Virtual Laboratory for Technology Input to Budget Planning Meeting

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VLT Director

Gaithersburg, Maryland
March 15, 2006

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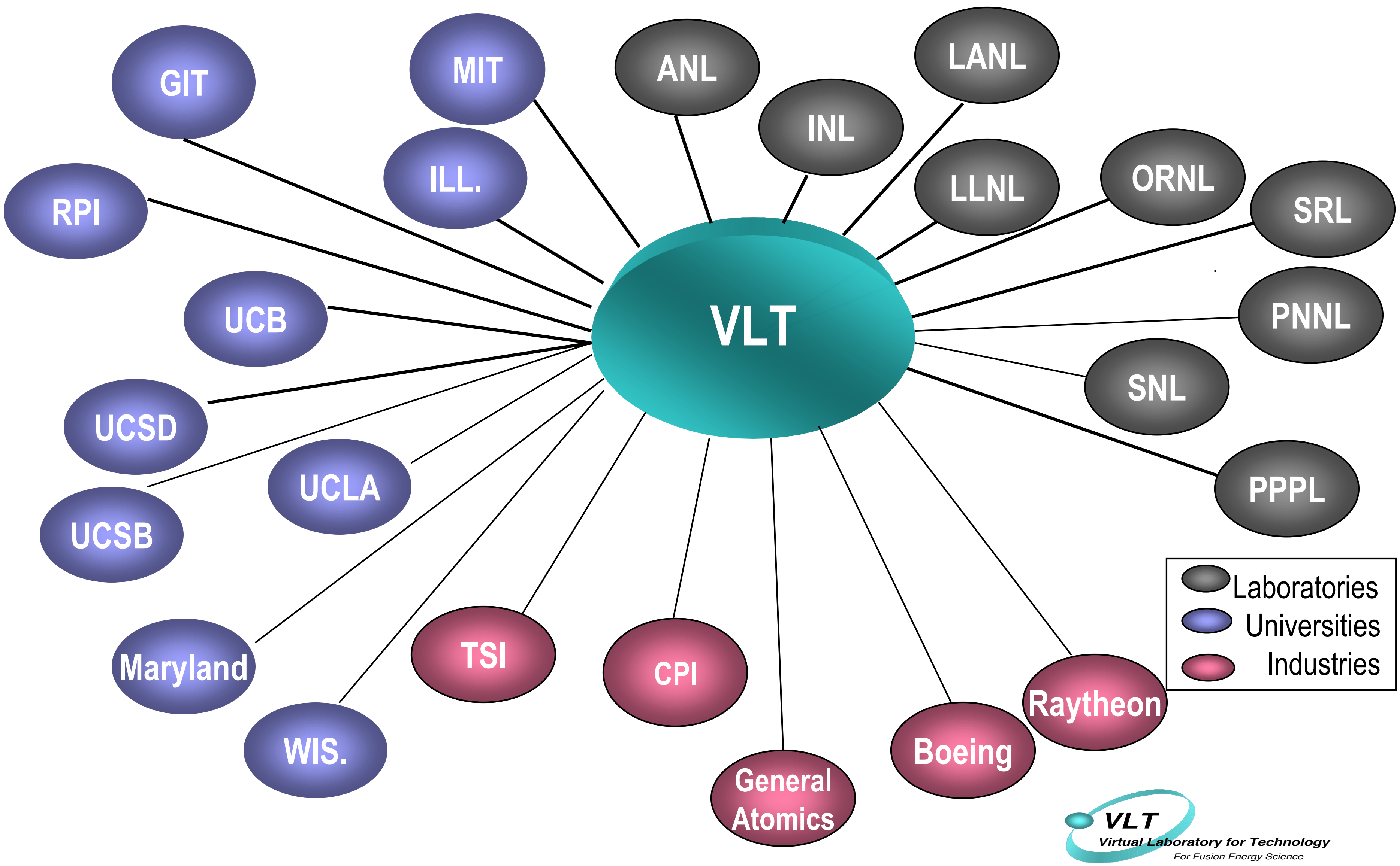
Outline

- **VLT Mission, Organization**
- **Overview of FY06/07 Budget Situation**
- **For each element**
  - **Highlights of technical accomplishments**
  - **FY07 tasks and funding**
  - **FY08 tasks and funding (-10%, Flat and Full Use cases)**
- **Special Issues**
  - **Declining technology funding trend**
  - **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 Program Element Leaders

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***
Safety & Tritium Research	**D. Petti - *INL***
Tritium Processing	**S. Willms - *LANL***
NSO/FIRE	**TBD**
ARIES	**F. Najmabadi - *UCSD***
Socio-Economic	**L Grisham - *PPPL***
Materials	**S. Zinkle* - *ORNL***

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FY07/08 Budget Considerations

- "In planning for the FY2008 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 a major factor in planning the VLT program.

- "Regarding FY2008 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 Sauthoff to cover work performed by VLT performers

- The VLT program is thoroughly integrated into three overarching goals and associated research campaigns:

  — Lead on O3 *(Develop technology to realize fusion energy)* through the *Fusion engineering science* campaign (T 13-15)

  — Strong support of O2 *(Create a star on earth)* and O1 *(Understand matter in high temperature state)*

- Plasma technologies is reduced by $1.3 M (9%) in FY07.

  Impacts ICH and ECH heating, Magnets

- The Materials Science area is reduced by $2.4 M (33%) in FY07.

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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**

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 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

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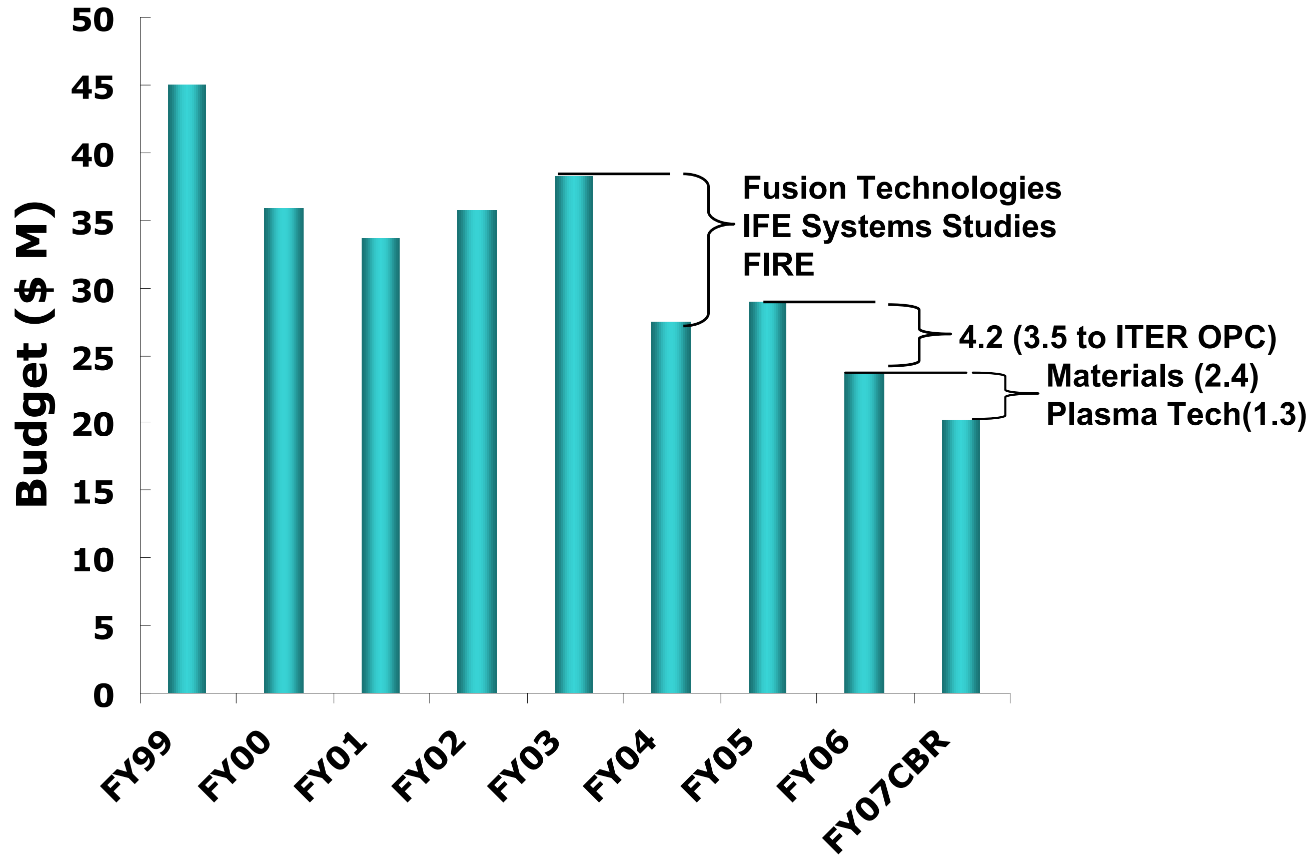
Base program enabling R&D budgets have eroded substantially since FY05. Materials Science and Plasma Technologies are reduced by 33% and 9% in FY07 .



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FY07 Enabling R&D Program Budget ($K) 2/1/06							
B&R	Program Area	Program Elements	OFES PM	FY 04	FY 05	FY 06 FEB	FY 07 CONG
AT6010301	Plasma Technologies	Plasma Facing Components	Nardella	5954	6932	5655	5625
AT6010301	Plasma Technologies	Magnet Systems	Marton	2144	2243	1137	90
AT6010301	Plasma Technologies	Plasma Chamber Systems	Nardella	0	1690	1620	1640
AT6010301	Plasma Technologies	ICH Systems	George	1334	1708	1360	1570
AT6010301	Plasma Technologies	Safety and Environment	Nardella	1325	1727	1643	1675
AT6010301	Plasma Technologies	ECH Systems	George	1185	1415	926	546
AT6010301	Plasma Technologies	Fueling Systems	George	930	1022	750	775
AT6010301	Plasma Technologies	Tritium Systems	Nardella	608	934	654	654
AT6010301	Plasma Technologies	Neutronics	Nardella	75	516	435	320
AT6010301	Plasma Technologies	Neutral Beam Systems	George	60	60	50	50
AT6010301	Plasma Technologies	IFE Closeout Costs	Nardella	0	156	0	0
	Plasma Technologies	**TOTAL**		**13615**	**18403**	**14230**	**12945**
AT6010501	Advanced Design	Next Step Option-FIRE	Bolton	635	431	0	0
AT6010501	Advanced Design	MFE System Studies	Opdenaker	1655	1686	1643	1716
AT6010501	Advanced Design	VLT Management	Nardella	704	696	701	744
AT6010501	Advanced Design	Socio-economic Studies	Opdenaker	30	80	80	50
AT6010501	Advanced Design	Burning Plasma Applications	Bolton	140	86	40	40
	Advanced Design	**TOTAL**		**3164**	**2979**	**2464**	**2550**
AT602010	**Materials Research**	**Materials Science**	Nardella	**7629**	**7338**	**7043**	**4687**
AT60	**Enabling R&D**	**TOTAL**		**24408**	**28720**	**23737**	**20182**

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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**

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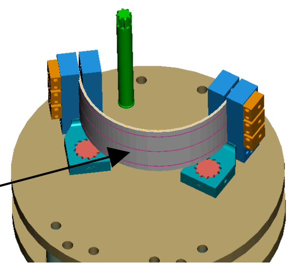
Presentation Format
(for each area/element presenter)

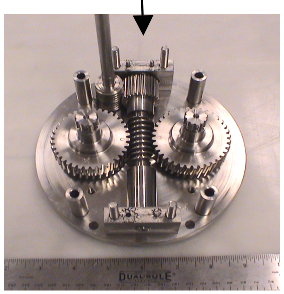
- **FY05/06 Technical Highlights/Accomplishments**
- **Proposed FY07 Tasks of Congressional Request Budget**
  List specific tasks with funding and deliverables
- **Proposed FY08 Tasks - Three Categories**
  Tasks with funding and deliverables FY07 Congressional Request level
  10% below FY07 Congressional Request level
  Full use of facilities and personnel

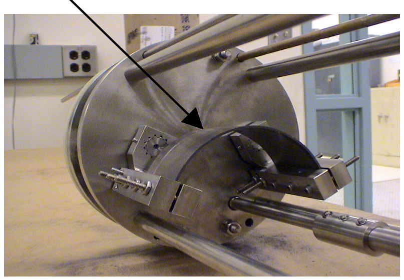
Magnet Technology FY05/06 Technical Highlights

- Base Program work is focused on understanding the effects of transverse compression and pure bending through analysis and 3 lab experiments (graduate student research):
  - —Pure bending in a single strand
  - —Fixed bending in a single strand/measurement of filament breakage
  - —Transverse compression in a multistrand cable



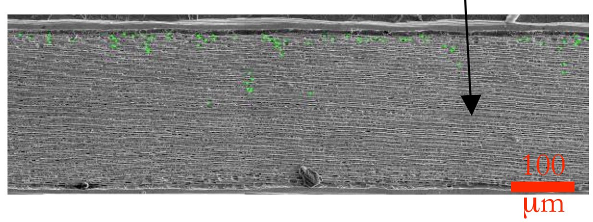
Pure bending in a single strand experiment

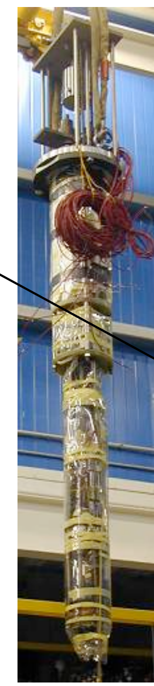


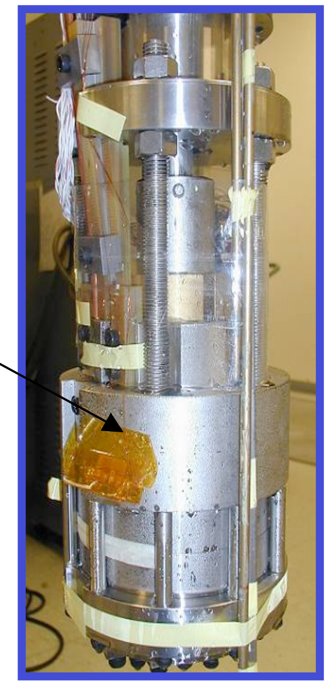


Transverse compression in a multistrand cable

Measurement of filament breakage

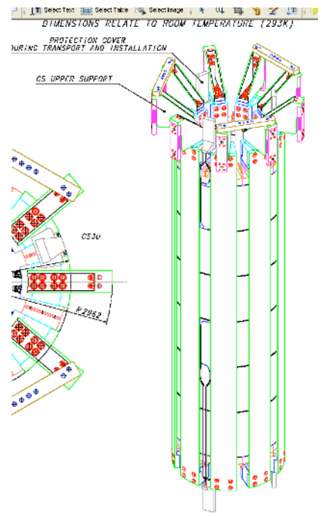


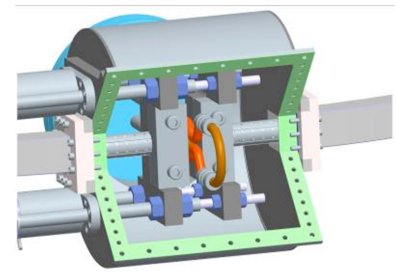


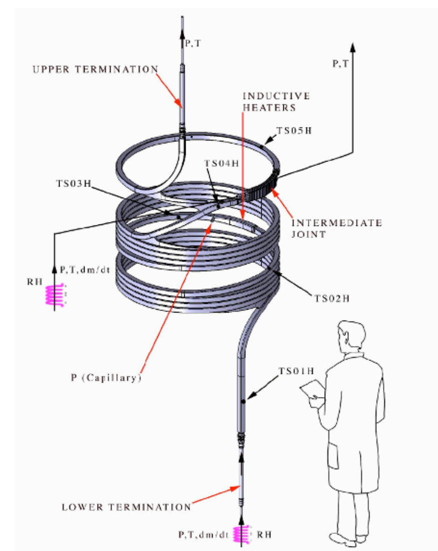


LLNL effort in magnet technology for fusion

- Butt joint development
- ITER CS Design
- PF Insert preparation for testing
- ITER CS Procurement Documentation



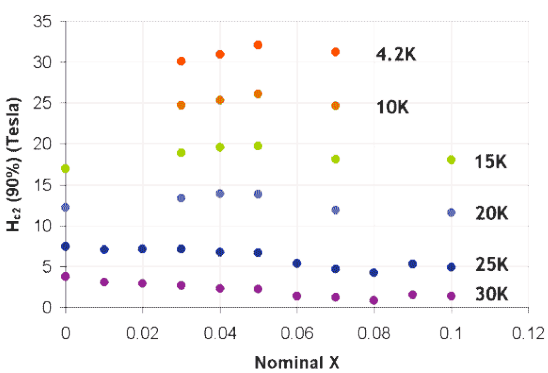




UW-ASC MgB_2: The Quest for Better and Cheaper High Field Superconductors for Fusion

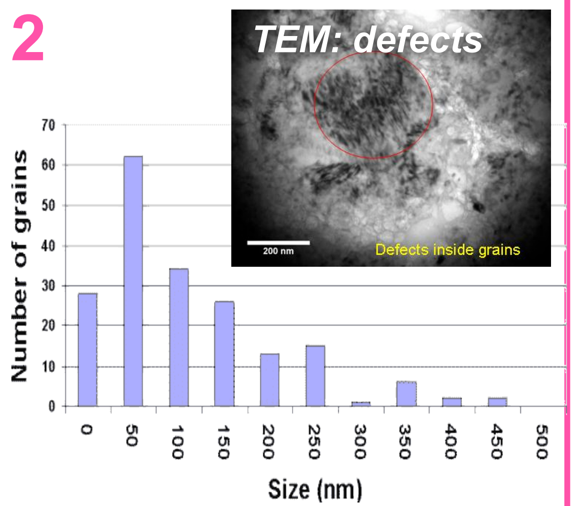
- Driving Force: MgB_2 has the potential for huge cost savings vs Nb based or Ag stabilized superconductors. ($s for MgB_2 vs $70/lb Nb).
- Goal: J_c(H) must be raised at high fields. There are three routes to this result:
  - 1) Increase H_{c2}, thereby decreasing the magnitude of $\delta J_c/\delta H$
  - 2) Increase pinning in the material
  - 3) Eliminate micro/nanostructural obstacles to current flow.
- We are making progress on all 3 approaches.

1



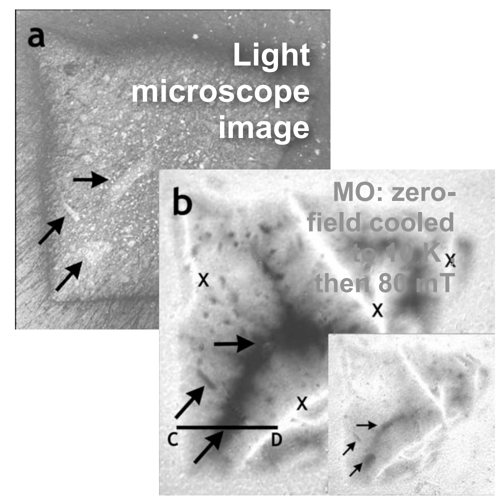
H_{c2} enhanced by dopant.

2



J_c improved by reducing grain size using ball milling and introducing pinning defects.

3



Bright islands in "a" correlate directly to important features in the MO image "b".

VLT PROGRAM ELEMENT: Magnets

Task Descriptions	FY07 (K$)	FY08 (K$)		
	CBR	-10%	Flat	Full
MIT (Small Scale experiments & jacket alloy)	**0**	0	0	889
LLNL (PF coil insert tests)	**0**	0	0	128
NIST (Strand Jc (B, T, ε))	**0**	0	0	20
FSU -Applied Superconductivity Center (MgB_2 development)	90	81	90	99
TOTALS	90	81	90	1136

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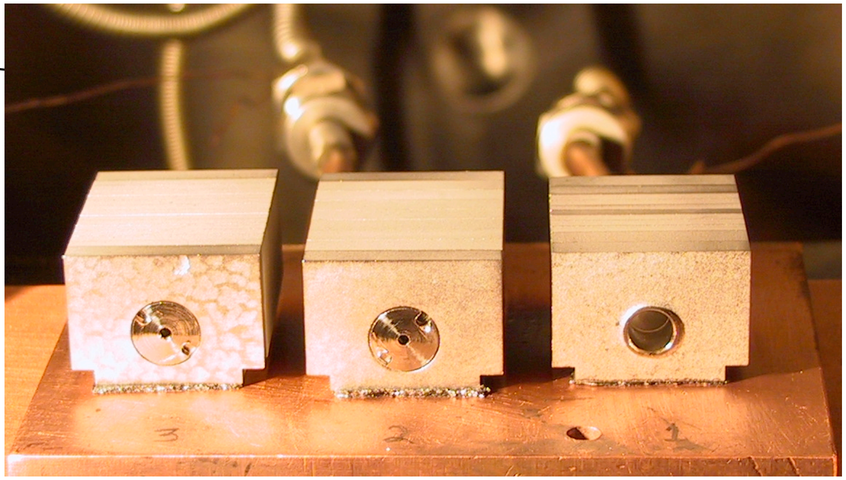
PFC Accomplishments

- Collaborated with C-Mod to develop W lamellae Divertor Tiles (HHF testing) (SNL&MIT)
- Measured ^{13}C transport in DIII-D by Nuclear Reaction Analysis (SNL)
- Continued development of liquid metal MHD code (UCLA)
- Modeled convective SOL transport effects on erosion of first wall in ITER (LLNL and ANL)
- SBIR support with test of PPI He-cooled W tube test. (SNL)



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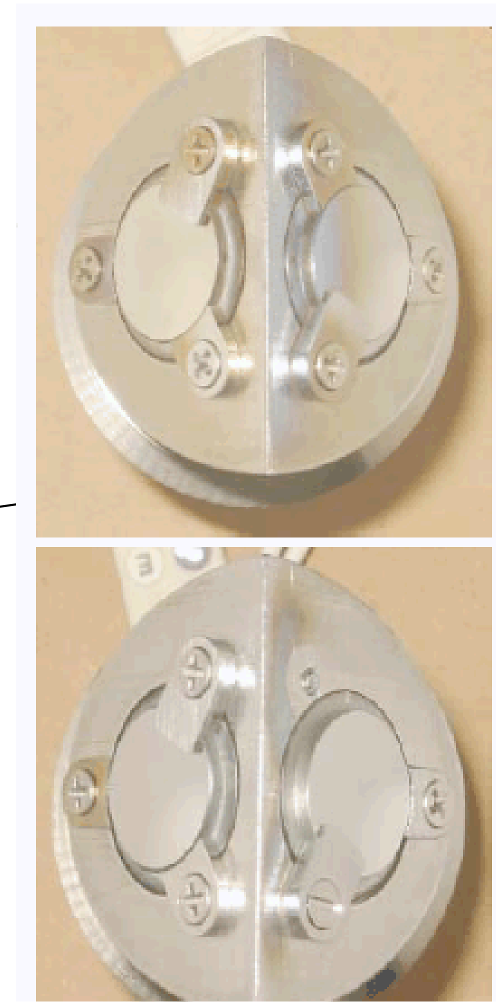
PFC Accomplishments

- Computed ELM strike on ITER First Wall, found high T at Be to Cu interface for thin Be (ANL)
- First ELM thermal transient materials experiments on PISCES (EFDA collaboration)
- Conducted DiMES tile gap experiment and DiMES mirror deposition experiment (GA)
- Gathered surplus e-guns and power supplies to improve robustness of PMTF for ITER testing (60kW gun and 250kW PS)



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PFC FY07 Major Plans

- **Solid Surface**
  - Testing of ITER first wall qualification mockups
  - QA development for FW for ITER
  - Testing of prototype shield module for ITER
  - Testing of DIII-D divertor tiles
- **Liquid Surface (slowed because of ITER priority)**
  - Modeling of NSTX evaporation experiments
  - Initial modeling of LTX
- **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

PFC FY08 Major Plans

- **Solid Surface**
  - ELM Testing of ITER PFCs
  - Testing of FW and shield prototypes for ITER
  - Testing of Port Limiter mockups for ITER
- **Liquid Surface (slowed because of ITER priority)**
  - Continued MTOR experiments and modeling
  - Modeling of NSTX and LTX experiments
- **Plasma Materials Interactions Exp.**
  - Tritium experiments on mixed materials (ITER)
  - Mixed material erosion studies (ITER)
- **Plasma Materials Interactions Model**
  - Extension of ITER erosion studies to more of the first wall
  - Modeling of ELM experiments with HEIGHTS
  - Modeling of T retention and release

VLT PROGRAM ELEMENT: Plasma Facing Components

Task Descriptions	FY07 (K$)	FY08 (K$)		
	CBR	-10%	Flat	Full
Solid Surface PFCs	1816	1764	1816	2016
Liquid Surface PFCs	819	608	819	1009
Plasma Materials Interactions Expts.	2926	2633	2926	3682
PMI Modeling	185	167	185	315
TOTALS	5746	5172	5746	7022

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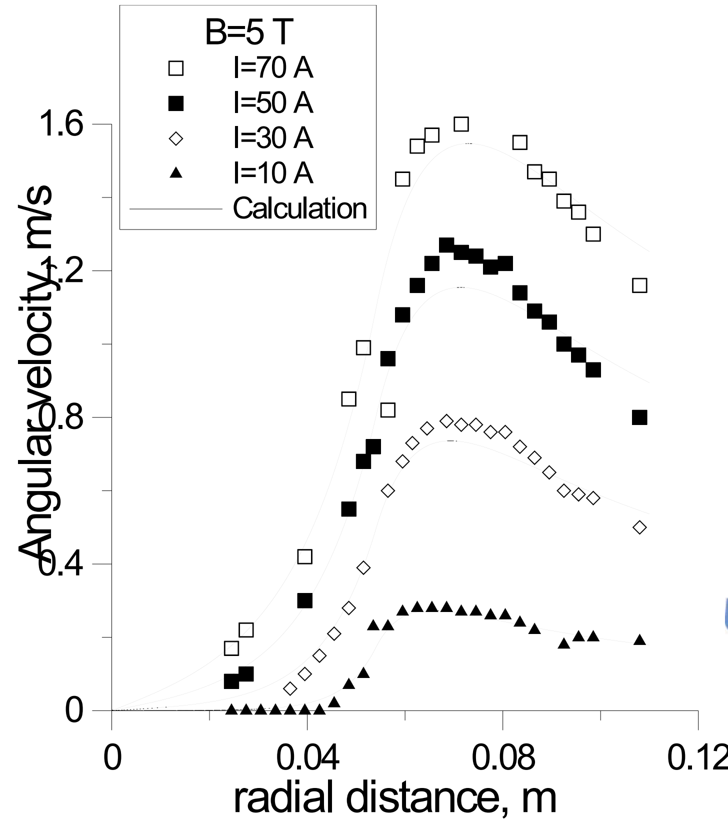
Plasma Chamber

FY06 Accomplishments ($1540k)
Examples:

- ❑ Complete US ITER TBM Technical Planning and Costing Report for DCLL and HCCB TBMs per DOE request (with input from other technology program elements)
- ❑ Strong contributions to TBWG
- ❑ Performed 1st MHD turbulence measurement experiments as part of JUPITER-II collaboration with Japanese University researchers
- ❑ Incorporated constitutive equations for experimentally derived thermo-mechanical properties into a commercial finite element code ready for HCCB TBM design analysis



Comparison of newly developed MHD turbulence model for TBM shows agreement with experimental data from Grenoble MATUR experiment –the model (developed at UCLA) will be integrated into 3D simulation tools in FY07

UCLA

Plasma Chamber

Planned FY07 Accomplishments ($1540k)

Examples:

- Complete establishment of ITER test blanket program framework by providing US TBM design and analysis needed for ITER licensing document, and TBM analysis of necessary resources for ITER interfaces. Continue active participation in TBWG
- Complete Jupiter-II collaboration with database of MHD turbulence and heat transfer behavior, and SiC plate contact behavior with solid breeder pebble beds
- Continue critical R&D for ITER TBM:
  - Initiate LM manifold experiments in UCLA MTOR Facility (possible post-Jupiter collaboration subject)
  - Verify high Hartmann number capability of HIMAG 3D simulation tool
  - Initiate small scale helium flow manifold experiments providing data for thermofluid simulation tool verification

VLT PROGRAM ELEMENT: Plasma Chamber Systems

Task Descriptions	FY07 (K$)	FY08 (K$)		
	CBR	-10%	Flat	Full
US contribution to the international test program on ITER (TBWG, machine interface)	600	630	700	800
TBM R&D	100	270	300	1900
TBM engineering design	100	90	100	1100
Predictive capability	540	286	340	500
JUPITER II collaboration	300	200	200	200
Support for ITER basic device				300
TOTALS	1640	1476	1640	4800

US ITER Test Blanket Module (TBM)

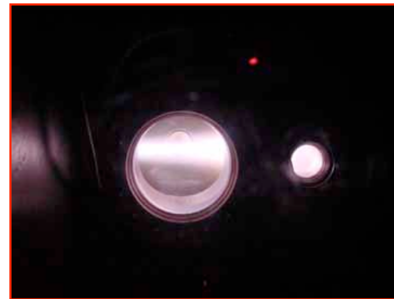
- Testing of blanket modules in special ports is one of the principal objectives of ITER. TBM is a key element in ITER utilization.
- The US has been an active participant and a leader in the ITER Test Blanket Working Group (TBWG), which is officially charged with: a) defining details of TBM engineering interfaces with the basic device, and b) developing a coordinated Test Blanket Module (TBM) program that takes into account ITER operational plans.
- US TBM activities have been carried out as a partnership among the Plasma Chamber, Materials, Safety, Tritium, and PFC programs.
- The TBM team has been engaged during the past year in developing strategy, technical plan, and cost estimates for US participation in ITER TBM. A draft report has been prepared. Reviews by the community and costing experts are expected this summer.
- The Plasma Chamber and Materials programs are focusing a substantial part of their resources on TBM.
    - These resources need to be augmented beginning in FY08.
- About $6.5M of new resources are needed in FY08 to support an optimum TBM effort. (These resources are to be utilized by the Plasma Chamber($2700k), Materials($2800k), Safety and Tritium($700k), and PFC programs ($450k).)

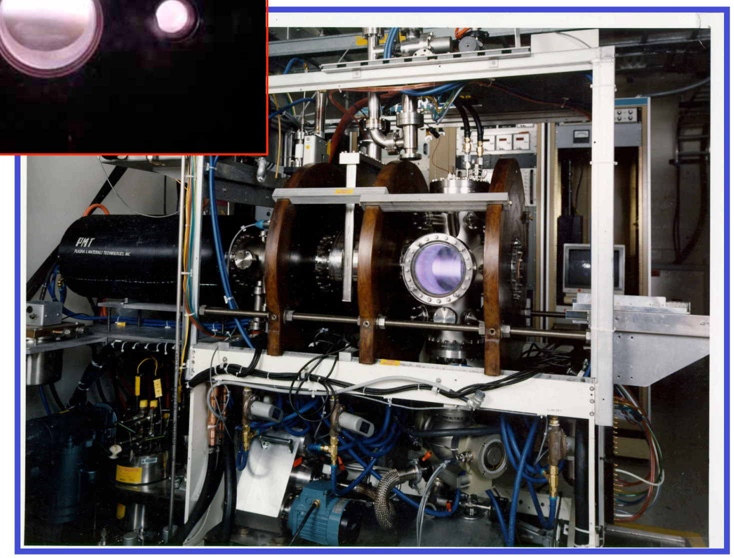
Key TBM Tasks for FY08

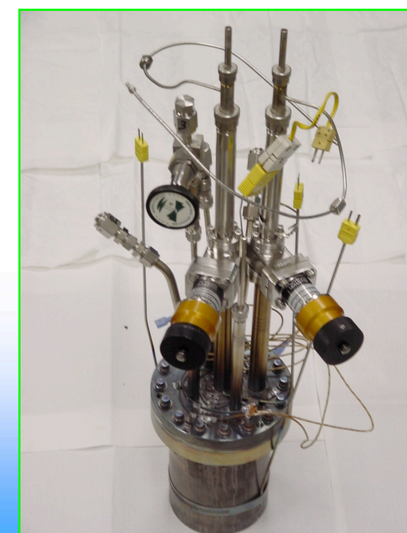
- Continued participation in TBWG and ITER Project to define and document licensing, qualification, and ITER interfaces for TBM systems (PC, Materials, Safety)
- Ferritic steel fabrication technology development with US vendors (Materials)
- Thermofluid liquid metal MHD tests with 1^{st}-generation SiC/SiC flow channel inserts (PC)
- US TBM systems preliminary engineering design and analysis phase (PC, Materials, Safety, Tritium, PFC)
- Begin helium coolant loop upgrades for TBM surface heat flux test facility (PFC)

Safety, Environment and Tritium

- FY-06 Accomplishments ($ 2230 K)
  - Initiated Tritium testing in STAR meeting DOE-OFES Milestone.
  - Completed first set of tungsten/tritium tests in Tritium Plasma Experiment
  - Completed Flibe molten salt corrosion testing under JUPITER-II collaboration
  - Provided safety support to ITER regulatory approval process
  - Led dust source term effort for ITER Team
  - Safety support for ITER TBM







Safety, Environment and Tritium

- FY-07 Planned Accomplishments ($ 2230 K)
  - **In-vessel Tritium Source Term:** Complete testing on tungsten in Tritium Plasma Experiment
  - **JUPITER II Support:** Complete JUPITER II Flibe/tritium experiments. Planning for post JUPITER II experiments on tritium permeation
  - **Dust Source Term:** Continue dust mobilization experiments and initiate dust chemical reactivity experiments
  - **Safety Codes, Magnet Safety and Safety Support:** Continue ITER safety analysis, verification and validation activities, magnet safety assessments and personnel safety evaluations. Support ITER safety report submission. Support ITER TBM
- FY-08 Plans ($ 2230 K)
  - **In-vessel Tritium Source Term:** Experiments on mixed materials in Tritium Plasma Experiment
  - **Post-JUPITER II Support:** Begin post-JUPITER II experiments on tritium permeation
  - **Dust Source Term:** Continue dust mobilization experiments and dust chemical reactivity experiments; begin to examine dust removal technologies
  - **Safety Codes, Magnet Safety and Safety Support:** Continue ITER safety analysis, verification and validation activities, magnet safety assessments and personnel safety evaluations. Resolve outstanding issues associated with ITER safety report. Support ITER TBM

VLT PROGRAM ELEMENT: Safety and In-Vessel Tritium

Task Descriptions	FY07 (K$)	FY08 (K$)		
	CBR	-10%	Flat	Full
Fusion Safety Codes	400	325	400	500
Magnet Safety	150	150	150	200
Dust Source Term	400	300	400	550
In-vessel Tritium Source Term	750	750	750	750
JUPITER II/Post JUPITER II Participation	280	280	280	280
Risk Assessment and Safety Support	250	200	250	1100
TOTALS	2230	2005	2230	3380

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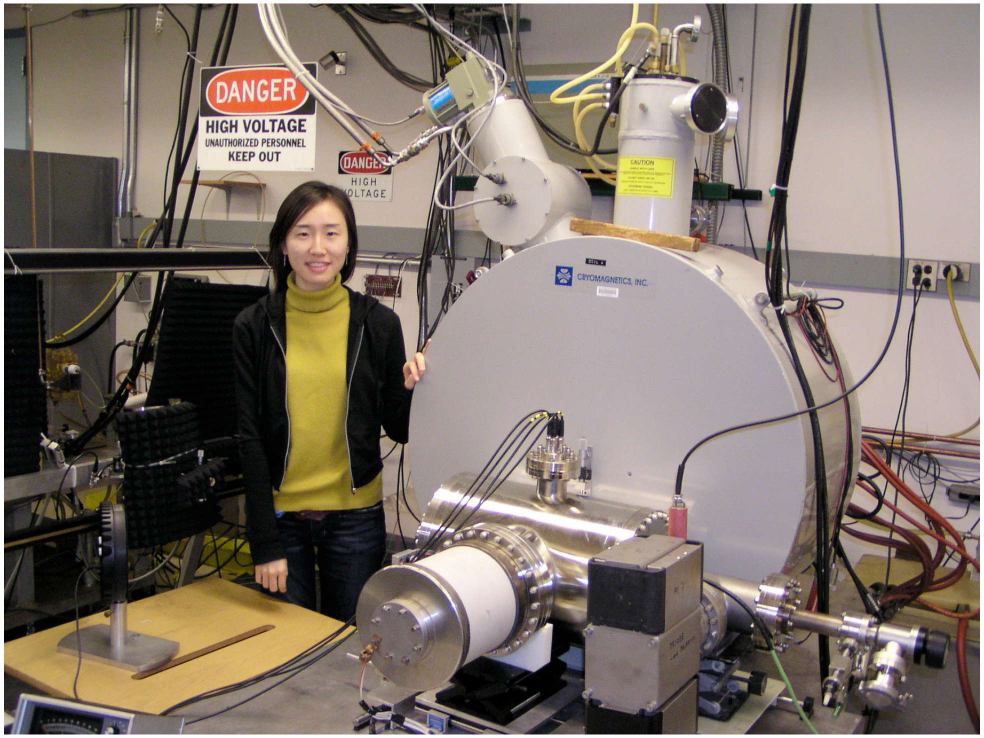
FY06 Advances: Gyrotrons & T-Lines



- Pulsed 1.5 MW, 110 GHz gyrotron with optimized cavity operated at MIT with internal mode converter and depressed collector.
- **Achieved efficiency > 50%.**

- **Cu coated CFC mirror** disk built by GA, to be tested in FY06 in a miter bend on a transmission line at DIII-D.

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FY07 ECH Technology Program

- Advanced, low loss **Transmission Line** components
  - Research on advanced concepts for reducing losses; helps ITER.
- **Experimental Gyrotron Research** on advanced gyrotrons, to demonstrate high efficiency and $> 10\%$ frequency tunability.
- Conduct a vigorous, pioneering program of research on **Modeling / Code Development** to provide advanced design tools for future transmission line and gyrotron development.
- **Research progress in FY07 is severely curtailed due to funding reductions at MIT, from $475k in FY06 to $180k in FY07. Support for three out of four students terminated.**
- **Industrial Gyrotron Development and Gyrotron Reliability Studies at CPI are terminated.**
  - Funding lost to ITER OPC, but no US ITER gyrotron task
  - Very major loss to US enabling technology programs.
  - Highly visible termination of world leading effort.

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FY08 ECH Technology Program

- **Level Funding Case:**
  - Continue development of ECH technology as outlined for FY07.
- **10% Reduction Funding Case:**
  - Reduce funding except for transmission lines.
- **Full Funding Case - Restore Funding to FY05 Level of $1415k.**
  - Restore MIT student-led research program on pioneering ECH technology, including gyrotron and transmission line research (+$295k)
  - Restore industrial development (CPI) program (+$540k)
    - Tunable (95 to 115 GHz) 1.5 MW gyrotron for DIII-D.
    - Studies of gyrotron reliability.

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VLT PROGRAM ELEMENT: ECH Systems

Task Descriptions	FY07 (K$)	FY08 (K$)		
	CBR	-10%	Flat	Full
Transmission Line Research	206	206	206	400
High Efficiency Gyrotron Research	210	170	210	275
Modeling / Code Development	130	115	130	200
Gyrotron Reliability Studies	0	0	0	140
Industrial Gyrotron Development	0	0	0	400
TOTALS	546	491	546	1415

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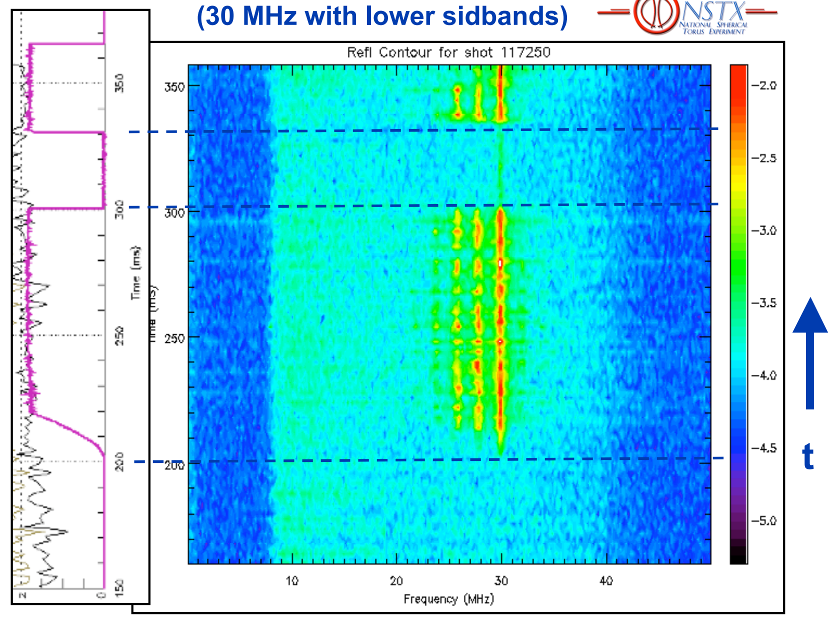
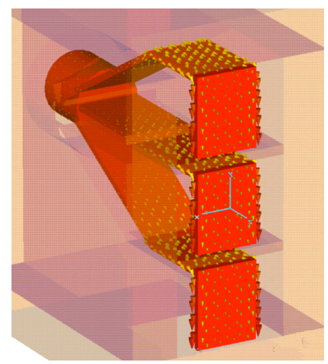
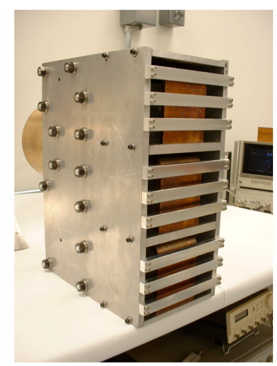
RF Research and Development

- FY-06 Accomplishments ($1255 K)
  - Candidate RF ceramics irradiated in HFIR for neutron damage evaluation/qualification for burning plasma applications.
  - RF/edge reflectometer on NSTX HHFW antenna upgraded to measure edge fluctuations (i.e. parametric decay sidebands).
  - Two steerable EBW emission receivers installed on NSTX to explore EBW coupling.
  - HV breakdown test stand for rf arc studies commissioned (ORNL & UIUC).
  - Externally tuned concept for ITER antenna modeled & compared to mockup measurements
  - Refurbished and installed DIII-D 60 MHz FW antenna
  - Preparation of estimates and schedules for ITER ICH transmission line and tuning procurement package

NSTX Reflectometer Fluctualtion Spectra
(30 MHz with lower sidbands)







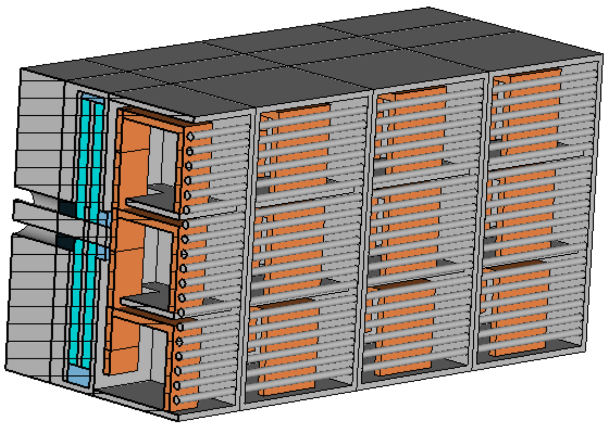
Strap array element for possible externally tuned ITER Antenna

RF Research and Development

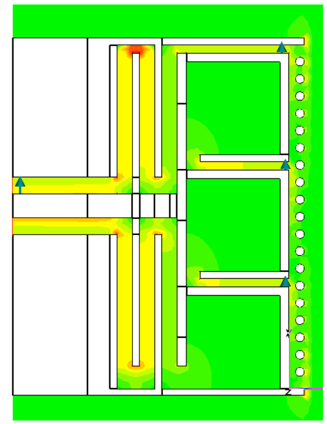
- FY-07 Planned Accomplishments ($1455 K)
  - **RF Component Development:** Burning plasma qualified ceramics, Faraday shields, compact inductive and capacitive tuning elements and cw transmission line components for ITER
  - **High Power Density Antenna Development:** Commission and operate the JET-EP antenna, conceptual design of long pulse, low voltage antenna for DIII-D and model ITER coupling physics
  - **Improve Control, Reliability, Protection and Operation of ICH on Fusion Facilities:** Flexible and reliable control systems and matching networks for NSTX, DIII-D, MST and ITER
  - **RF-edge Interactions:** Modeling and diagnostics/experiments on fusion facilities with arc detectors, probes and refectometers on NSTX, DIII-D, C-Mod and ITER
  - **RF Breakdown Studies:** ORNL and University of Illinois facilities
  - **Innovative Approaches to Advanced Heating & CD for New Concepts:** EBE -> EBW for STs and stellarators

- FY-08 Planned Accomplishments ($1455 K)
  - **RF Component Development:** Compact inductive and capacitive tuning elements and long pulse components
  - **High Power Density Antenna Development:** JET-EP antenna operation, long pulse, low voltage antenna design.
  - **Improve Control, Reliability, Protection and Operation of ICH on Fusion Facilities:**
  - **RF-edge Interactions and HV Breakdown Studies**
  - **Innovative Approaches to Advanced Heating & CD for New Concepts**

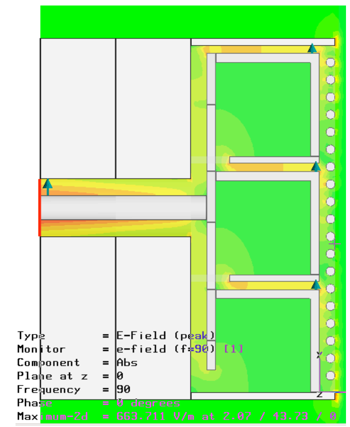
We are Exploring the Advantages of Low Voltage Antenna Array Concepts for Long Pulse H&CD



4X3 antenna array for long pulse FW H&CD in ELMing H-mode plasmas



E-field distribution for internally tuned FW Antenna



E-field distribution for externally tuned FW Antenna

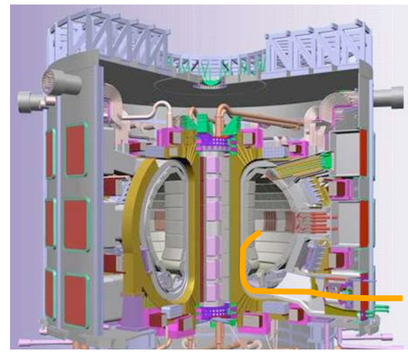
- **Long pulse (10s) to allow steady state FW H&CD**
- **Short strap array (4x3 vs 4x6) and DIII-D edge plasma conditions (H-mode ELMs, gradients, large plasma gaps) are similar to ITER challenges**
- **Poloidally-short segments**
  - **more uniform distribution of excitation current (higher loading).**
  - **lower voltages on the straps and other internal components**
- **2006/2007 DIII-D experimental campaign results will guide design choices**
- **Internal and external tuned designs are both under consideration**
- **Internal capacitor is the near term development challenge**

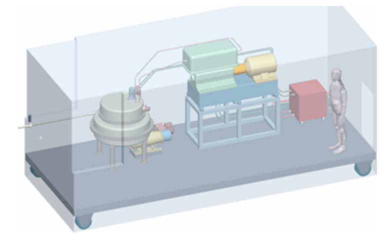
VLT PROGRAM ELEMENT: ICRF Technology

Task Descriptions	FY07 (K$) CBR	FY08 (K$) -10%	FY08 (K$) Flat	FY08 (K$) Full
RF component development	300	290	300	330
High power density antenna development	500	400	500	650
Improve ICRF reliability on fusion facilities	200	190	200	200
RF Edge interactions & diagnostics	200	190	200	225
RF Breakdown studies	155	145	155	155
Advanced heating and CD for new concepts	100	100	100	100
TOTALS	1455	1315	1455	1660

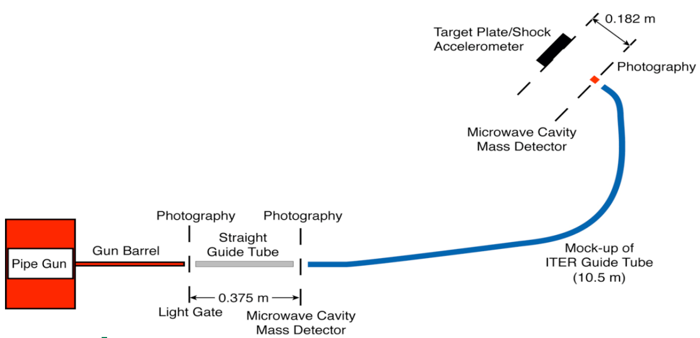
Fueling Development

- FY-06 Accomplishments ($ 670 K)
  - Test of pellet survivability in pressurized ITER guide tube
  - ITER pellet injector concept development
  - Conceptual design of pellet ELM triggering device for DIII-D
  - Modeling of ITER fueling scenarios
  - High throughput fast valve testing for massive gas puff disruption mitigation
  - Preparation of estimates and schedules for ITER fueling and pumping procurement packages
  - Flexible pellet injector and pellet plasma diagnostics for MST fueling and transport studies

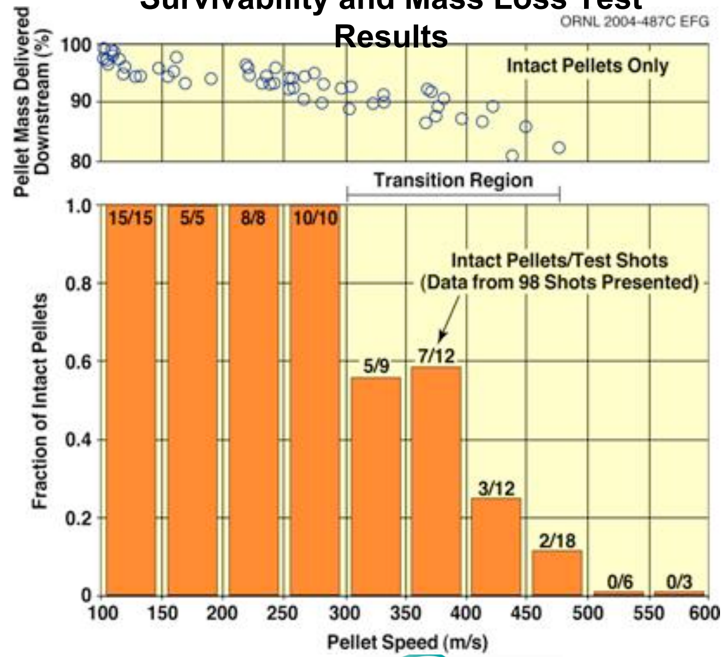




ITER Pellet Guide Tube and Injector in Cask



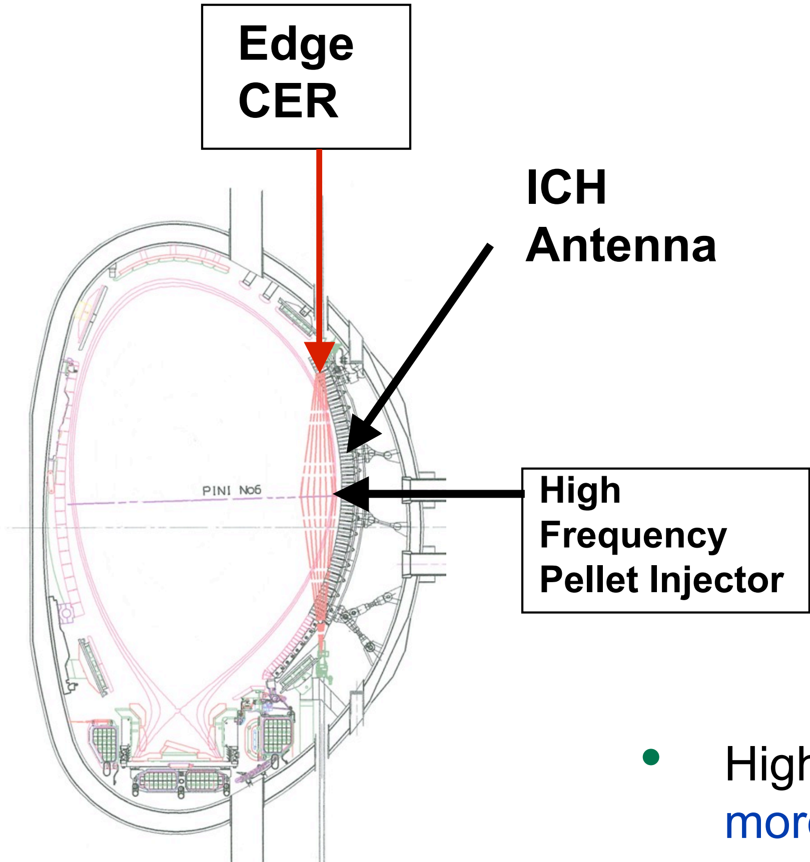
ITER Guide Tube Pellet Survivability and Mass Loss Test Results



Fueling Development

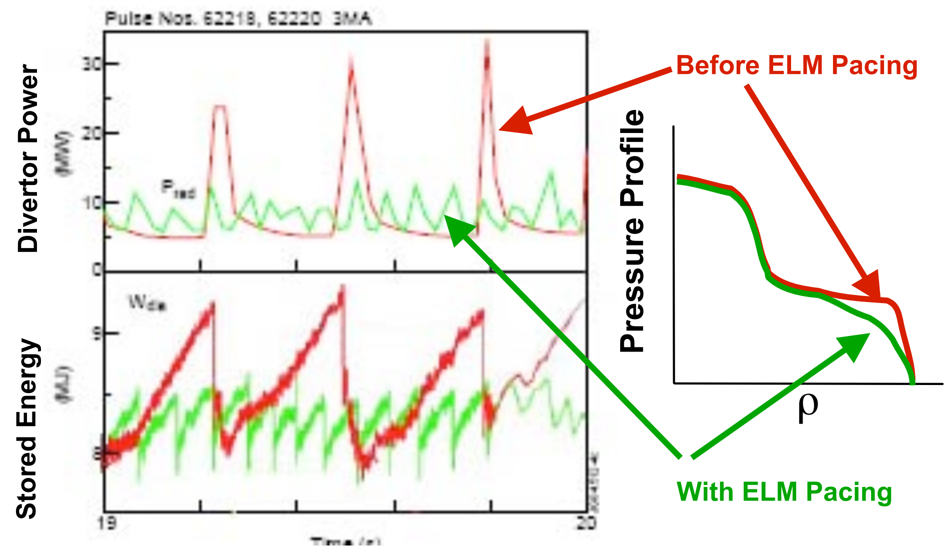
- FY-07 Planned Accomplishments ($ 700 K)
  - **High throughput pellet formation:** Prototype continuous deuterium twin screw extruder testing (ITER)
  - **Deep pellet fueling:** Test compact two-state gas gun injector up to 3 km/s (BPX)
  - **ELM mitigation:** Evaluate pellet dropper and pellet pacing for ELM mitigation (DIII-D, JET)
  - **Disruption mitigation:** Develop/evaluate massive gas puff technology (DIII-D, C-Mod)
  - **Fueling and transport tools for alternates:** Pellet injection for low wall recycling (lithium) devices (LTX, NSTX)
- FY-08 Plans ($ 700 K)
  - **Pellet formation:** ITER high throughput extruder development with cryocooler
  - **Pellet fueling:** Optimize guide tube designs for pellet survivability
  - **ELM mitigation:** Improve/evaluate pellet dropper and pellet pacing for ELM mitigation
  - **Disruption mitigation:** Optimize massive gas puff technology
  - **Fueling and transport tools for alternates:** Implement pellet injection on low wall recycling (lithium) devices

ELM Mitigation via Pellet Injection and Extrapolation for ITER



JET plan for ELM Mitigation with high frequency pellets and ORNL edge CER

DIII-D to use pellet dropper



4 Hz ELMs on JET are BIG,
20 Hz ELMs are tolerable

J. Pamela et al., 20th IAEA (2004) OV/1-2

- High freq ELMs from Pellet Pacing results in more favorable edge conditions
  - Reduced Heat flux to divertor
  - Increased ICH plasma loading stability
- Physics Interpretation from JET and DIII-D and ITER Extrapolation

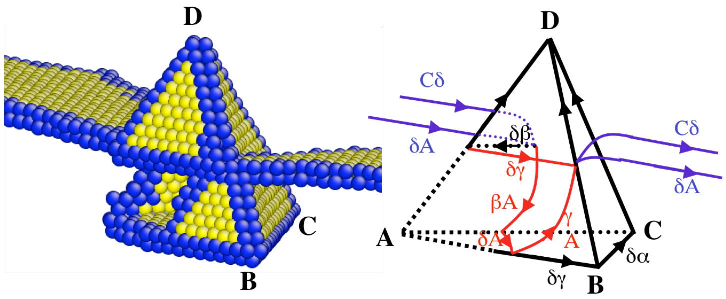
VLT PROGRAM ELEMENT: Fueling and Pumping

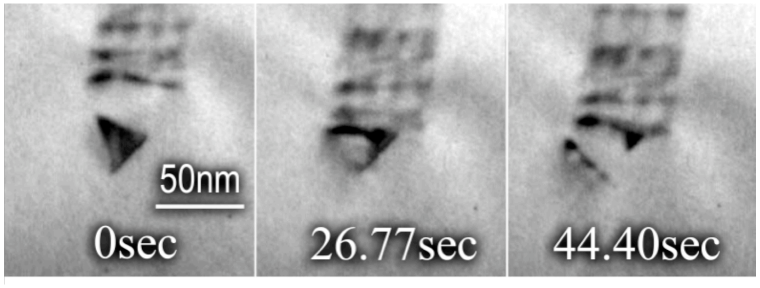
Task Descriptions

Task Descriptions	FY07 (K$)	FY08 (K$)		
	CBR	-10%	Flat	Full
High througput extrusion development	130	130	130	200
High throughput injector development	150	150	150	150
Deep fueling injector development	50	50	50	50
ITER guide tube tests and optimization	50	50	50	50
ITER fueling scenario modeling	50	50	50	50
Fueling tools for alternate concepts	120	100	120	120
Disruption and ELM mitigation	120	100	150	150
TOTALS	670	630	700	770

FY05-06 Materials Science Achievements

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

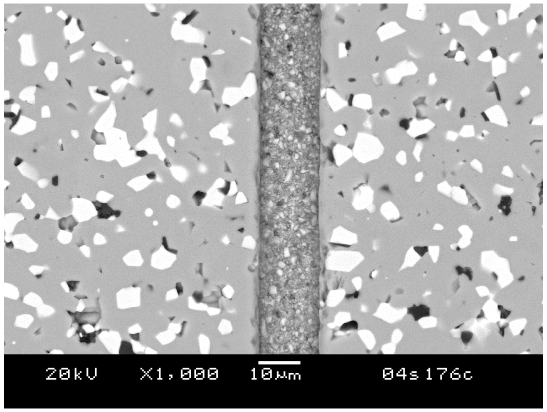




•Effect of high temperature neutron irradiation on properties of SiC has been accurately determined for the first time; upper operating temperature limit may be near 950 C due to cavity swelling.

•New methods for joining SiC composites using polymer precursors have been developed

•Applicable for field repairs



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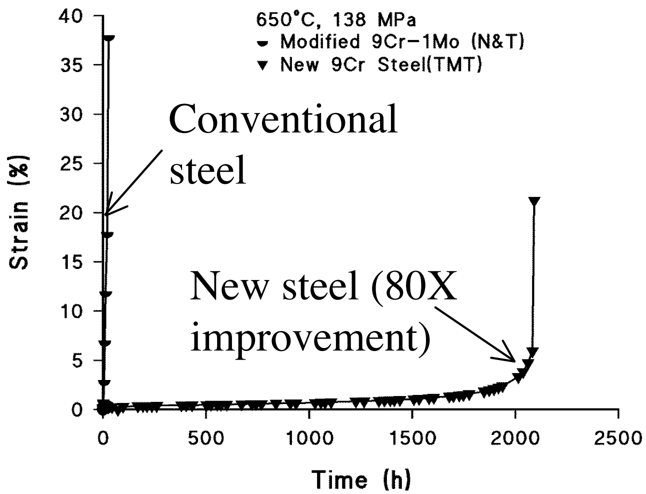
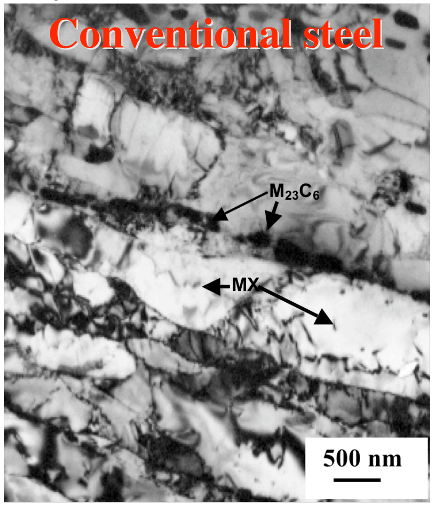
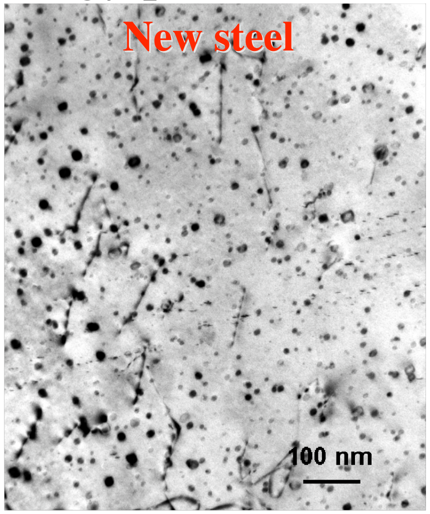
FY05-06 Materials Science Achievements

• A new class of nano-particle strengthened martensitic steel has been developed with the potential to increase the steel upper operating temperature by 100-150 C. Unlike ODS steels, this new steel can be produced by conventional metallurgy processes.







•Completed new modeling analyses that explain the physical basis of the fracture mechanics behavior of unirradiated and irradiated ferritic steels

•Completed first set of DOE/JAEA experiments using a novel He injector technique to investigate fusion-relevant helium/dpa levels during fission neutron irradiation

- •Some significant effects of fusion vs. fission He/dpa levels observed in ferritic steels

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Fusion Materials Science: FY08 plans

- High-performance structural materials
  - As part of DOE/JAEA and post-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

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VLT PROGRAM ELEMENT: Materials Science

Task Descriptions	FY07 (K$) CBR	FY08 (K$) -10%	FY08 (K$) Flat	FY08 (K$) Full
ITER R&D*	0	0	0	0
Structural materials				
Ferritic steels (DOE/JAEA, ITER TBM)	1535	1525	1635	4435
DOE-MEXT (SiC, V-Li system, tritium issues)	850	750	750	750
Improved materials (ODS steel, ductile Mo, SiC)	650	500	650	650
Crosscutting theory and modeling	1350	1250	1350	1350
Functional materials (insulators, Cu)	280	200	280	280
Neutron source	22	0	22	22
TOTALS	4687	4225	4687	7487

*ITER R&D to be covered by non-VLT funds

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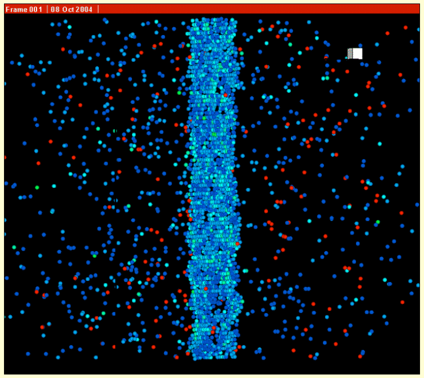
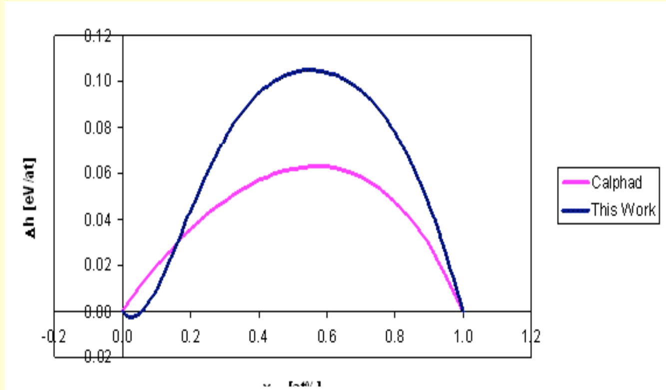
An Integrated Modeling Platform

to predict properties of nuclear materials

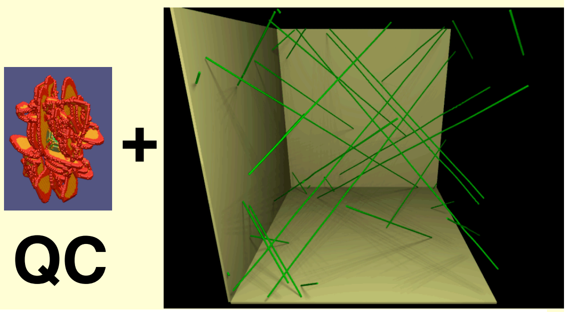


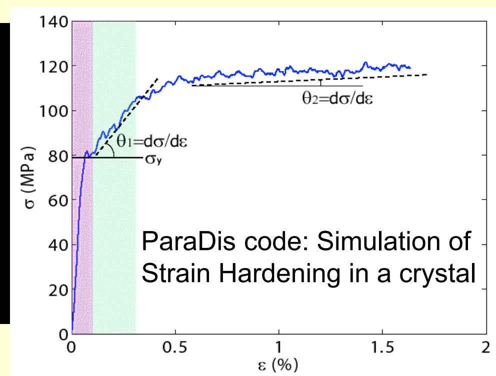
Solute precipitate in dislocation core



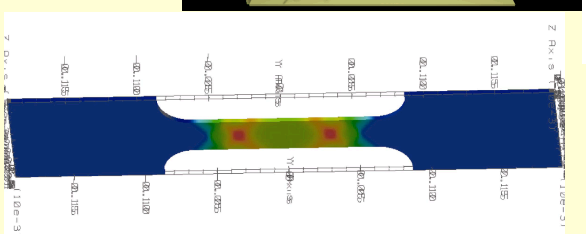
Heat of formation of FeCr from a thermodynamic database and from recent calculations

- Thermodynamics of alloys incorporated to classical potentials





- Automatic coupling of Dislocation Dynamics and Quasi Continuum to study precipitation hardening



Simulation of irradiated copper tensile specimen

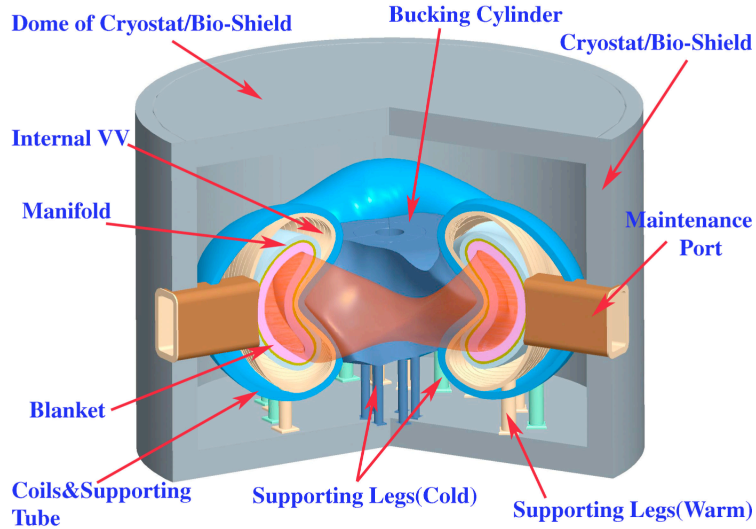
- Polycrystal Plasticity: Engineering scale materials strength models for irradiated materials

Improved physics-based methodologies are used to accurately pass information between length/time modeling scales

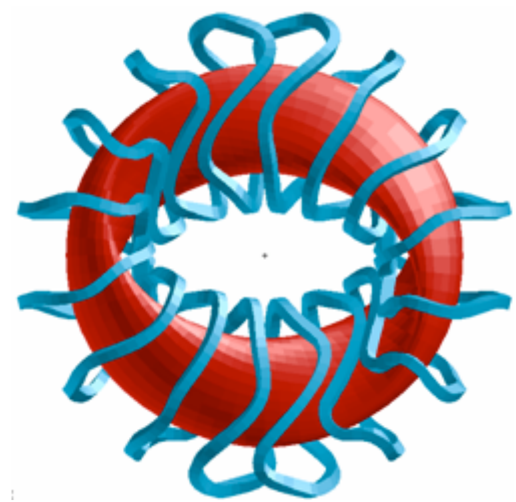
Advanced Design (ARIES)

FY05/FY06 Accomplishments–
ARIES Compact Stellarator Study

- Three classes of stellarator configurations developed all aiming at low plasma aspect ratios (A ≤ 6) and with special emphasis on reducing a particle losses ≤ 5%.
- Systems analysis indicate that resulting power plants have similar sizes as advanced tokamak designs.
- We have made major progress in magnet & support structure design as well as optimizing divertor and PFCs.
- An integrated and self consistent point design will be completed during Calendar year 06.



NCSX-Like



MHH2

Advanced Design (ARIES)

FY07 Plans

- Completion and documentation of ARIES Compact Stellarator Study (~ 25% of effort)
- Revisit and update of TITAN RFP to reflect latest physics understandings (~30% of effort)
- Preparation for the next major ARIES project (discussion on the scope of the project is on-going).

Issues and are both near term (now and FY07) and longer term (a few years)

- **FY06**
  - **The VLT contributed \$3.5 M to ITER R&D (Other Project Costs) from Magnets, Fueling, PFC, ICH and ECH area**
    - **Contributions from ICH (\$400 k) and ECH(\$459 k) were not returned to VLT performers.**
- **FY07 (above + \$3.7 M cut)**
  - **Materials Science is reduced by 33%**
  - **Magnet R&D is eliminated**
  - **Gyrotron R&D in industry is eliminated, student led research curtailed**
  - **ICH R&D is reduced by 11% relative to the beginning of FY06**
- **Longer term**
  - **R&D from ITER will taper off in 3 years**
    - **Technology program contributions will need to be restored**

ITER Project R&D (Other Project Costs) is not a sustainable strategy to long term technology funding

Fiscal Year	Total Estimated Costs (TEC)	Other Project Costs (OPC)	Total Project Costs (TPC)
2006	15.9	3.4	19.3
2007	37.0	23.0	60.0
2008	149.5	10.5	160.0
2009	208.5	6.0	214.5
2010	208.5	1.5	210.0
2011	180.8	.5	181.3
2012	130.0	0	130.0
2013	116.9	0	116.9
2014	30.0	0	30.0
Total	**1,077.1**	**44.9**	**1,122.0**

Impacts of the 07 CBR

- *Materials science*
  - Hinders ITER test blanket development of international partners (DOE/JAEA materials collaboration) and U.S. Test Blanket Module plans.
  - Compromises ability to leverage other resources (Basic Energy Sciences, DOE-NE Gen IV, DOE-NE GNEP etc.).
  - Loss of technical staff and students with 1/3 budget reduction
- *Magnets*
  - Terminates magnet research program except for small UW effort
    - Loss of expertise and student led research
- *ECH/ICH*
  - Curtails development of heating and current drive tools for U. S. facilities (i.e. next step gyrotron)
    - Industrial gyrotron research eliminated
- *In general*
  - Raises concerns for our ability to deliver on and exploit ITER
  - Weakens the fourth leg of DOE fusion strategy- *Materials, Components, Technologies*

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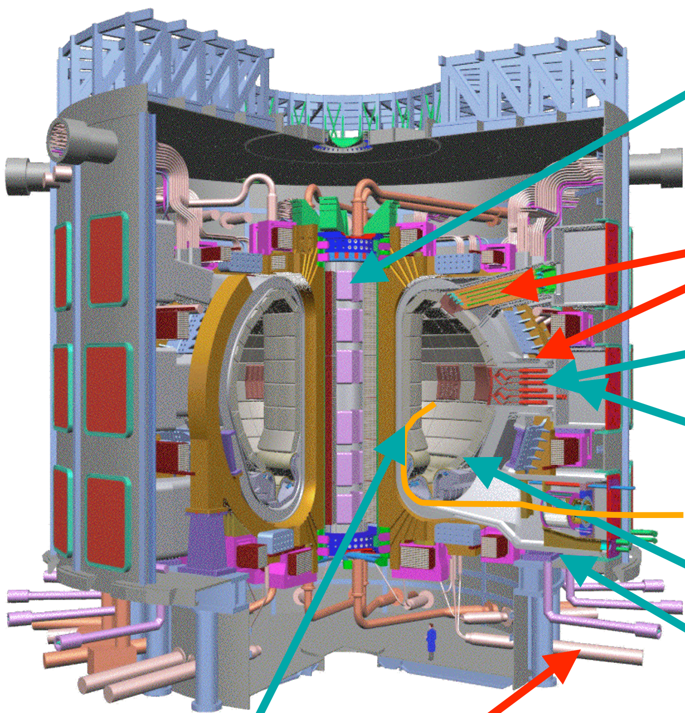
VLT participants led the planning and R&D activities for all but three of the U. S. "provisional" procurement packages



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

Summary

- **The VLT is increasing its support of burning plasma issues--will exceed 60% of the budget in FY07 and FY08.**
- **The F07 CBR results in a cut of $3.7 M (following a $4.2 M cut in FY06)**
- **There are important needs and opportunities for incremental funding**
  - **FY07: Restore the Plasma Technologies and Materials Science budgets**
    - **Some impacts may be mitigated by ITER project funds**
  - **FY08: ~$6.5 M incremental needed for the U.S. TBM**