Virtual Laboratory for Technology Input to Budget Planning Meeting

S. L. Milora
VLT Director

Rockville, Maryland
16 March 2005

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

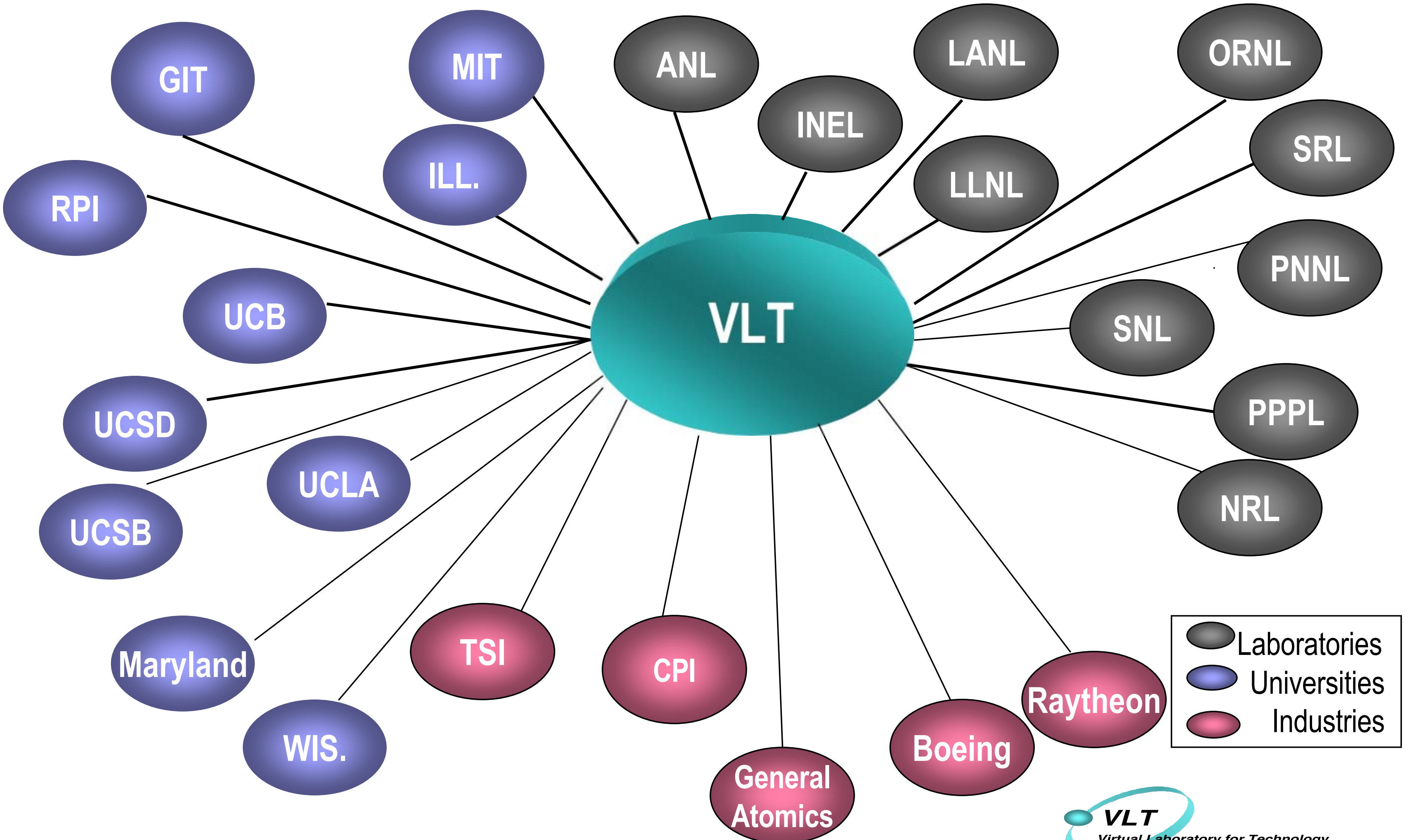
Outline

- VLT Mission, Organization, PAC
- Overview of FY05/06 Budget Situation
- For each element
  - Highlights of technical accomplishments
  - FY06 tasks and funding
  - FY07 tasks and funding (-10%, Flat and Full Use cases)
- Special Issues —Materials Science, Plasma Technologies

The Enabling Technology 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 Technology Program is a Multi-institutional National Resource



VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT Program Element Leaders

Deputy Director — **S. Milora**

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*
Safety & Tritium Research	D. Petti - *INEEL*
Tritium Processing	S. Willms - *LANL*
NSO/FIRE	D. Meade - *PPPL*
ARIES	F. Najmabadi - *UCSD*
Socio-Economic	J. Schmidt - *PPPL*
Materials	S. Zinkle - *ORNL*

VLT Program Advisory Committee Members

PAC Member

***J. Freidberg, Chair**
***R. Hawryluk, Acting Chair**
D. Batchelor
J. Dahlburg
***B. Hooper**
***T. Jarboe**
***A. Kellman**
***J. Kwan**
P. Peterson
***K. Schoenberg (*S. Willms)**
***J. Sethian**

**** attended October 21-22, 2004 meeting***

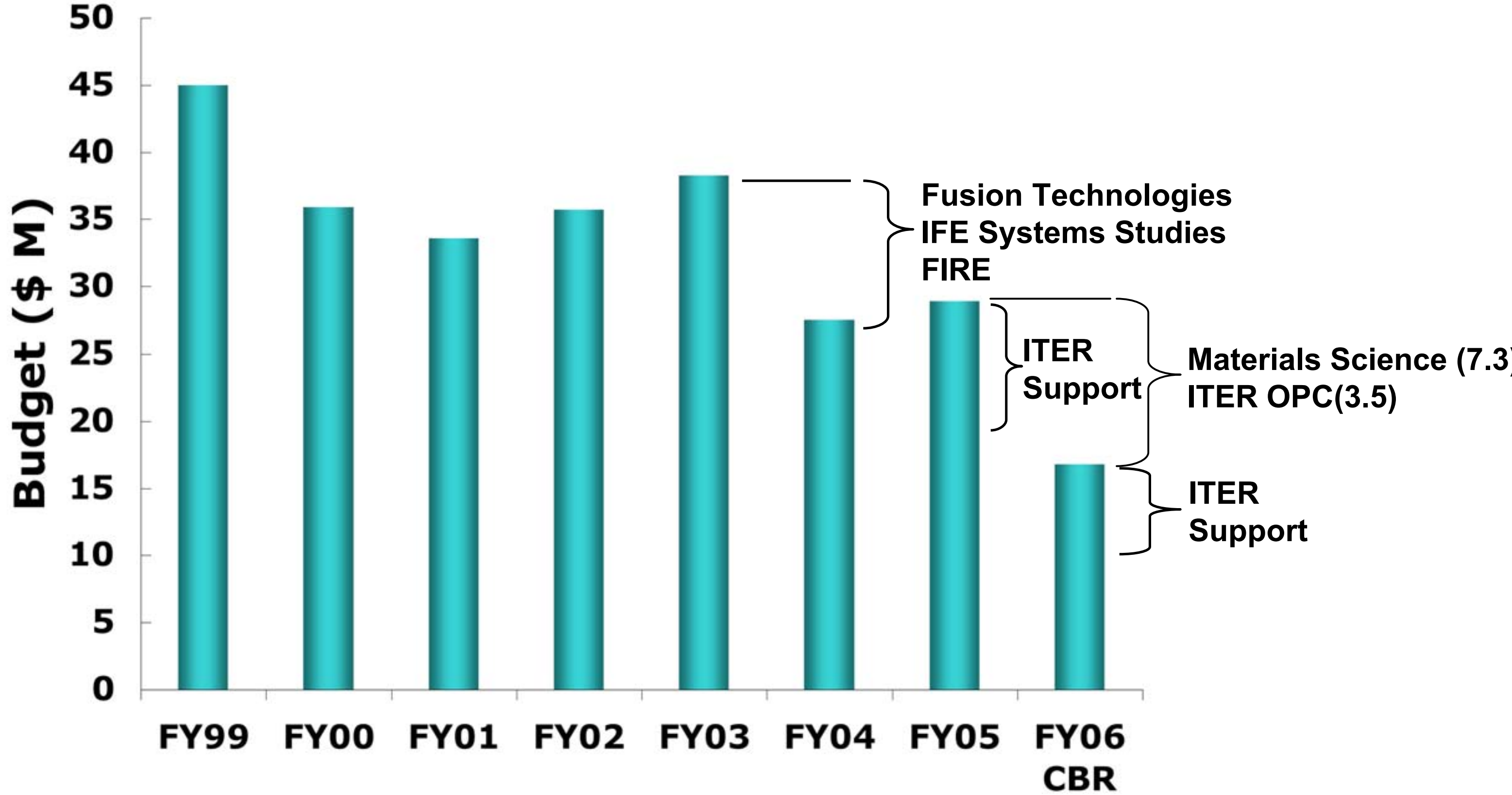
VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT PAC Comments

- **The PAC considers the three missions (*support of existing experiments, and ITER, and research on MFE /IFE fusion technology*) as "critical to the development of fusion."**
- **Believes that ITER is an outstanding opportunity for the VLT. Notes that the VLT is ahead of the pack on planning for ITER and burning plasma research**
- **Supports the near-term emphasis on ITER and burning plasma research but cautions that "care should be taken that these shifts [in funding] do no compromise the capability of the VLT."**
- **ARIES study on compact stellarator should definitely be supported to completion**

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Issue: Enabling R&D budgets have eroded substantially since FY03. Materials Science is latest capability to be lost.



VLT Virtual Laboratory for Technology For Fusion Energy Science

Presentation Format
(for each area/element presenter)

- **FY05/06 Technical Highlights/Accomplishments**

- **Proposed FY06 Tasks of President's Budget**
  1. List specific tasks with funding and deliverables
  2. Designate those tasks directly supporting ITER but not funded by ITER Project funds

- **Proposed FY07 Tasks - Three Categories**
  1. Tasks with funding and deliverables FY06 President's Budget level
  2. 10% below FY06 President's Budget level
  3. Full use of facilities and personnel

  For all three categories, identify those tasks directly supporting ITER, but not funded by ITER project funds.

FY06/07 Budget Considerations

- “In planning for the FY2007 ongoing base program, institutions should increase their focus on burning plasmas and identify specific tasks, such as high-priority ITPA R&D, theory, and technology R&D...”

  This is the major factor in planning the VLT program.
  Our planning assumes a positive ITER decision.

- “Regarding FY2007 funding for the U.S. contributions to the ITER project, the U. S. ITER Project Office will be responsible for preparing a funding plan for the BPM.”

  Ned to cover $3.5 M scope transferred from VLT

- The VLT program is thoroughly integrated into the IPPA Program Goals:
  - Lead on MFE Goal 4 (technology, materials, systems)
  - Major support on MFE Goal 3 (burning plasma)
  - Small support on MFE Goal 2 (innovative confinement concepts)

- Plasma technologies is reduced by $4.2 M in FY06.

  $3.5 M of work is transferred to the ITER Project Office as Other Project Costs (R&D and design).

- The Materials Science area is to be eliminated in FY06.

FY06 Enabling R&D Program Budget ($K) 1/14/05

Program Area	Program Elements	OFES PM	FY 04	FY 05 CBR	FY 05 IFP	FY 05 FEB	FY 06 Cong
Plasma Technologies	Plasma Facing Components	Nardella	5954	7054	7040	7195	5972
Plasma Technologies	Magnet Systems	Marton	2144	2248	2243	2243	1184
Plasma Technologies	Plasma Chamber Systems	Nardella	0	1894	1890	1690	1540
Plasma Technologies	ICH Systems	George	1334	1611	1608	1608	1205
Plasma Technologies	Safety and Environment	Nardella	1325	1580	1577	1727	1576
Plasma Technologies	ECH Systems	George	1185	1418	1415	1415	951
Plasma Technologies	Fueling Systems	George	930	1024	1022	1022	670
Plasma Technologies	Tritium Systems	Nardella	608	654	654	904	654
Plasma Technologies	Neutronics	Nardella	75	197	196	391	388
Plasma Technologies	Neutral Beam Systems	George	60	60	60	60	60
Plasma Technologies	IFE Closeout Costs	Nardella	0	0	156	156	0
Plasma Technologies	Taxes	Nardella	0	100	0	0	0
Plasma Technologies	**TOTAL**		**13615**	**17840**	**17861**	**18411**	**14200**
ITER Support	Magnet Systems	Marton					1091
ITER Support	Plasma Facing Components	Nardella					1200
ITER Support	ECH Systems	George					459
ITER Support	ICH Systems	George					400
ITER Support	Fueling	George					350
ITER Support	Tritium Systems	Nardella					0
ITER Support	Safety and Environment	Nardella					0
ITER Support	Neutronics	Nardella					0
ITER Support	**TOTAL**						**3500**
Advanced Design	Next Step Option-FIRE	Bolton	635	0	600	600	0
Advanced Design	IFE System Studies	Opdenaker	0	0	0	0	0
Advanced Design	MFE System Studies	Opdenaker	1655	1636	1686	1686	1686
Advanced Design	VLT Management	Nardella	704	697	696	696	695
Advanced Design	Socio-economic Studies	Opdenaker	30	150	80	80	80
Advanced Design	Burning Plasma Applications	Bolton	140	98	99	101	99
Advanced Design	ITER Cost Estimating	Marton	0	0	0	0	0
Advanced Design	**TOTAL**		**3164**	**2581**	**3161**	**3163**	**2560**
Materials Research	**Materials Science**	Nardella	**7629**	**7379**	**7323**	**7323**	**0**
Enabling R&D	**TOTAL**		**24408**	**27800**	**28345**	**28897**	**20260**

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Magnet Technology Mission

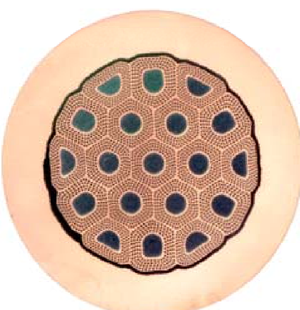
Reduce the size and cost of superconducting magnets by higher fields, current densities, stress levels and operating temperatures. Develop high critical temperature superconductors. Develop improved conductors and components for a Burning Plasma Experiment and advanced magnet concepts to achieve better physics performance. Develop cost effective design and fabrication techniques for IFE-HIF focusing magnets.

- **Support of LDX**
  - **Low and High Temperature superconducting magnet design, fabrication and testing**
- **Support of IFE-HIFD**
  - **HCX magnet and cryostat design, fabrication and test**
- **Support of Next Step Options**
  - **FIRE and ITER magnets**
- **Basic R&D**
  - **Superconductors and magnet insulation and structural materials**
  - **Education and training of students**

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Magnets Accomplishments FY05

- The Magnetics team has been working on magnet technology issues related primarily to the ITER Central Solenoid.
- Task Agreements completed in 3 areas:
  - **Stress Analysis of the Helium Inlet Regions (ITA 11-20)**
  - **Conductor Performance and Design Criteria (ITA 11-22)**
  - **CS Jacket Weld Defect Assessment (ITA 11-23)**
- VHTP
  - Nicolai Martovetsky/LLNL and Philip Michael/MIT have been working with the IT in Naka and are increasing their presence to 1 FTE total this year.
- Jacket Material Characterization
  - Measurements at 4K of processed JK2LB alloy showed unsuitability for use as jacket material
- Three new strand/cable experiments in process. Measurements/analysis expected this summer.
- ITER strand development contracts underway (US ITER funding-Task Agreement ITA 11-21).
  - First strand delivery in late Spring.



OXFORD INSTRUMENTS

Outkumpu Advanced Superconductors

SUPERCONDUCTING SYSTEMS, INC.

MIT PSFC

The University of Wisconsin-Madison Applied Superconductivity Center

VLT Virtual Laboratory for T For Fusion Energ

Magnets Program

- FY-06 Planned Accomplishments ($1184K)
  - **Advanced Superconductor:** Begin development of new $J_c(B,T,\varepsilon)$ test probe
  - **Modified Alloy Development:** Make trial heats of Boron-added Incoloy Alloy 908 for reduced SAGBO sensitivity
  - **Quench Detection Sensors:** Develop samples of optical fiber bundles and extraction methods
  - **Small Scale Experiment:** Characterize new ITER strands for transverse stress/bending strain sensitivity using test probes developed in FY05
- FY-07 Plans ($1184K)
  - **Advanced Superconductor:** Develop long lengths of MgB_2 superconductor and characterize
  - **Modified Alloy Development:** Full mechanical characterization of new alloys for jacket service (Base and Weld)
  - **Quench Detection Sensors:** Fabricate test coil with new sensors and measure for temperature/quench detection performance
  - **Small Scale Experiment:** Develop modified cables and support methods to reduce/limit transverse/bending degradation

MIT PSFC

The University of Wisconsin-Madison
Applied Superconductivity Center

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT PROGRAM ELEMENT: Magnets

Task Descriptions	FY06 (K$)		FY07 (K$)					
	CBR	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
Advanced Superconductor Development	125	50	125	20	125	50	243	143
Modified Alloy Development	120		75		120		120	
Quench Detection Sensors	256	256	250	250	256	256	256	256
Butt-Joint Development	159	159	159	159	159	159	159	159
Small Scale Experiment/Graduate Research	524	524	457	457	524	524	524	524
TOTALS	1184	989	1066	886	1184	989	1302	1082

Mission and Goals for Plasma Facing Components

- **The PFC Program mission is the development of plasma facing component systems capable of interfacing with the extreme conditions at the boundary of fusion grade plasmas.**

- **There are three goals:**

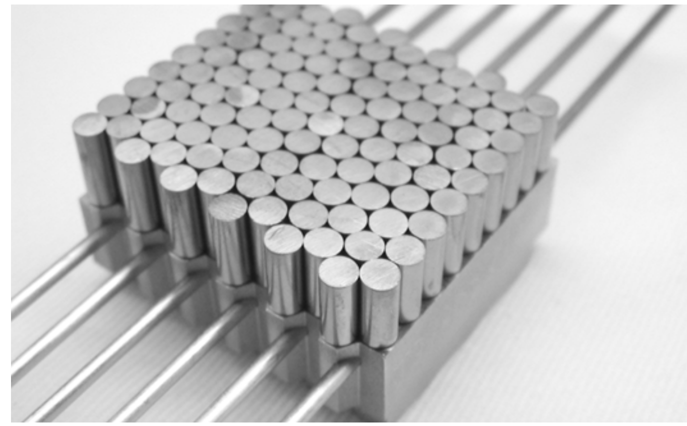
  - Engineering and design of innovative PFC systems for present day and next generation fusion experiments including burning plasma experiments such as ITER

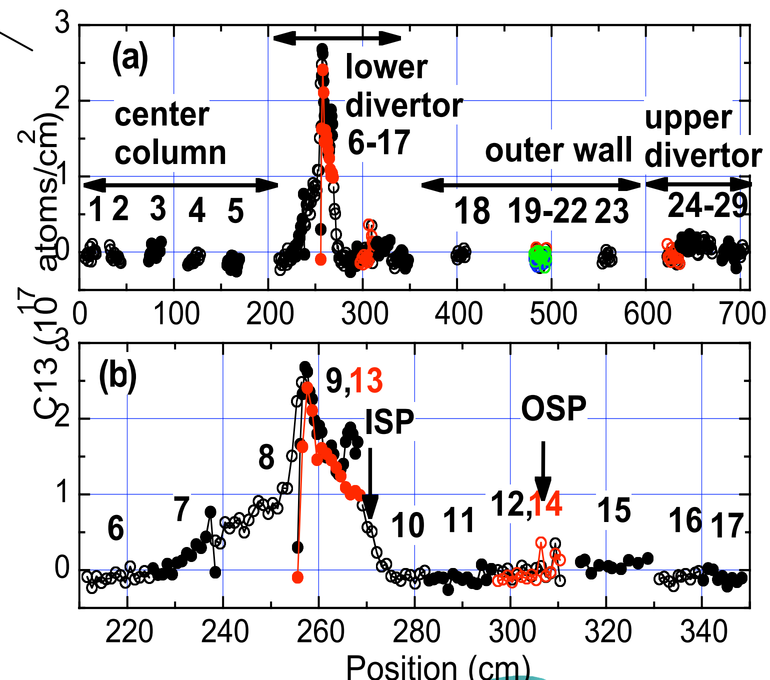
  - Advancing the scientific field of plasma materials interactions (PMI)

  - Developing the science and engineering foundation for the PFC system of DEMO.

PFC Accomplishments

- Collaborated with C-Mod to develop W rod on Inconel Divertor Tiles (brazing, HHF testing) (SNL&MIT)
- Measured ^{13}C transport in DIII-D by Nuclear Reaction Analysis (SNL)
- Measured H and He bubble formation in liquid Li (SNL)
- Continued development of liquid metal MHD code (UCLA)
- Began modeling of convective SOL transport effects on erosion of first wall in ITER (LLNL and ANL)

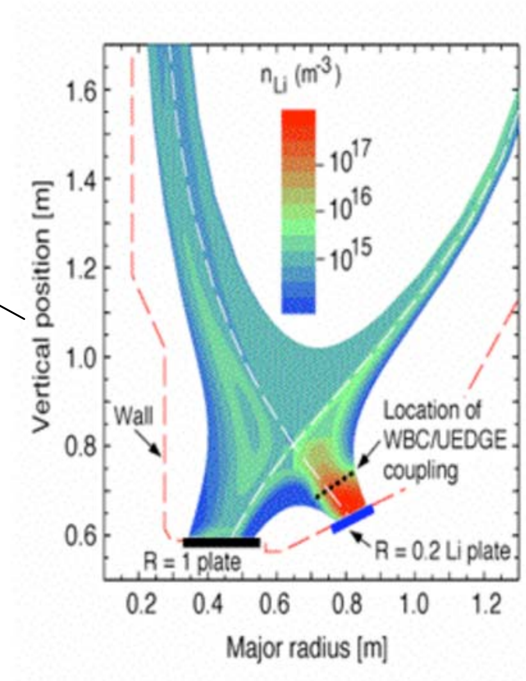


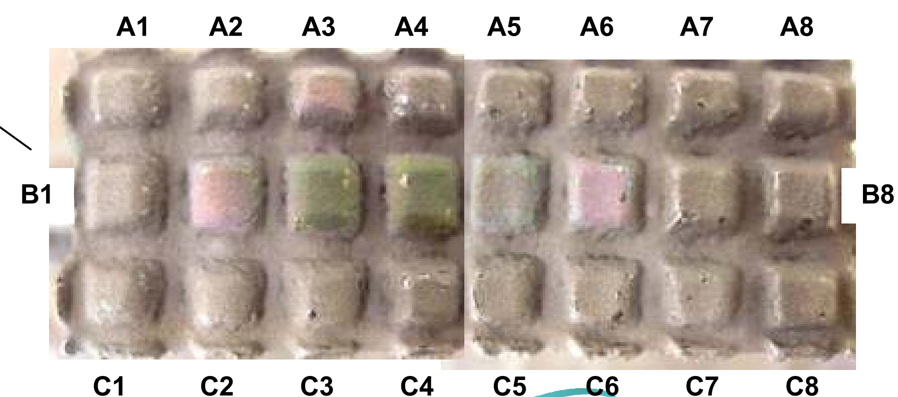


VLT
Virtual Laboratory for Technology
For Fusion Energy Science

PFC Accomplishments

- Calculated Li evolution and transport from a liquid Li surface on the NSTX divertor (ANL&LLNL)
- Computed vapor expansion from ELM strike on Dome PFC and found vapor get to X-point (ANL)
- Began development of ELM simulating plasma gun (UIUC)
- Modified EB-1200 to simulate ELM heat loads including fast IR temperature (SNL)
- Tested plasma sprayed Be on Cu for first wall in ITER (SNL)
- Conducted DiMES tile gap experiment (GA)





VLT
Virtual Laboratory for Technology
For Fusion Energy Science

PFC FY06 Major Plans

- **Solid Surface**
  - Improved W rod tiles for C-Mod
  - ELM Testing of ITER PFCs
  - Testing of FW options for ITER
  - Testing of Cu/SS heat sinks for ITER
- **Liquid Surface (slowed because of ITER priority)**
  - Improvements to MTOR and more Ga experiments
  - Liquid heat removal exp.
  - Liquid ELM experiments
  - Improved modeling of liquid MHD
- **Plasma Materials Interactions Exp.**
  - Tritium experiments on mixed materials (ITER)
  - Mixed material erosion studies (ITER)
- **Plasma Materials Interactions Model**
  - Improved coupling to UEDGE and WBC/REDEP for ITER
  - Modeling of ELM experiments with HEIGHTS
  - Modeling of T retention and release

PFC FY07 Major Plans

- **Solid Surface**
  - Continued ELM Testing of ITER PFCs
  - Testing of full size FW for ITER
  - Testing of prototype shield module for ITER
- **Liquid Surface (slowed because of ITER priority)**
  - Continued liquid experiments on MTOR
  - Continued Liquid ELM experiments
  - Improved modeling of liquid MHD
- **Plasma Materials Interactions Exp.**
  - Tritium experiments on mixed materials (ITER)
  - Mixed material erosion studies (ITER)
- **Plasma Materials Interactions Model**
  - Improved coupling of UEDGE and WBC/REDEP for ITER
  - Modeling of ELM experiments with HEIGHTS
  - Modeling of ITER SOL and ELMs

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT PROGRAM ELEMENT: Plasma Facing Components

	FY06 (K$)		FY07 (K$)					
	CBR	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
Task Descriptions								
Solid Surface PFCs (Expt. & modeling)	1305	680	1305	680	1305	680	2255	1580
Liquid Surface PFCs (Expt. & modeling)	1009		672		1009		1009	
Plasma Materials Interactions Expts.	2264	850	2024	800	2264	850	2364	850
PMI Modeling	1275	400	1264	400	1275	400	1625	450
TOTALS	5853	1930	5265	1880	5853	1930	7253	2880

VLT Virtual Laboratory for Technology
For Fusion Energy Science

Scope of Plasma Chamber Systems Activities

1. ITER test blanket module (TBM) program

- Active participation in ITER test blanket working group (TBWG).
- Evaluate blanket options for DEMO and evaluate R&D results for key issues to select primary US blanket concepts for testing in ITER in collaboration with materials, PFC, and safety communities.
- Perform concurrently R&D on the most critical issues required (e.g., MHD flow and insulators, tritium recovery and control, SiC inserts, solid breeder/multiplier/structure/coolant interactions).
- Enhance and focus current international collaborative R&D to provide data for ITER TBM.
- Develop engineering scaling and design, in collaboration with ITER partners, for TBMs.

2. Support for the basic ITER device

- Provide more accurate prediction in the nuclear area for critical ITER components as we move toward construction (e.g. diagnostics damage, personnel access, activation to assess site specific safety issues)

3. Predictive capabilities and tools needed by elements of fusion program

- Improve our predictive capabilities in areas of neutronics, activation, neutron-material interactions, heat transfer, fluid mechanics, MHD, tritium recovery and control, fuel cycle dynamics, reliability and availability.

4. International collaboration: JUPITER-II (Funds from Japan), IEA

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Progress in FY05 & expected accomplishments in FY06 on ITER TBM

Plasma Chamber Systems

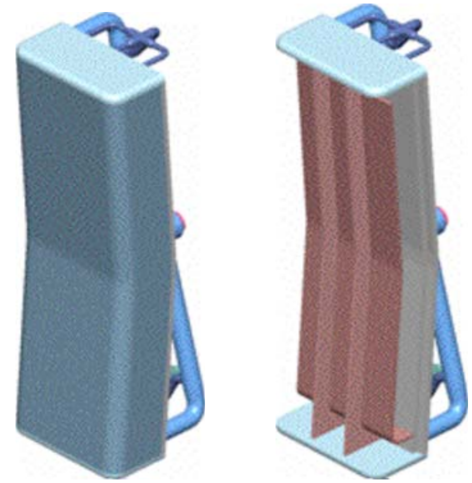
FY05

- Contributed to TBWG
- Evolved details of US strategy
- Delivered Design Description Document, meeting TBWG milestone

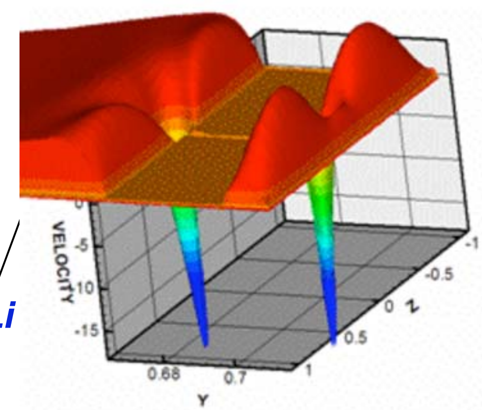
FY06

- Define engineering interface with ITER
- Contribute to the formation of international test plan for ITER
- Perform R&D needed for TBM systems

R&D Examples

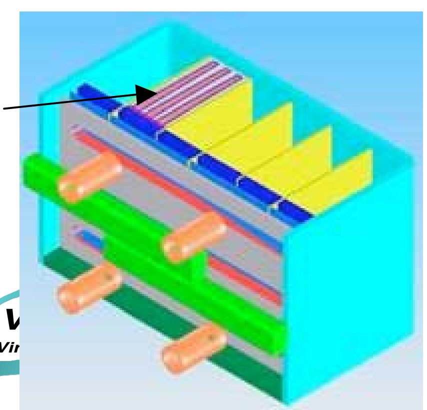


Dual Coolant Lead-Lithium TBM Views showing complete structure (left) and internal poloidal channels (right).

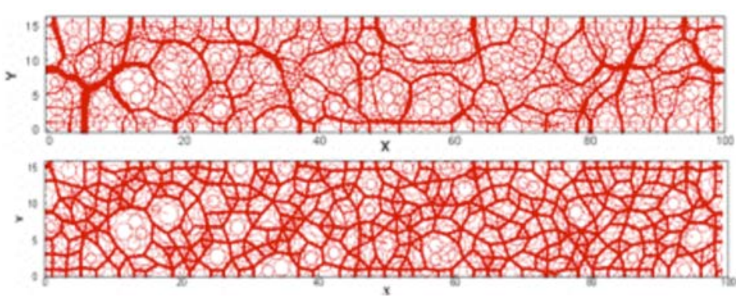


Reversed MHD flow jets near crack in SiC Flow channel insert

PbLi



US Unit Cell experiments in EU Helium Cooled Pebble Bed TBM

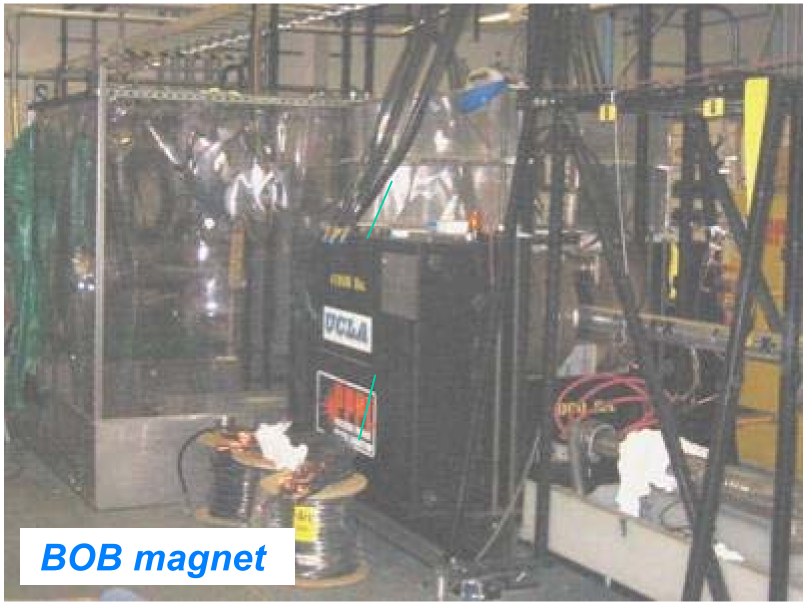


Force distribution at breeder particle contacts before and after onset of creep deformation

Progress in FY05 & expected accomplishments in FY06 on International Scientific Collaborations (Jupiter-2, IEA)

Plasma Chamber Systems

2T Open-Top gap magnet delivered by PPPL and installed in UCLA FLIHY loop for MHD turbulence experiments



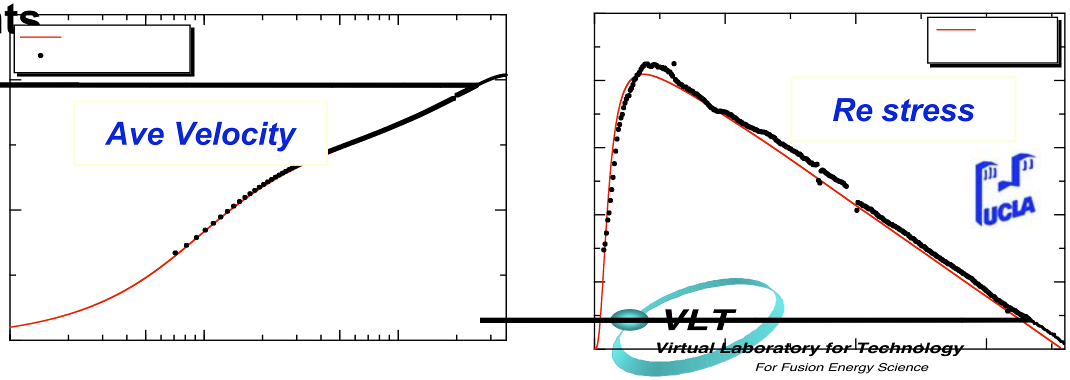
FY05

- ❑ Complete benchmarking phase of Jupiter-2 thermofluid task with turbulence and heat transfer measurements comparison to theory and modeling
- ❑ Complete facility transition to MHD operation with installation of special 2T gap magnet

FY06

- ❑ First-of-a-kind MHD turbulence and turbulence heat transfer experiments (2-year effort)

Agreement between experimental measurement and DNS turbulence modeling at Re = 11,300



Plasma Chamber Systems Activities in FY07

Effort will focus on essential needs of ITER and the US Fusion Program:

1. ITER test blanket module (TBM) program (ITER Utilization)

- **Active participation in ITER test blanket working group (TBWG).**
- **Perform R&D on the most critical issues required (e.g., MHD flow and insulators, tritium recovery and control, SiC inserts, solid breeder/multiplier/structure/ coolant interactions), in collaboration with ITER partners, for TBMs.**

The US has developed flexible strategy for the US participation in the International Test Program on ITER that:

a- maintains US flexibility in adjusting program based on available resources and international collaboration with ITER Partners, and

b- does not preclude US from utilizing its share of ITER space prior to negotiating future international agreement on the test program.

2. Predictive capabilities and tools needed by elements of fusion program

neutronics, activation, neutron-material interactions, heat transfer, fluid mechanics, MHD, tritium recovery and control, fuel cycle dynamics

3. International collaboration: JUPITER-II (Funds from Japan), IEA

Much of the current international collaborative programs have been refocused to provide data for ITER TBM.

4. Support for the basic ITER device

Note: ITER is a "nuclear" machine. Effort in the above tasks, despite being small budget, also serves the essential function of maintaining US core competence in fusion nuclear science and issues

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT PROGRAM ELEMENT: **Plasma Chamber Systems**

Task Descriptions	FY06 (K$) CBR	(ITER*)	FY07 (K$) -10%	(ITER*)	Flat	(ITER*)	Full	(ITER*)
US Contribution to the International Test Program on ITER (TBWG, Machine Interface)	600	(600)	630	(630)	700	(700)	700	(700)
TBM R&D	100	(100)	270	(270)	300	(300)	600	(600)
Predictive Capability	540	(540)	286	(286)	340	(340)	540	(540)
JUPITER-II Collaboration	300	(300)	200	(200)	200	(200)	200	(200)
Support for ITER Basic Device							300	(300)
TOTALS	1540	(1540)	1386	(1386)	1540	(1540)	2340	(2340)

*ITER (including TBM)

VLT Virtual Laboratory for Technology For Fusion Energy Science

Fusion Safety Program Mission

- Characterize and assess the safety and environmental issues associated with magnetic and inertial fusion. Assist the various design teams in improving the safety and environmental attributes of their design.
- Demonstrate the safety and environmental potential of fusion by (1) avoiding any need for off-site public evacuation during worst case accidents and (2) minimizing the amount of radioactive waste that would pose a burden for future generations.
- This is accomplished by:
  - Understanding the behavior of the largest sources of radioactive and hazardous materials in a D-T machine
  - Understanding how energy sources in a fusion facility could mobilize those materials
  - Developing integrated state of the art analytic tools to demonstrate the safety and environmental potential of fusion
  - Assessing/evaluating safety and environmental issues associated with emerging fusion concepts such as those studied in the MFE ARIES, ALPS, APEX, NSO projects, and the IFE program

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Safety, Environment and Tritium

- **FY-05 Accomplishments ($ 2631 K)**
  - **Completed installation and checkout of Tritium Plasma Experiment**
  - **Demonstrated REDOX control in Flibe molten salt under JUPITER-II collaboration**
  - **Initiated ITER safety tasks on safety codes, magnet safety and dust**
  - **Safety support for ITER TBM**
  - **Tritium plant R&D to support ITER**

Safety, Environment and Tritium

- **FY-06 Planned Accomplishments ($ 2230 K)**
  - In-vessel Tritium Source Term: **Experiments on tungsten and mixed materials in Tritium Plasma Experiment**
  - JUPITER II Support: **Lower concentration REDOX experiments (250 ppm) and corrosion experiments in Flibe as part of JUPITER-II collaboration**
  - Dust Source Term: **Dust characterization and mobilization studies**
  - Safety Codes, Magnet Safety and Safety Support: **Continue ITER safety analysis and magnet safety assessments. Initiate personnel safety task**
- **FY-07 Plans ($ 2230 K)**
  - In-vessel Tritium Source Term: **Experiments on mixed materials in Tritium Plasma Experiment**
  - JUPITER II Support: **Complete Flibe JUPITER II experiments. Preparing for post JUPITER II experiments**
  - Dust Source Term: **Continue dust mobilization experiments and initiate dust chemical reactivity experiments**
  - Safety Codes, Magnet Safety and Safety Support: **Continue ITER safety analysis, magnet safety assessments and personnel safety evaluations**

VLT PROGRAM ELEMENT: **Safety and In-Vessel Tritium**

Task Descriptions	FY06 (K$)		FY07 (K$)					
	CBR	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
Fusion Safety Codes	450	450	450	450	450	450	500	500
Magnet Safety	150	150	150	150	150	150	200	200
Dust Source Term	450	450	325	325	450	450	600	600
In-vessel Tritium Source Term	600	600	600	600	600	600	600	600
JUPITER II Participation	280		280		280		280	
Risk Assessment and Safety Support	300	150	200	150	300	150	350	200
TOTALS	2230	1800	2005	1675	2230	1800	2530	2100

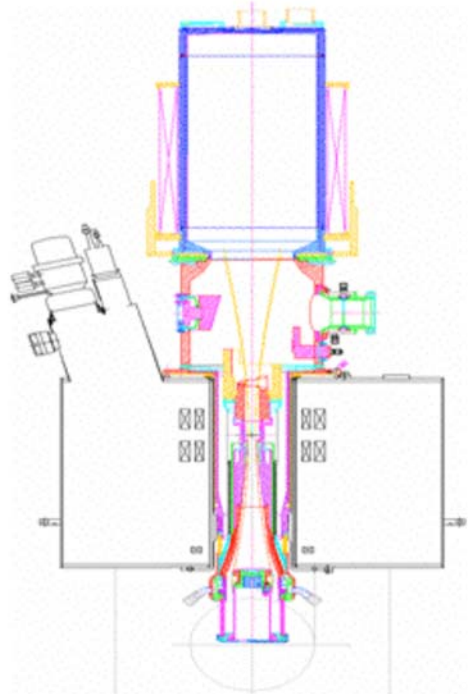
VLT
Virtual Laboratory for Technology
For Fusion Energy Science

ECH Mission / Scope

- Develop advanced, reliable technology for ECH, ECCD, EBW
  - Gyrotrons, Windows, Transmission Lines and Antennas.
- Support near term and burning plasma ECH experiments.
- Foster international collaboration.

- Increase the reliability, power and efficiency of gyrotrons.
  - Develop tunable gyrotrons for use at a range of B field values.
- Develop efficient mode converters to Gaussian beams.
- Increase the efficiency of transmission lines.
- Develop remote, steerable launchers.
- Develop the theory and design tools for the accurate design of new gyrotrons and transmission line components.
- Reduce the cost of all gyrotron system components.
- Develop a low cost gyrotron power supply system.

FY05 Advance: New Gyrotron World Record!!



- **Operation of CPI 140 GHz Gyrotron at <u>0.8 MW for 30 minutes</u> at <u>Greifswald / W7-X !!</u>**
- New <u>world</u> gyrotron Joule record.
- ITER relevant.

- 1.5 MW, 110 GHz gyrotron.
- <u>Achieved 0.5 MW, 10 s at CPI</u>
  - Pulse length limited by Test Set
- <u>Expect to test to > 1 MW, 10s at GA in FY05.</u>

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

FY06 ECH Technology Program

- Design, fabricate and test the **ITER 1 MW, 120 GHz Gyrotron** needed for the start-up of ITER.
- Conduct research on the **ITER Transmission Line and Launcher** system. The US is expected to supply all of the ITER transmission lines for both 120 GHz and 170 GHz gyrotrons, rated for power levels of up to 2 MW.
- Conduct **Gyrotron Reliability Studies** to understand and correct problems that limit gyrotron lifetime.
- Conduct **Experimental Gyrotron Research** on advanced gyrotrons in short pulse operation to demonstrate gyrotrons of up to 2 MW power level with at least 10% frequency tunability.
- Conduct a vigorous, pioneering program of research on **Modeling / Code Development** to provide advanced design tools for future gyrotron and transmission line development.

FY07 ECH Technology Program

- Level Funding Case:
  - Continue development of ECH technology as outlined for FY06.
- 10% Reduction Funding Case:
  - Reduce technology development about 10% in all areas.
- Full Funding Case:
  - Increase funding for the ITER 1 MW, 120 GHz Gyrotron development.
    - Develop 1 MW, 120 GHz gyrotron more rapidly.
    - Will allow early testing of transmission line components with 1 MW, 120 GHz gyrotron.

VLT PROGRAM ELEMENT: ECH Systems

Task Descriptions

	FY06 (K$)		FY07 (K$)					
	CBR	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
ITER 1 MW, 120 GHz Gyrotron	400	(400)	360	(360)	400	(400)	700	(700)
ITER Transmission Line and Launcher	140	(140)	126	(126)	140	(140)	140	(140)
Gyrotron Reliability Studies	100	(50)	90	(45)	100	(50)	100	(50)
Experimental Gyrotron Research	150	(50)	135	(45)	150	(50)	150	(50)
Modeling / Code Development	161	(80)	145	(72)	161	(80)	161	(80)
TOTALS	951	(720)	856	(648)	951	(720)	1251	(1020)

The long-term objectives are to develop reliable, advanced ICRF heating & current drive systems that:

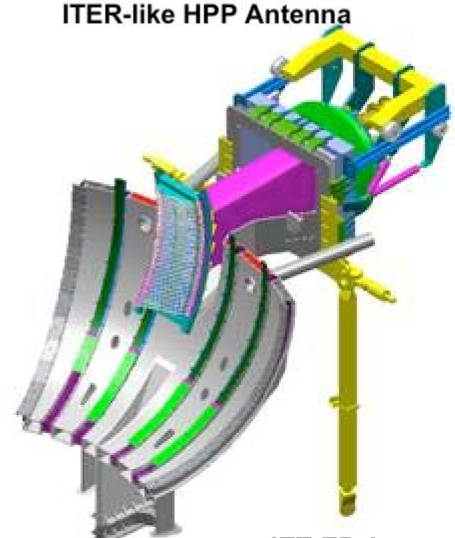
- Operate routinely at their design power and voltage.
- Reduce the required port size - high power density launchers.
- Are robust - tolerant of rapidly varying plasma loads.
- Are flexible
  - Operate over a wide range of density and magnetic fields.
  - Heat either ions or electrons
  - Control plasma conditions via heating and current profile.
- Support long pulses - essentially steady-state.
- Work reliably in a reactor environment.

RF Research and Development

•FY-05 Accomplishments ($ 1494 K)

- ITER ICH system planning, scheduling, and cost estimation.
- JET ITER-like High Power Prototype Antenna redesigned, rebuilt, and tested.
- Candidate RF ceramics to be irradiated in FY05 for neutron damage testing.
- Low power ITER mockup antenna built
- Initiated HV breakdown tests for rf arcing studies (ORNL & UIUC).
- RF/edge diagnostics improved on NSTX antennas.
- EBW emission receiver installed on NSTX.

ITER-like HPP Antenna



JET-EP Antenna

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

RF Research and Development

- FY-06 Planned Accomplishments ($ 1155 K)
  - **RF Component Development:** Faraday Shield and Tuning Elements (ITA 51-02 & 07)
  - **ITER ICH Antenna Design Support (ITA 51-01)**
  - **Ceramic Testing For Use in ITER Environment (ITA 51-08):** Loss tangent measurements
  - **High Power Density Antenna Development:** Commission and operate the JET-EP Antenna
  - **Improve Control, Reliability and Operation of ICH on Fusion Facilities**
  - **RF-edge Interactions** Modeling and diagnostics/experiments on fusion facilities
  - **RF Breakdown Studies:** ORNL and University of Illinois facilities
  - **Innovative Approaches to advanced heating and CD for new concepts**

- FY-07 Planned Accomplishments ($ 1155 K)
  - **RF Component Development:** Faraday Shield and Tuning Element Development (ITA 51-02 & 07), Long Pulse, High Power Prototype ITER Antenna Sector
  - **High Power Density Antenna Development:** JET-EP ITER-like antenna operation
  - **Improve Control, Reliability and Operation of ICH on Fusion Facilities**
  - **RF-edge Interactions**, **HV Breakdown Studies, and RF Test Facilities**
  - **Innovative Approaches to advanced heating and CD for new concepts**

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

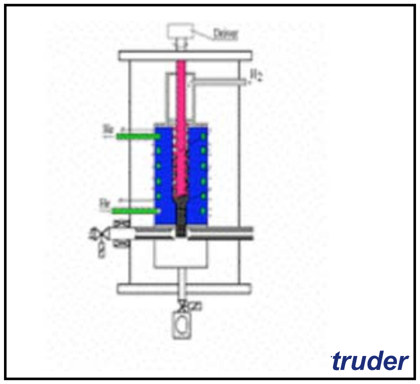
VLT PROGRAM ELEMENT: ION CYCLOTRON HEATING AND CURRENT DRIV

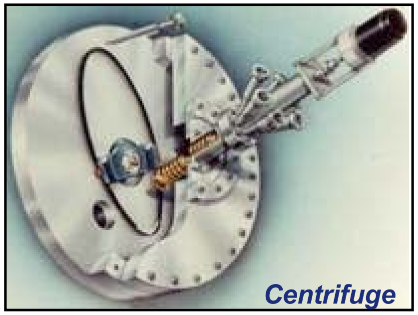
Task Descriptions	FY06 (K$)		FY07 (K$)					
	CBR	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
ITER ICH Antenna Design Support (ITA 51-01)	110	110	0	0	0	0	0	0
Ceramic Testing for Use in ITER (ITA 51-08)	50	50	0	0	0	0	0	0
RF Component R&D	300	300	300	300	300	300	300	300
Faraday Shield Development (ITA 51-02)								
Tuning Element Development (ITA 51-07)								
Long Pulse, HP Prototype Antenna Sector								
RF Test Facilities			100	100	200	200	350	350
High power density antenna development & test	100	100	50	50	50	50	100	100
(JET-EP antenna commissioning & operation)								
Improve control, reliability and operation of ICH on Fusion facilities	100		130		145		200	
RF-edge interactions	150	150	150	150	150	150	150	150
RF Breakdown Studies	245		210		210		245	
Innovative approaches to advanced heating and CD for new concepts	100		100		100		100	
TOTALS	1155	710	1040	600	1155	700	1445	900

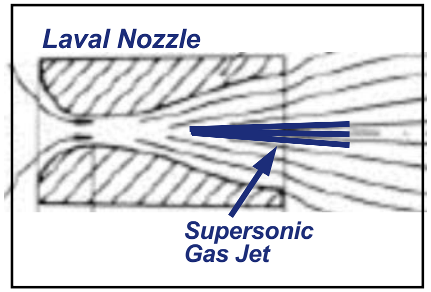
VLT
Virtual Laboratory for Technology
For Fusion Energy Science

New Technical Challenges for ITER Fueling System

- ITER pellet injector baseline is a centrifuge fed by a continuous screw extruder
- High throughput and tritium compatibility
  - Continuous screw extruder rates are ~5-10 times lower than that required (Viniar, RF)
  - Highest ice flow rates to date are ~67% of ITER requirements using three batch extruders operating in sequence (Combs et al.)
  - Snail pump needed for excess extrusion material
- Centrifuges have not yet achieved the reliability objective (~100% intact pellets).
- Pneumatic injectors can more easily meet reliability requirements, but have a gas load issue.
- Significant R&D effort still required before final ITER design; development and testing program will be needed to validate the proposed design.
- Generic technology development may lead to supplemental approaches (supersonic gas jet, high-speed vertical injector, inner bore PI, etc.)



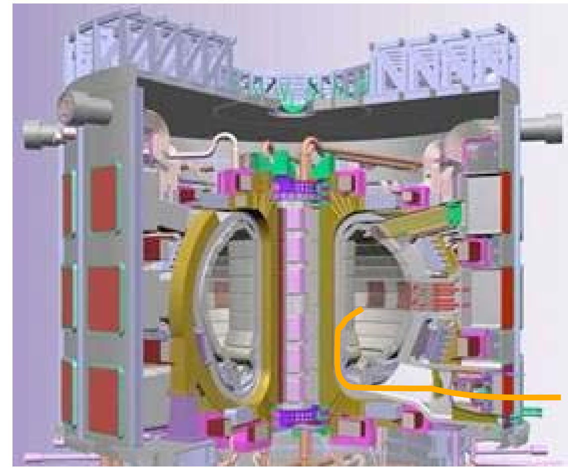


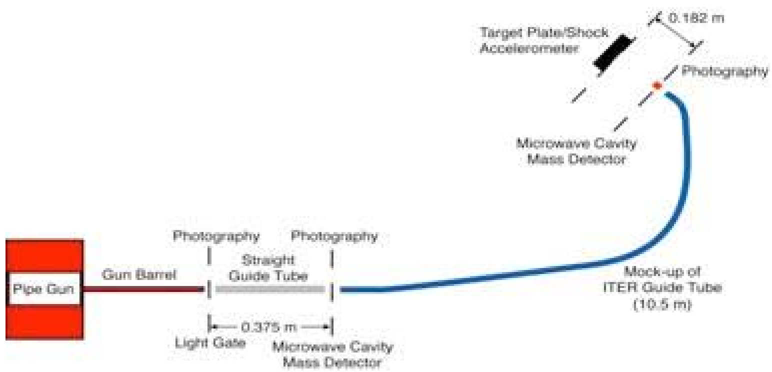


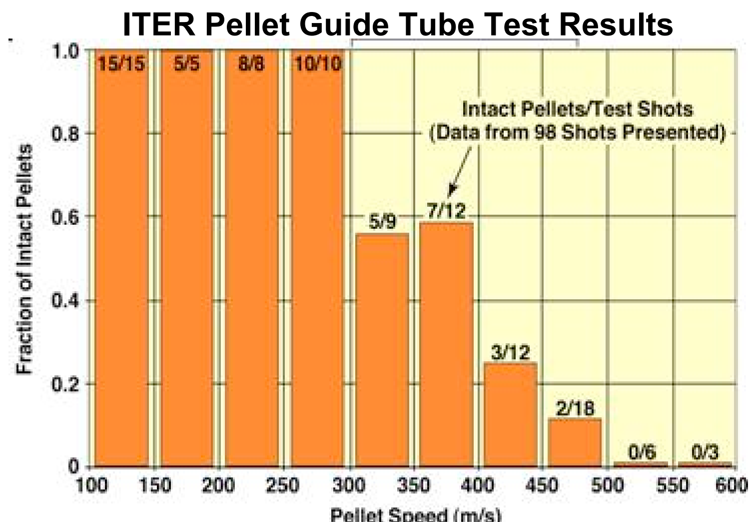
VLT Virtual Laboratory for Technology
For Fusion Energy Science

Fueling Development

- FY-05 Accomplishments ($ 942 K)
  - Test of ITER pellet guide tube survivability
  - ITER pellet injector concept development
  - Development of pellet ELM triggering device concept
  - Modeling of ITER fueling scenarios
  - High throughput fast valve development for massive gas puff disruption mitigation
  - Preparation of CD-1 and CD-2 estimates and schedules for ITER fueling and pumping procurement packages
  - Flexible pellet injector and pellet plasma diagnostics for MST fueling and transport studies







VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Fueling Development

- FY-06 Planned Accomplishments ($ 670 K)
  - **High throughput formation:** Evaluate continuous extrusion technologies
  - **Deep pellet fueling:** Test compact two-state gas gun injector developed for use on burning plasmas
  - **ELM mitigation:** Development of compact high repetition rate pellet dropper for ELM mitigation with pellets
  - **Disruption mitigation:** Test of high throughput fast valve on DIII-D
  - **Fueling and transport tools for alternates:** Development of compact flexible pellet injectors and pellet plasma diagnostics
- FY-07 Plans ($ 670 K)
  - **Pellet formation:** High throughput extruder development with cryocooler
  - **Pellet fueling:** Optimize guide tube design for pellet survivability
  - **ELM mitigation:** Evaluate compact pellet dropper for ELM mitigation
  - **Disruption mitigation:** Continue development of massive gas puff technology
  - **Fueling and transport tools for alternates:** Pellet injection for low wall recycling devices

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT PROGRAM ELEMENT: Fueling and Pumping

	FY06 (K$)		FY07 (K$)					
	CBR	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
Task Descriptions								
High throughput	200	200	0	0	0	0	0	0
Deep fueling	50	50	50	50	50	50	50	50
Centrifuge prototype development	150	150	150	150	150	150	150	150
ITER Guide tube tests and optimization	50	50	0	0	0	0	0	0
ITER fueling scenarios	50	50	50	50	50	50	50	50
Fueling tools for alternates	70		120	120	120	120	220	220
Disruption and ELM mitigation	100	100	150	150	150	150	150	150
Fueling/pumping and diagnostic test facility			80	80	150	150	300	300
TOTALS	670	600	600	600	670	670	920	920

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Fusion Materials Science Mission Statement

- Advance the materials science base for the development of innovative materials and fabrication methods that will establish the technological viability of fusion energy and enable improved performance, enhanced safety, and reduced overall fusion system costs so as to permit fusion to reach its full potential

- Assess facility needs for this development, including opportunities for international collaboration

- Support materials research needs for existing and near-term devices

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

FY04-05 Materials Achievements: science-based research with a long-term view is yielding numerous near-term tangible benefits

•Resumed ITER in-vessel materials work, including critical assessment of properties data and R&D to fill database gaps for ITER design and construction

• Five materials patented by US fusion materials researchers are being commercialized, including a cast stainless steel (R&D100 award) and a 3Cr steel that is in the final stages of ASME code qualification (potentially 1 B$/year alloy)

•A fracture mechanics Master Curve model was successfully developed for V alloys and ferritic-martensitic steels. (ANS Mat. Sci.&Technol. best paper 2004)

• Modeling and experiments revealed key physical mechanisms for flow localization in irradiated metals, which will lead to improved radiation-resistant materials

• 4th-generation radiation-resistant SiC/SiC composites utilizing advanced SiC fibers, SiC multilayer interphases, and novel matrix infiltration methods have been designed

• High-impact scientific discoveries: Research published in high-impact journals including PRL, Nature, Science uncovered new mechanisms for He diffusion and clustering in metals, defect cluster annihilation by gliding dislocations, one-dimensional defect cluster diffusion, and plastic deformation mechanisms

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Outstanding ITER materials issues assigned to US

- Critical assessment of data for ITER materials properties handbook
  - In-vessel structure and armor materials (Cu alloys, 316SS, superalloys, etc.)
  - candidate polymer materials for the vacuum vessel support system
- Fill gaps in existing ITER materials database that are needed for realistic engineering design
  - Investigate potential for irradiation assisted stress corrosion cracking in copper alloys
  - Allowable dose limits for IC plasma heating feedthrough insulators
  - CuCrZr irradiated fracture toughness
  - Effect of various plasma facing material bonding techniques on properties
- Identify potential for new degradation phenomena under ITER-relevant conditions
  - Various electrical degradation mechanisms in plasma diagnostics during irradiation
- Establish viability of materials systems for proposed ITER test blanket modules
  - Low dose neutron effects on properties of various weldments and base materials
  - Effects of thermomechanical treatment on the properties of candidate materials after low dose neutron irradiation
  - Chemical compatibility of material, coolants and fusion environment (including tritium)

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Fusion Materials Science: FY07 plans

- ITER in-vessel materials activities
  - Complete critical assessment of existing data; perform R&D to fill missing gaps
  - Complete testing and analysis to determine maximum allowable doses for IC plasma heating feedthrough insulators and polymers for vacuum vessel support system
  - Examine effect of various plasma facing material bonding techniques on properties
  - Identify potential degradation mechanisms in plasma diagnostics during irradiation
- High-performance structural materials
  - As part of DOE/JAERI and Jupiter-II collaborations, assess feasibility of candidate structural materials for ITER test blanket modules and follow-on machines
    - Effects of thermomechanical processing, joining, and low dose neutron irradiation
    - Chemical compatibility of materials and coolants in fusion environment (including tritium)
    - Stress and structural integrity analyses
- Functional materials
  - Examine feasibility of buried insulator layers for mitigating MHD effects in liquid metal cooled systems; mechanical testing of ductile Mo alloys for high heat flux applications
- Cross-cutting theory and modeling
  - Multiscale modeling of radiation effects on mechanical properties of materials; structural analyses of ITER test blanket module structures

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

VLT PROGRAM ELEMENT: Materials Sciences

Task Descriptions	FY06 (K$)		FY07 (K$)					
	Flat	(ITER)	-10%	(ITER)	Flat	(ITER)	Full	(ITER)
ITER structure and insulator materials R&D	1700	1700	2000	2000	2000	2000	2200	2200
High performance structural materials (including US match for US/Japan R&D)	3420	2280	2800	2300	3270	2400	3550	2680
Functional Materials (insulators, ductile Mo,etc.)	380	150	200	150	330	200	360	230
Cross-cutting theory and modeling	1820	1090	1590	1130	1720	1180	1900	1360
IFMIF fusion neutron materials test facility	0		0		0		0	
TOTALS	7320	5220	6590	5580	7320	5780	8010	6470

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

ARIES Research Bridges the Science and Energy Missions of the US Fusion Program

- Mission Statement:

  Perform advanced integrated design studies of the long-term fusion energy embodiments to identify key R&D directions and provide visions for the program.

- Commercial fusion energy is the most demanding of the program goals, and it provides the toughest standard to judge the usefulness of program elements.

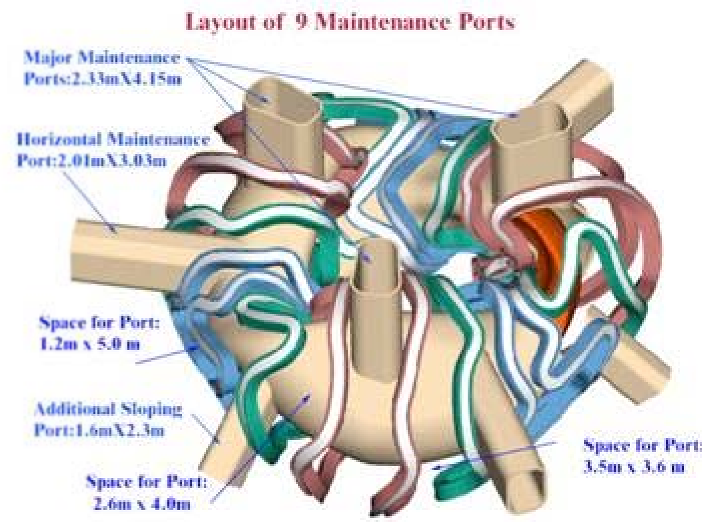
- Knowledge base of fusion power plants involves subtle combinations of physics, technology, and engineering. Extensive systems studies are needed to identify not just the most effective experiments for the moment, but also the most cost-effective routes to the evolution of the experimental, scientific and technological program.

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

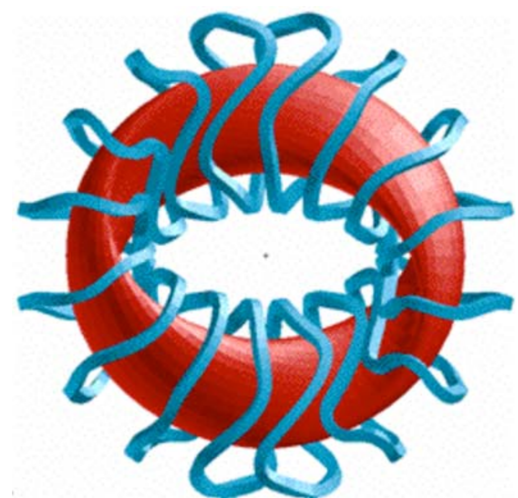
Advanced Design (ARIES)

FY05 Accomplishments ($1,686k) –
ARIES Compact Stellarator Study

- The physics basis of QA as candidate of compact stellarator power plants has been assessed. New configurations have been developed, others refined and improved, all aimed at low plasma aspect ratios (A ≤ 6), hence compact size.
- Modular coils are designed to examine the geometric complexity and the constraints of the maximum allowable field, desirable coil-plasma spacing, coil-coil spacing, etc.
- Assembly and maintenance appears to be the key issue in configuration optimization.
- 11 publications.



NCSX-Like



MHH2

Virtual Laboratory for Technology for Fusion Energy Science

Advanced Design (ARIES)

FY06 Plans ($1,686k)

- Continuation of ARIES Compact Stellarator Study
  - ✓ Deployment of tools to compute heat and particles (edge plasma and α particles) on in-vessel components (useful also for NCSX)
  - ✓ Detailed comparison of compact stellarator configuration developed. A town-meeting with Stellarator community is planned.
  - ✓ Choosing one compact stellarator configuration for detailed study

FY07 Plans ($1,686k)

- Completion and documentation of ARIES Compact Stellarator Study

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Issues: Materials and Plasma Technologies

- **Elimination of Materials Sciences program**
  - **Seriously compromises the fourth leg of DOE fusion strategy-** ***Materials, Components, Technologies***
  - **Jeopardizes ITER test blanket development of international partners (DOE/JAERI materials collaboration)**
  - **OFES is steward of DOE radiation effects materials science program**
  - **Loss of ability to leverage other resources (NASA/DOE-NR space reactors, DOE-NE Gen IV etc.).**
- **$3.5 M of Plasma Technologies (heating and current drive, fueling, PFCs, and magnets) was transferred out of the VLT to ITER R&D and design (Other Project Costs).**
  - **OK assuming ITER is going forward.**

Summary

- **The VLT is increasing its support of burning plasma issues--will be about 50% of the CRB budget in FY06 and FY07.**

- **The CRB results in the loss of the materials science capability and transfer of $3.5 M out of the VLT to support the ITER project.**

- **There are important needs and opportunities for incremental budgets**
  - **FY06: Restore the Materials Science program**
  - **FY07: ~$2 M**

The European view.

"In parallel the long-term technology programme has been generating the technological knowledge base that should allow Europe to design and operate fusion power plants. Without this accompanying work, JET would probably have not achieved its remarkable success. It is this coordinated effort and integration of the overall Fusion Community which has allowed Europe to lead the world in this field of research.“

Janez Potocnik,
European Commissioner for Science and Research
March 3, 2005 speech at the JET fusion facility

VLT
Virtual Laboratory for Technology
For Fusion Energy Science