



# Plasma Facing Components

Presented By  
M. Ulrickson

# Participating Institutions

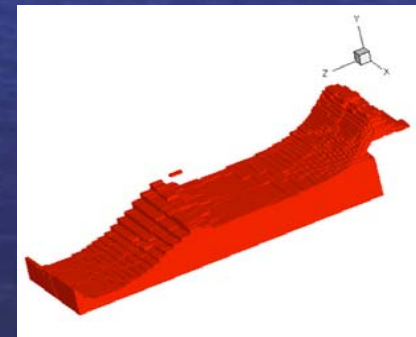
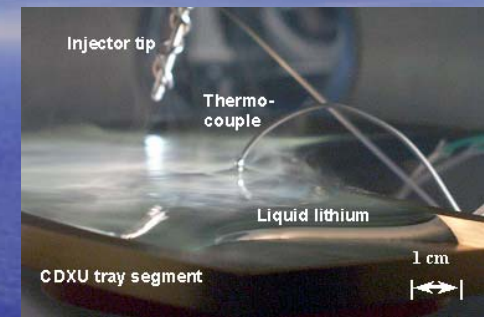
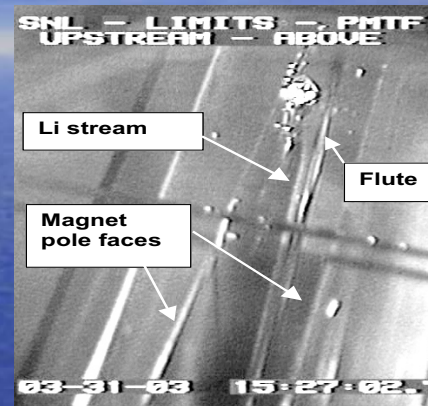
- Argonne National Laboratory
- General Atomics
- Lawrence Livermore National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratories
- University of Illinois
- University of California, Los Angeles
- University of California, San Diego

# Mission and Goals for PFCs

- *The PFC Program mission is the development of plasma facing component systems capable of interfacing with the extreme conditions at the boundary of fusion grade plasmas.*
- *There are three goals:*
  - *Engineering and design of innovative PFC systems for present day and next generation fusion experiments including burning plasma experiments such as ITER*
  - *Advancing the scientific field of plasma materials interactions (PMI)*
  - *Developing the science and engineering foundation for the PFC system of DEMO.*

# PFC Accomplishments

- Injected 10 m/s flowing Li jet into NSTX like magnetic field and measured MHD effects (SNL).
- A multiple-materials (C, Be, V, W) DIMES sample was exposed to 22 upper single null discharges to simulate chamber wall erosion. Erosions was measured by Ion beam analysis at SNL. (GA)
- Analysis of lithium motion out of DIMES sample holder suggests better grounding arrangement for upcoming tests in DIII-D (UCLA)
- He and H retention and diffusivity measurements in flowing liquid lithium as a function of energy and lithium temperature in FLIRE (UIUC)



# PFC Accomplishments

- Developed flat free surface nozzle for LM (SNL)
- Experimentally demonstrated that depleted codeposited C layers do not refill with H after annealing. (SNL)
- Moved TPE to INEEL. (SNL)
- Upgraded the science of integrated erosion and redeposition analysis of liquid lithium and other liquid metal and solid divertors. (MD, T dependent sputtering, fluid and kinetic code impurity transport SOL plasma). (ANL)
- PISCES experiments show carbon erosion suppressed by small amount of beryllium impurity in boundary plasma. (UCSD)
- Very clean liquid Li Fill of limiter tray on CDXU (UCSD)
- Molecular Dynamics modeling of D sputtering of liquid Li to calculate reflection coefficients and sputtering. (UIUC)
- Predict low intrusion of lithium to the core of NSTX (full coverage, with UEDGE utilizing WBC and vice versa) (LLNL)

# Key to Budget Slides

- Argonne National Laboratory
- General Atomics
- Lawrence Livermore National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratories
- University of Illinois
- University of California, Los Angeles
- University of California, San Diego
- *ITER base program activities (italics)*

# PFC Technology Thrust Areas

- Liquid Surface PFC Development (35%)
- Plasma Materials Interactions (PMI) and Scrape-Off Layer (SOL) Experiments (33%)
- Solid Surface PFC Development (16%)
- PMI and PFC Modeling (16%)
- Total funding \$7054K (*ITER* 34%)



Fiscal Year 2005



# Liquid Metal PFC Research (high)

- Conduct high heat flux experiments on Li jet (\$250K) 1/05
- Design and test conceptual LM system for NSTX (\$250K) 9/05
- Complete installation of conducting, wide-channel test section (\$50K) 4/05
- Modification of MTOR for higher field in larger magnetic volume (\$200K) 3/05

# Liquid Metal PFC Research (high)

- Experimental surface height measurements on wide, electrically conducting channel film flow in NSTX relevant magnetic fields (\$250K) 8/05
- 3D Simulations of experimental film and jet flow data (\$250K) 8/05

# Liquid Metal PFC Research (high)

- Continue liquid lithium limiter experiments on NSTX & CDX-U/LTX. Analysis of lithium layer formation and evolution on graphite and metallic substrates. (\$700K) 8/05
- Experiments on Lithium Thin-film Coatings Erosion Response and Hydrogen Trapping for NSTX (IMPACT device) (\$97K) 9/05

# Liquid Metal PFC Research (high)

- Conceptual Design of Liquid Li module for NSTX (\$59K) 9/05
- Conduct experiments on FLIRE (H/He retain, ELM Simulation,...) (\$38K) 3/05

# Liquid Metal PFC Research (med.)

- Modify and learn how to use the Hanford pumps (\$100K) 5/05
- Test heat exchanger for Li (\$186K) 4/05
- Conduct experiments on IIAX (Sn, Mo, mixed) (\$72K) 6/05

# Plasma Materials Interactions Experiments (high)

- PFC Material Evaluation on DiMES (\$190k)  
9/05
- *Develop advanced PFC diagnostics using  
DiMES (\$20k) 9/05*
- DiMES mechanism modification (\$40k) 9/05
- Complete US-EU Collaboration on Be/C  
deposition studies and H retention. (\$754K)  
10/05

# Plasma Materials Interactions Experiments (high)

- PISCES experiments on bursty plasma fluxes and molecular ions. (\$500K) 11/05
- Verification of helium bubble formation in liquid metals (\$83K) 11/04
- Plasma Materials Interaction experiments on liquid surfaces (\$70K) 9/05

# Plasma Materials Interactions Experiments (high)

- Measure surface composition of wall components in DIII-D; validate computer models of impurity generation and transport (\$70K) 9/05
- Measure DiMES sample erosion (C due to Ar) (\$70K) 9/05



# Plasma Materials Interactions Experiments (high)

- *Tritium uptake in mixed materials (W, Be) (\$140K) 5/05*
- *He-O glow discharge removal of heated codeposited carbon/tritium layer (\$140K) 12/04*
- *Tritium permeation through ITER TBM materials (\$70K) 5/05*

# Plasma Materials Interactions Experiments (med.)

- *Surface analysis of impurity layers (\$70K)  
6/05*
- *DiMES collaboration (\$105K) 9/05*

# Plasma Materials Interactions Experiments (low/incremental)

- DiMES system improvement (\$40k) 9/05
- Outboard DiMES station (\$100k/yr) (3 yr.)
- Smart tile development (\$35k/yr) (3 yr.)

# Solid Surface PFC Research (high)

- *Complete 3000 cycle test at 10 MW/m<sup>2</sup> on W rods (\$220K) 2/05*
- *ELM testing of W Rods II (\$212K) 6/05*
- *HHF testing of PS Be from LANL II (\$150K) 9/05*
- *Continue measurements of low-energy sputtering from mixed materials used in ITER (W/BE, C/BE, etc.). (\$18K) 9/05*

# Solid Surface PFC Research (high)

- PFC Management-PFC Steering Committee  
Chair (J. Brooks) (\$98K) 9/05

# Solid Surface PFC Research (med.)

- *Test new design of W rod attachment (\$100K) 4/05*
- *Support for selection of Hypervapotron, swirl tape, etc. (\$100K) 9/05*
- *Prototype refractory He cooled heat sink testing (\$70K) 9/05*
- *Coordination of DiMES (\$60K) 9/05*

# Solid Surface PFC Research (low)

- Liquid Metal Heat pipe PFC R&D (\$50K)  
9/05

# PMI and SOL Modeling (high)

- Modeling of Erosion/redeposition and He/H trapping of NSTX thin film Li coatings and liquid Li module and longer term Liquid PFCs (Li, Ga, Sn). (\$342K) 9/05
- Modeling of enhanced erosion of liquid metals and DiMES disruption expts. (\$49K) 9/05



# PMI and SOL Modeling (high)

- Model droplet lifetime on CLIPS laser facility (Ioffe) and *results of MK200 and QSPA plasma guns* experiments on liquid metal. (\$97K) 9/05
- *Modeling of current DiMES tokamak experiments, PISCES mixed material studies, and ELM effects.* (\$293K) 9/05

# PMI and SOL Modeling (high)

- Model NSTX plasma edge to support design of liquid surface divertor (\$70K) 9/05
- *Limited ITER edge modeling to support US FW shield design and MD simulations of sputtering from redeposited carbon (\$65K+60K) 9/05*
- Complete MD modeling of liquid metal surfaces; both reflection and erosion studies of liquid lithium. (\$17K) 9/05

# PMI and SOL Modeling (med.)

- Begin MD simulations for sputtering of liquid Li (\$50k) 9/05
- Utilize BOUT 3D turbulence to assess convective transport (\$50k) 9/05
- Complete MD modeling of reflection from carbon layers with mixed impurities for HC molecules and MD-TRIM modeling. (\$34K) 9/05

# Incremental Funding 05 (in priority order)

- Optical spectrometer to determine impurity levels in the plasma of TPE (\$25K)
- Modeling of ITER materials (\$90K)
- Li cleanup loop for LM experiments (\$75K)
- GA \$175K listed above for DiMES

# Issues and Concerns for PFCs

- The PFC community is performing a wide range of research with limited funding. (LM to He cool)
- The PMI Research Facilities are aging and there is inadequate funding for maintenance and upgrades needed to support ITER.
- Flat budgets continue to erode capabilities.
- PMI/SOL modeling activities are not adequately supported.

# Summary of PFC Technology (05)

Institution	Base PFC	ITER PFC	Total (\$K)
ANL	636	340	976
GA	390	20	410
LLNL	130	65	195
ORNL	59	0	59
SNL	1424	1132	2556
UIUC	184	70	254
UCLA	675	75	750
UCSD	1150	704	1854



Fiscal Year 2006

# Key to FY06 Slides

- **Tasks to be done with 10% cut**
- Tasks to be added with flat budget
- *Incremental funding requests*



# Liquid Metal PFC Research (high)

- **Test prototype NSTX system (flow control, dT, etc.) (\$200K) 2/06**
- **Conduct HHF testing on typical NSTX segment (\$150K) 2/06**
- **Design full NSTX module (\$250K) 12/06**
- **Prepare for NSTX review (\$110K) 6/06**
- **Report on experimental and simulation results and concept for NSTX flowing module (\$75K) 12/05**

# Liquid Metal PFC Research (high)

- **Install reduced scale NSTX module mockup for MHD testing in MTOR \$150k/ 5/06**
- **Experimental data on NSTX mockup (\$250K) 8/06**
- **3D Simulations of experimental mockup (\$200K) 8/06**

# Liquid Metal PFC Research (high)

- **Final design of Liquid Li module for NSTX (\$59K) 6/06**

# Liquid Metal PFC Research (med.)

- **Increased liquid metal flow capability in MTOR for near-full scale module testing (\$75K) 2/06**
- **Continue FLIRE Experiments (HE/H retain, desorption kinetics,...) (\$103K) 9/06**
- **Plan MHD studies with high-intensity pulse plasma gun ELM simulator. (\$15K) 9/06**
- **Plan for Liquid Metal Experiments on EB-1200 (\$30K) 9/06**

# Liquid Metal PFC Research (med.)

- MHD experiments with plasma gun ELM simulator and modeling on flowing metal and mixed mtl. surfaces. (\$25K) 9/06

# Liquid Metal PFC Research (low)

- *Alkali metal flow capability for better lithium flow simulation capability in MTOR (\$75K) 5/06*

# Solid Surface PFC Research (high)

- ***Participate in round-robin HHF testing of final divertor heat sink configuration (\$150K) 9/06***
- ***Participate in HHF testing of final first wall design (\$168K) 9/06***
- ***Test capability of proposed TBM FW surface (\$150K) 9/06***

# Solid Surface PFC Research (med.)

- ***Continue IIAX measurements (ion-induced e and i emission, low E sputtering mixed materials). (\$81K) 9/06***
- **Install upgraded gun and power supply on EBTS (\$50K) 9/06**



# Solid Surface PFC Research (low)

- **Small scale prototype development for refractory He cooled PFC (\$230K) 9/06**
- **Upgrade He loop (\$100K) 9/06**
- **Complete He loop upgrade (\$150K)**
- *Upgrade EB-1200 power supply (\$350K)*

# Plasma Materials Interactions Experiments (high)

- **Tritium retention in Mo, *ITER TBM materials, Be/W mixed* (\$360K) 9/06**
- ***ITER wall analysis study (PMI diagnostics), develop distributed PMI diagnostics* (\$248K) 9/06**
- **Analyze erosion samples from DiMES, C-Mod, etc. (\$140K) 9/06**
- ***Qualification of advanced materials* (\$70K) 9/06**

# Plasma Materials Interactions Experiments (low/incremental)

- *Outboard DiMES station (\$100k/yr) (3 yr.)*
- *Smart tile development (\$35k/yr) (3 yr.)*

# PMI and SOL Modeling (high)

- **Model NSTX plasma edge to support design of liquid surface divertor (\$70K) 9/06**
- ***ITER edge modeling to support US FW shield design (\$75K) 9/06***
- **Continue modeling of temperature dependent sputtering and reflection for lithium and other liquids and solids. (\$15K) 9/06**

# PMI and SOL Modeling (med.)


- **Begin kinetic Monte Carlo simulation of surface evolution for carbon (\$50K) 9/06**

# PMI and SOL Modeling (low)

- *Conduct MD simulations for sputtering of liquid Li (\$50K) 9/06*
- *Assess toroidal asymmetries (3D) for plasma wall fluxes (\$50K) 9/06*
- *Equipment including a mass spectrometer, ionization chamber, flow controllers, heater unit, etc is required for an experimental setup to allow tritium permeation tests for ITER TBM materials. (\$20K)*
- *Ellipsometer to determine real-time erosion and growth of codeposited layers. The instrument will be utilized both in TPE and in surface analysis instrumentation. (\$60K)*

# Summary of PFC Technology (06)

Institution	Base	ITER	Total (\$K)
ANL	636	340	976
GA	390	20	410
LLNL	130	65	195
ORNL	59	0	59
SNL	1360	1196	2556
UIUC	184	70	254
UCLA	675	75	750
UCSD	1150	704	1854



ITER First Wall Shield Module  
FY05/06



# US Contribution to ITER PFCs

- Module 18 of the First Wall Shield
  - Complete design of module with ITER Team (VHTP).
  - Conduct critical R&D to support design, fabrication, and quality control.
  - Fabricate a prototype FW portion and HHF test.
  - Fabricate a prototype Shield module section and test.
  - Fabricate a full prototype FW/S module to verify manufacturing processes.
  - Fabricate the modules and spares for ITER.

# FY05 ITER Specific Tasks (\$650K)

- Participate in the final design with Russia, China, Korea, and the host (\$250K) 9/05
- Negotiate critical fabrication specifications with IT (\$50K) 9/05
- Begin R&D on Be/Cu application and joining and HHF test (\$150K) 9/05
- Begin R&D on Cu/SS joining and test. (\$100K) 9/06
- Begin R&D on casting of shield module with small prototypes (\$100K) 9/05

# FY06 ITER Specific Tasks (\$1200K)

- Complete final design of FW/S module 18 (\$100K) 6/06
- Complete specifications for module fabrication (\$100K) 6/06
- Prepare request for quotation for fabrication and prototypes (\$50K) 9/06
- Continue R&D on Be/Cu with testing. (\$200K) 9/06
- Continue R&D on Cu/SS with testing. (\$200K) 9/06
- Continue R&D on Casting development (\$200K) 9/06
- Begin weld development (\$100K) 9/06
- Fabricate small FW prototype (\$100) 9/06
- Fabricate prototype Shield segment (\$150K) 9/06
- Postpone testing of prototypes and QA/QC to FY07 (ramp up!)

# FW/Shield Issues

- Serious industrial R&D needs to be conducted to reduce fabrication risks.
  - Funding is limited in FY05 and 06 which limits the rate of progress
  - Selection of vendors is complicated by the selection of the ITER host and later assignment of WBS manager
  - Start of funding delayed in FY04