLT technical areas have developed planned research thrusts for several means of participation in burning plasma research

- Supporting U.S. contributions to ITER (R&D and design for the USIPO, maintaining facilities necessary for testing ITER hardware, etc.)
- Supporting areas that are outside of our ITER contributions, but that still support making ITER a success. (e.g. tritium in mixed materials, all metal first wall, 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. DIIIID, CMOD, NSTX, JET, ICCs, etc.) and future (e.g. LTX, NCSX, KSTAR, ITER, etc.) machines including international experiments and test facilities

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 beyond			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

Concern: Base program enabling R&D funding has eroded substantially since FY03



Conclusions

- The technology program is developing new tools to enable present and future research facilities to meet their research potential
- Technology program is committed to the success of ITER
 - Design, R&D and test facilities for the construction phase
 - Contributions in safety and other cross cutting areas
 - Participation through the U. S. BPO on physics tasks and ITER design improvements (issue cards)
 - Preparations to utilize ITER as a test bed for follow on devices (in particular the Test Blanket Program)
- Painful cuts in funding threaten several elements of the program
 - Magnets, heating and current drive and particularly materials science (33%)
 - R&D from ITER will provide partial relief BUT this ends in about 3 years.