Enabling R&D Plans and Budgets

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

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Oak Ridge National Laboratory

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USBPO Fusion Engineering Science Topical Group Leader
Sandia National Laboratories

OFES Budget Planning Meeting
Gaithersburg, Maryland
March 11-12, 2010

The Virtual Laboratory for Technology represents the diverse technology research activities of 22 institutions

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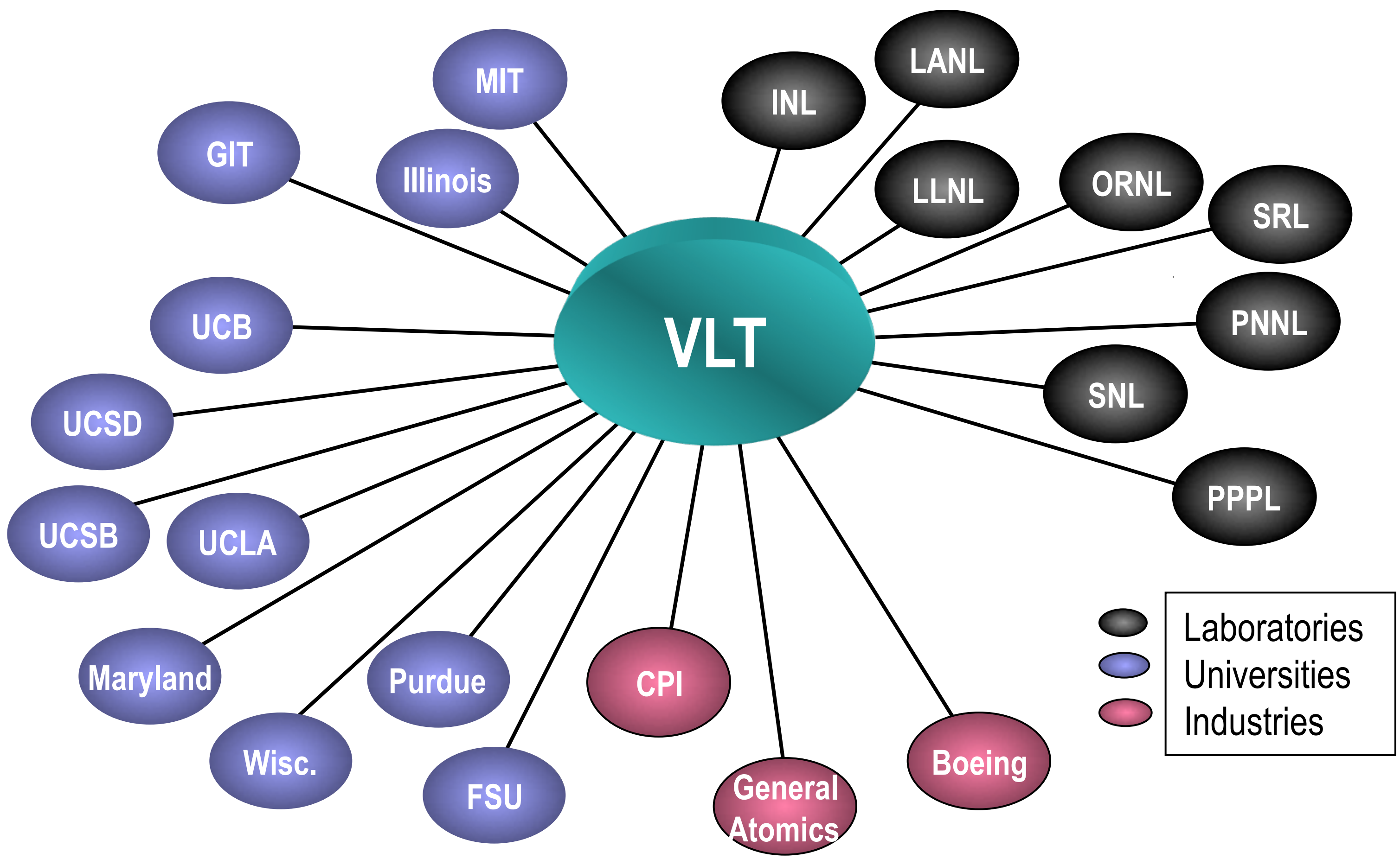

http://www.ornl.gov/sci/vlt/index.shtml

Outline

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- **Budget considerations**
  - **Relevance of research to ITER and ReNeW**
  - **Overview of FY10/11 Budget Situation**

- **For each VLT technical area**
  - **Highlights of technical accomplishments**
  - **FY11 tasks and funding**
  - **FY12 tasks and funding (-10%, +2% and +10%)**
  - **Milora: magnets, ECH, ICH, fueling and systems studies**
  - **Nygren: PFC, materials, chamber, safety and tritium**

- **Issues and opportunities**

FY10/11 Budget Considerations

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- "In planning for the FY 2012 **ongoing base program,** to the extent that it makes sense, 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

- "In addition, for magnetic fusion related work, the proposed tasks should also be related to a theme identified in the report: "Research Needs for Magnetic Fusion Energy Sciences,"
  - All VLT research is relevant to one or more of the 5 ReNeW themes

- FY11 Congressional request increases by 2.4% relative to FY10
  - Overall FY11 budget is still 25% 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 (ELM and disruption mitigation, choice of divertor materials) and
  - operational issues and potential performance enhancements (higher efficiency/power ECH systems and ITER relevant ICH antennas)

- Utilizing ITER as a fusion engineering science test bed and stepping stone to complementary facilities and next step devices such as FNSF.

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

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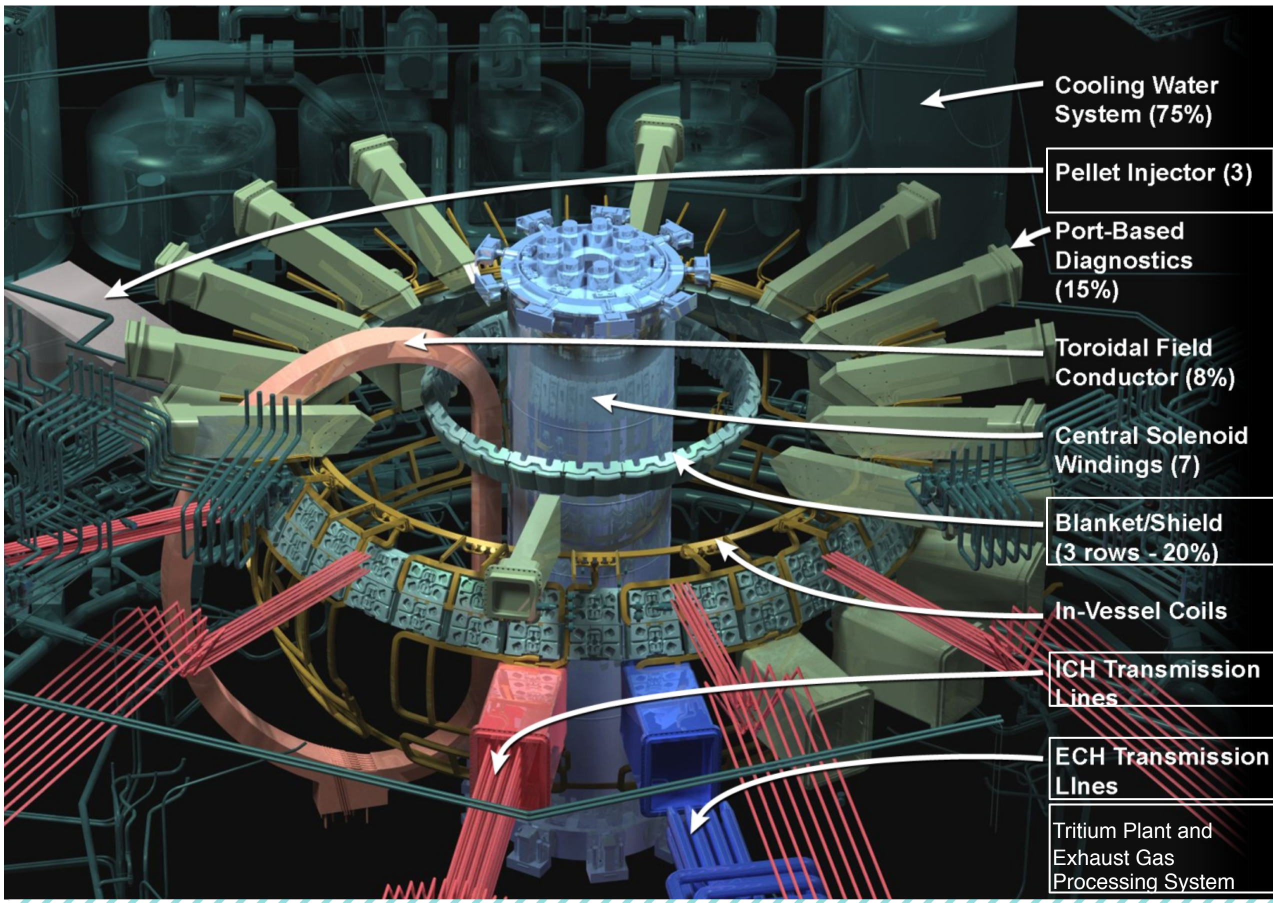

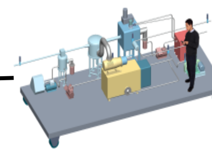
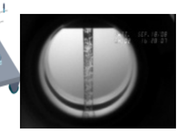
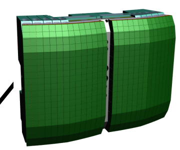





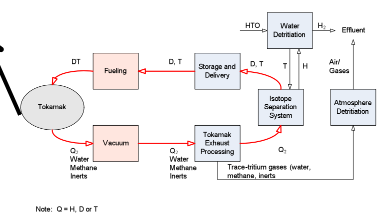

Cross cutting activities (Materials, Nuclear Analysis, Safety), Test Blanket Program Committee and Port Interface Coordination Fuel Cycle IPT Deputy Lead, STAC, IRP

VLT engagement in ITER is pervasive.

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	Program Element	Element Leader
√	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

"The base technology program, through the Virtual Laboratory (VLT), is clearly well linked to the ITER project. The IO is using the US analyses to support high-priority needs. As is true in the physics area, the US is contributing to the ITER technology needs well in excess of its status as a "junior" partner. "

US ITER TAC report, April 2009

http://www.ornl.gov/sci/vlt/research/20090414_10-USITER_TAC_Nygren_BAF39.pdf

Engineering science and technology issues and VLT performers figured prominently in ReNeW.

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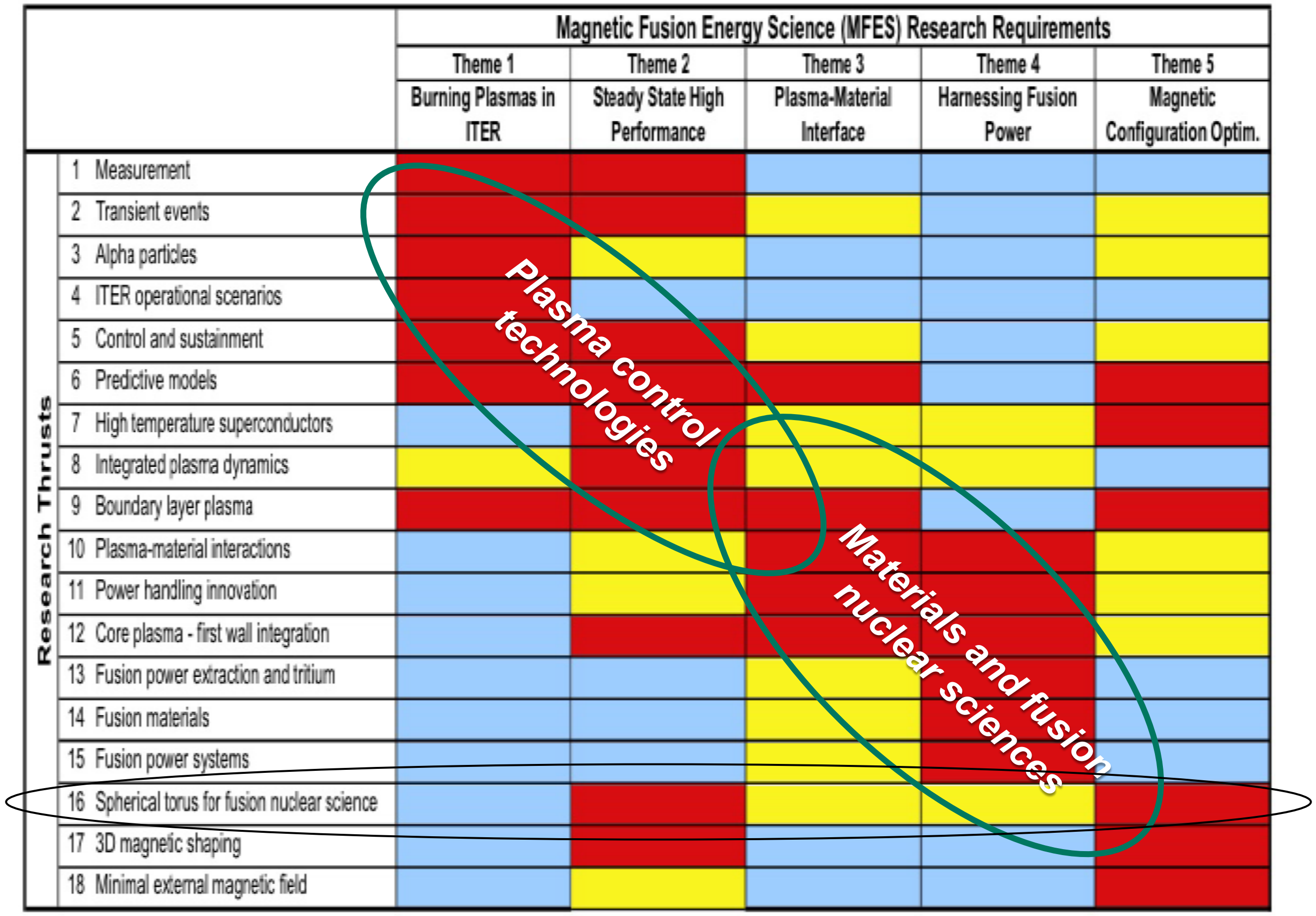

http://www.ornl.gov/sci/vlt/pdfs/20090622_ReNeW_Technology_Thrusts.pdf

The FY11 budget is status quo except for a welcome increase in Materials Research. Funding is 25% below FY05 level.

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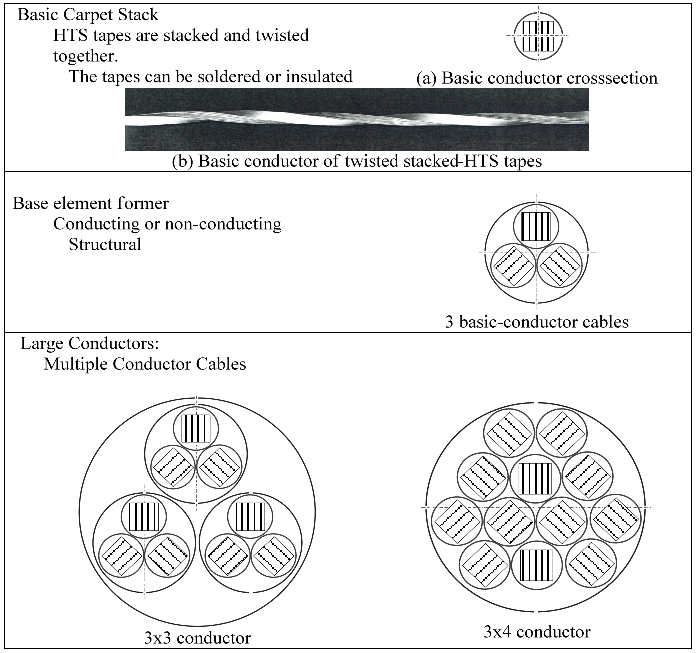
FY11 Enabling R&D Program Budget ($K) 2/1/10							
B&R	**Program Area**	**Program Elements**	**OFES PM**	**FY 09**	**FY 10**	**FY 11 CONG REQUEST**	**FY05**
AT6010301	Plasma Technologies	Plasma Facing Components	Nardella	5709	5029	**5029**	**6932**
AT6010301	Plasma Technologies	Magnet Systems	Sullivan	1000	800	**800**	**2243**
AT6010301	Plasma Technologies	Plasma Chamber Systems	Nardella	1910	2230	**2230**	**1690**
AT6010301	Plasma Technologies	ICH Systems	Sullivan	1540	1540	**1540**	**1708**
AT6010301	Plasma Technologies	Safety and Environment	Nardella	1518	1518	**1518**	**1727**
AT6010301	Plasma Technologies	ECH Systems	Sullivan	795	795	**795**	**1415**
AT6010301	Plasma Technologies	Fueling Systems	Sullivan	775	775	**775**	**1022**
AT6010301	Plasma Technologies	Tritium Systems	Nardella	839	654	**654**	**934**
AT6010301	Plasma Technologies	Neutronics	Nardella	385	310	**310**	**516**
	Plasma Technologies	**TOTAL**		**14471**	**13651**	**13651**	
AT6010501	Advanced Design	MFE System Studies	Opdenaker	1906	1783	**1783**	**1686**
AT6010501	Advanced Design	VLT Management	Nardella	740	740	740	
AT6010501	Advanced Design	Socio-economic Studies	Opdenaker	2	50	50	
AT6010501	Advanced Design	Strategic Planning	Opdenaker	1454	1750	2087	
	Advanced Design	**TOTAL**		**4102**	**4323**	**4660**	
AT602010	**Materials Research**	**Materials Science**	Nardella	**4817**	**5217**	**5729**	**7338**
AT60	**Enabling R&D**	**TOTAL**					
		TOTAL		**23390**	**23191**	**24040**	

MAGNETS (Themes 1, 2-Thrust 7,4,5)

- FY 09-10 Accomplishments
  - Developed new concept for making high current cables from HTS tapes
    - 4-tape twisted stacked conductor test using BSCCO (1G) and YBCO (2G) tapes
  - Critical current tests in magnetic fields up to 1.8 T at 77 K
    - Magnetic field orientation tests at 77 K
  - Joint development
    - Two strand model analysis
    - Joint finite element model analysis
    - Joint test at 77 K
  - AC loss analysis of twisted stack cable
  - Fatigue analysis of magnet structural materials
  - Development of Quench Code SOLXPORT3-D
    - 3D simulation of quench in all hydraulic circuits of CICC fusion magnets
    - Includes field effects from plasma currents and passive structure eddy currents
    - Includes criteria to dump energy upon quench propagation



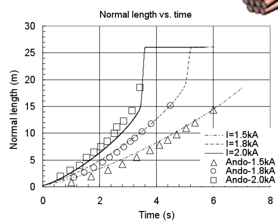


FIGURE 1.5 Simulation results by SOLXPT3D-Quench for normal length compared to Ando results.

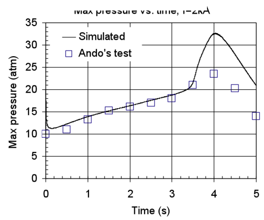


FIGURE 1.6 Simulation by SOLXPT3D-Quench for max helium pressure compared to Ando results.

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MAGNETS

- FY 10-11 Planned Accomplishments
  - Fabricate a short length conductor of twisted stacked-tapes (~10 kA size)
  - Perform critical current tests with helium gas at 4.2 K to 70 K **(No applied magnetic field)**
  - Measure AC losses and electrical and mechanical properties of bending on conductor
  - Joint evaluation
    - ❖ **Note: Requires additional funding to procure expensive 2G tape from industry**
  - Simulate electro-magneto-thermal operation of HTS magnets
  - Modify SOLXPORT3-D for high current conductors made from YBCO tapes

- FY 12 Plans
  - Short length conductor test in **high field to 15 T** at 4.2 K and temperatures below 77 K
    - Must use magnet lab facilities at NHMFL-FSU
  - Perform AC loss and stability tests in background field and analyses
    - Must use magnet lab facilities at NHMFL-FSU
    - ❖ **Note: Requires additional funding for sample shipping to and from NHMFL and helium consumption**
  - Modify SOLXPORT3-D to include helium system manifolds, valves, pumps for more realistic simulation
  - Development of multiaxial fatigue criteria

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VLT PROGRAM ELEMENT: MAGNETS

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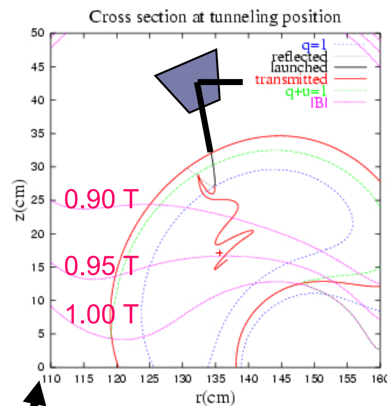
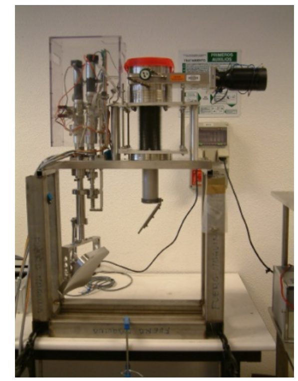
Task Descriptions	FY11 (K$)	FY12 (K$)		
	CBR	-10%	2%	10%
Short length conductor development (~10 kA)	710	349	388	426
Conductor tests (B, I, T)		101	112	123
Conductor Tests (AC losses and Stability)		73	82	90
SOLXPORT3-D		92	102	112
Strutural mechanics		37	41	45
TOTALS	710	652	724	797

Note: (FY12+10%) case required for conductor development and test tasks; procure HTS tape and consummables for lab tests

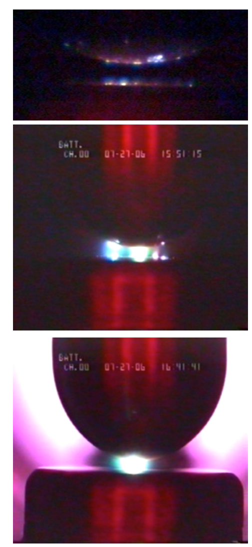
RF Research and Development
(ReNew Thrusts 4, 5, 6, 9, 10, 16)

- FY 09-10 Accomplishments ($1540 K)
  - Reliability improvements to increase power and pulse length of DIII-D Fast Wave systems.
  - Obtained improved power limits and core heating with modified NSTX HHFW antenna.
  - Analysis of load-tolerant JET antenna matching systems to guide ITER matching design.
  - Completed conceptual design study for DIII-D long pulse 60 MHz Fast Wave antenna.
  - Commissioned test facilities for ITER ICH transmission line and tuning system.
  - Initiated EBW H&CD collaboration with MAST.
  - Measured mode conversion efficiency with steerable **EBW emission radiometers on TJ-II**.
  - Measured and analyzed **RF breakdown limits and arc precursors** with imposed ultraviolet light and as a function of plasma density and surface imperfections (ORNL and UIUC).
  - Fabrication, operation, analysis of reflectometer edge density profiles - optimize coupling on C-Mod, DIII-D and NSTX RF antennas.





EBW emission pattern => Optimum launch angle for EBW heating of TJ-II



- Unipolar arcs
- Initial small breakdown arc
- Large breakdown arc

Increasing rf voltage

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RF Research and Development

- FY 10-11 Planned Accomplishments ($1540 K)
  - **RF Component Development:** Compact active and passive tuning and pre-tuning elements and cw transmission line components for ITER and DIII-D. **Thrust 9, 4**
  - **High Power Density Antenna Development:** Evaluate matching/tuning algorithms for JET in ELMing H-mode (ITER relevant). Design of long pulse, low voltage antenna for DIII-D. **Thrust 4, 5, 9**
  - **Improve Control, Reliability, Protection and Operation of ICH on Fusion Facilities:** Flexible and reliable control, matching and arc protection for NSTX, DIII-D (ITER. relevant). **Thrust 4, 5**
  - **RF-edge Interactions:** Modeling and diagnostics/experiments on fusion facilities with arc detectors, probes, optics and reflectometers on NSTX, DIII-D, C-Mod, JET, Tore Supra and ITER. **Thrust 9, 6, 4, 5**
  - **RF Breakdown and Arc Detection:** Plasma, UV, and surface material effects on RF and DC breakdown thresholds (at ORNL, UIUC, and NC State facilities). Develop arc detection/localization techniques for DIII-D, JET (ITER relevant) and coupler/filter technology using ultra wideband guided radar systems with POLITO and IUPUI- Ft. Wayne (ITER relevant). **Thrust 10, 9**
  - **Innovative Approaches to Advanced Heating & CD for New Concepts:** EBE -> EBW heating for STs, stellarators and RFPs. (MAST, Pegasus, TJ-II, MST) **Thrust 16**
- FY 12 Planned Accomplishments ($1570 K)
  - **RF Component Development:** Compact active and passive tuning and pre-tuning elements and long pulse components for ITER and DIII-D. **Thrust 9, 4**
  - **High Power Density Antenna Development:** Begin fabrication of low voltage, long pulse DIII-D antenna. **Provide waveguide antenna for EAST.** **Thrust 4, 5, 9**
  - **Improve Control, Reliability, Protection and Operation of ICH on Fusion Facilities:** NSTX, DIII-D & ITER. **Thrust 4, 5**
  - **RF-edge Interactions and HV Breakdown Studies:** ORNL, UIUC, NSTX, DIII-D, C-Mod, JET & ITER. **Thrust 10, 9, 6, 4, 5**
  - **Innovative Approaches to Advanced Heating & CD:** EBE -> EBW heating for STs and stellarators. LH current drive for ITER. **Thrust 16**

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VLT PROGRAM ELEMENT: RF Technology

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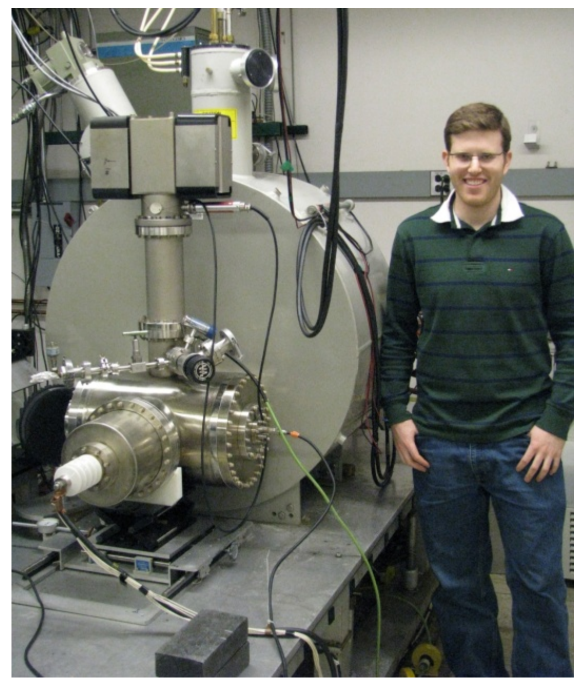
Task Descriptions	FY11 (K$)	FY12 (K$)		
	CBR	-10%	2%	10%
RF component development (Prototypes and experiments)	300	290	300	300
High power density & long pulse antennas (Antennas and experiments)	500	395	500	624
RF breakdown studies & reliability improve (Experiments and modeling)	370	350	400	400
RF edge interactions & diagnostics (Diagnostics and experiments)	200	190	200	200
Advanced H&CD concepts (Prototypes, experiments, modeling)	105	100	105	105
University Programs	65	65	65	65
TOTALS	1540	1390	1570	1694

FY10 ECH Technology Advances: Themes 1,2,5

- **Tests of ITER ECH Transmission Line (TL) Components at JAEA Test Stand** (GA, JAEA)
  - Sliding joint compressed and expanded as expected
- **Analysis of losses on the ITER test line using new EM theoretical approach (MIT, JAEA)**
  - HE_{11} mode purity > 95% required
- **Design and demonstration of internal mode converter with smooth mirrors**
  - Successfully tested at MIT (MIT, Univ. Wisconsin, Calabazas Creek Res.)
  - Mirrors are easier to fabricate and more tolerant to misalignment

GA Sliding Joint Tested at JAEA



Advanced internal mode converter tested on MIT Gyrotron Test Stand (grad student David Tax)

FY11 ECH Technology Advances

- **Design low loss components for the ITER Transmission Line (TL)**
  - Build improved TL components; test at low / high power (GA, MIT)
  - Test ITER prototype mode analyzer at JAEA (GA)
  - Fabricate prototype miter bend long pulse power monitor (GA)

- **Test 1.5 MW, 110 GHz gyrotron with direct coupling of output power to an internal corrugated waveguide** (Cal. Creek Res., MIT)

- **Fabricate a multi-frequency gyrotron, 1.5 MW at 110 to 140 GHz**
  - Prepare MIT test stand for short pulse tests (MIT)
  - Test prototype multi-frequency mode converter (Univ. Wisconsin)

- **Analyze backward-wave excitation in beam tunnels and its effect on electron beam energy spread / gyrotron efficiency (Univ. MD)**

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FY12 ECH Technology Advances

- **Continue pioneering efforts on Design and Test of improved, low loss components for the ITER Transmission Line (TL) (GA, MIT)**
  - Test improved 170 GHz, 2.5” mode analyzer and waveguide sliding joint on prototype ITER transmission line (GA)
  - Collaborate on research at Oak Ridge ITER ECH Test Stand (all)
- **Develop accurate 3D model of transmission efficiency in a highly overmoded TL, including miter bend losses** (MIT, Calabazas Cr.)
  - Measure high order mode content of ITER TL components and compare to 3D theory (MIT, JAEA)
- **Test prototype multi-frequency gyrotron, 1.5 MW at 110 to 140 GHz (MIT, Univ. MD, Univ. WI)**

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VLT PROGRAM ELEMENT: ECH Technology

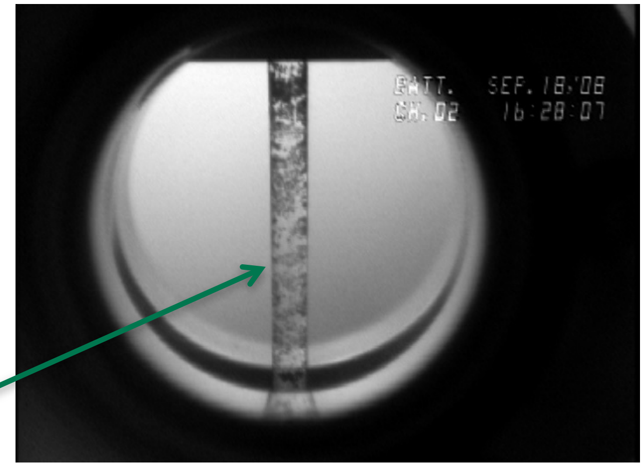
Task Descriptions	FY11 (K$)	FY12 (K$)		
	CBR	-10%	2%	10%
ECH / ITER Transmission Line Research	335	335	351	385
High Efficiency / Tunable Gyrotron	310	250	310	340
Modeling & Code Development	150	131	150	150
TOTALS	795	716	811	875

+10% Case: Augment fabrication of TL prototype components and begin gyrotron test stand upgrade at MIT

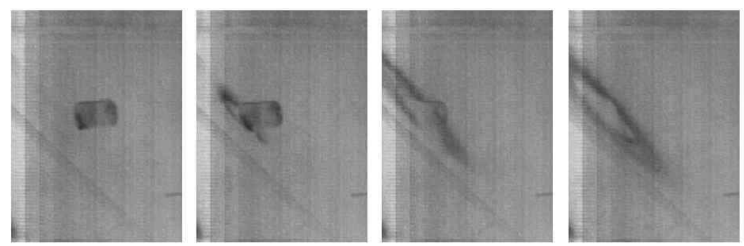
-10% Case: Reduce effort on prototype gyrotron testing.

Fueling Development (Themes 1,2,4,5)

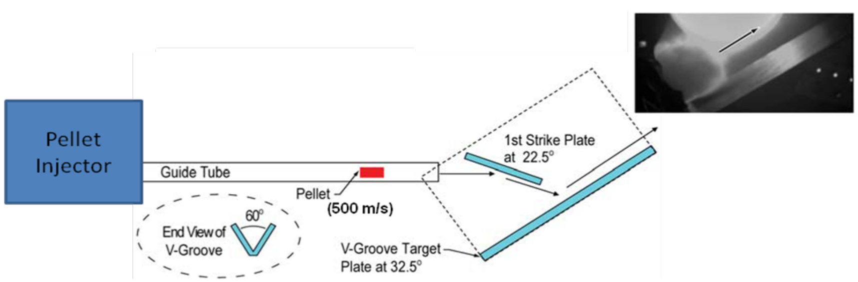
- FY 09-10 Accomplishments
  - Development of shattered pellet injection technique for disruption mitigation (ITER relevant)
  - Installation/Operation of shotgun pellet injector on DIII-D for disruption mitigation studies
  - Flexible pellet injector development and upgrades for MST and TJ-II fueling and transport studies
  - Continuous twin-screw extruder demonstration for ITER D-T pellet injector design
  - Modeling of ITER fueling and pellet ELM pacing scenarios
  - High speed two-stage gas gun injector commissioned with ENEA



Solid deuterium extrusion from twin-screw extruder.



16.5 mm diameter Ne pellet impacting a plate at 340 m/s



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

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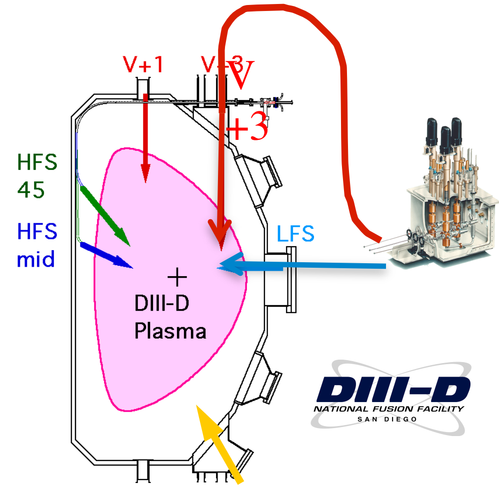
Fueling Development

- FY 10-11 Planned Accomplishments
  - **High rep-rate pellet formation:** Develop low gas throughput propellant valve for high rep-rate fueling and ELM pacing (DIII-D, ITER relevant)
  - **ELM mitigation:** Evaluate pellet pacing with high-frequency small slow pellets for ELM mitigation (DIII-D, JET) Needs incremental funding FY11 to accelerate injector upgrade for high rep-rate
  - **Disruption mitigation:** Develop/evaluate burst cartridge gas jet and large pipe-gun shattered pellet (DIII-D)
  - **Deep pellet fueling:** Test compact two-state gas gun injector up to 3 km/s



- FY 12 Plans
  - **Pellet fueling:** Develop re-circulating fuel gas and propellant gas systems (ITER relevant)
  - **ELM mitigation:** Improve pellet pacing technology for ITER ELM mitigation
  - **Disruption mitigation:** Optimize shattered pellet/gas jet technology
  - **Fueling and transport tools for alternates:** Implement pellet fueling for low wall recycling (lithium) devices

VLT PROGRAM ELEMENT: Fueling Systems

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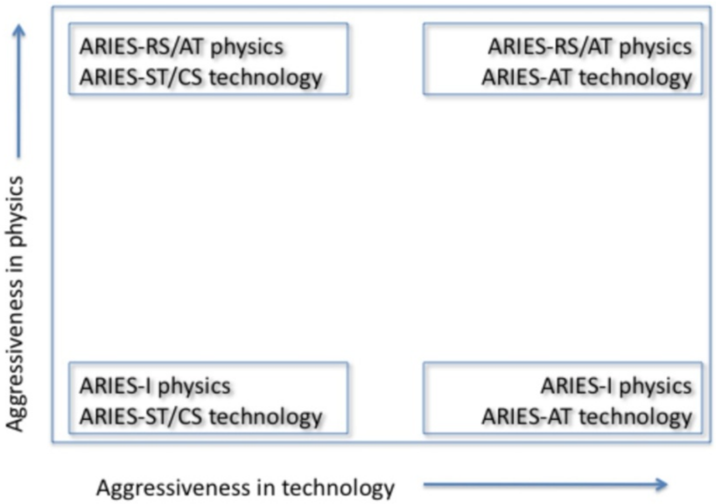
Task Descriptions	FY11 (K$)	FY12 (K$)		
	CBR	-10%	2%	10%
High throuput fueling development (Prototypes, experiments and modelling)	460	400	460	470
Deep fueling developmemt (Prototypes, experiments and modelling)	50	45	50	55
Fueling tools for alternate concepts (Injector improvements and experiments)	120	110	120	120
Disruption and ELM mitigation (Prototypes, experiments and modelling)	145	145	160	210
TOTALS	775	700	790	855

ARIES (MFE Systems Studies) Research Bridges the Science and Energy Missions of the US Fusion Program (integrates ReNeW themes)

FY10 Highlights:

1) Completed "ARIES Pathways" study: ***tools to aid in R&D planning***

- Application of "Technical Readiness Levels' to quantify gaps
- Fielding of new Systems Analysis tool for improved exploration of parameter space
- Application of the tool to analyze "four corners" of tokamak operation



2) Initiated study of edge plasma physics and plasma-material interactions, high heat flux components and off-normal events *in a fusion power plant*.

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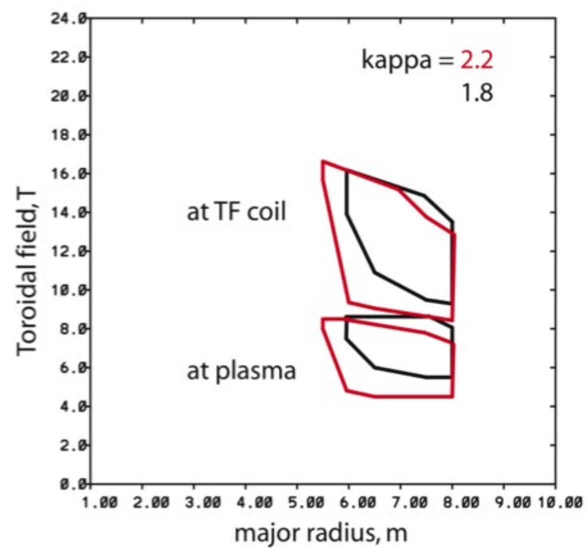
The ARIES program will evaluate gaps and quantify high-leverage R&D needs using the new system analysis tool

FY'11-12 Plans:

1) Thorough exploration of parameter space, as opposed to design point optimization

2) Special emphasis on "Taming the plasma material interface"

- What would ARIES designs look like if we use current predictions on heat/particles fluxes?
- Can current physics predictions be accommodated and/or new solutions have to be found?
- What would be the maximum fluxes that can be handled by in-vessel components in a power plant?
- What level of off-normal events is acceptable in a commercial power plant?



- Do recent divertor proposals help reduce the gap and by how much?

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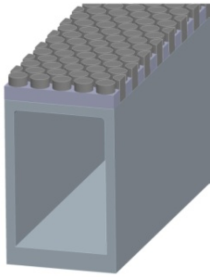
The ARIES program will explore the limits of high heat flux components with innovative design and state-of-the-art engineering analysis

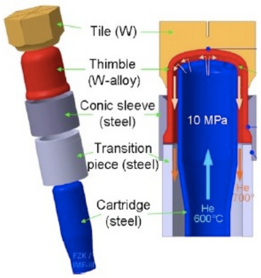
FY'11-12 Plans:

1) Design innovations for operation well beyond 10 MW/m^2 heat flux, with an eye on reliability, fabricability, *etc*.

2) Intensive analysis of first wall and divertor designs

- Consider residual stress and damage caused by fabrication
- Include cycling and off-normal events (ELM's, disruptions, VDE's …)
- Consider time-dependent inelastic behavior: *"design by analysis" rather than "design by rule"*
    - Yield, strain hardening, creep, *etc*.


Advanced first wall



Finger modules

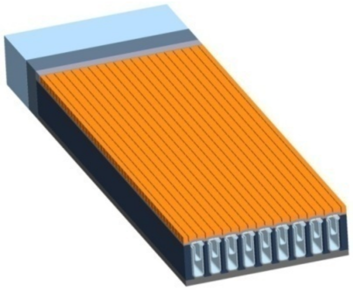
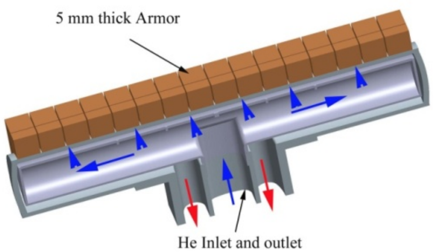
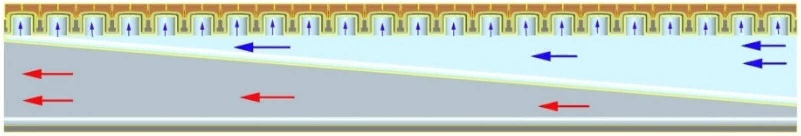


Plate divertor



T-tube divertor

2-zone integrated concept



VLT PROGRAM ELEMENT: MFE System Studies

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Task Descriptions	FY11(K$)		FY12 (K$)		
	CBR		-10%	2%	10%
ARIES	1783		1605	1819	1961
TOTALS	1783		1605	1819	1961

More Enabling Technology

Stan

ICH/ECH, Fueling, Magnets, Advanced Design Studies

Richard

		FY 2009	FY 2010	FY 2011 CR	FY2012 (0.2%)
1	**Plasma Facing Components**	5709	5029	5029	5130
2	**Plasma Chamber Systems**	1910	2230	2230	2275
	Neutronics	385	310	310	316
3	**Tritium Systems**	839	654	654	667
	Safety and Environment	1518	1518	1518	1548
4	**Materials Science**	4817	5217	5729	5844

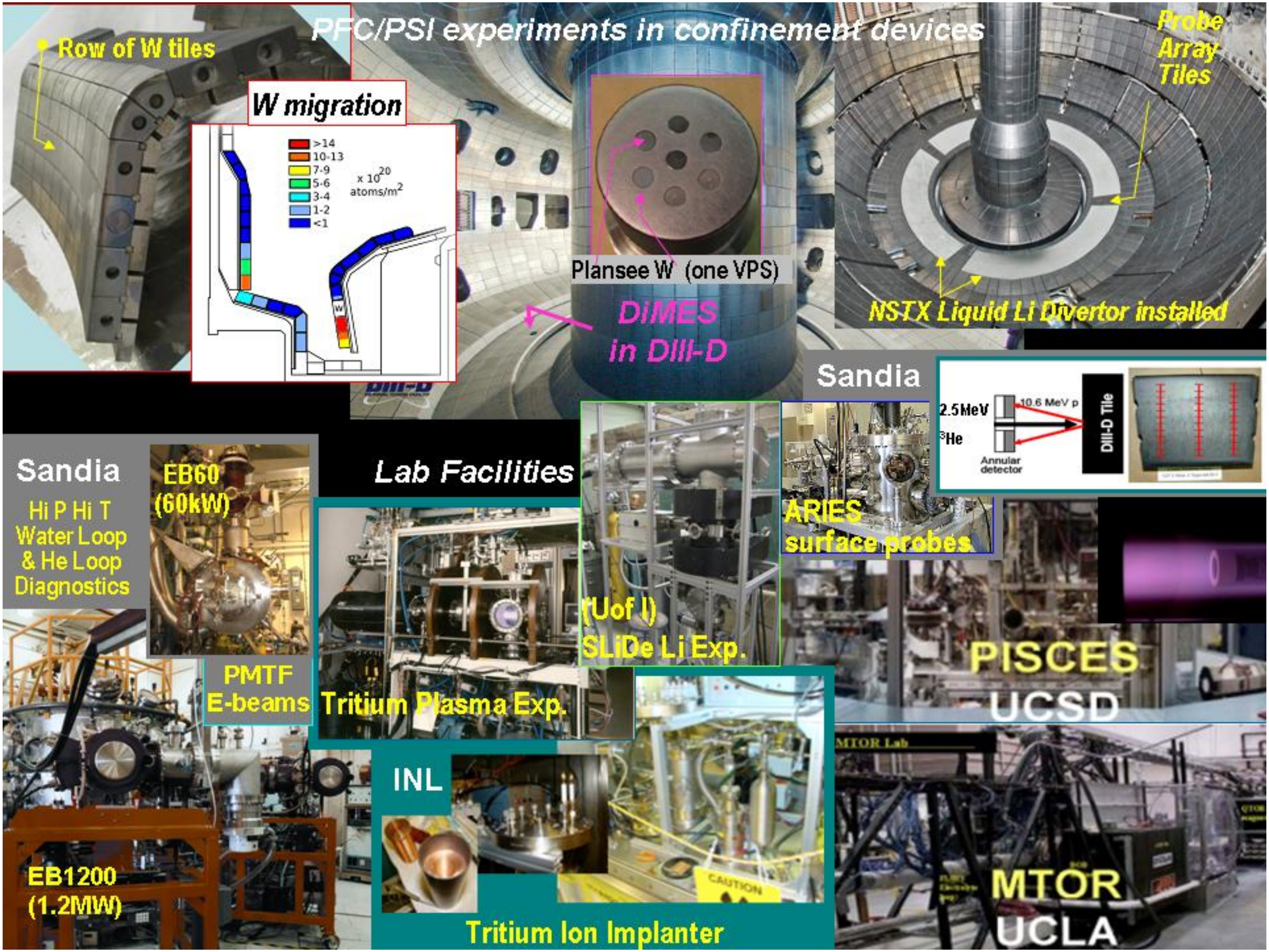
ReNeW: our thanks to all leaders and particularly those in technology:

Theme 3 Ulrickson/Maingi/Dagazian, Theme 4 Meier/Raffray/Dagazian;

Thrusts 9, 10: Rognlien-Maingi-LaBombard-Stangeby; Hillis-Doerner
11, 12: Allain-Majeski- Wong; Leonard
13, 14: Morley; Kurtz-Mauel-Nastasi-Odette-Sharafat-Stoller/Zinkle
15: Raffray-El-Guebaly-Reiersen-Sawan-Sharpe-Waganer-Willms-Ying

ReNeW: Promise & Challenge Enabling (Eroding) Technology needs investment.

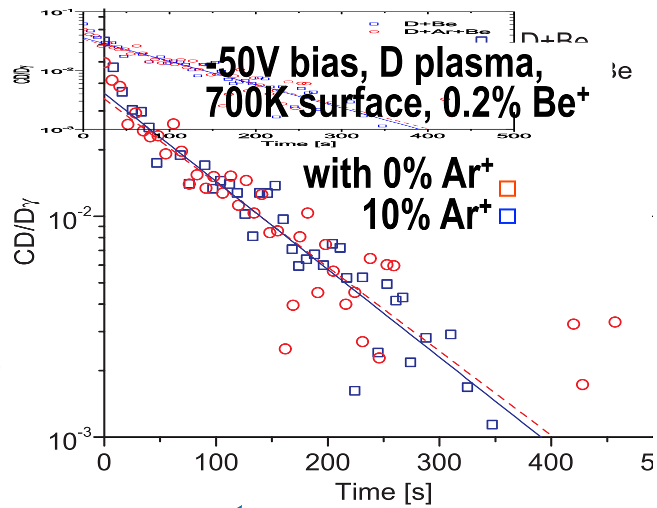
- provide expertise: stem increasing loss of expertise, develop new staff
- upgrade aging facilities (**PMTF**), develop new facilities/projects (**TBM**, **PSI**, …)
- engage with national community on **FNSF** and with international community on opportunities for smart collaborations in FNST


PFC/PSI experiments in confinement devices
Row of W tiles
W migration
>14
10-13
7-9
5-6
3-4
1-2
<1
x 10^20 atoms/m^2
Plansee W (one VPS)
DiMES in DIII-D
Probe Array Tiles
NSTX Liquid Li Divertor installed
Sandia
2.5MeV
3He
10.6 MeV p
Annular detector
DIII-D Tile
Sandia
Hi P Hi T Water Loop & He Loop Diagnostics
EB60 (60kW)
Lab Facilities
ARIES surface probes
(U of I) SLiDe Li Exp.
PMTF E-beams
Tritium Plasma Exp.
PISCES UCSD
EB1200 (1.2MW)
INL
Tritium Ion Implanter
MTOR UCLA

FY10 PFC Accomplishments

High Heat Flux Testing

- **PMTF test capability to support ITER** *(Sandia)*
  Unique: large targets IR views, handle Be (toxic)
  tests: FW quality mockups (R,J,K,C); Critical Heat Flux for hypervaportron FW (new ITER enhanced heat flux units)
  - **First Be cleanup of EB1200**
  - **Prepare EB1200 for FW semi-prototpype**



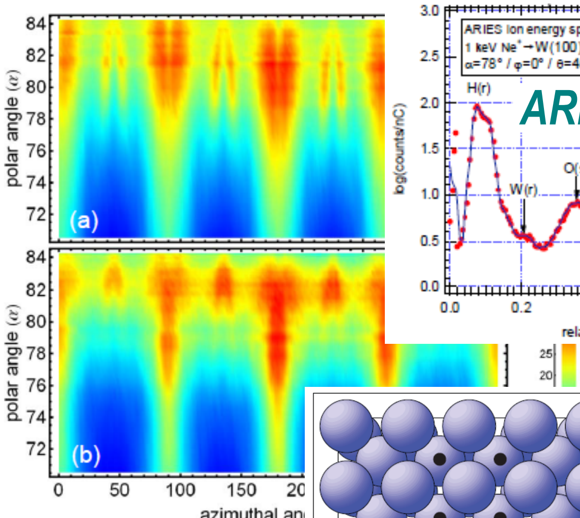
PSI Tests

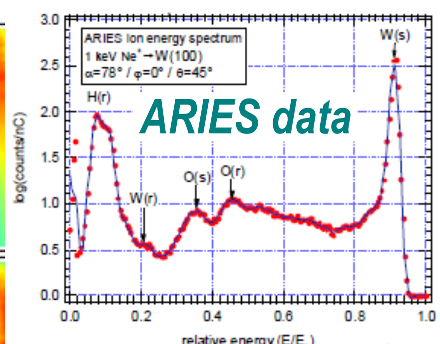
- **PISCES- B** *(UCSD)*
  - **Be mitigates chemical erosion of C, *and* the beneficial effect survives Argon sputtering**
  - **Continued work on W "fuzz"**

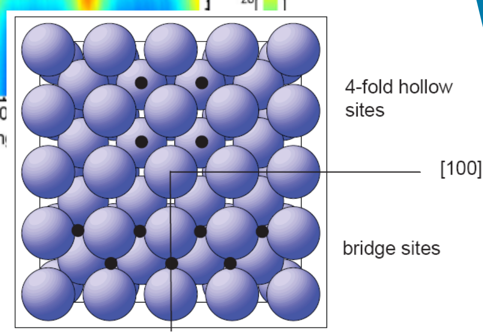
- **Dust on DiMES; mirrors in MiMES** *(GA/UCSD/SNL/ANL)* → *Gas puff mitigates C deposition*

- **D (T) retention in He damaged W;**

- **C erosion marker in EAST tile for ITER; ARIES spectroscopy D on W** *(Sandia)*





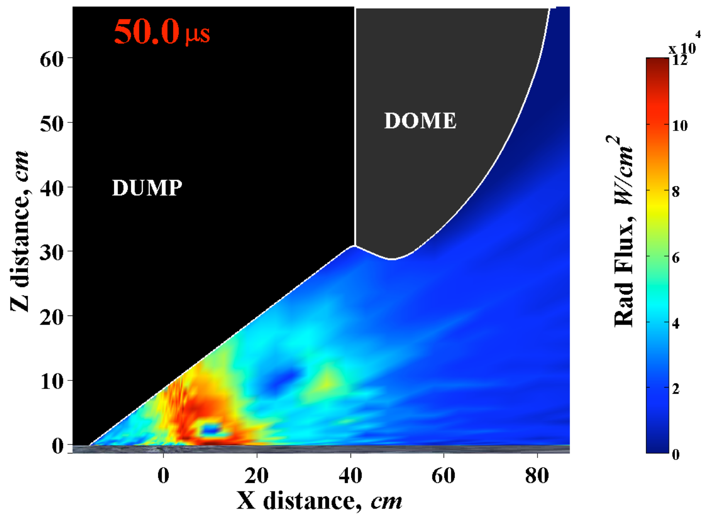


MARLOWE simulations

FY10 PFC Accomplishments

Modeling and Simulations

- Mixed-material sputtering & mixing for ITER, materials on DiMES/MiMES *UCSD/PU/LLNL*
- PFC response to ELMs, disruptions *PU*
- *Thermal model LLD* [grant] *SNL*
- CFD models of He cooling *SNL*
- Free surface liquid metal divertors *UCLA*
- D/T on Be surfaces *SNL*



Radiation Fluxes to Nearby Components during ELM with 0.1 ms duration (Purdue)

FY11 PFC Major Plans

PFCs: Support ITER FW testing; simulate ITER ELMs in PISCES (H in surface); He-cooled PFC & structure for US TBMs; possible LLD upgrade in NSTX

PSI: Understand multi-component plasma interaction with mixed materials; Liquid Li Divertor operation and bonding of Li with C, O and impurities; continued DIII-D experiments with DiMES & MiMES

Models: Use kinetic transport code to predict non-thermal wall fluxes; detailed surface evolution of mixed materials, including MD model; Lithiated graphite and liquid Li divertor; PFC response to plasma transients

FY12 PFC Major Plans

Engage with community on FNSF & PFC/PSI Initiative, **basis: ReNeW, >10%**

PFC and PSI Experiments

- **PMTF:** - modify (EB1200 door) for ITER first wall prototype testing
  - test advanced PFCS with high temperature He cooling
- **PISCES:** - simulate ELM ablation plume transport
  - develop an understanding of multi-component plasma interaction with mixed material surfaces
- **DIII-D:** - study C deposition and D concentration vs. temperature
  - use DiMES & MiMES in DIII-D with further material samples
- Compare thermal/fluid and stress modeling of modified TBM with initial test results on small mockups
- Evaluate NSTX liquid lithium divertor results and further options
- Surface science of D and T in metals, He effects, coupons & tiles

Plasma Materials Interactions Model

- Utilize edge turbulence code to 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 including lifetime, tritium retention/codeposition.

FY11-12 Budget - Plasma Facing Components

***PFC/PSI Gap highlighted in ReNeW** (high priority, Greenwald Report)*

Theme 3. Taming the plasma material interface

– 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.

	FY11 (K$)	FY12 (K$)		
Task Descriptions	**CBR**	**-10%**	**+2%**	**FULL**
• **PFCs Expt. & modeling**	**1105**	**995**	**1127**	
2395 (PMTF capital equipment upgrade*)				
			3300	
• **Plasma Materials Interaction Experiments**	**197517772013**		**2171**	
• **PMI Modeling**	**1950**	**1755**	**1989**	**2145**
TOTAL	**5029**	**4526**	**5130**	**10011**

*includes $2.4M equipment for EB1200 power supply plus installation and data acquisition

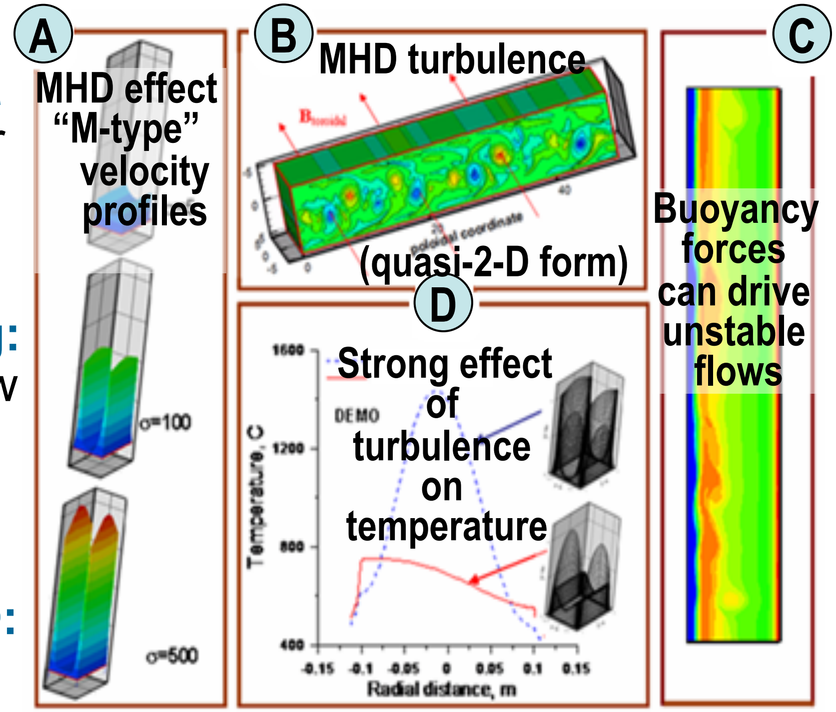
FY10-11 Chamber Accomplishments & Plans

Theory and Modeling

- **Continue to develop integrated FW-blanket simulations:** mate different meshes/codes for neutronics-thermofluid-thermomechanics integrated analysis for tritium blankets* [UCLA]
- **MHD flow & mass transfer theory/modeling:** improve simulations of MHD effects on 3D flow elements plus physics of turbulence, wall wetting, and non-uniform properties* [UCLA]

  ***ReNeW Thrust 15**
- **US expertise on TBM* and interfaces for IO:** help JA/KO coordinate half-port in Port 18; provide US expertise to ITER TBM Program Comm.

**TBM program is an official part of the ITER project.*



MHD severely modifies flow dynamics, heat & mass transport in liquid metal blankets.

Experiments LM-MHD Experiments for the US/JA TITAN Collaboration:

- Year-3 experiments on impact of MHD on transition (3-D to 2-D) fluctuations and turbulence completed.
- Establish high temperature PbLi flow capability and initial experiments.

FY12 Chamber Major Plans

Engage with community on FNST & FSNF
basis: ReNeW, >10%

- **Continue Basic Research and Predictive Capabilities**
  - Effects of MHD-controlled velocity profiles on corrosion and transport (liq. metal)
  - Tritium fuel cycle models, tritium permeation database
  - Characterization of thermo-mechanics in solid breeder pebble beds
- **Experiments for TITAN and International Collaborations:**
  - Including 1st time with MHD - heat transfer - PbLi - SiC flow channel inserts
- **Simulation for Integrated Fusion Nuclear Science & Technology (FNST):**
  - Continue to develop integrated system with mesh & data hierarchy for FW/ blanket simulations - link to design activities and Fusion Simulation Project
- **Fusion Nuclear Science Experiments in Fusion Environment:**
  - Continue participation in planning for ITER blanket module testing, program committee and interface coordination.
  - Provide analysis, mission, features to define a Fusion Nuclear Science Facility

Responsive to RENEW Technology & Material Thrusts 13,14,15

FY11-12 Budget – Chamber Technology

Engage with community on FNST & FSNF basis: ReNeW, >10%

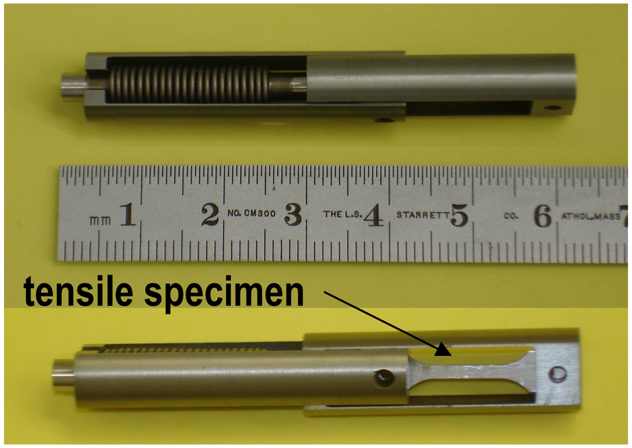
Task Descriptions	FY11(K$) CBR	FY11(K$) -10%	FY12 (K$) 2%	FY12 (K$) 10%
Basic Research & Predictive Capabilities (MHD, Tritium, Corrosion, modeling and database)	680	610	695	700
TITAN & International Collaborations (Experiments for blanket and international collaboration)	590	590	590	590
Simulation for Integrated FNST (Thermomechanics, Thermofluids, etc.)	315	280	340	400
Definition, Exploration & Analysis of Fusion Nuclear Science Experiments in a Fusion Environment	390	300	390	485
Totals	1975	1780	2015	2175

FY10 Materials Accomplishments & Plans

(ReNeW Thrusts 1,7,9-12,13,14,15)

Experimental results

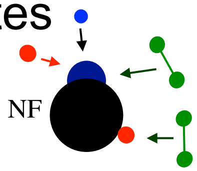
- **Predicted changes due to irradiation verified**
  - Change in flow (yield) stress vs. shift in temperature below which (brittle) fracture occurs
  - Cavity evolution in He implanter using advanced multi-scale model of He transport and fate
- **Completed two irradiation experiments**
  - Post-irradiation examination of DOE/MEXT 18J: *determined response of SiC and SiC composites to high-temperature irradiation*
  - DOE/JAEA 15J (lithium-bonded experiment): *microstructural evolution and mechanical properties of advanced RAFM and ODS ferritic alloys*

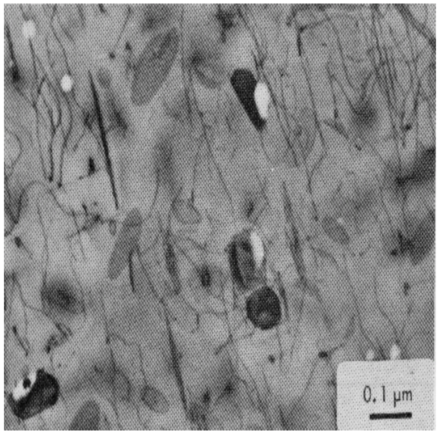


Novel capsule to test in-reactor creep of metals and ceramics with internal load frame

Theory - Extensive computational studies

- He diffusion & clustering to form bubbles, and ballistic escape
- Dislocation interaction with nano-scale oxide precipitates
- Major progress in how to manipulate nano-features that imbue ODS ferritic alloys with remarkable high-temperature strength and tolerance to neutron damage





FY11 Materials Plans

Structural Materials

- **Reduced Activation Materials:** Fundamental research, ferritics, SiC composites
- **DOE/JAEA –** Complete work on effects of intermediate neutron dose on constitutive properties of advanced alloys; He effects on microstructure.
- **DOE/MEXT -** Continue work on synergistic effects of He, tritium & neutron irradiation on properties of bonded materials and irradiation creep of SiC ceramics and composites.
- **Advanced Materials:** Continue development and evaluation of oxide and nitride dispersion-strengthened ferritic alloys.
- **Tungsten**: Explore ways to improve ductility and toughness of tungsten and tungsten alloys using computational materials science and key experiments.
- **Irradiation Effects in Blanket Materials:** Understand how damage evolves (creep, fatigue, creep-fatigue); electrical & thermal conductivity (SiC ceramics, composites).

Crosscutting Theory & Modeling

- Multiscale modeling of radiation effects on mechanical properties with He effects (e.g., validate atomistic & kinetic simulations, use fission data from implanter experiments).
- Microstructure-based multiscale modeling of high-temp. deformation and fracture.
- Develop "coarse-graining" methods for advanced kinetic models.

***Neutron Source* -** No support for development at target funding level.

FY12 Materials Plans ($5729 K)

Structural Materials

- **Reduced Activation Materials:** Fundamental research on ferritic steels & SiC.
- **DOE/JAEA Collaboration:** Assess effects of high-dose (>50 dpa) irradiation on constitutive properties of advanced RAFM steels.
- **DOE/MEXT Collaboration:** Determine strength and cohesiveness of joints (weld, HIP) in irradiated RAFM steels. Continue work [synergistic effects of He, tritium & neutron irrad. on properties of bonded materials and irradiation creep of SiC composites.]
- **Advanced Materials:** Continue [advanced oxide & nitride dispersion-strengthened ferritic alloys.] (+10%) study advanced solid state joining, e.g. friction stir welding.
- **Tungsten**: Continue [improve ductility and toughness of tungsten and tungsten alloys.] Synthesize promising alloys and experimentally determine properties. (+10%) begin to assess low dose, low temperature radiation effects.
- **Irradiation Effects in Blanket Materials:** Continue work [how damage evolves]

Crosscutting Theory & Modeling

- Continue [Multiscale modeling of radiation effects on mechanical properties with He effects]
- Continue [Microstructure-based multiscale modeling of high-temp. deformation and fracture.]

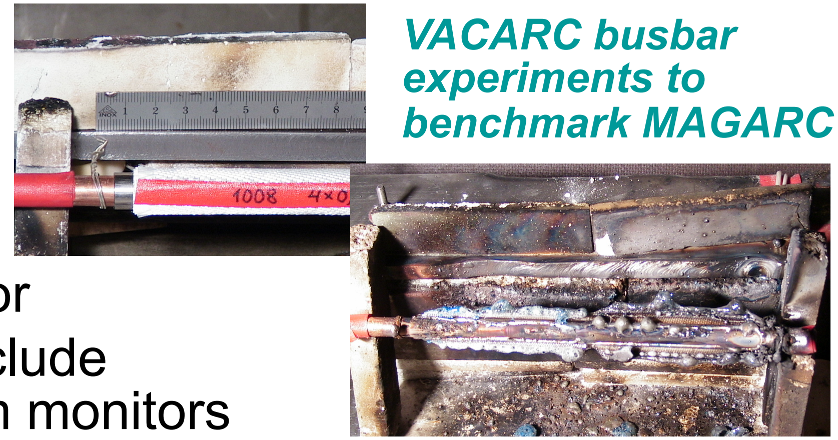
Neutron Source - No support. (+10%) small effort.

FY11-12 Budget - Materials Science

Greenwald Tier 1 Issue: Understand basic materials science for breeding blankets, structural components, plasma diagnostics and heating components in areas of high neutron fluence. Solutions not in hand; major extrapolation from current state of knowledge; need both qualitative improvements and substantial development for both short and long term.

Task Descriptions	**FY11(K$)**	**FY12 (K$)**		
Structural Materials	**CBR**	**-10%**	**2%**	**10%**
Reduced Activation Materials (Ferritic Steels, SiC)	**379**	**300**	**385**	**400**
DOE/JAEA - Ferritic Steels	**1550**	**1400**	**1550**	**1550**
DOE/MEXT - Tritium/Irradiation Synergism	**700**	**650**	**700**	**700**
Advanced Materials (ODS Ferritic Alloys)	**500**	**500**	**590**	**750**
High Heat Flux Materials (Tungsten)	**900**	**900**	**920**	**1100**
Blanket Materials (TBM relevant)	**400**	**250**	**400**	**400**
Cross-cutting Theory & Modeling	**1300**	**1160**	**1300**	**1300**
Neutron Source	**0**	**0**	**0**	**100**
Totals	**5729**	**5160**	**5845**	**6300**

FY10 Tritium & Safety Accomplishments & Plans



VACARC busbar experiments to benchmark MAGARC

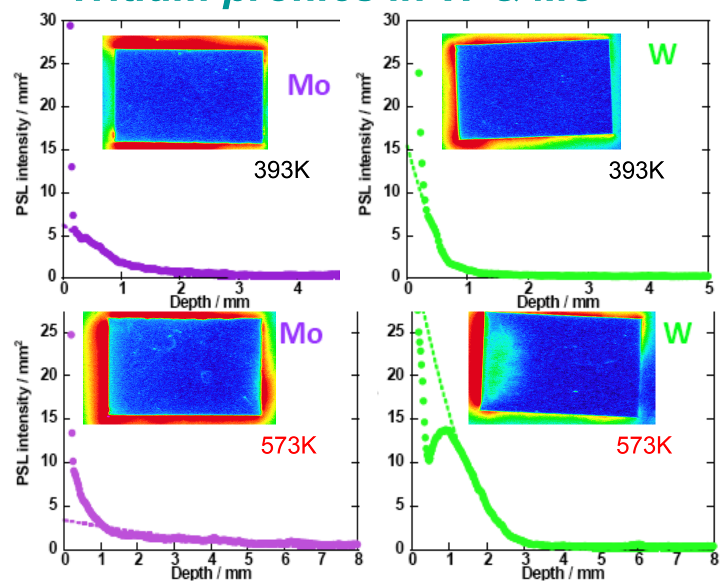
SAFETY AND ENVIRONMENT

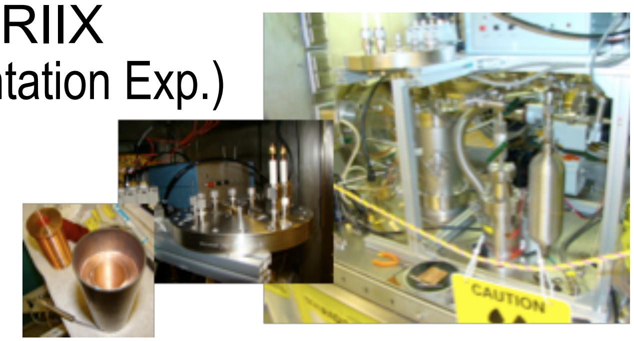
- Initiated testing for dust explosion indices of Be, W, C, and mixtures
- Magnets safety code MAGARC extended to evaluate busbar behavior
- Extended failure rate database to include plasma diagnostics systems & tritium monitors

TRITIUM SYSTEMS

- Tritium retention tests, irradiated W & Mo
- Extended measurement of tritium solubility in molten Pb-Li eutectic at very low partial pressures
- Evaluated concepts and requirements for a tritium extraction test loop
- Operated the TRIIX (Tritium Ion Implantation Exp.) for irradiated samples

Tritium profiles in W & Mo





LLE solubility test system

FY11 Tritium & Safety Plans

SAFETY AND ENVIRONMENT

- ***Fusion Safety Codes:*** Verification/validation (V&V) for ITER (Final Safety Report); Support US ITER TBM program and advanced design studies; Upgrade aerosol transport models in MELCOR; V&V planning for MAGARC
- ***Experiments & Analysis:*** Participate in developing the ITER Dust Mockup Facility; Determine needs for experiments to close any gaps for safety code V&V for ITER and other fusion pathway facilities
- ***Risk and Safety Support***: Compile failure rate data for advanced cycle heat transport systems; Evaluate system reliability/maintainability for economic impacts of safety on ITER, DEMO, and commercial plants; Extend the Fusion Safety Standard as parties go forward in "fast track" development.

TRITIUM SYSTEMS

- ***First Wall:*** Continue to measure tritium retention in irradiated W with TPE and TRIIX at various irradiation doses and temperatures); Determine tritium concentration profiles in various metals & mixed materials.
- ***Blanket:*** Specify the design of a molten Pb-Li loop for studying tritium extraction methods; Measure the effectiveness of various tritium permeation barriers.

FY12 Tritium & Safety Plans

Engage with community FNST & FSNF Initiative
basis: ReNeW, >10%

SAFETY AND ENVIRONMENT

- ***Fusion Safety Codes:*** ITER safety calculations 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 & Analysis:*** Perform measurements of explosion indices for mixed-materials dust prototypic of dust in ITER (tritiated & activated)
- ***Risk & 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

- ***First Wall:*** Measure tritium permeation in-situ in metals using TPE & TRIIX; Perform tests for baseline qualification testing of tritium behavior in joined ITER materials.
- ***Blanket:*** Measure effectiveness of various tritium permeation barriers as applied to advanced designs

Responsive to RENEW Harvest Fusion Energy Theme 4

FY11-12 Budget - Tritium & Safety

Engage with community on FNST & FSNF Initiative
basis: ReNeW

Task Descriptions	FY11(K$) CBR	FY12 (K$) -10%	FY12 (K$) 2%	FY12 (K$) 10%
Safety and Environment				
Fusion Safety Codes	650	550	660	700
Experiments & Analyis	650	600	680	720
Risk & Safety Support	268	255	268	275
TRITIUM SYSTEMS				
First Wall Tritium Behavior	327	300	329	350
Blanket Tritium Behavior	327	295	329	400
TOTALS	2222	2000	2266	2445

Summary

VLT Virtual Laboratory for Technology For Fusion Energy Science

The VLT is fully engaged in support of ITER activities

- Ongoing R&D in plasma technologies continues for a few years, then we need a plan to retain vital expertise in base program
- New plasma technology test stands (ICH, ECH, fueling), an anticipated role in the test blanket program and opportunities in ITER upgrades and international collaboration on unique facilities provide numerous opportunities..

We need to reload after several years of declining budgets

- FY12 guidance is $5M below the $29M FY05 levels.
- Must rebuild sufficient capability in PFC/PSI, FNST, Materials, etc. to move forward on the vision of FES that

"..requires launching of a vigorous materials and nuclear science program that will be part of defining and constructing a fusion nuclear science facility, and will fill gaps en route to a DEMO"