



4th International Workshop on Plasma Material Interaction
Facilities for Fusion Research (PMIF 2013)
 joint with **Fusion & Materials for Nuclear Systems Division**
Plasma Facing Components 2013 Meeting (PFC 2013)
 Sept. 9th-13th, 2013, Oak Ridge, TN, USA
OAK RIDGE NATIONAL LABORATORY
 Managed by UT-Battelle for the Department of Energy

<http://www.ornl.gov/sci/fed/PMIF13/>

Agenda

Note: All talks will be held in the ORNL Conference Center (Bldg 5200), Tennessee Room (202-B).

Time	Title	Speaker
Wednesday	September 11, 2013	
7:15 AM	Bus pick-up at Quality Inn	
7:20 AM	Bus pick-up at Double Tree Hotel	
7:30 AM	Bus pick-up at Hampton Inn (Holiday Inn walk over)	
8:00 AM	Registration, badging, and coffee at ORNL	
8:20 AM	Workshop Organizational Information (10 min.)	T. Biewer (ORNL)
	Session V: PFC-PMIF Joint Session	Chairs: J. Rapp, J. Brooks
8:30 AM	PFC Steering Committee Chair Report (15 min)	J. Brooks (Purdue)
8:45 AM	DOE Report (15 min)	P. Pappano (DOE)
9:00 AM	VLT Report (10 min)	S. Milora (ORNL)
9:10 AM	Summary of PMI facilities (15 min)	B. Unterberg (FZJ)
9:25 AM	Summary of facility research highlights (15 min)	N. Ohno / Y. Nakashima
9:40 AM	Summary of diagnostics and modeling (15 min)	R. Doerner (UCSD)
9:55 AM	Discussion (20 min)	
10:15 AM	Break (15 min.)	
10:30 AM	ITER PFC Status, Needs, Perspectives (20 min)	M. Ulrickson (SNL)
10:50 AM	SciDAC activities on Plasma Material Interactions (20 min)	B. Wirth (UT-Knoxville)
11:10AM	High-Z PFC Erosion & Alternatives to Tungsten (20 min)	J. Brooks (Purdue)
11:30 AM	Tore Supra W Environment in Steady-State Tokamak (WEST) Project Activities (20 min)	E. Tsitrone (CEA)
11:50 AM	Lunch (70 min.)	
	Session VI: Tokamak Experiments	Chair: C. Wong
1:00 PM	Materials and Plasma Facing Components R&D for the NSTX-U 5-year plan (15 min.)	M. Jaworski (PPPL)
1:15 PM	The dependence of discharge performance on pre-discharge lithium evaporation in high triangularity H-mode discharges on NSTX (15 min.)	R. Maingi (PPPL)
1:30 PM	Heat flux width study for ELM-free and ELMy H-mode plasmas in NSTX (15 min.)	J.-W. Ahn & T. Gray (ORNL)

1:45 PM	Discharges with electron-beam assisted lithium deposition in LTX (15 min.)	D. Majeski (PPPL)
2:00 PM	AIMS: Accelerator-based In-situ Materials Surveillance (15 min.)	G. Wright (MIT)
2:15 PM	EAST/MAPES material migration experiment (15 min.)	B. Wampler (SNL)
2:30 PM	DiMES probe measurements and thermal modeling to support sheath power transmission studies (15 min.)	D. Donovan (SNL)
2:45 PM	Net versus gross erosion of W and other recent DiMES experiments (15 min.)	D. Rudakov (GA)
3:00 PM	Break (15 min.)	
	Session VII: Plasma Edge/PMI Modeling	Chair: T. Rognlien
3:15 PM	New comprehensive approach of modeling plasma instability events (15 min.)	V. Sizyuk (Purdue)
3:30 PM	Particle and heat fluxes to PFCs during snowflake divertor operation (15 min.)	T. Rognlien (LLNL)
3:45 PM	Modeling of Melt Layer Splashing, Transport, and Erosion Losses of PFC (15 min.)	G. Miloshevsky (Purdue)
4:00 PM	Dynamics of sub-surface He clustering in Tungsten (15 min.)	B. Wirth (U. Tenn)
4:15 PM	Computational Studies of Thermoelectric MHD in Flowing Lithium in Metal Trenches (15 min.)	D. Curreli (UIUC)
4:30 PM	Modeling of mixed materials (15 min.)	T. Sizyuk (Purdue)
4:45 PM	Discussion (30 min.)	
5:15 PM	Adjourn Meeting	
5:30 PM	Bus departs for Riverside Grill from ORNL	
6:00 PM	Banquet – Riverside Grill @ Oak Ridge Marina	
	Presentation: The Program Strategy of the ORNL Fusion & Materials for Nuclear Systems Division	P. Ferguson (ORNL)
9:00 PM	Bus returns to Oak Ridge hotels	



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Time	Title	Speaker
Thursday	September 12, 2013	
8:15 AM	Bus pick-up at Quality Inn	
8:20 AM	Bus pick-up at Double Tree Hotel	
8:30 AM	Bus pick-up at Hampton Inn (Holiday Inn walk over)	
9:00 AM	Coffee and refreshments available at ORNL	
9:00 AM	Closed Session: FES final instructions/updates for reviewers (30 min.)	P. Pappano, B. Wirth, G.R. Odette, A. Sabau
9:20 AM	Workshop Organizational Information in foyer (10 min.)	T. Biewer (ORNL)
	Session VIII: PFC Program Review 1	
9:30 AM	Program Review of UCSD (60 min.): UCSD PISCES Program: Plasma Boundary Science, Materials Interactions, and Collaborative Fusion Research	G. Tynan (UCSD)
10:30 AM	Working Break (30 min.)	
11:00 AM	Program Review of Purdue (60 min.): Plasma/material interaction science, modeling, simulation, and validation in fusion devices	A. Hassanein (Purdue)
12:00 PM	Lunch (60 min)	
1:00 PM	Program Review of Sandia Nat. Lab.-CA (60 min.): Program Introduction and Activities in Plasma Wall Interactions and Tritium Permeation	D. Buchenauer, R. Kolasinski, W. Wampler (SNL)
2:00 PM	Program Review of Sandia Nat. Lab.-NM (30 min.): Fusion Materials and High Heat Flux	D. Youchison (SNL)
2:30 PM	Program Review of GA (30 min.): DiMES and ALPS PSI Research at DIII-D	C. Wong (GA)
3:00 PM	Working Break (30 min.)	
3:30 PM	Program Review of Univ. Illinois-UC (30 min.): Surface Interactions for Controlled Nuclear Fusion	D. Curreli (UIUC)
4:00 PM	Program Review of LLNL (30 min.): Technology Innovation (ALPS)	T. Rognlien (LLNL)
4:30 PM	Adjourn, Closed Session for FES and Reviewers (60 min)	
5:00 PM	Bus returns to Oak Ridge hotels for participants	
6:30 PM	PFC Steering Committee Dinner Meeting – Burchfield's @ Doubletree Hotel in the Board Room.	



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Time	Title	Speaker
Friday	September 13, 2013	
7:15 AM	Bus pick-up at Quality Inn	
7:20 AM	Bus pick-up at Double Tree Hotel	
7:30 AM	Bus pick-up at Hampton Inn (Holiday Inn walk over)	
8:00 AM	Coffee and refreshments available at ORNL	
8:20 AM	Workshop Organizational Information (10 min.)	T. Biewer (ORNL)
	Session IX: PFC Steering Committee Meeting Report	Chair: J. Brooks
8:30 AM	PFC Steering Committee Meeting Report (15 min)	J. Brooks, <i>et al.</i>
	Session X: PMI Lab Experiments	Chair: D. Buchenauer
8:45 AM	Isotope Exchange Studies in Damaged Tungsten (15 min.)	J. Barton (UCSD)
9:00 AM	Design of a Plasma Permeation Experiment for TPE (15 min.)	D. Buchenauer (SNL)
9:15 AM	Thermoelectric-Driven Liquid-Metal Plasma Facing Structures (15 min.)	D. Curreli (UI-UC)
9:30 AM	DIII-D Boundary Physics Update (15 min.)	R. Maingi (PPPL)
9:45 AM	Flow instabilities in heat high density and pressure (10 min.)	D. Youchison (SNL)
9:55 AM	Summary of US ITER work on fluid flow for FW-Blanket (10 min.)	D. Youchison (SNL)
10:05 AM	Discussion (25 min.)	
10:30 AM	Break (10 min.)	
10:40 AM	Session XI: Poster Session for SBIR/STTR & Others	Chair: D. Youchison
	Reduced Activation Tungsten for Fusion	S. O'Dell (Plasma Processes)
	Tungsten Coatings for ICRF Antenna Materials	S. O'Dell (Plasma Processes)
	Electroformed Tungsten and Tungsten Alloy Heat Sinks	S. O'Dell (Plasma Processes)
	Ductile Tungsten Alloy Using Low-Activation Alloying Elements	T. Stewart (Ultramet)
	Innovative Surfaces for Controlled Flow of Molten Lithium	A. Fortini (Ultramet)
	Robust Cellular Solid Breeder Material for Enhanced Tritium Production and Release	T. Stewart (Ultramet)
	Porus Media Heat Sinks for High Heat Flux Fusion Applications	J. Rosenfeld (Thermacore)

	The use of Plasma Diagnostics in the PhIX, High Intensity Plasma Source	G. Shaw (UT-Knoxville)
	Title TBD	W. Xu (Univ. Illinois)
	Title TBD	S. Jung (Univ. Illinois)
12:00 PM	Lunch (60 min.)	
	Session XII: Heat Transfer & Fluid Flow	Chair: R. Nygren
1:00 PM	Introduction & Activities (5 min.)	R. Nygren (SNL)
1:05 PM	Li flow systems for Asian Tokamaks (20 min.)	L. Zakharov (PPPL)/ D. Curreli (UI-UC)
1:25 PM	Progress on Li safety awareness working group (15 min.)	R. Nygren (SNL)
1:40 PM	Progress on He flow loop at GIT (15 min.)	M. Yoda (G.I.T.)
1:55 PM	HHF capability at ORNL; testing for PHENIX (10 min.)	A. Sabau (ORNL)
2:05 PM	In-situ TEM studies and plasma-surface interactions in extreme grain-refined tungsten (15 min.)	J.P. Allain (UI-UC)
2:20 PM	Discussion (15 min.)	
2:35 PM	Break (15 min.)	
	Session XIII: PFC Meeting Summary (2 vg max, 8 min ea.)	Chair: J. Rapp
2:50 PM	Summary of Session VI (8 min.)	C. Wong
	Summary of Session VII (8 min.)	T. Rognlien
	Summary of Session X (8 min.)	D. Buchenauer
	Summary of Session XI (8 min.)	D. Youchison
	Summary of Session XII (8 min.)	R. Nygren
3:30 PM	Adjourn Meeting	
3:35 PM	Leave for Tour of Fusion Facilities Bldg 7625	
3:40 PM	Tour of Fusion Facilities Bldg 7625 (~60 min.)	Goulding/Caughman
4:40 PM	Bus returns to Oak Ridge hotels/airport	

Session VI. Tokamak Experiments

1. DIII-D Boundary and Pedestal Program for 2013, **R. Maingi and A.W. Leonard**

Rajesh reported on the long term planning on: ELMs and divertor heat flux control, and PSI model validation, including the use of DiMES. In FY13, DiMES got three ½ day experiments.

2. "Materials and Plasma-Facing Components Research and Development for the NSTX-U 5-year plan" **Mike Jaworski**

Mike reported the NSTX Upgrade Mission Elements and High-Level goals for NSTX-U 5 year plan from FY14 to 18, including the assessment of high-Z PFCs + liquid lithium to develop high-duty-factor integrated PMI solutions as the next-steps.

3. "The dependence of discharge performance on pre-discharge lithium evaporation in high triangularity H-mode discharges in NSTX" **Rajesh Maingi**

Rajesh reported on the new data taken in highly shaped plasmas, more prototypical of NSTX-U; optimized for LITER deposition between 2008 and 2009. ELMs were eliminated gradually, recycling and neutral pressure decreased, energy confinement increased and edge stability improved with increase Li. Results will need to be compare with data from Liquid Lithium Divertor

4. "AIMS: Accelerator-based In-situ Materials Surveillance " **Graham Wright**

AIMS was successful protyped at C-MOD: The tokamak magnetic fields can be used between plasma shots to steer a charged particle beam to surfaces of interest. Gammas and neutrons produced by low-energy, deuteron-induced nuclear reactions provide a comprehensive diagnostic tool for PSI

5. "ELM Heat Flux Study in NSTX" "SOL Width Studies on NSTX" **Joon-Wook Ahn, Travis Gray**

Travis found that Inter-ELM averaged λ_q is narrower at higher I_p , and Inter-ELM averaged λ_q is a strong

function of I_p . ELM-free λ_q 's are narrower than inter-ELM λ_q 's and show a weaker dependence on I_p . Soon-Wook showed that the calculation of the mean peak heat flux and heat flux width in the toroidal direction, and quantified. q_{peak} , I_q and asymmetry change during ELM rise time were compared for different type of ELMs and triggered by 3-D fields

6. "Discharges with electron-beam assisted lithium deposition in LTX" Dick Majeski

Dick noted that the simplest approach to low recycling static liquid lithium film - is prone to surface impurity issues. Flow appears to be required to maintain a clean surface. A liquid lithium PFC may need to be strongly mixed. Another approach to low recycling is very fast deposition of thin solid films

7. "EAST/MAPES material migration experiment" Bill Wampler

Bill showed the toroidally shaped test structure of 12 carbon-coated Mo tiles, with recessed central region representing a scaled down ITER surface. They were exposed to the plasma. Carbon was used instead of Be. He plasma was used to avoid chemical effects. RBS measured results matched modeling results.

8. "DiMES probe measurements and thermal modeling to support sheath power transmission studies" David Donovan

On SPTF, theory matches well with experimental results in L-mode. David showed the use of new diagnostic heads to measure ion temperature, and updated results from the 3-LP DiMES head. He also introduced 3-D modeling analysis of heat flow in divertor ATJ graphite tiles with embedded TCs.

9. "Net versus gross erosion of W and other recent DiMES experiments" Dmitry Rudakov

Dmitry noted that the modeled net to gross erosion matched quite well with the experimental measurements. C net erosion rate is 100 times higher than W. He also reported on the recently performed Al coating exposure which is used to simulate Be. He showed that local controlled methane injection can reduce the erosion of Mo as shown by spectroscopy.

Summary of Plasma Edge/PMI modeling – Sept. '13 PFC Meeting

- **New comprehensive approach of modeling plasma instability, V. Sizyuk**
 - Include 3D SOL domain with adaptive mesh refinement in HEIGHTS
 - Benchmarked HEIGHT's kinetic ion/electron loss from core to divertor plates
 - Secondary radiation damage to ITER dome supports is real concern
- **Plasma fluxes to PFCs for snowflake divertors & comparison of tilted-/flat-plate divertors T. Rognlien**
 - NSTX snowflake heat flux reduction qualitatively reproduced, but need additional loss (e.g., Li radiation)
 - ACT-1 tilted/flat-plate divertor simulations yield partial/full plasma-detachment
 - DIII-D snowflake heat-flux reduction follows to flux expansion ratio
- **Modeling of melt-layer splashing, transport, and erosion losses of PFC (VOF-MHD modeling), G. Miloshevsky**
 - No plasma flow: surface waves develop for $B=0$, but largely suppressed if $B=5T$
 - With plasma flow: surface waves develop at $B=5T$, can lead to droplets
 - Surface wave growth faster & wavelength smaller for high-speed plasma flow

Summary of Plasma Edge/PMI modeling – Sept. '13 PFC Meeting

- **Dynamics of sub-surface helium clustering in tungsten, B. Wirth**
 - MD W/He shows adatom formation/islands & bubble burst -> surface roughening; prelude to fuzz formation
 - Developing kinetic models for He bubble radius, density, pressure (SciDAC)
 - Uncertainties: He implantation rate, He diffusion/nucleation, temp/stress grads
- **Computational studies of thermoelectric MHD in flowing lithium in metal trenches, W. Xu**
 - Thermoelectric MHD installed in COMSOL & validated to Hartmann num. = 45
 - TE flow increases with B until 0.05 T, then decreases
 - Need addition of Li free-surface model
- **Modeling of mixed materials, T. Sizyuk**
 - Small impurity content can affect recycling, sputtering, H-retention, & blisters
 - Mixed materials can significantly change hydrogen isotope recycling
 - Liquids can improve heat removal, but surface/chemistry analysis needed

Laboratory Session Summary (1 of 2)

- **Deuterium retention in tungsten after heavy ion damage and hydrogen isotope exchange in PISCES (J. Barton)**
 - Examined exchange at 473 K for 75 eV (10^{26} m⁻² D+, then various fluences H+) in W & W with displacement damage (.01/.1/1 dpa) [retention saturates for > 0.2 dpa]
 - For 0 dpa, D exchange ↑ with ↑ H+ (largest near surface; extends >> range)
 - Retention ↑ with ↑ dpa (2-4×); W or Cu similar below 10 appm Cu
 - Exchange more effective in damaged W (total retained D ↓ with ↑ H+ to ~ DL)
 - 200 keV He implantation (200 appm) reduces D+ retention at depths >> He range
- **Design of a Plasma Permeation Experiment for TPE (D. Buchenauer)**
 - Fabrication of a high temperature permeation membrane holder was completed
 - Seal tests showed acceptable He carrier gas leak rates into TPE (< 1000 °C); sequestration of leaked He by the TPE pumping system was also demonstrated
 - Flow modeling for the He carrier gas demonstrated < 700 Pa pressure drop
 - Thermal modeling shows good heat removal even up to peak TPE ion fluxes (membrane T ~ 1000 °C, with membrane T variation of only +/- 2%).



Laboratory Session Summary (2 of 2)

■ Thermoelectric-Driven Liquid-Metal Plasma Facing Structures (S. Jung)

- Described TELS: TEMHD in liquid metal trench, with steady-state e-beam heating and plasma gun assisted θ -pinch for pulsed plasma loading
- Plasma gun (.02-.04 MJ/m²) increased previous θ -pinch only energies by 14× (up to 0.065 MJ/m²)
- Diagnostics: T-LP/TOF calorimeter; modeling velocity & θ -pinch dynamics (rMHD)
- Increasing θ -pinch compression time for higher energy density (1.5× shown)

■ In-situ TEM studies and plasma-surface interactions in extreme grain-refined tungsten (J.P. Allain)

- Performed TEM studies with in-situ He⁺ irradiations (2 keV) at 950 °C on ultra-fine grain (< 500 nm) / nano-crystalline (< 100 nm) tungsten (from large strain extrusion)
- High mobility for vacancies and interstitials -> form defect clusters and bubbles
- Found high bubble density at grain boundaries (faceted -> high pressure); small grains (<50 nm) had low bubble density and no defect clusters
- Some larger grains (> 200 nm) exhibited high density of cluster defects; others showed homogeneous distribution of high contrast of bubbles (grain orientation)

Higher efficiency in grain boundary trapping compared with micron-size grain W





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Session XII: Heat Transfer & Fluid Flow

Summary Chair: Richard Nygren

13:00	Introduction & Activities (5 min.)	R. Nygren (SNL)
09:30	<i>Flow instabilities in heat high density and pressure</i>	<i>D. Youchison (SNL)</i>
09:40	<i>Summary of US ITER work on fluid flow for FW-Blanket</i>	<i>D. Youchison (SNL)</i>

▪ He cooling of PFCs and blankets (Youchison, morning)

Dennis summarized design, testing, building and deployment of various PFCs and SNL's roles.

- We need to understand flow at high T and P.
- We cannot at present perform tests at high T and P.
- Potential impact is major change in designs for FNSF.

▪ US ITER Work

Dennis summarized analysis in CFD, EM and thermal stress and the skill set developed to support ITER.

- Wonderful capability developed in US that should be carried into preparatory activities for FNSF
- Unique expertise as well as important perspective

Session XII: Heat Transfer & Fluid Flow

Summary Chair: Richard Nygren

GIT – Minami described the lab for HHF testing of HE cooled targets and ongoing analyses to understand the thermal-hydraulics and thermal response.

- Progress on technical issues reflects good response to feedback raised in technical meetings for PHENIX.
- Instrumentation for targets and flexibility and heating method and choice of materials for future testing

13:25 Progress on He flow loop at GIT

M. Yoda (GIT)

13:40 HHF capability at ORNL; testing for PHENIX

A. Sabau (ORNL)

ORNL – Adrian described the plasma arc lamp (PAL) and its use and calibration for surface heating and testing of irradiated samples.

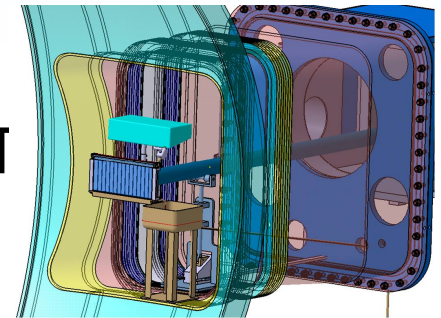
- Progress on technical issues reflects good response to feedback raised in technical meetings for PHENIX
- confirmation of thermal performance and temperature measurement for thin-foil targets

Session XII: Heat Transfer & Fluid Flow

Summary Chair: Richard Nygren

Discussion topics:

- **Two systems being deployed in Asia**
 - Zakharov (PPPL) unit built for HT-7/EAST
 - U-IL unit built for HT-7/EAST, presentation by Prof. David Curreli



13:05 Li flow systems for Asian Tokamaks

Discussion

13:15 Li safety awareness working group

R. Nygren (SNL)

- **Potential concerns**
- **Potential benefits**
- **Discussion related to “users’ group” and process**
 - ISLA 2013
 - Blanket Workshop at ISFNT