Enabling R&D Plans and Budgets

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

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Oak Ridge National Laboratory

OFES Budget Planning Meeting
Gaithersburg, Maryland
March 11-12, 2008

The Virtual Laboratory for Technology represents the diverse technology research activities of 24 institutions

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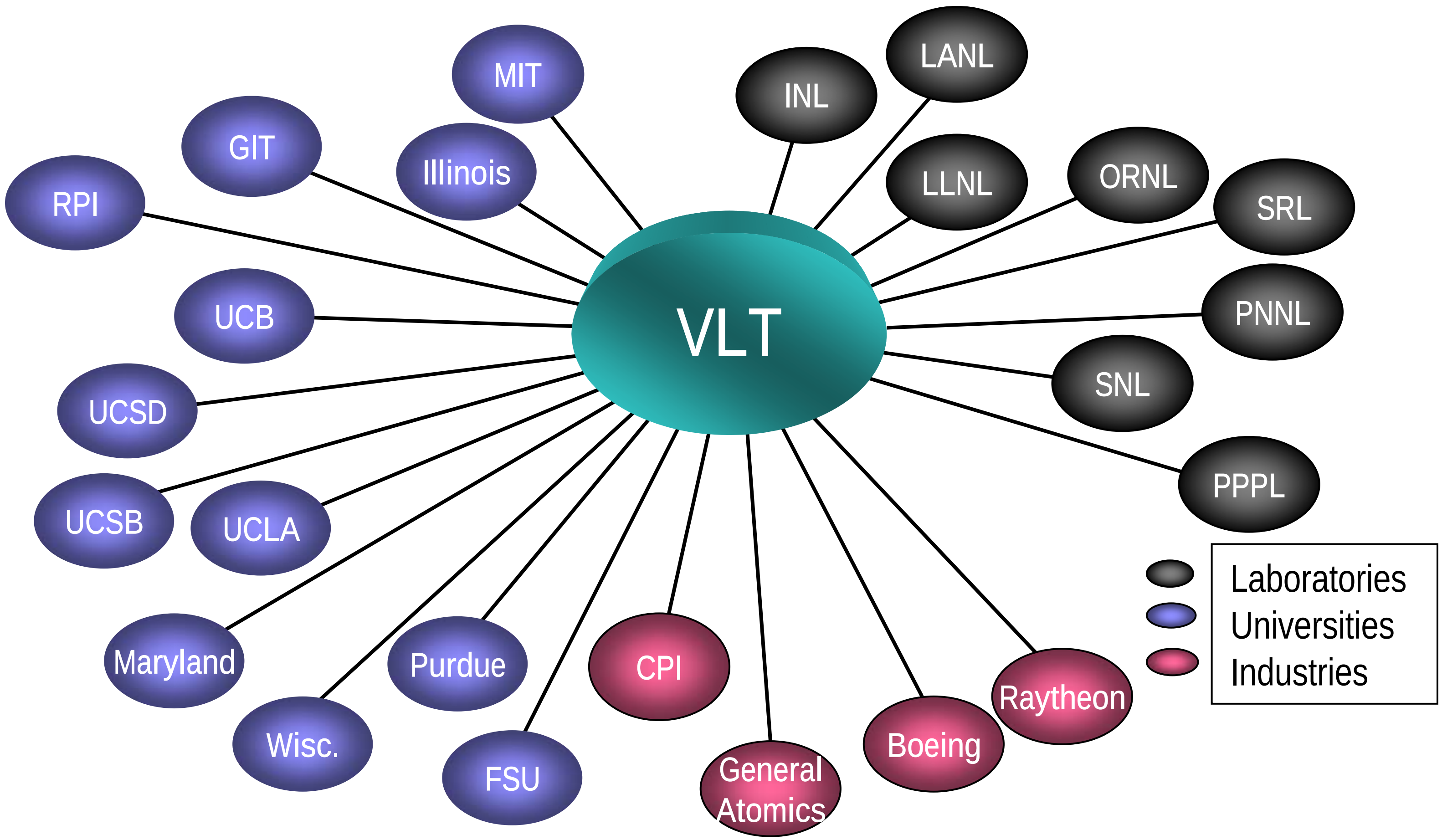

Outline

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- Budget considerations
  - Relevance research to ITER and Greenwald FESAC panel
  - Overview of FY08/09 Budget Situation
- For each VLT technical area
  - Highlights of technical accomplishments
  - FY09 tasks and funding
  - FY10 tasks and funding (-10%, +2% and Full Use cases)
- Issues
  - Impacts of reduced technology budgets in the ITER era

FY09/10 Budget Considerations

- "In planning for the FY 2010 institutions should increase their focus on burning plasmas and identify specific tasks, such as high-priority International Tokamak Physics Activity (ITPA) R&D, theory, and technology R&D for heating, current drive, diagnostics, etc. The results of such research will be relevant to the fusion program, including ITER."
  - The VLT focuses heavily on ITER
- ".. it would also be beneficial to indicate proposed research activities that are, or could evolve into being, relevant to the overarching research issues identified in the <u>October 2007 FESAC Report on Priorities, Gaps, and Opportunities…</u>"
  - Virtually all VLT research is relevant to one or more of the 3 themes
- FY09 Congressional request *decreases* by 0.7% relative to FY08 Congressional request
  - Status quo budget
- Overall FY09 budget is still 28% below the FY 05 level

The VLT contributes to ITER in three important ways

- Contributions to the ITER Project (R&D and design)
- Base program research addressing
  - high priority ITER issues (T co-deposition, ELM and disruption mitigation, choice of divertor materials) and
  - operational issues and potential performance enhancements (higher efficiency/power ECH systems and ICH relevant antennas)
- Utilizing ITER as a fusion engineering science test bed and stepping stone to complementary facilities and next step devices.

VLT participants are actively engaged in all aspects of the ITER Project

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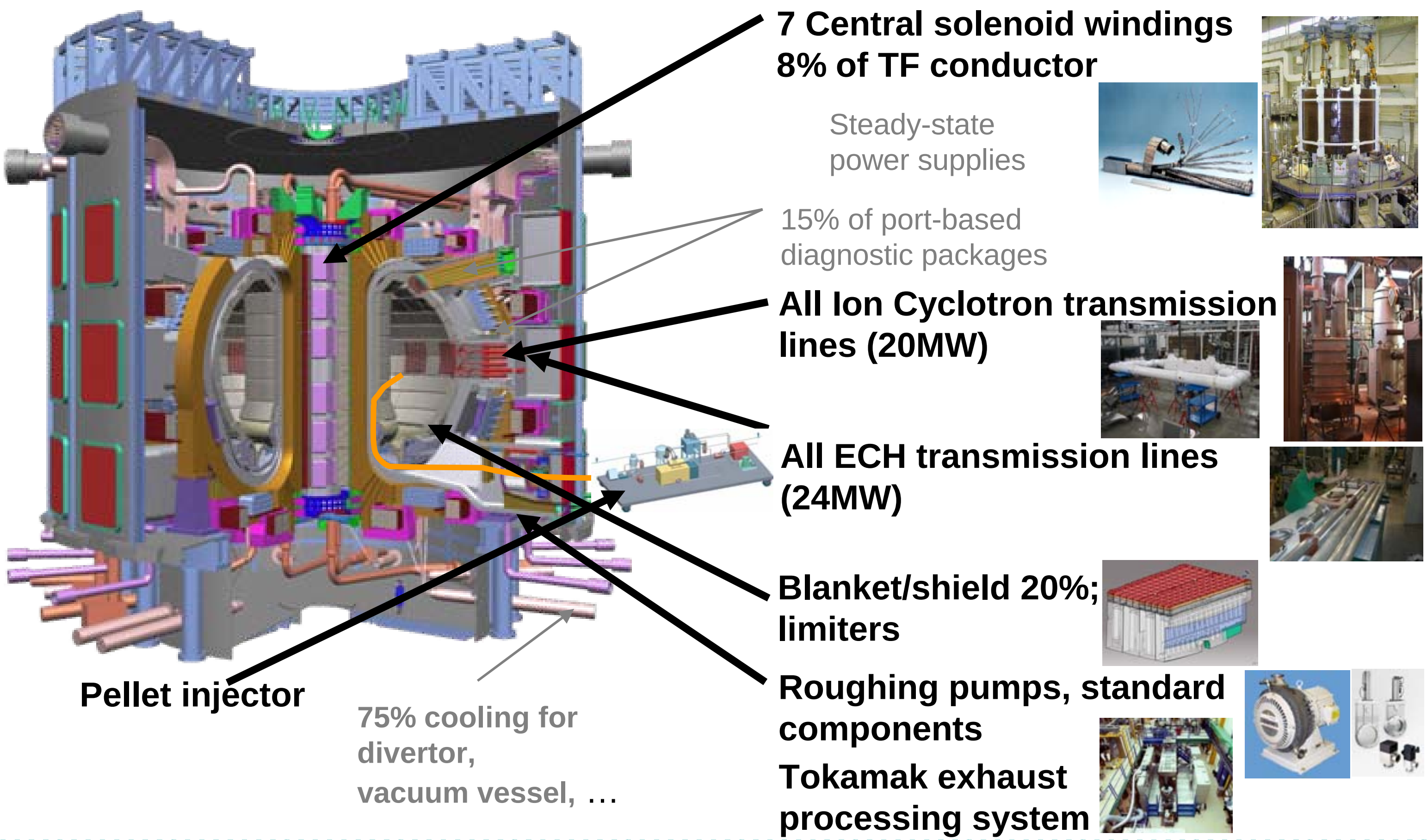

Cross cutting activities (Materials, Nuclear Analysis, Safety), Design Working Groups and Test Blanket Working Group

VLT engagement in ITER is pervasive.

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	Program Element	Element Leader
√	Magnets	J. Minervini - MIT
√	PFC	R. Nygren - SNL
√	Chamber	M. Abdou - UCLA
√	ICH	D. Rasmussen - ORNL
√	ECH	R. Temkin - MIT
√	Fueling	S. Combs - ORNL
√	Tritium Processing	S. Willms – LANL
√	Safety & Tritium Research	P. Sharpe – INL
√	Materials	R. Kurtz - PNNL
	NSO/FIRE	TBD
	ARIES	F. Najmabadi - UCSD
	Socio-Economic	L. Grisham - PPPL

Engineering science and technology issues figured prominently in the Greenwald panel deliberations.

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How Initiatives Could Address Gaps

Legend

Major Contribution	3
Significant Contribution	2
Minor Contribution	1
No Important Contribution	

	Theme A								B		C				
	G-1 Plasma Predictive capability	G-2 Integrated plasma demonstration	G-3 Nuclear-capable Diagnostics	G-4 Control near limits with minimal power	G-5 Avoidance of Large-scale Off-normal events in tokamaks	G-6 Developments for concepts free of off-normal plasma events	G-7 Reactor capable RF launching structures	G-8 High-Performance Magnets	G-9 Plasma Wall Interactions	G-10 Plasma Facing Components	G-11 Fuel cycle	G-12 Heat removal	G-13 Low activation materials	G-14 Safety	G-15 Maintainability
I-1. Predictive plasma modeling and validation initiative	3	2		2	2	3	1		2						
I-2. ITER – AT extensions	3	3	3	3	3		2		2	2	1	1		1	1
I-3. Integrated advanced physics demonstration (DT)	3	3	3	3	3	1	3	2	3	3	1	1	1	1	1
I-4. Integrated PWI/PFC experiment (DD)	2	1		1	2		2	1	3	3	1	1		1	1
I-5. Disruption-free experiments	2	1		2	1	3		1	1	1					
I-6. Engineering and materials science modeling and experimental validation initiative							1	3	1	3	2	3	3	2	1
I-7. Materials qualification facility							1			3	2	1	3	3	
I-8. Component development and testing			1				2	1		3	3	3	2	2	2
I-9. Component qualification facility	1	1	2	1	2		3	2	2	3	3	3	3	3	3

A - Creating predictable high-performance steady - state plasmas: Magnets, ICH, ECH, Fueling
B - Taming the plasma-material interface: PFC, Materials
C - Harnessing fusion power: Chamber, Safety &T Research, T Processing, Materials, ARIES

The FY09 budget is flat across the board but substantially lower than the pre ITER era

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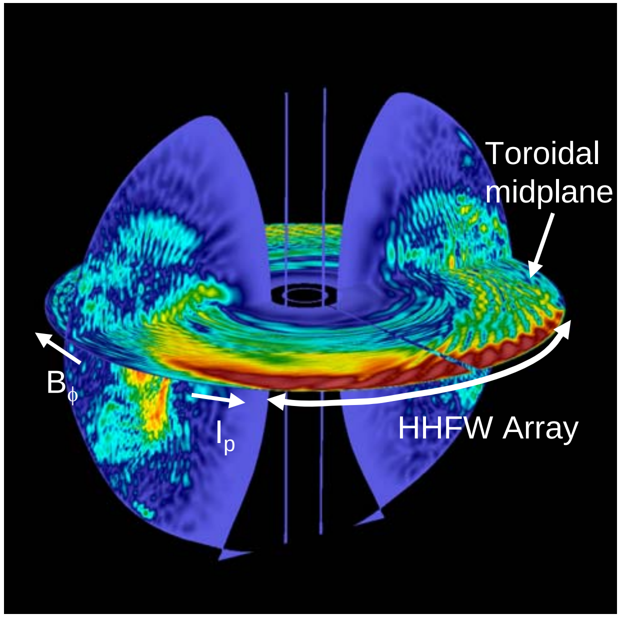
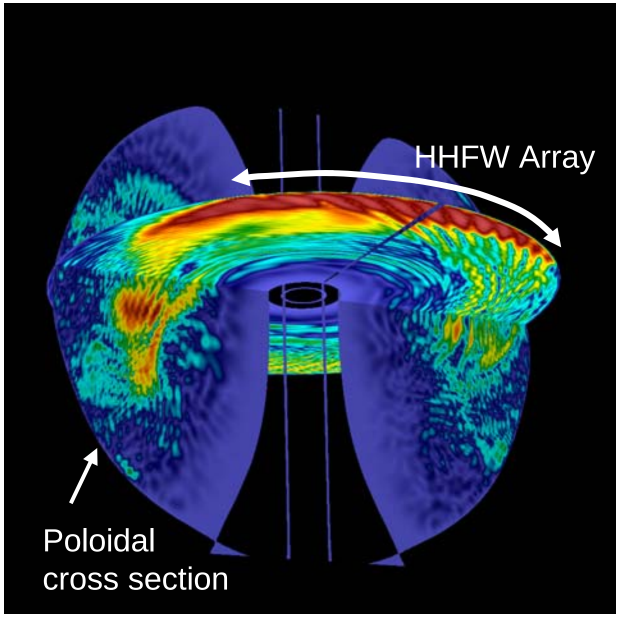
FY09 Enabling R&D Program Budget ($K) 2/4/08							
Program Area	**Program Elements**	**OFES PM**	**FY 05**	**FY 06**	**FY 07**	**FY 08**	**FY 09 CONG**
Plasma Technologies	Plasma Facing Components	Nardella	6932	5655	5625	5619	5559
Plasma Technologies	Magnet Systems	Sullivan	2243	1137	90	500	500
Plasma Technologies	Plasma Chamber Systems	Nardella	1690	1620	1640	1700	1700
Plasma Technologies	ICH Systems	Sullivan	1708	1360	1570	1570	1540
Plasma Technologies	Safety and Environment	Nardella	1727	1643	1675	1528	1518
Plasma Technologies	ECH Systems	Sullivan	1415	926	546	796	795
Plasma Technologies	Fueling Systems	Sullivan	1022	750	775	775	775
Plasma Technologies	Tritium Systems	Nardella	934	654	654	654	654
Plasma Technologies	Neutronics	Nardella	516	435	320	310	310
Plasma Technologies	Neutral Beam Systems	Sullivan	60	50	50	0	0
Plasma Technologies	IFE Closeout Costs	Nardella	156	0	0	0	0
Plasma Technologies	**TOTAL**		**18403**	**14230**	**12945**	**13452**	**13351**
Advanced Design	Next Step Option-FIRE	Bolton	431	0	0	0	0
Advanced Design	MFE System Studies	Opdenaker	1686	1643	1716	1798	3783
Advanced Design	VLT Management	Nardella	696	701	744	752	740
Advanced Design	Socio-economic Studies	Opdenaker	80	80	50	50	50
Advanced Design	Burning Plasma Application	Bolton	86	40	40	0	0
Advanced Design	**TOTAL**		**2979**	**2464**	**2550**	**2600**	**4573**
Materials Research	**Materials Science**	Nardella	**7338**	**7043**	**4687**	**4815**	**4791**
AT60 Enabling R&D	**TOTAL**						
	TOTAL MFE		**28564**	**28189***	**43182***	**31317***	**22715**
	TOTAL IFE		**156**	**0**	**0**	**0**	**0**
* includes ITER OPC							

RF Research and Development (Theme A)

- FY-08 Accomplishments ($1570 K)
  - Successful rebuild of the DIII-D 60 MHz Fast Wave heating antenna.
  - Obtained improved core heating with HHFW antenna on NSTX. Modeled coupling and H&CD with AORSA.
  - Initial operation of load-tolerant antenna on JET
  - Prepared test facilities for ITER ICH transmission line and tuning system
  - Combined heating from two Fast Wave antennas with ECH pre heating to obtain H-mode operation on DIII-D.
  - Measured high mode conversion efficiency with steerable EBW emission radiometers on NSTX and TJ-II.
  - Measured and analyzed RF breakdowns and arc precursors as a function of gas pressure and magnetic field.
  - Fabricating edge density reflectometer for installation on C-Mod RF antenna.





RF Research and Development

- FY-09 Planned Accomplishments ($1540 K)
  - **RF Component Development:** Compact inductive and capacitive tuning and pre-tuning elements and cw transmission line components for ITER and DIII-D.
  - **High Power Density Antenna Development:** Operate and evaluate the JET-EP antenna in ELMing H-mode plasmas. Develop conceptual design of long pulse, low voltage antenna for DIII-D.
  - **Improve Control, Reliability, Protection and Operation of ICH on Fusion Facilities:** Flexible and reliable control systems,matching networks, and arc protection for NSTX, DIII-D, MST =>ITER.
  - **RF-edge Interactions:** Modeling and diagnostics/experiments on fusion facilities with arc detectors, probes and refectometers on NSTX, DIII-D, C-Mod, JET and ITER.
  - **RF Breakdown Studies:** Plasma, UV, and surface material effects on RF and DC breakdown thresholds (at ORNL and University of Illinois facilities). New arc detection techniques.
  - **Innovative Approaches to Advanced Heating & CD for New Concepts:** EBE -> EBW heating for STs and stellarators.

- FY-10 Planned Accomplishments ($1570 K)
  - **RF Component Development:** Compact inductive and capacitive tuning and pre-tuning elements and long pulse components.
  - **High Power Density Antenna Development:** JET-EP load tolerant antenna operation. Low voltage, long pulse DIII-D antenna preliminary design.
  - **Improve Control, Reliability, Protection and Operation of ICH on Fusion Facilities:** NSTX, DIII-D, MST & ITER.
  - **RF-edge Interactions and HV Breakdown Studies:** ORNL, UIUC, NSTX, DIII-D, C-Mod, JET & ITER.
  - **Innovative Approaches to Advanced Heating & CD for New Concepts:** EBE -> EBW heating for STs and stellarators. LH current drive for ITER.

VLT PROGRAM ELEMENT: rf Technology

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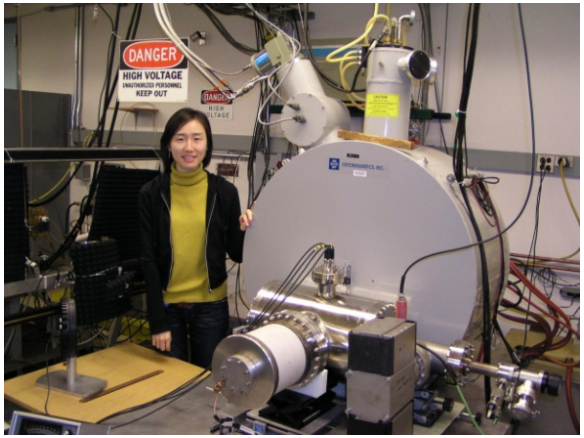
Task Descriptions	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
RF component development (Prototypes and experiments)	300	290	300	300
High power density & long pulse antennas (Antennas and experiments)	500	395	500	800
RF breakdown studies & reliability improvements (Experiments and modeling)	370	350	400	400
RF edge interactions & diagnostics (Diagnostics and experiments)	200	190	200	250
Advanced H&CD concepts (Prototypes, experiments, modeling)	105	100	105	120
University Programs	65	65	65	70
TOTALS	1540	1390	1570	1940

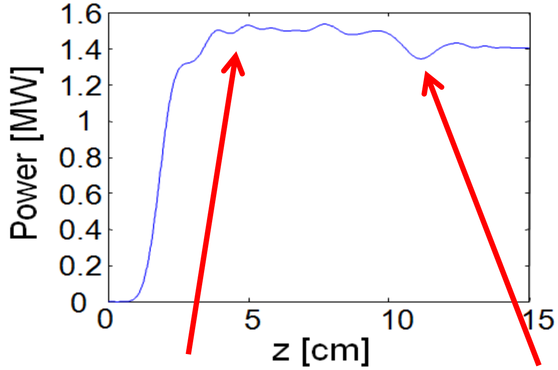
FY08 ECH Technology Major Advances (Theme A)

1. Identified a Major Cause of Gyrotron Efficiency Reduction (MIT, Univ. MD)

- Second region of cyclotron resonance interaction ($\omega = \omega_c - k_z v_z$) after the cavity
    - Spent electron beam robs power from the microwave output beam
- Observed in MIT experiments; predicted by MAGY code of Univ. MD
- Responsible for Experimental Gyrotron Efficiency of 40 – 50% vs. >60% in theory



MIT Gyrotron Lab



Microwave power generated in cavity

Power loss after the cavity

2. Fabricated an All-Metal Beam Splitter (GA)

- Used in 1 MW, 110 GHz, 1.25″ mode analyzer, measures HE_{11} mode purity in transmission lines

3. Developed new algorithms to speed up design of mirror systems for gyrotrons by more than a factor of ten (Univ. WI)


GENERAL ATOMICS

New Beam Splitter Plates

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FY09 ECH Technology Advances

- Design and build a short pulse gyrotron that eliminates the “After Cavity Interaction” responsible for reduced efficiency in gyrotrons (MIT, U MD)
  - The goal is a gyrotron efficiency > 60% with a depressed collector
  - Results important to US and international gyrotron development
- Improve overall efficiency of quasi-optical mode converters for multi-frequency gyrotrons (Univ. WI)
- Support research by graduate students on the US ITER Transmission Line R&D including:
  - Determine mode conversion at miter bends (MIT)
  - Help design resonant ring for ORNL (Univ. WI)
- Design next step gyrotron: 1.5 to 1.8 MW, 110 GHz
  - Frequency tunability is desirable
- Design and fabricate a high power 170 GHz 2.5” mode analyzer for use in determining HE_{11} mode purity in ITER transmission lines (GA)
- Continue development of advanced Cu-coated CFC mirrors (GA)
- Model and Measure low-frequency oscillations on gyrotron beams before and after the resonator (Univ. MD, MIT)
  - Suppress backward-wave oscillations in gyrotron beam tunnels

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FY10 ECH Technology Advances

- **Target FY10 Funding Case (+2% vs. FY09):**
  - Experimental and Theoretical Research on Gyrotron Efficiency
  - Experimental and Theoretical Research on Gyrotrons tunable in frequency, particularly from 105 to 140 GHz
  - Test a 170 GHz, 2.5” mode analyzer and an improved bellows in a prototype ITER transmission line
  - Conceptual design of full size DIII-D antenna using CFC mirrors
  - Design a direct injection internal gyrotron mode converter which bypasses the external mirror optical unit
  - Conceptual analysis of frequency-step tunable gyrotrons for ITER; compare tunability with steerable mirror for NTM suppression
  - Design of Improved Components for ITER transmission lines.

- **Full Funding Case - Restore Funding for Industrial Gyrotrons**
  - Funding of $450k to rebuild existing 1.5 MW, 110 GHz gyrotron
  - Test high efficiency operation, advanced internal mode converter and advanced depressed collector in an industrial gyrotron

VLT PROGRAM ELEMENT: ECH Technology

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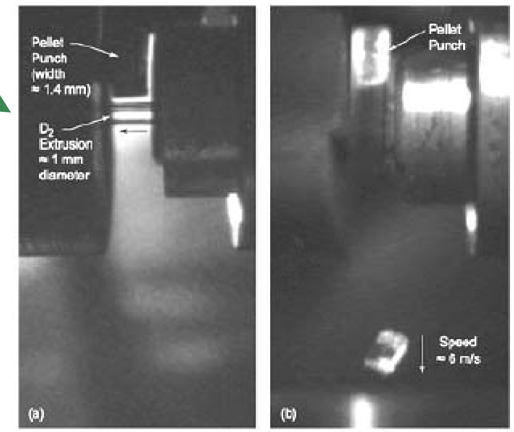
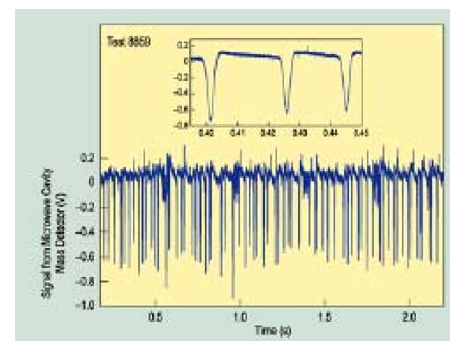
Task Descriptions	FY09 (K$) CBR	FY10 (K$) -10%	FY10 (K$) 2%	FY10 (K$) Full
Transmission Line Research	275	290	295	295
High Efficiency / Tunable Gyrotron Research	360	300	360	360
Modeling & Code Development	160	126	156	156
Industrial 1.5 MW, 110 GHz Gyrotron Development	0	0	0	450
TOTALS	795	716	811	1261

Fueling Development (Theme A)

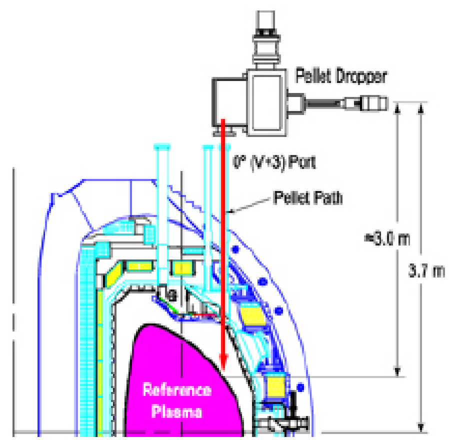
- FY 07-08 Accomplishments
  - Installation/Operation of pellet dropper ELM-triggering device on DIII-D
  - High throughput "Medusa" fast valve on DIII-D for massive gas injection disruption mitigation
  - Flexible pellet injector upgrades for MST fueling and transport studies
  - ITER D-T pellet injector conceptual design
  - Modeling of ITER fueling and pellet ELM pacing scenarios
  - Conceptual design and test of burst diaphragm gas jet for disruption mitigation

1-mm solid D_2





Punch operating at 33 Hz. Only the first 2 seconds from the 5 second test sequence are shown.



Medusa Gas Jet System on DIII-D

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

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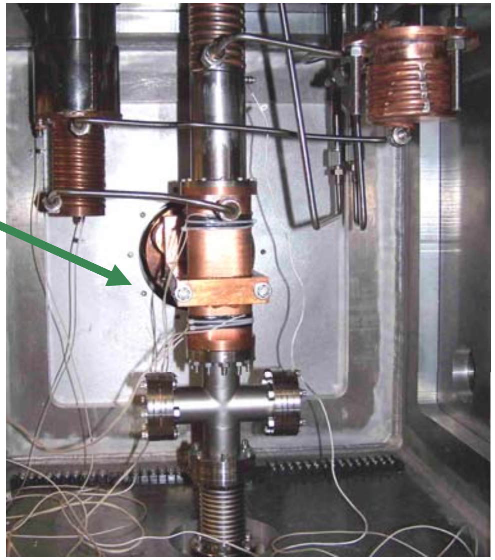
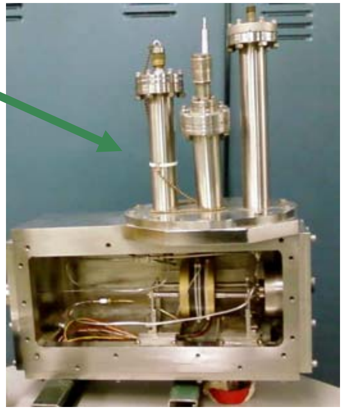
OAK RIDGE National Laboratory

Fueling Development

- FY 08-09 Planned Accomplishments
  - **High throughput pellet formation:** Prototype continuous deuterium twin screw extruder testing (low DT inventory)
  - **Deep pellet fueling:** Test compact two-state gas gun injector up to 3 km/s
  - **ELM mitigation:** Evaluate pellet dropper and pellet pacing for ELM mitigation (DIII-D, JET)
  - **Disruption mitigation:** Develop/evaluate burst diaphragm gas jet and large pipe-gun pellet (DIII-D, C-Mod)
- FY 10 Plans
  - **Pellet fueling:** Develop low gas throughput propellant valve and recirculating fuel gas system (ITER relevant)
  - **ELM mitigation:** Improve pellet dropper and develop pellet pacing technology for ITER ELM mitigation
  - **Disruption mitigation:** Optimize killer pellet/gas jet technology
  - **Fueling and transport tools for alternates:** Implement pellet injection for low wall recycling (lithium) devices



Continuous Extruder



Pipe-Gun Pellet Injector

VLT PROGRAM ELEMENT: Fueling Systems

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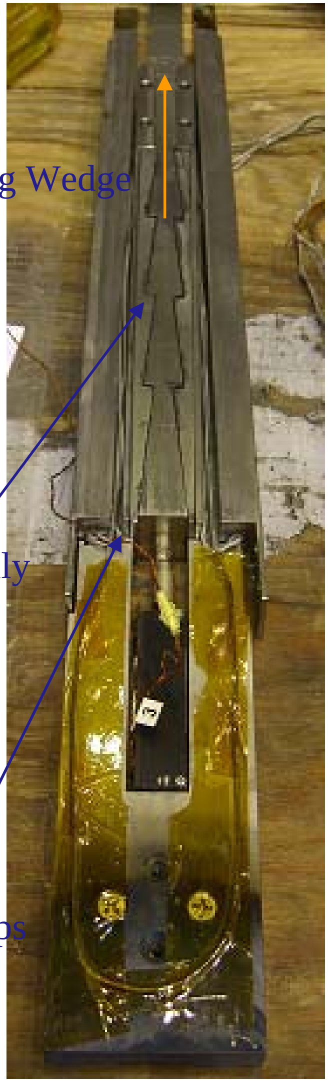
Task Descriptions	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
High throuput fueling development (Prototypes, experiments and modelling)	460	400	465	485
Deep fueling developmemt (Prototypes, experiments and modelling)	50	45	50	55
Fueling tools for alternate concepts (Injector improvements and experiments)	120	110	120	120
Disruption and ELM mitigation (Prototypes, experiments and modelling)	145	145	155	345
TOTALS	775	700	790	1,005

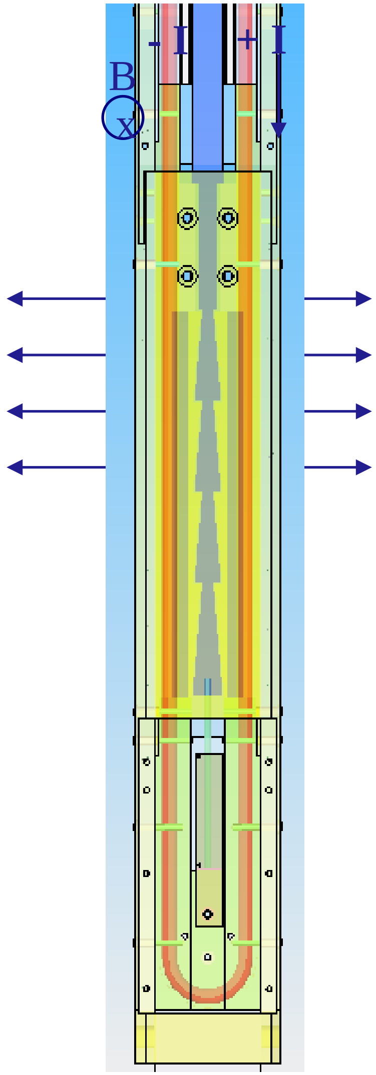
Fusion Technology and Engineering FY08 Technical Highlights in Magnet Research (Theme A)

- Base Program work is focused on:
  - Understanding the effects of transverse compression and pure bending on Nb_3Sn through analysis, computation and 3 lab experiments
  - Ab-initio calculation of strain behavior of A15 Superconductors on a microscopic basis
  - Development of fiber optic temperature and strain measurement system for superconducting magnets
  - Development of MgB_2: Next Generation of Superconductor for Fusion – Low cost, high temperature margin (T_c ~35 K), lower radiation damage

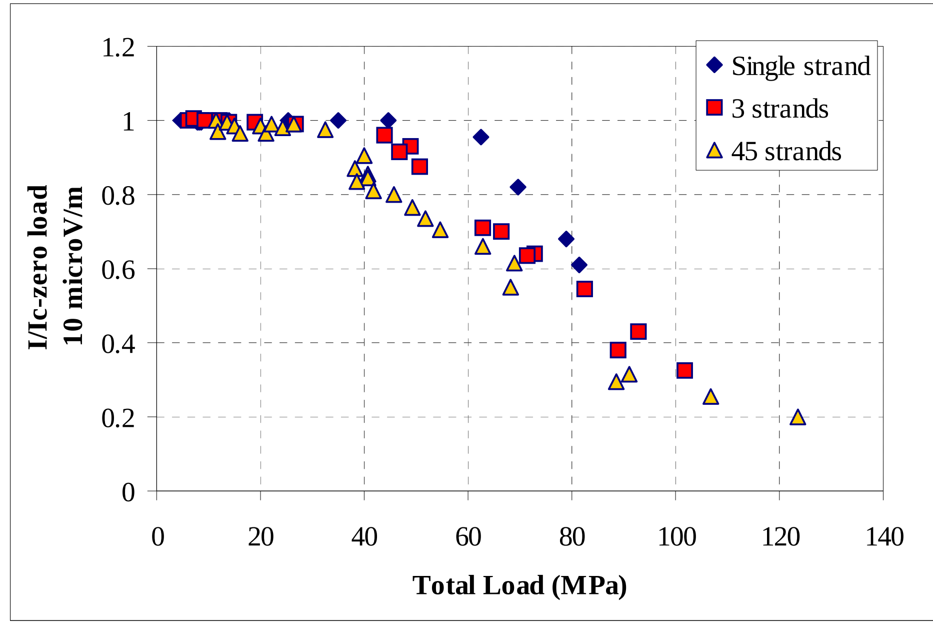
Hairpin Sample Setup

Transverse Load Cable Test-Simulation of Lorentz Force





Experimental Results



All the samples show degradation for higher values than the cables previously tested.
As expected, a single strand is less sensitive to the applied load.

VLT Magnets FY08/FY09

- **FY08/09 Budgets**
  - **FY08 Budget and FY09 Guidance: $500K for Magnets Enabling Technology**
    - **Superconducting Magnet Development (experiments and modeling) - MIT $410K**
    - **Superconducting Materials Development - FSU $90K**
- **ITER (USIPO) Magnets only partially funded for FY08**
    - **Combined reductions in Base and ITER programs have led to permanent loss of core interdisciplinary magnet capabilities**
      - **Loss of ~ 8 FTE Engineers and only remaining technician**
      - **Cease all lab scale development and testing**
      - **Loss of hands-on lab experience for students**
- **Present funding level for magnets leaves only vestigial program**

FY2010

Guidance level: $410K MIT, $90K FSU-NHMFL

- **MgB_2 (ASC at NHMFL)**
  - Continued development of MgB_2 as low-cost radiation resistant Fusion Conductor
    - Optimization of doping levels and reduction of grain size to enhance J_c and H^*
    - Understand and improve grain-to-grain connectivity
  - Apply developments to multifilamentary strand.
  - Continue to provide Superconducting Conductor - relevant materials support for Fusion Community applications.
- **Superconducting Magnets (MIT)**
  - Optimize cable pattern to minimize transverse stress degradation in Nb_3Sn depending on FY09 results
  - Integration of Fiber Optic temperature and strain sensor in laboratory scale coil and test
  - Incorporation of self-consistent J_c as a function of both longitudinal and transverse strain into magnet design codes

FY2010-Additional Tasks for "Full" Funding

Full Funding Level: $2000K MIT, $200K FSU

- Superconducting Materials (ASC at NHMFL)
  - Hire Post-Doc in addition to graduate student position
  - Establish international collaboration to better understand the fracture behavior of existing ITER Nb_3Sn strand.
  - Develop an economical, standardized test for evaluating filament fracture propensity at the strand level.
  - Initiate a strand modeling effort to assess the impact of architectural changes on the fracture properties.
  - Provide the fracture data needed by existing strand and cable modelers to incorporate fracture events into existing degradation models.

- Superconducting Magnets (MIT)
  - Hire 2 Post-Docs, recover 2 research staff members and add 3-4 graduate students
  - Initiate program in development of HTS 2nd generation superconductor for fusion magnet applications
    - as guided by ARIES studies and new advanced design initiative
    - Include development of demountable joints for superconducting magnets in an advanced fusion machine
    - Consider designs for tokamak or stellarator type coil configurations in collaboration with other lab partners
  - Restore effort in development and characterization of advanced, high strength structural alloys
  - Procure relevant materials for HTS and structural studies, along with consumables and laboratory equipment upgrades.
  - Add advanced Nb_3Sn wire stability studies

VLT PROGRAM ELEMENT: Magnets

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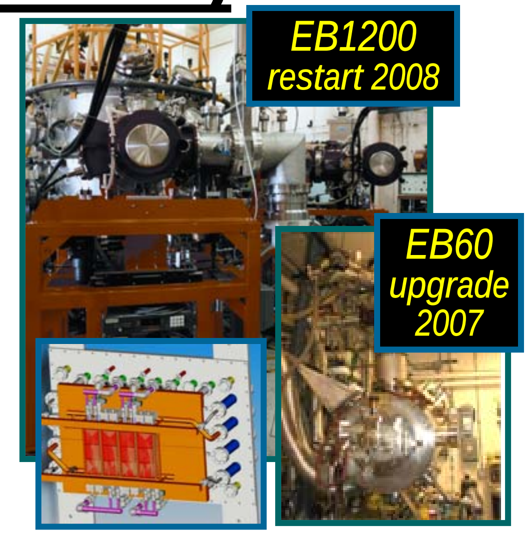
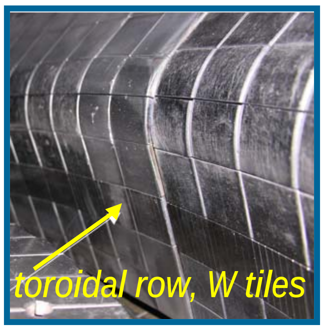
Task Descriptions	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
Superconducting Magnet Development (Expt. & modeling)	410	369	418	2000
Superconducting Materials Research (Expt. & modeling)	90	81	92	200
TOTALS	500	450	510	2200

FY08 PFC Accomplishments (Theme B)

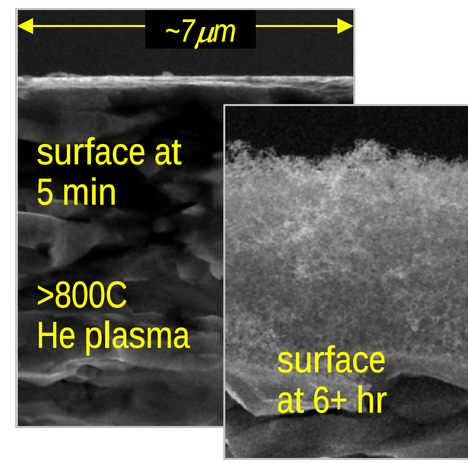


Experimental results

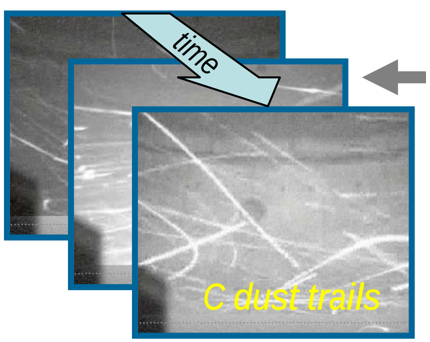
- **ITER Parties using PMTF e-beams.** *(Sandia)*
  Unique capability: large visible heated area of (toxic) Be
  - US,EU,J,K,C first wall mockups in EB1200
  - **Korean** Be/CuCrZr joining samples in EB60



- **W laminate tiles in C-MOD.** *(MIT)*
- **Unification of PISCES-B and other data on erosion of mixed-materials Be/C.**
  (UCSD/EU, UCSD/ANL/LLNL)



- **W "fuzz" seen in PISCES-B. *(UCSD)***
- ***Assess D*** *(T)* ***retention in W.*** *(UCSD/Sandia)*



- **Dust in DiMES; mirrors in MiMES**
  - no deposits on down-looking mirror (div. view)
  (GA/UCSD/SNL/ANL)
- **Prep to install NSTX Liquid Li Divertor this summer.**
  (NSTX Team, Sandia, with Purdue, UCLA)

FY08 PFC Accomplishments

Facilities – upgrades/additions

- **PMTF: EB60 on-line; EB1200 repaired/restarted** ***(Sandia)***
- **DIII-D: MiMES mid-plane probe deployed** ***(GA, UCSD/KFJ/Sandia)***
- **C-MOD: CLASS accelerator probe and DIONISIS plasma source** ***(MIT)***
- **ANL/Purdue: PSI facilities** ***(Brooks/Hassanien/Allain → Purdue)***
- **U-ILL: SLIDE lithium flow experiment** ***(U. of Illinois)***

Modeling and Simulations

- **Mixed-material sputtering and mixing for ITER** ***(ANL/LLNL/UCSD)***
  - initial model of Be surface coverage in divertor, core impurity, T/Be codep, sputter/transport/ redep
- **SOL Blob, higher sheath fluctuations & sputtering** ***(ANL/LLNL)***
- **Continued assessment of Li surface for NSTX** ***(PU/LLNL/PPPL/Sandia)***
- **Assessed PFC response to ELM's, other plasma transients** ***(PU)***
- **3D simulation, B field strength, hot spot on free Li surface** ***(UCLA)***
- **CFD benchmarking of He-cooled FZK W PFC** ***(UCLA)***

PFC FY09 Major Plans

Prepare FY10 PFC/PSI Initiative

PFCs

- Test US & foreign ITER FW (Be) Quality mockups
- Simulate ITER ELMs in PISCES, impact of H in surface
- Develop He-cooled PFC & structure for breeding blanket research
- Prepare for possible LLD upgrade in NSTX

Plasma Materials Interactions Experiments

- Results from NSTX campaign with the Liquid Lithium Divertor and Purdue results on bonding of lithium with C, O and impurities
- Continued mixed-material experiments in PISCES
- Continued DIII-D experiments with DiMES and MiMES

Plasma Materials Interactions Model

- Use kinetic transport code to predict non-thermal wall fluxes
- Detailed surface evolution of mixed materials, including MD model
- PFC response to plasma transients (continued)
- Lithiated graphite and liquid Li divertor (continued)

PFC FY10 Major Plans

Propose PFC/PSI Initiative

PFCs

- Upgrade PMTF for ITER first wall prototype testing and testing of advanced PFCS with high temperature He cooling
- Simulate ELM ablation plume transport in PISCES
- Compare thermal/fluid and stress modeling of breeding blanket first wall with test results on small mockups

Plasma Materials Interactions Experiments

- Continuing analysis of NSTX liquid lithium divertor results
- C deposition and D concentration versus temperature in DIII-D
- Material samples in DiMES & MiMES in DIII-D

Plasma Materials Interactions Model

- Utilize edge turbulence code for model impurity “blob” transport
- Couple MD codes with BCA and kinetic-based codes for temperature-dependent surface response
- Assess ITER PFC sputtering and transient performance with respect to lifetime, tritium retention/codeposition.

VLT PROGRAM ELEMENT: Plasma Facing Components

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Task Descriptions	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
PFCs (Expt. & modeling)	2760	2520	2825	4300
Plasma Materials Interaction Expts.	1375	1237	1387	1800
PMI Modeling	1424	1300	1458	2000
TOTALS	5559	5057	5670	8100

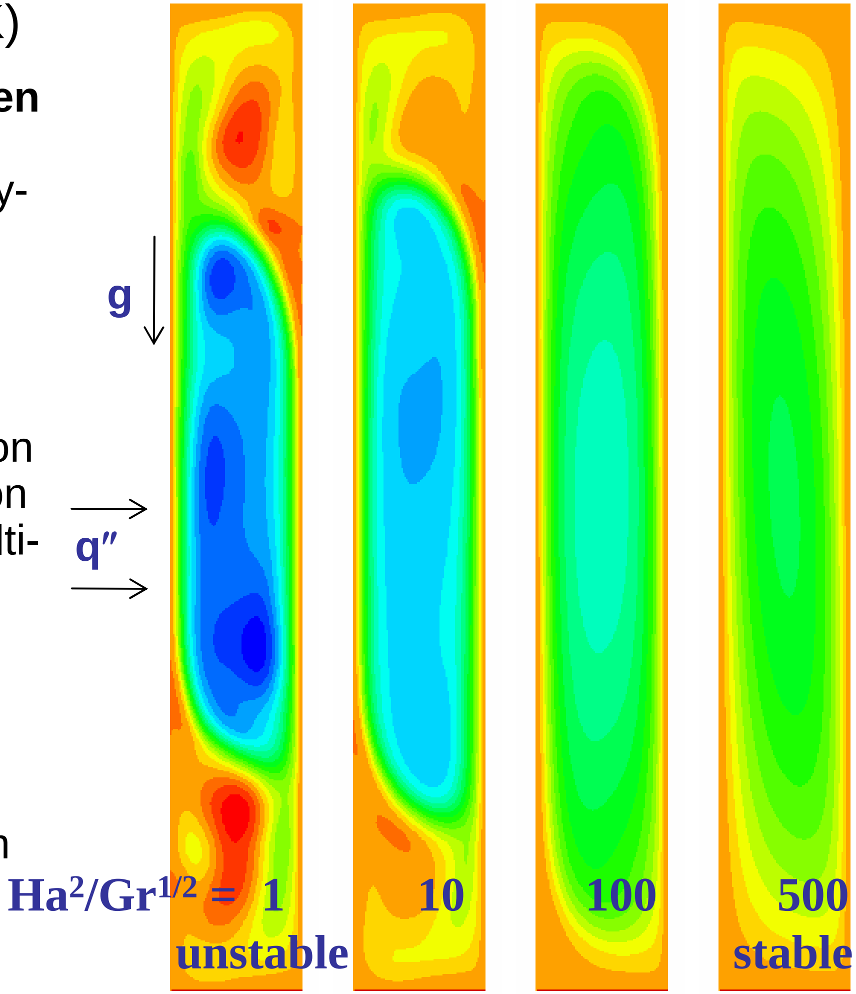
PFC/PSI Initiative: high priority in Greenwald Report

<u>Theme B. The plasma material interface</u>

– The state of knowledge must be sufficient to design and build, with high confidence, robust material components which interface to the hot plasma in the presence of high neutron fluences.

Plasma Chamber Research and Development (Theme C)

- FY-08 Planned Accomplishments ($1540 K)
  - **Discovery and exploration of Buoyancy-Driven flow effects for DCLL blanket system:** 1st modeling showing the strong impact of buoyancy-driven flows on the peak temperatures (pictured right), thermal loads and interactions with 2-D turbulent MHD flows in the DCLL blanket
  - **LM-MHD Experiments for the US/JA TITAN Collaboration:** Completed year 1 experiments on MHD flow distribution in insulated flow distribution manifold. Completed initial experiments with multi-dimensional ultrasonic velocity measurements system.
  - **Began development of integrated blanket simulations:** data translation between different meshes/codes for an integrated neutronics-thermofluid-thermomechanics analysis for tritium blanket systems.
  - **Provided to ITER IO US expertise on TBM interfaces:** Input for US position and possible needs regarding space and interfaces in the TCWS Vault, Tritium Building, hot cell area etc.



Stream function contours in a surface heated lead-lithium cavity as a function of increasing magnetic field (no average flow)

Plasma Chamber Research and Development

- FY-09 Planned Accomplishments ($1540 K)
  - **Simulation for Integrated Fusion Nuclear Science and Technology (FNST):** Develop groundwork for integrated simulation system, mesh and data hierarchy, and explore coupling into Fusion Simulation Project
  - **Core Predictive Capabilities:** e.g. Continue to develop LM-MHD simulation capabilities to include impacts of unsteady flow and buoyancy driven convection on mass and heat transfer. Continue to develop tritium fuel cycle modeling, tritium permeation database, and solid breeder pebble bed thermomechanics characterization
  - **Titan and International Collaborations:** Perform 2nd year experiments including electrically conducting manifold flow , PbLi alloy/SiC interface slip and conductance measurements with SiC.
  - **US Collaboration on ITER Test Program:** Participation in TBWG and ITER IO meetings regarding test program collaborations and qualification, safety and interface planning

Plasma Chamber Research and Development

- FY-10 Planned Activities ($1540 K)
  - **Simulation for Integrated Fusion Nuclear Science and Technology (FNST):** Continue work towards better integration of meshes, data from, and execution of custom research code for MHD flow, heat transfer and tritium transfer, with standard commercial codes for CAD, electromagnetics, and stress/deformation
  - **Core Predictive Capabilities:** e.g. Continue FY09 work to develop LM-MHD simulation capabilities to include impacts of unsteady flow and buoyancy driven convection on mass and heat transfer. Perform simulations in support of TITAN experiments in this area. Experimental investigations of thermal cycle effects on pebble bed thermo-mechanical state.
  - **Titan and International Collaborations:** Perform 3rd year experiments involving MHD buoyancy driven flows and small scale PbLi exps.
  - **US collaboration on ITER Test Program :** Continue participation in TBWG and ITER IO meetings regarding test program collaboration and qualification, safety and interface planning
- FY-10 Full Utilization ($2600 K total)
  - **Revitalization of Fusion Nuclear Science and Technology (FNST):** Provide vital human resources and enhance research activities in critical areas with high payoff and strong scientific content (Core Predictive Capabilities and Integrated Simulation)

VLT Program Element: Plasma Chamber

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Task Descriptions	FY09 (K$) CBR	FY10 (K$) -10%	FY10 (K$) 2%	FY10 (K$) Full
Simulation for Integrated FNST (integrated modeling)	100	50	130	630
Core Predictive Capabilities (MHD, Tritium, Neutronics, etc. modeling & database)	540	436	540	1070
TITAN & International Collaborations (key experiments for Blanket and TBM collaboration)	590	590	590	590
US collaboration on ITER Test Program (TBWG, Test & Qualification Plan, etc.)	310	310	310	310
TOTALS	1540	1386	1570	2600

Safety, Environment, and Tritium (Theme C)

FY-08 Principle Accomplishments ($2,167 k)

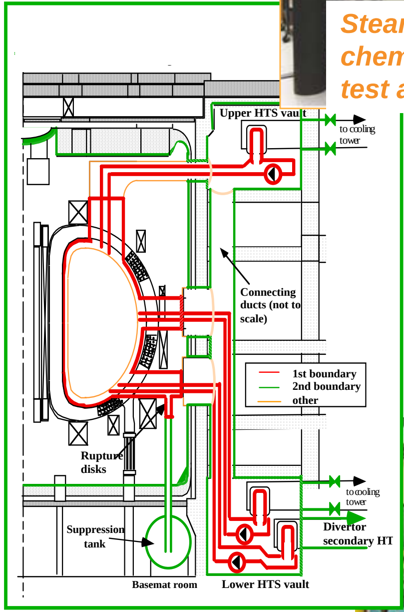
SAFETY AND ENVIRONMENT ($1,513k)

- Analyzed steam reactivity behavior of beryllium and mixed materials dusts (ITER)
- Initiated upgrades in MELCOR to address anticipated needs for ITER Final Safety Analysis
- Extended failure rate database to include plasma heating/current drive systems and tritium plant components (ITER)

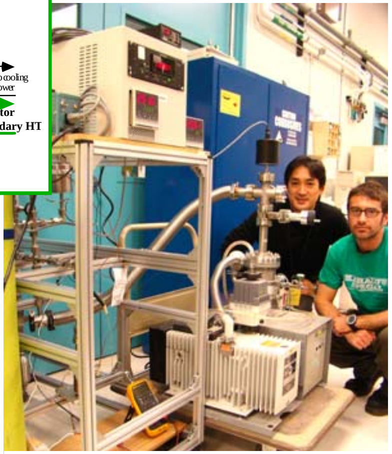
TRITIUM SYSTEMS ($654k)

- Established several techniques to measure tritium concentrations in materials (imaging plate, electrochemical etching, and nuclear reaction analysis)
- Measured tritium solubility in molten lead-lithium eutectic at very low partial pressures
- Refurbish Tritium Ion Implantation Experiment (TRIIX)

Steam and air chemical reactivity test apparatus



ITER Confinement Boundary for Licensing Assessment



Molten lead-lithium solubility testing system

Safety, Environment, and Tritium (continued)

FY-09 Expected Accomplishments ($2,217k requested)

SAFETY AND ENVIRONMENT *($1563k)*

- *Fusion Safety Codes:* Verification and validation (V&V) activities supporting of ITER Final Safety Report; Support tritium blanket collaborative program and advanced design studies; Upgrade arc behavior model in magnet safety code
- *Experiments and Analysis:* Perform measurements of explosion indices for beryllium dust; Participate in developing the ITER Dust Mockup Facility; Determine experiment needs to close any gaps for safety code V&V for ITER and other fusion pathway facilities
- *Risk and Safety Support*: Extend failure rate data for plasma diagnostics systems and advanced cycle heat transport systems; Evaluate system reliability and maintainability for safety and economic impacts on ITER, DEMO, and commercial plants; Extend the Fusion Safety Standard as parties go forward in fast track fusion power development

TRITIUM SYSTEMS *($654k)*

- *First Wall Tritium Behavior:* Measure tritium retention in irradiated tungsten with TPE and TRIIX; Determine tritium concentration profiles in various metals and mixed materials
- *Blanket Tritium Behavior:* Design of a molten lead-lithium loop for studying tritium extraction methods; Measure effectiveness of various tritium permeation barriers

Safety, Environment, and Tritium (continued)

FY-10 Plans ($2261k target)

SAFETY AND ENVIRONMENT ($1,603k)

- *Fusion Safety Codes:* Safety calculations on ITER with features of the final design; Apply safety codes to IFMIF, CTF, and other proposed facilities needed before DEMO; Evaluate evolving requirements by licensing authorities for safety analysis tools applied to advanced nuclear systems
- *Experiments and Analysis:* Perform measurements of explosion indices for mixed-materials dust
- *Risk and Safety Support:* Estimate personnel radiation doses expected for commercial fusion plants; Update the Fusion Safety Standard, including waste management and recycling strategies, to address fast track fusion power development

TRITIUM SYSTEMS ($658k)

- *First Wall Tritium Behavior:* Measure in-situ tritium permeation in metals with TPE and TRIIX; Perform tests for baseline qualification testing of tritium behavior in ITER joined material
- *Blanket Tritium Behavior:* Construct a molten lead-lithium loop for studying tritium extraction methods; Continue measure effectiveness of various tritium permeation barriers as applied to advanced designs

VLT PROGRAM ELEMENT: Safety, Environment, and Tritium

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Task Descriptions	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
SAFETY AND ENVIRONMENT				
Fusion Safety Codes	650	550	660	680
Experiments and Analysis	650	600	680	700
Risk and Safety Support	263	250	263	275
TRITIUM SYSTEMS				
First Wall Tritium Behavior	327	300	329	350
Blanket Tritium Behavior	327	295	329	400
TOTALS	2217	1995	2261	2405

Materials Science (Theme C)

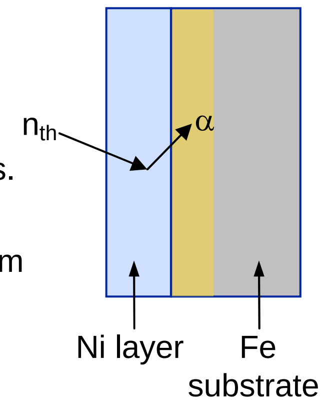
- **FY-08 Accomplishments ($5315 K)**
  - Novel He injector technique (μ-IFMIF) shows effectiveness of nanoclusters for trapping He and possible detrimental effects of He on RAFM steels.
  - Completed DOE/JAEA irradiation experiment to determine microstructural evolution and mechanical properties of advanced RAFM and ODS steels.
  - Completed DOE/MEXT experiment to examine response of SiC and SiC composites to high-temperature irradiation.
  - Fracture toughness of irradiated CuCrZr (supports ITER divertor) characterized.
  - New interatomic potentials for Fe-He and Fe-Cr implemented to study He diffusion and irradiation effects in ferritic alloys.
  - A new model of fracture toughness - a validated model for the effect He embrittlement of RAFM steels.
  - Constitutive models of radiation and thermo-mechanical damage developed for use in large-scale finite element codes.
  - Electronic Fusion Materials Database constructed.

Helium Injector Experiment

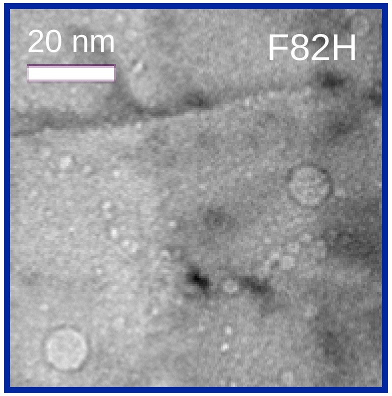
$^{58}Ni + n_{th} \rightarrow {}^{59}Ni + \gamma$

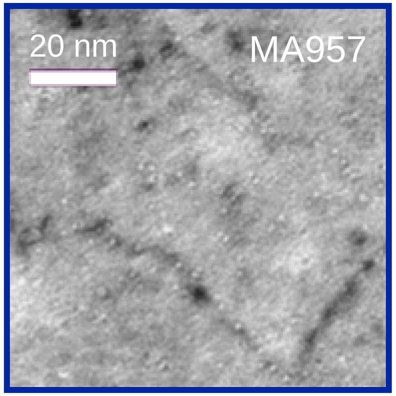
$^{59}Ni + n_{th} \rightarrow {}^{56}Fe + {}^{4}He$

- Use n,α reactions in mixed spectrum reactors to produce controlled He/dpa at fusion relevant conditions.
- Avoids most confounding factors.
- Apply to any material.
- Ni injector produces up to ~10 μm uniformly deposited He in Fe.



- F82H (RAFM steel) and MA957 (ODS) were irradiated at the same temperature to the same dose.
- ~380 appm He is trapped in MA957 and prevented from forming large bubbles because the material contains ~$10^{24}/m^3$ of ~5 nm diameter Y-Ti-O particles.





Materials Science

- **FY-10 Planned Accomplishments ($4890 K**)

Structural Materials

- **Reduced Activation Materials:** Continue fundamental research on ferritic steels and SiC.
- **DOE/JAEA Collaboration:** Assess effects of high-dose (>50 dpa) irradiation on constitutive properties of advanced RAFM steels.
- **DOE/MEXT Collaboration:** Continue investigation of the synergistic effects of He, tritium and neutron irradiation on properties of bonded materials and dynamic deformation of SiC composites. Determine strength and cohesiveness of joints (weld, HIP) in irradiated RAFM steels.
- **Advanced Materials:** Continue exploration of nanostructured ferritic alloys. Under full funding examine feasibility of using Nb or Ta alloys for tritium permeation in PbLi blankets.
- **Blanket Materials Engineering:** Continue development of mechanistic understanding of damage evolution due to creep, fatigue and creep-fatigue under irradiation including high-temperature design methodology.
- **Joining:** Full funding only - investigate effects of irradiation on joining methods relevant to ferritic steels and advanced nanostructured ferritic alloys.
- **Corrosion/Compatibility:** Full funding only - explore potential for environmentally assisted cracking of ferritic steels in PbLi due to radiation induced segregation.

Crosscutting Theory & Modeling

- Continue multiscale modeling of radiation effects on mechanical properties of materials, with emphasis on effects of helium.
- Continue development of high-temperature microstructural evolution and deformation models.

Neutron Source

- Small effort at full funding.

VLT PROGRAM ELEMENT: Materials Science

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Task Descriptions	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
Structural Materials				
Reduced Activation Materials (Ferritic Steels, SiC)	250	200	250	500
DOE/JAEA - Ferritic Steels	1540	1500	1540	1540
DOE/MEXT - Tritium/Irradiation Synergism	700	700	700	700
Advanced Materials (ODS, Nb Alloys)	500	400	600	1400
Blanket Materials Engineering (TBM Relevant)	500	350	400	600
Joining	0	0	0	400
Corrosion/Compatibility	0	0	0	400
Crosscutting Theory & Modeling	1300	1160	1400	1800
Neutron Source	0	0	0	100
TOTALS	4790	4310	4890	7440

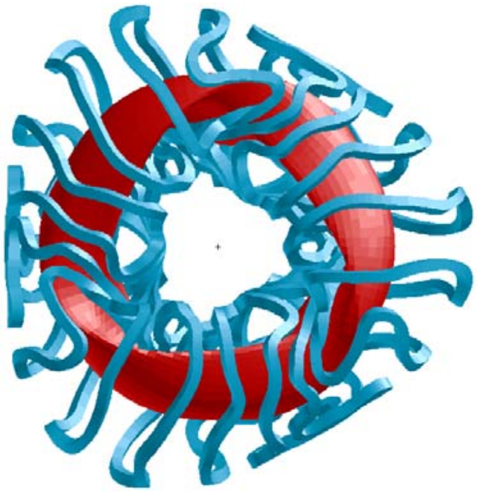
ARIES Research Bridges the Science and Energy Missions of the US Fusion Program

FY07 Highlights:

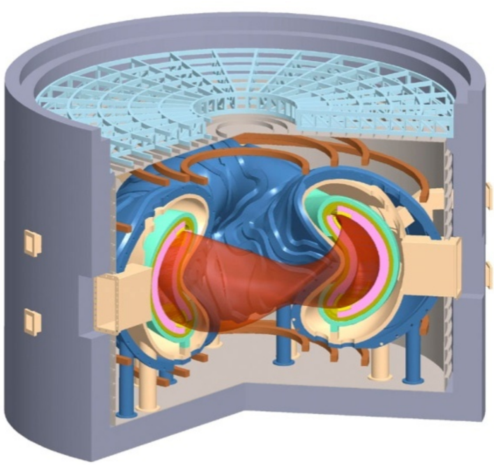
1)Completed documentation of ARIES compact stellarator study.

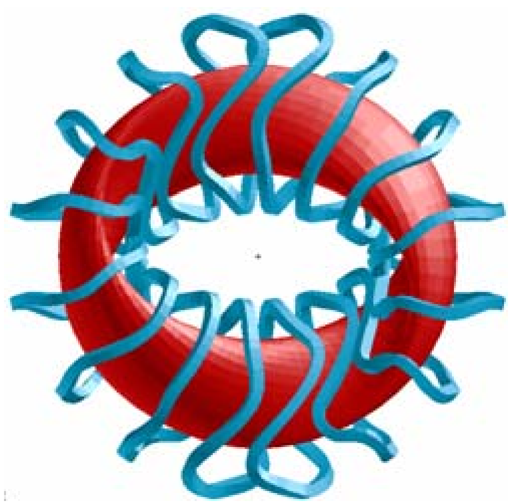
- ✓ Final report will appear in a special issue of Fusion Science and Technology.
- ✓ Preprints are available on ARIES Web site.

2) Initiated ARIES Pathways study, a 3-year program.



NCSX-Like





MHH2

The ARIES Pathways program is developing quantitative measures to assess fusion development needs and pathways.

- **What are the data bases needed to field a fusion power plant?**
  1. Formed an Industrial Advisory Committee to help define R&D issues which are not usually considered by the scientific community (e.g., data base needed for licensing, operation, reliability, etc.)
  2. Developed "Technical Readiness Levels" as a quantitative measure of maturity and R&D needs in each technical area.
     - ✓ TRL was originally introduced by NASA and is now adopted by DoD and recommended by GAO for "Technology" Development. TRL structure, however, is readily applicable to scientific areas.
     - ✓ TRL structure provides a framework to plan and execute R&D programs as they can be utilized to assess cost, risk, and benefits of new initiatives.
     - ✓ Used a system-based (concurrent physics/engineering) approach to identify interconnected physics/engineering constraints and issues

The ARIES Pathways program is developing quantitative measures to assess fusion development needs and pathways (cont'd)

- **What it the impact of each R&D item on the attractiveness of the final product? (Metrics for prioritization of R&D)**
  - Experience indicates that "optimum" design points are usually driven by the constraints. In some cases, a large design window is available when the constraint is "slightly" relaxed, allowing a more "robust" and credible design.
  - ✓ Developed a new approach to Systems Analysis based on surveying the design space (instead of finding only an optimum design point)
  - ✓ The data base currently contains over 10^6 self-consistent physics/engineering points. Modern visualization and data mining techniques are used to explore design space.
  - ✓ This approach provides a direct measure of R&D on the characteristics of the final product.
- **What are the possible embodiments for CTF and what are the their cost/performance attributes? (FY09 research)**

VLT PROGRAM ELEMENT: Advanced Design

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Task Descriptions

	FY09 (K$)	FY10 (K$)		
	CBR	-10%	2%	Full
ARIES	1,800	1,620	1,836	2,200
Other Advanced Design Projects	800	720	816	840
New Initiatives	1,973	1,776	2,012	2,072
TOTALS	4,573	4,116	4,664	5,112

Summary

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- The VLT is fully engaged in support of ITER activities
  - Opportunity: for upgrades and exploitation of ITER
  - Concern: loss of competency as ITER project R&D winds down in 2010.

- The F10 guidance is 28% below FY05 levels ($29 M).

- Full funding case ($30M) in FY10 restores budgets to pre ITER era and:
  - Lifts the magnetic program up off its knees
  - Restores industrial gyrotron research
  - Provides resources to address urgent ITER issues (first wall material choice, disruption and ELM mitigation, heating and current drive mix, etc.)
  - Restores 33% cut in materials research
  - Funds the development of tools to participate in test blanket program as a collaborator
  - Provides resources to start initiatives identified in Greenwald panel

Materials Science

- **FY-09 Planned Accomplishments ($4790 K)**

Structural Materials

- **Reduced Activation Materials:** Fundamental research on ferritic steels and SiC composites.
- **DOE/JAEA Collaboration:** Complete investigation on the effects of intermediate dose irradiation on constitutive properties of advanced alloys.
- **DOE/MEXT Collaboration:** Continue investigation of the synergistic effects of helium, tritium and neutron irradiation on properties of bonded materials and dynamic deformation (irradiation creep) of SiC ceramics and composites.
- **Advanced Materials:** Continue development and evaluation of oxide and nitride dispersion strengthened ferritic alloys.
- **Blanket Materials Engineering:** Develop mechanistic understanding of damage evolution due to creep, fatigue and creep-fatigue under irradiation including high-temperature design methodology. Continue study of the effects of irradiation on electrical and thermal conductivity of SiC ceramics and composites.

Crosscutting Theory & Modeling

- Multiscale modeling of radiation effects on mechanical properties of materials, with emphasis on effects of helium. Validate atomistic and kinetic simulations of helium effects using data from fission reactor irradiations (e.g. implanter experiments).
- Microstructure-based, multiscale modeling of high-temperature deformation and fracture.
- Develop “coarse-graining” methods for advanced kinetic models.

Neutron Source

- No support for neutron source development at CBR funding level.