US PMI and PFC Test Facilities

(a work in progress)

Dean Buchenauer and Bob Bastasz

With inputs from the PMI / PFC community

Outline

- Types and purpose
- Facilities
  - Beam experiments
  - Plasma experiments
  - Integrated experiments
  - Ancillary experiments

PFC Meeting, Princeton Plasma Physics Laboratory, June 22, 2012

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Experimental PMI / PFC Facilities

- **Four main categories of facility**
  - Ion beam experiments
  - Plasma simulator experiments
  - Integrated experiments
  - Ancillary experiments

- **Experiments in each category are needed to effectively address the needs of the PFC program**
  - To characterize PMI effects in PFC materials
  - To help qualify PFC materials / concepts
  - To provide data for testing PMI models

Ion Beam Experiments

Description:	An ion beam of known energy, flux and composition bombards a sample and its effects on materials properties are measured.
Uses:	Study and characterize individual PMI processes
Key features:	✓ Provide highest level of control over PMI parameters ✓ Can study basic physical processes ✓ Generate fundamental data ✓ Can be quantitative for calibrating models

Plasma Simulator Experiments

Description:	A controlled plasma is formed, contacts a sample, and its effects on materials properties are measured.
Uses:	Study PMI effects and test materials under a wide variety of conditions
Key features:	✓ Provide a high level of control over PMI parameters ✓ Produce conditions that may approximate the fusion reactor environment ✓ Can study PMI and test material performance

Integrated Experiments

Description:	PFC material samples are exposed to plasmas in operating confinement devices.
Uses:	Provide PMI and performance data under actual plasma confinement conditions
Key features:	✓ Most closely reproduces the conditions experience by plasma-facing materials in confinement devices ✓ Can study PMI and test material performance

Ancillary Experiments

Description:	PFC material samples are exposed to particular conditions experienced by PFCs.
Uses:	Test material response to high heat fluxes or strong magnetic fields
Key features:	✓ Provides a high level of control over a single PSI-like parameter ✓ Can generate conditions accompanying PMI over a wide range ✓ Avoid effects caused by energetic ion bombardment

PMI Experimental Facilities

PMI Experiments By Category			
Beam	Plasma	Integrated	Ancillary
ARIES (SNL)	DEVex (UIUC)	DiMES/MiMES (GA)	MTOR (UCLA)
IBL (SNL)	DIONISOS (MIT)	LTX (PPPL)	SLiDE (UIUC)
IIAX (UIUC)	DPE (SNL)	MAPP (PPPL)	
IMPACT (PU)	PISCES (UCSD)	NSTX (PPPL)	
PRIHSM (PU)	TPE (INL)	SSS (MIT)	

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PMI Experiment Descriptions (example)

ARIES

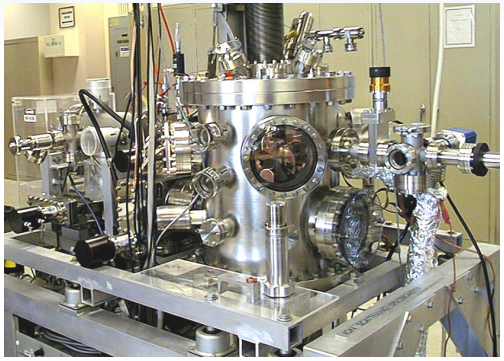
Angle-Resolved Ion Energy Spectrometer

Site: Sandia National Laboratories / California

Staff: Rob Kolasinski, rkolasi@sandia.gov, 925 294–2872

Josh Whaley, jawhale@sandia.gov, 925 294–2677

Link: http://energy.sandia.gov/?page_id=1003



Description: The Angle-Resolved Ion Energy Spectrometer at SNL/CA is an ion beam experiment that provides PMI data on surface composition, sputtering, mixing, segregation effects, and hydrogen isotope recycling on either solid or liquid materials. ARIES obtains PMI data through energy analysis of ions scattered or recoiled from a sample. Recent addition of a neutral time-of-flight analyzer improved the sensitivity and accuracy of the measurements.

Parameters:

Species: H^+, H_2^+, H_3^+, D^+, D_2^+, D_3^+, He^+, Ne^+, Ar^+ (mass selected)

Beam energy: 100-3000 eV, monoenergetic to ±1 eV

Flux: $10^{13\text{-}15}$ cm^{-2} s^{-1}

Angular ranges: 0-90° beam impact, 15-85° observation, 0-360° azimuth

Sample size: up to 2.5 cm diameter

Substrate temperature: -100 to 1200 °C

Upgrade: Detailed comparisons of ion scattering data with density functional theory calculations used to determine hydrogen binding on surfaces would be greatly improved by applying advanced uncertainty quantification methods. Algorithm development and high performance computing resources are needed.

Ion Beam Experiments (1 of 3)

ARIES

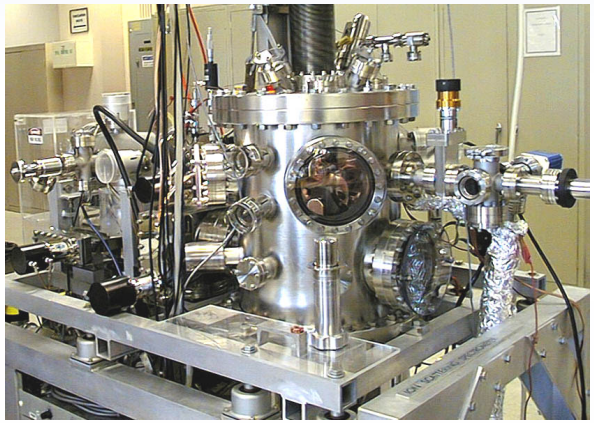
Angle-Resolved Ion Energy Spectrometer

Site: Sandia National Laboratories / California

Staff: Rob Kolasinski, rkolasi@sandia.gov, 925 294–2872
Josh Whaley, jawhale@sandia.gov, 925 294–2677

Link: http://energy.sandia.gov/?page_id=1003

Description: The Angle-Resolved Ion Energy Spectrometer at SNL/CA is an ion beam experiment that provides PMI data on surface composition, sputtering, mixing, segregation effects, and hydrogen isotope recycling on either solid or liquid materials. ARIES obtains PMI data through energy analysis of ions scattered or recoiled from a sample. Recent addition of a neutral time-of-flight analyzer improved the sensitivity and accuracy of the measurements.



IBL

Ion Beam Laboratory

Site: Sandia National Laboratories / New Mexico

Staff: Bill Wampler, wrwampl@sandia.gov, 505 844-4114
Stuart Van Deusen, sbvande@sandia.gov, 505 844-7782

Link: http://energy.sandia.gov/?page_id=1003

Description: The new Sandia Ion Beam Laboratory houses a 6.5 MV tandem accelerator lab with a 1.9 MeV/amu RFQ booster and a TEM end station for studies of displacement damage combined with low-energy H and He implantation. The IBL also has a 400 kV implanter and a new 3MV Pelletron with a microbeam and beamlines for ion channeling, UHV surface science, hydrogen uptake & release studies, and ion beam analysis of large components for MFE research such as tokamak tiles.

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Ion Beam Experiments (2 of 3)

IIAX

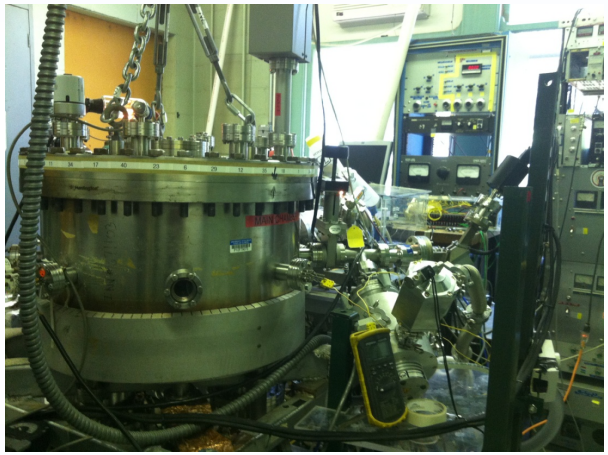
Ion Inter-Action eXperiment

Site: University of Illinois at Urbana Champaign

Staff: David. N. Ruzic, druzic@illinois.edu, 217 333-0332
Daniel Andruczyk, andruczy@illinois.edu, 609 243-3745

Link: http://cpmi.illinois.edu/2009/02/27/iiax-the-ion-surface-interaction-experiment/

Description: The Ion-surface InterActive eXperiment is an ion beam experiment designed to measure the energy and angular dependence of sputtering characteristics for solid and liquid materials. IIAX uses a magnetic-sector residual gas analyzer to measure the products that evolve during the ion bombardment, providing fundamental PMI data.



IMPACT

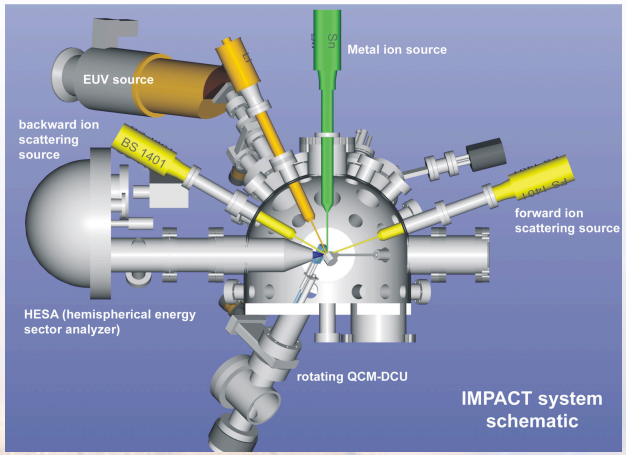
Interaction of Materials with charged-Particles And Components Testing

Site: Purdue University

Staff: Jean Paul Allain, allain@purdue.edu, 765 496-9718

Link: https://engineering.purdue.edu/CMUXE/Research-IMPACT.html

Description: The Interaction of Materials with charged-Particles And Components Testing facility is an low flux ion beam experiment being used to study the properties of thin-film Li coatings on various materials. It utilizes X-ray and extreme ultra-violet photon surface analysis components and a quartz microbalance for composition and sputtering measurements.



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Ion Beam Experiments (3 of 3)

PRIHSM

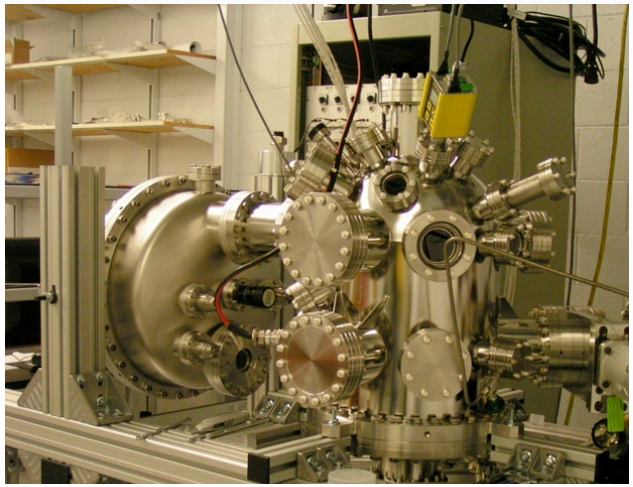
Particle and Radiation Interaction with Hard and Soft Matter

Site: Purdue University

Staff: Jean Paul Allain, allain@purdue.edu, 765 496-9718

Link: https://engineering.purdue.edu/NE/Research/radiationsurfacescience.html

Description: The Particle and Radiation Interaction with Hard and Soft Matter experimental facility utilizes a broad beam ion source and thermal evaporator to examine modification of surfaces under ion and neutral irradiation. Characterization is done by ultraviolet photo-electron spectroscopy, quartz crystal microbalance, ion surface scattering, and angle resolved photo-electron spectroscopy to determine electronic bonding and compositions on surfaces.



Plasma Simulator Experiments (1 of 3)

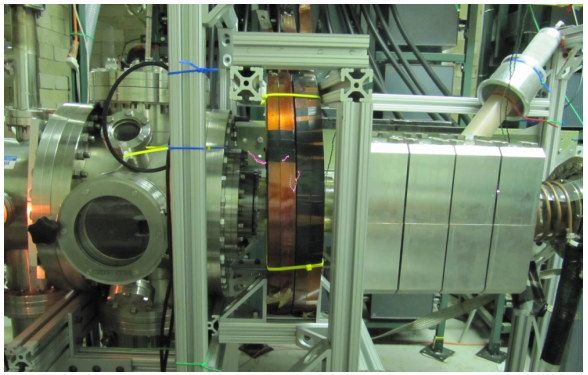
DEVex

Ion Inter-Action eXperiment

Site: University of Illinois at Urbana Champaign

Staff: David. N. Ruzic, druzic@illinois.edu, 217 333-0332
Daniel Andruczyk, andruczy@illinois.edu, 609 243-3745

Link: http://cpmi.illinois.edu/2009/02/27/devex-divertor-edge-and-vapor-shielding-experiment/



Description: DEVeX uses a high density (10^{19} - 10^{20} m^{-3}) theta pinch plasma directed at high velocity toward substrates to simulate pulsed plasma heat loading of surfaces. Vapor shielding effects of Li on molybdenum have been demonstrated by surface temperature measurements and visible observations using filtered high speed cameras.

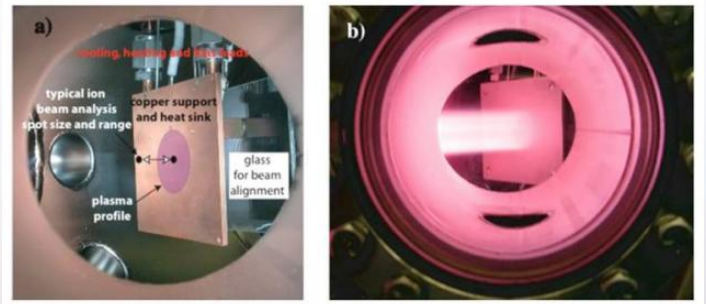
DIONISOS

Dynamics of IONic Implantation and Sputtering on Surfaces

Site: Massachusetts Institute of Technology

Staff: Dennis Whyte, whyte@psfc.mit.edu, 617 253-1748
Graham Wright, wright@psfc.mit.edu, 617 253-5956

Link: http://www.psisc.org/



Description: The Dynamics of IONic Implantation and Sputtering on Surfaces (DIONISOS) facility couples an in-situ MeV ion beam for surface analysis with plasma exposure from a high-density steady-state helicon source. Independent control of sample temperature and ion beam analysis techniques allow for studies of dynamic PSI processes.

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Plasma Simulator Experiments (2 of 3)

DPE

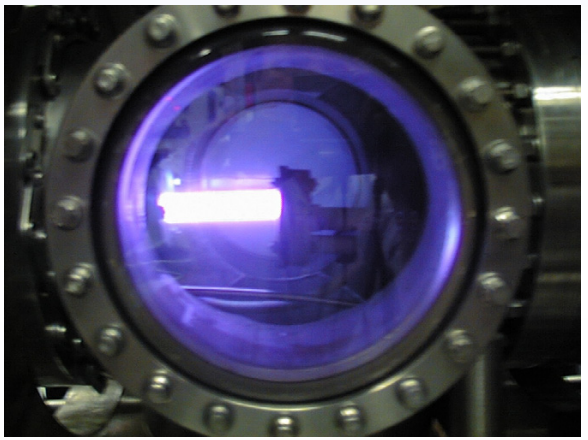
Deuterium Plasma Experiment

Site: Sandia National Laboratories, California

Staff: Dean Buchenauer, dabuche@sandia.gov, 925 294-3570
Josh Whaley, jawhale@sandia.gov, 925 294-2677

Link: http://energy.sandia.gov/?page_id=1003

Description: The Deuterium Plasma Experiment is a plasma experiment at SNL/CA used to study retention and release of H and He in solid materials and to simulate redeposition. DPE can irradiate samples of various sizes to a high fluence in the sub-keV ion energy range.



PISCES

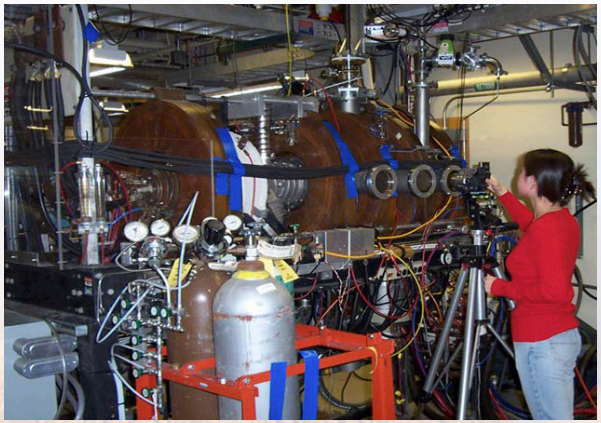
Plasma Interaction with Surface and Components Experimental Simulator

Site: University of California, San Diego

Staff: Russ Doerner, rdoerner@ucsd.edu, 858 534–7830
Matt Baldwin, mbaldwin@ucsd.edu, 858 534-1655

Link: http://www.pisces.ucsd.edu/pisces/

Description: The Plasma Interaction with Surface and Components Experimental Simulator is a linear plasma experiment used to study erosion, redeposition, materials mixing, and recycling. Boundary plasma physics experiments related to PMI are also studied. Two versions, PISCES-A and PISCES-B, each use a high-flux plasma source and are equipped with both surface and plasma diagnostics. PISCES-B can handle Be samples.



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Plasma Simulator Experiments (3 of 3)

TPE

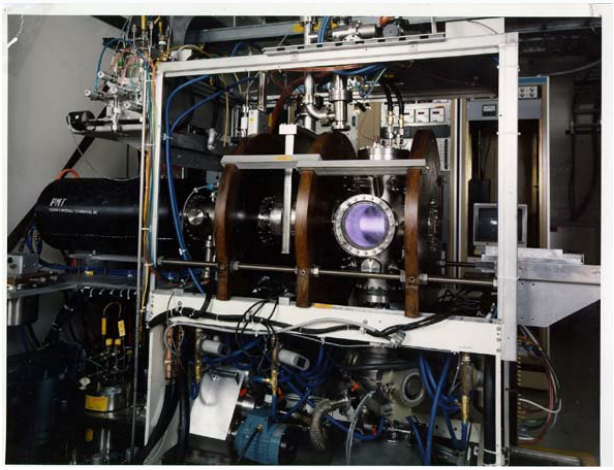
Tritium Plasma Experiment

Site: Idaho National Laboratories

Staff: Masa Shimada, Masashi.Shimada@inl.gov, 208 533-4472
Rob Kolasinski, rkolasi@sandia.gov, 925 294–2872

Link: https://inlportal.inl.gov/portal/server.pt/community/advanced_nuclear_energy_systems/338/fusion_safety/1556

Description: The Tritium Plasma Experiment produces a high flux of tritium seeded plasmas for the study of hydrogen retention and associated surface modification of candidate PFC materials. The facility is licensed to study neutron damaged materials and will soon have a capability for plasma driven permeation measurements.



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Integrated Experiments (1 of 3)

DiMES/MiMES

Divertor Materials Evaluation System and Mid-plane Materials Evaluation System

Site: General Atomics

Staff: Clement Wong, wongc@fusion.gat.com, 858 455–4258
Dimitry Rudakov, rudakov@fusion.gat.com, 858 455–2895

Link: https://fusion.gat.com/global/DIII-DDiagnostics

Description: The Divertor Materials Evaluation System (DiMES) and Mid-plane Material Exposure Sample (MiMES) at GA are designed to expose surface materials and advanced diagnostics to the divertor floor and mid-plane of the DIII-D tokamak, during plasma discharges. They provide integrated PSI testing, diagnostics development and bench marking of modeling codes.

LTX

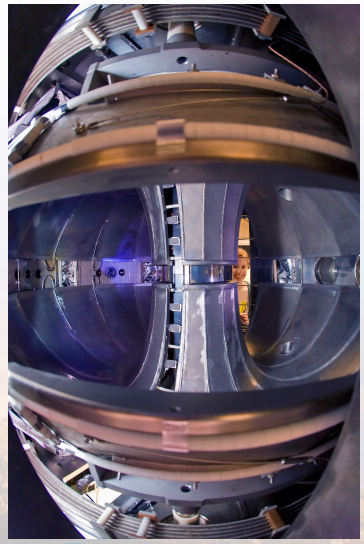
Lithium Tokamak eXperiment

Site: Princeton Plasma Physics Laboratory

Staff: Dick Majeski, majeski@pppl.gov, 609 243–3112
Bob Kaita, rkaita@pppl.gov, 609 243–3275

Link: http://www.pppl.gov/lithiumtokamak.cfm

Description: The Lithium Tokamak eXperiment (LTX) at PPPL is a medium-scale low aspect ratio tokamak with conformal hot high-Z walls. LTX has provisions for coating the walls with solid or liquid lithium. The primary research goal is to investigate modifications to tokamak stability and confinement with a low recycling liquid lithium wall.



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Integrated Experiments (2 of 3)

MAPP

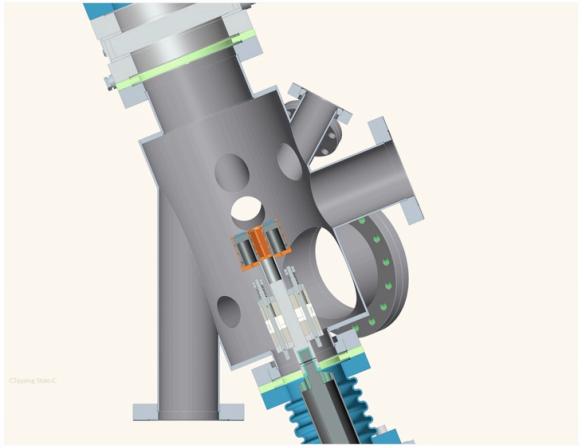
Materials Analysis Particle Probe

Site: Princeton Plasma Physics Laboratory

Staff: Jean Paul Allain, allain@purdue.edu, 765-496-9718
Charles Skinner, cskinner@pppl.gov, 609 243-2214

Link: http://www.pppl.gov/nationalsphericaltorus.cfm

Description: MAPP is an in-vacuo surface analysis diagnostic directly integrated into NSTX and capable of shot-to-shot chemical surface analysis of PMI. X-ray photoelectron spectroscopy (XPS) and low-energy ion surface spectroscopy (LEISS) can show the chemical functionalities between D and lithiated graphite at both the near surface (5-10 nm) and top surface layer (0.3-0.6 nm) for XPS and LEISS respectively.



NSTX

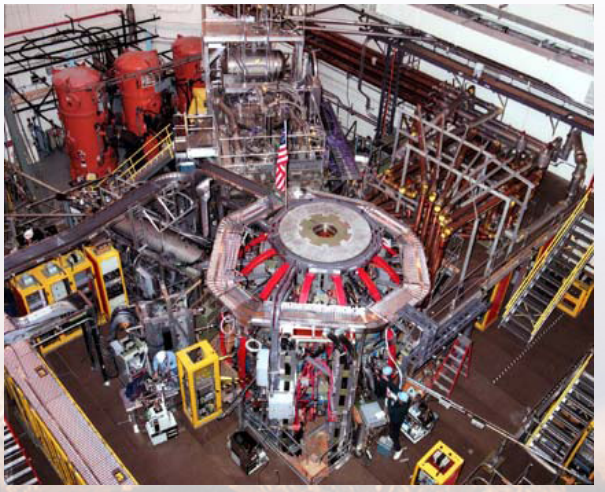
National Spherical Torus eXperiment

Site: Princeton Plasma Physics Laboratory

Staff: Robert Kaita, kaita@pppl.gov, (609) 243-3275
Rajesh Maingi, rmaingi@pppl.gov, 609 243–3176

Link: http://www.pppl.gov/nationalsphericaltorus.cfm

Description: The National Spherical Torus eXperiment (NSTX) is a major integrated experimental facility. It is used to study boundary and edge-physics effects with lithium plasma-facing components (PFCs). Techniques for achieving them include lithium evaporation onto carbon surfaces and metallic surfaces in the future. Flowing liquid lithium PFCs are under consideration in long term plans for the divertor region.



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Integrated Experiments (3 of 3)

SSS

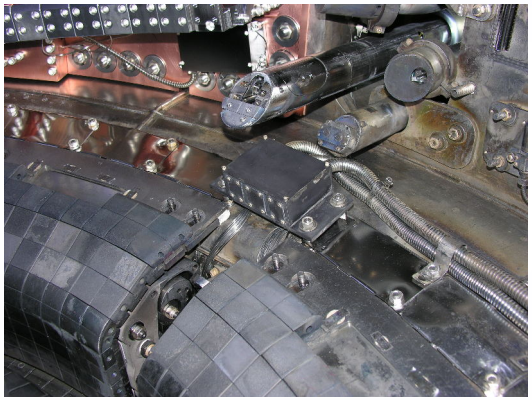
Surface Science Station

Site: Massachusetts Institute of Technology

Staff: Dennis Whyte, whyte@psfc.mit.edu, 617 253-1748
Bruce Lipschultz, blip@psfc.mit.edu, 617 253-8636

Link: http://www.psfc.mit.edu/research/alcator/program/index.html

Description: The Surface Science Station is a scanning diagnostic probe on Alcator C-Mod that can be used to position various plasma probes or quartz crystal micro balances at various in-vessel major radii positions on Alcator C-Mod (0.22 m below the midplane). It features a replaceable head that was used to characterize boronization films and is currently used for RF sheath rectification studies of ICRF-heated plasmas.



Ancillary Experiments (1 of 1)

MTOR

Magneto-Thermofluid Omnibus Research Laboratory

Site: University of California, Los Angeles

Staff: Sergey Smolentsev, sergey@fusion.ucla.edu, 310 794-5354
Alice Ying, ying@fusion.ucla.edu, 310 206–8815

Link: http://www.fusion.ucla.edu/

Description: The MTOR laboratory is a flexible set of facilities for studying liquid metal and aqueous electrolyte flow interactions with magnetic fields that are typical of magnetic confinement fusion. The laboratory consists of multiple magnet systems (1.8 T gap and 1 T quarter section torus) and liquid metal (PbLi, Ga alloy, Hg) and electrolyte flow loops that can be utilized in multiple configurations, including the study of free surfaces.

SLiDE

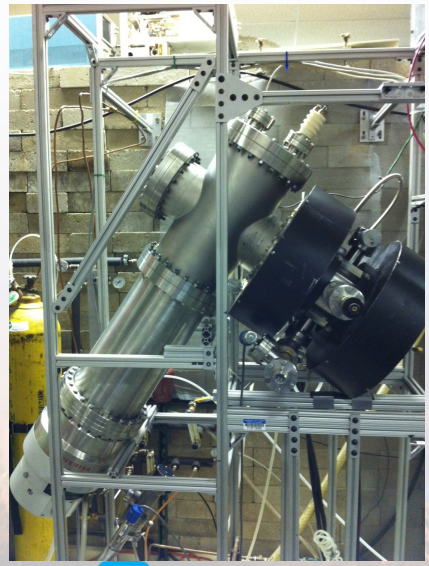
Solid/liquid Lithium Divertor Experiment

Site: University of Illinois at Urbana Champaign

Staff: David. N. Ruzic, druzic@illinois.edu, 217 333-0332
Daniel Andruczyk, andruczy@illinois.edu, 609 243-3745

Link: http://cpmi.illinois.edu/2009/02/26/solidliquid-lithium-divertor-experiment-slide/

Description: The SLiDE facility is an electron beam facility that was developed to perform high heat flux experiments on innovative liquid lithium concepts. The facility can generate e-beam fluxes comparable up to 20 MW m^{-2} needed in long pulsed machines. Currently SLiDE is used to test and develop the lithium-metal infused trenches (LiMIT) concept.



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Status

- **The listing will be available to everyone in the fusion community to provide general information about our PMI / PFC facilities.**
- **The listing will be posted on the PFC website:**

  ➔ https://engineering.purdue.edu/PFC/PFC_Home.html

- **Some experiment descriptions are incomplete. All need to have the experimental parameters added.**
- **Information on potential upgrades is also being collected and will be supplied to OFES.**
- **Please check over your experiment description and send me additions, corrections, and updates.**

  ➔ dabuche@sandia.gov

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