SAND2014-0058C

Overview of U.S. Programs in Plasma-Materials Interactions & Heat Removal

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Sandia National Laboratories, Hydrogen and Metallurgical Science Department, Livermore, CA

Japan-U.S. Workshop / 7-8 January 2014

Organization overview: Key Personnel

Fusion Energy Sciences

Edmund Synakowski

Associate Director, Office of Science

Research Division

James W. Van Dam

Director

Fusion Materials and Technology

Gene Nardella: *Lead*

Peter Pappano: *Materials Science*

Ed Stevens: *Enabling Technologies, MECI, U.S. ITER Project Cost & Schedule, ITER test blanket module*

Barry Sullivan: *Enabling Technologies, NSTX-U project, ES&H, SBIR*

Coordination of PMI activities through two key entities

Virtual Laboratory for Technology (VLT)

- Stan Milora (ORNL), Director (Retiring at beginning of 2014)
- Richard Nygren (SNL), Deputy

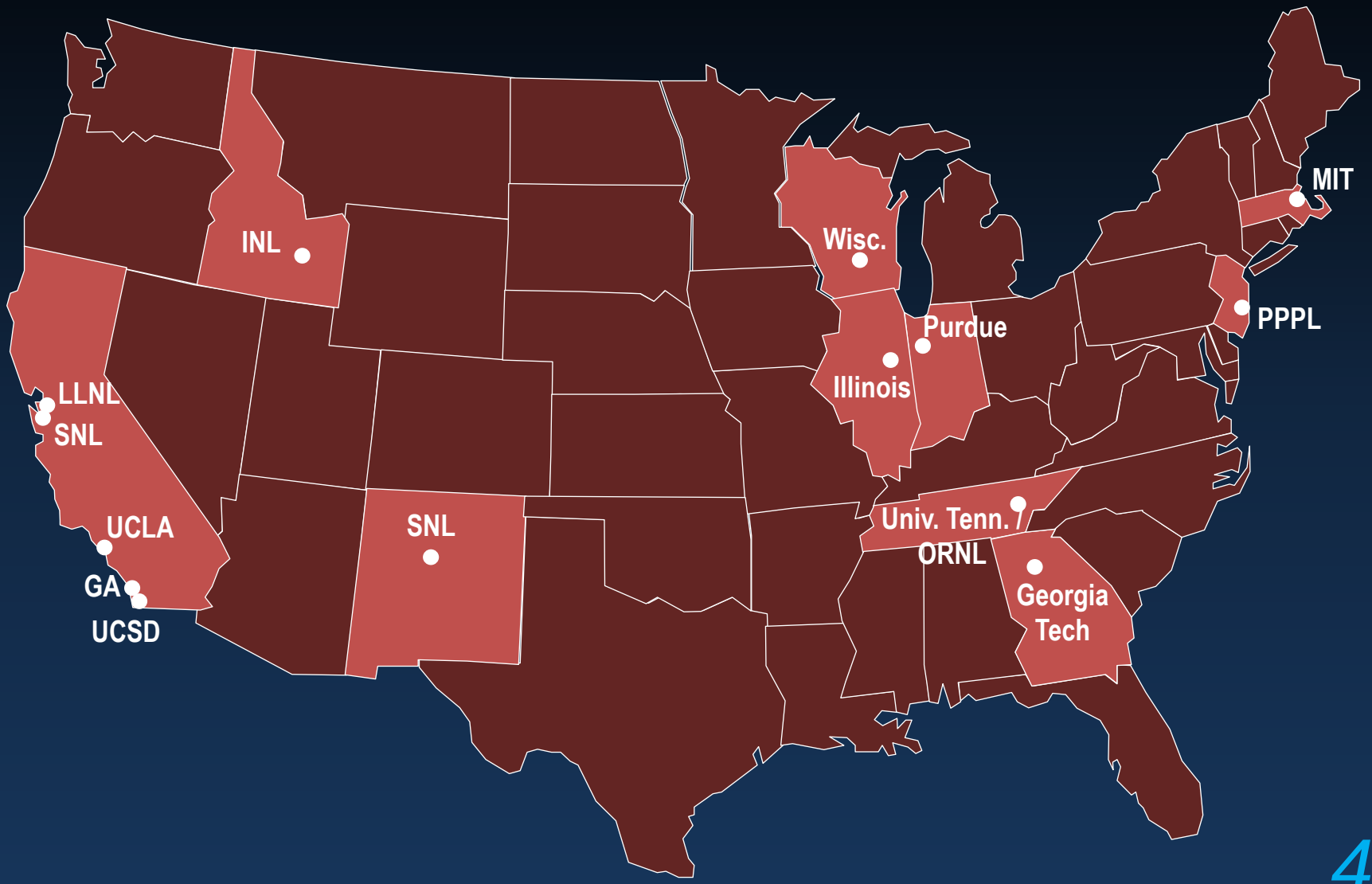
- Coordinates technology programs
- Provides a single point of contact to DOE/FES

Plasma-Facing Materials Group

- Jeff Brooks (Purdue), Chair

- Narrower scope than VLT, focuses on PMI activities
- Steering committee, annual meeting, conference calls

Principal U.S. sites with PFC/PMI Activities



Principal U.S. sites with PFC/PMI Activities

Alcator
C-Mod

Fusion Energy Sciences
U.S. Dept. of Energy

MIT

INL

Wisc.

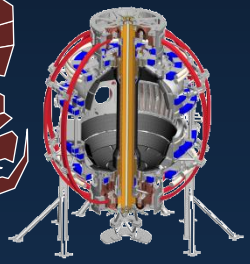
Purdue

PPPL

Illinois

LLNL

SNL



NSTX

UCLA

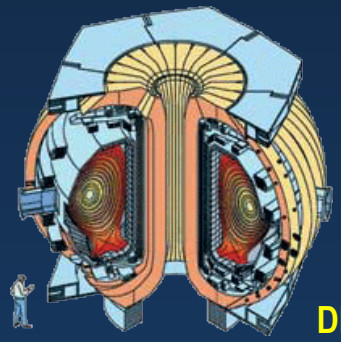
SNL

Univ. Tenn.
ORNL

GA

UCSD

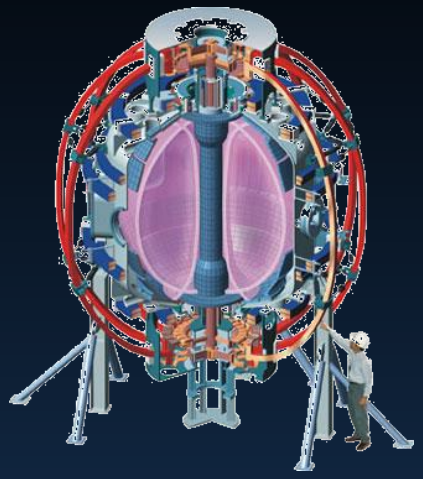
Georgia
Tech

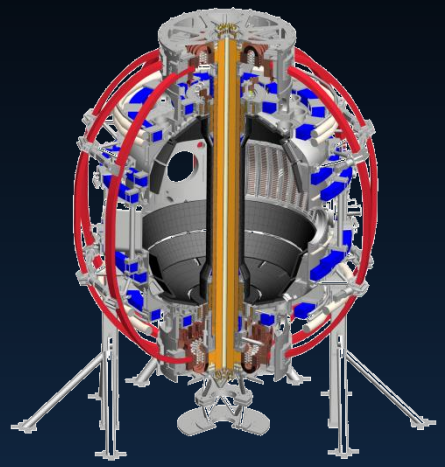


DIII-D

U.S. ITER Project Office

Start of operations in NSTX-U planned for late 2014





Parameter	NSTX	NSTX-U
Major Radius R_o [m]	0.86	0.94
Aspect Ratio R_o / a	≥1.3	≥1.5
Plasma Current [MA]	1	2
Toroidal Field [T]	0.5	1
Auxiliary Power [MW]	≤ 8	≤ 19
P/R [MW/m]	10	20
P/S [MW/m^2]	0.2	0.4-0.6

KEY UPGRADES

- New center stack for 1 T, 2 MA, 5 x long pulse length operation.
- Highly tangential 2nd neutral beam injector
- Magnet coils to test heat-flux mitigation concepts (e.g. snowflake divertor.)
- Structural reinforcements to handle higher electromagnetic loads.

PMI studies with NSTX-U: In-vacuum MAPP diagnostic

Material Analysis and Particle Probe (MAPP)

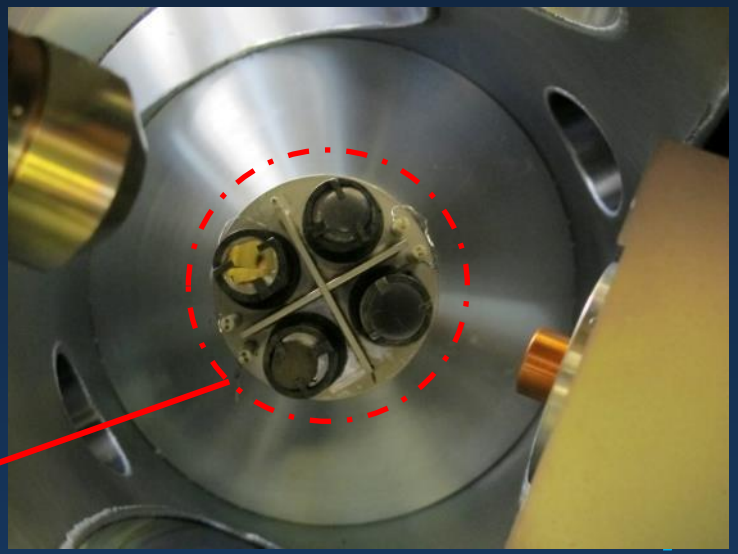
- In-vacuum PMI diagnostic to determine material composition and surface chemistry
- Up to 4 samples exposed to divertor plasma
- Prepared for use in LTX this year.

MAPP capabilities

LEIS/DRS

XPS

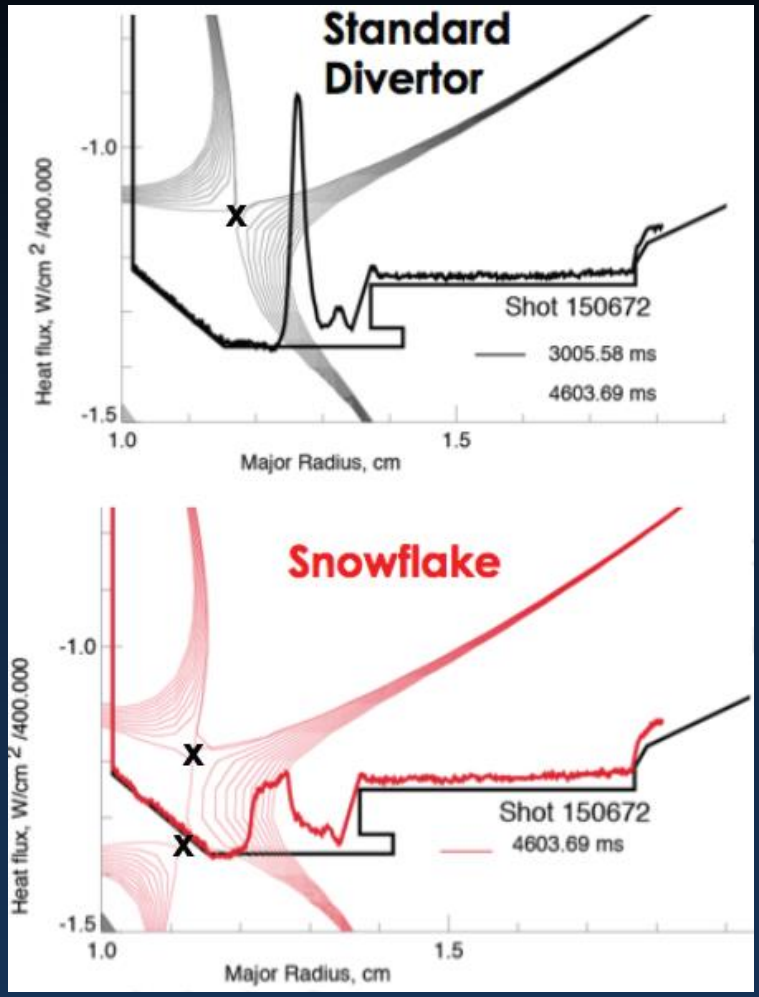
TDS



Lawrence Livermore

Edge plasma modeling for PFC's

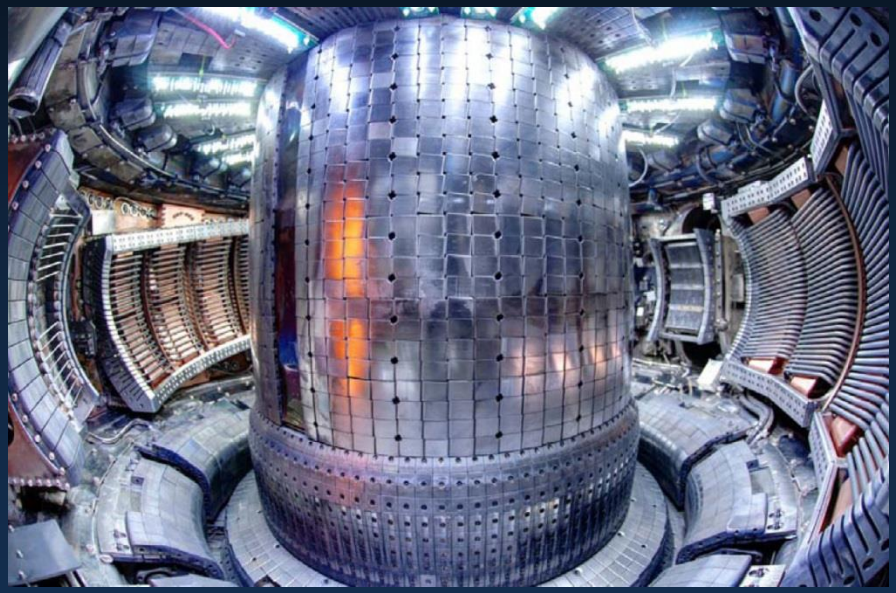
- Simulation of magnetic configurations for reduced divertor heat flux (snowflake)
- NSTX and DIII-D configurations considered, UEDGE heat flux predictions consistent with experiments for NSTX



See talk by T. Rognlien (S4)

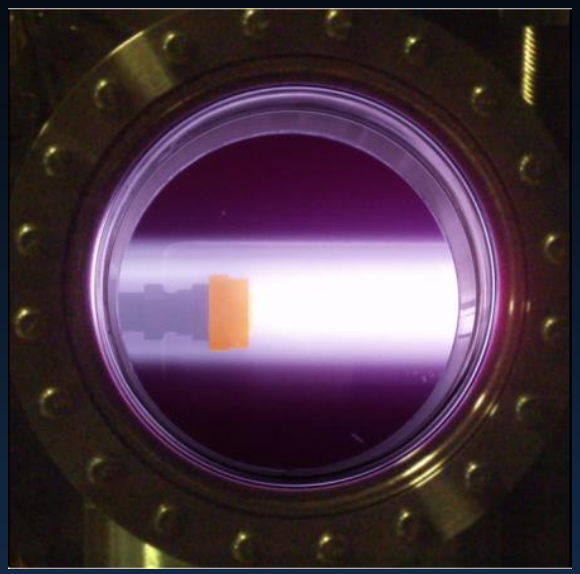
- R&D 100 Award for "Snowflake Divertor for Nuclear Fusion Reactors" (LLNL/CRPP/PPPL/ORNL)

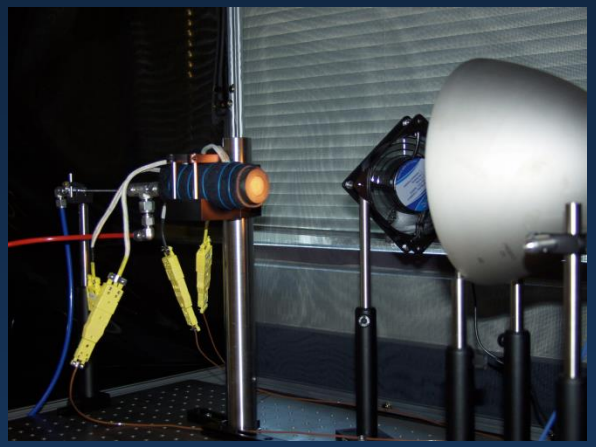
MIT: Alcator C-Mod status



- Alcator C-Mod terminated research operations in Oct. 2012
- Funding cut from Alcator redirected to support ITER
- CR in place for FY13 did not allow for restoration of program.
- In cold-shutdown as of October 2013, possible that funding could be restored in FY14.

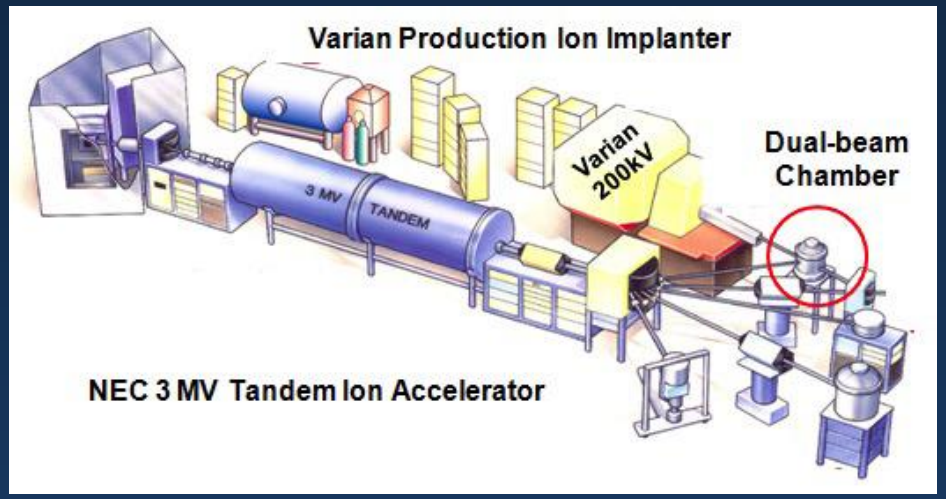
UC San Diego: PISCES





Recent Activities:

- Mixed materials (Be/C, Be/W)
- Be erosion/re-deposition
- Co-deposited D (T) trapping, diffusion, retention & removal
- ELM thermal transient and plasma transient studies.
- Steady-state heat flux source for PISCES-A; new LANL collaboration



See talk by J. Yu (S3)

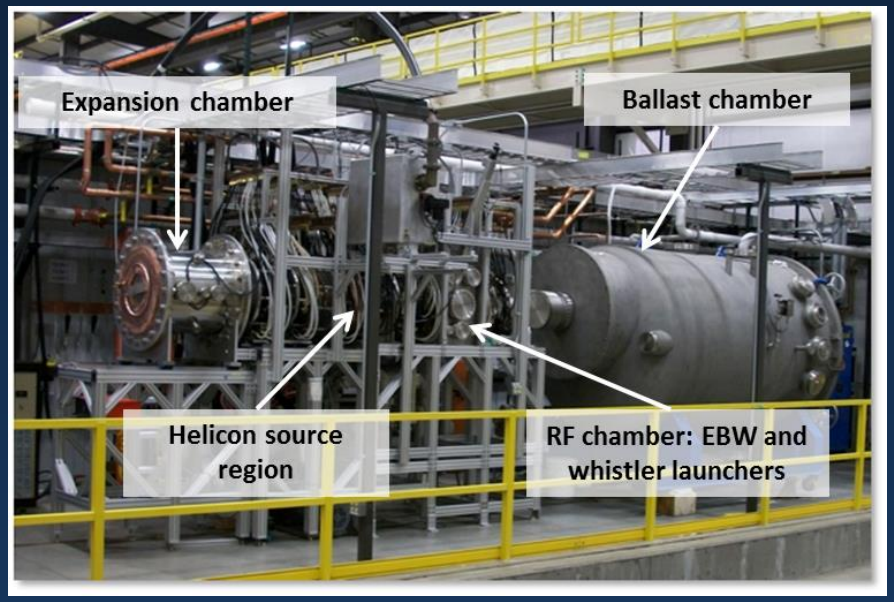
Oak Ridge: MPEX

OAK RIDGE National Laboratory

Material Plasma Exposure eXperiment

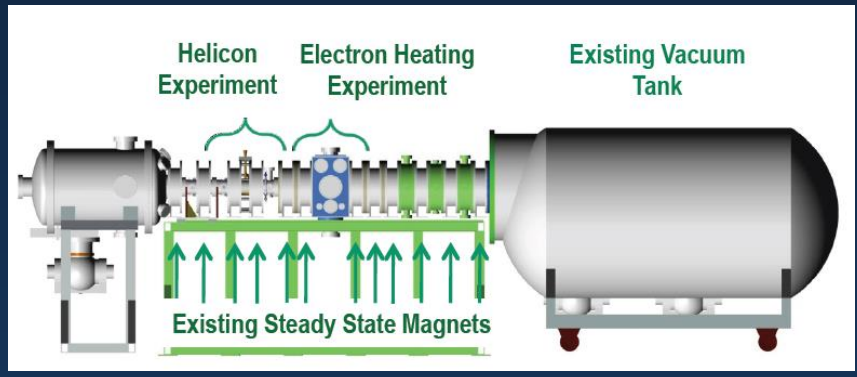
- Address underlying science of high-flux / fluence plasmas in a DEMO-style reactor. (Goal of handling n-irradiated materials.)

Phase 1 Physics Integration eXperiment ongoing. Includes characterization and modeling of high density helicon plasma source (>4×10^{19} /m^2)



Phase 2 "Proto-MPEX" upgrade underway.

- Addition of transport section
- Upgraded EBW and ICH
- Diagnostics incorporated
- Target chamber design

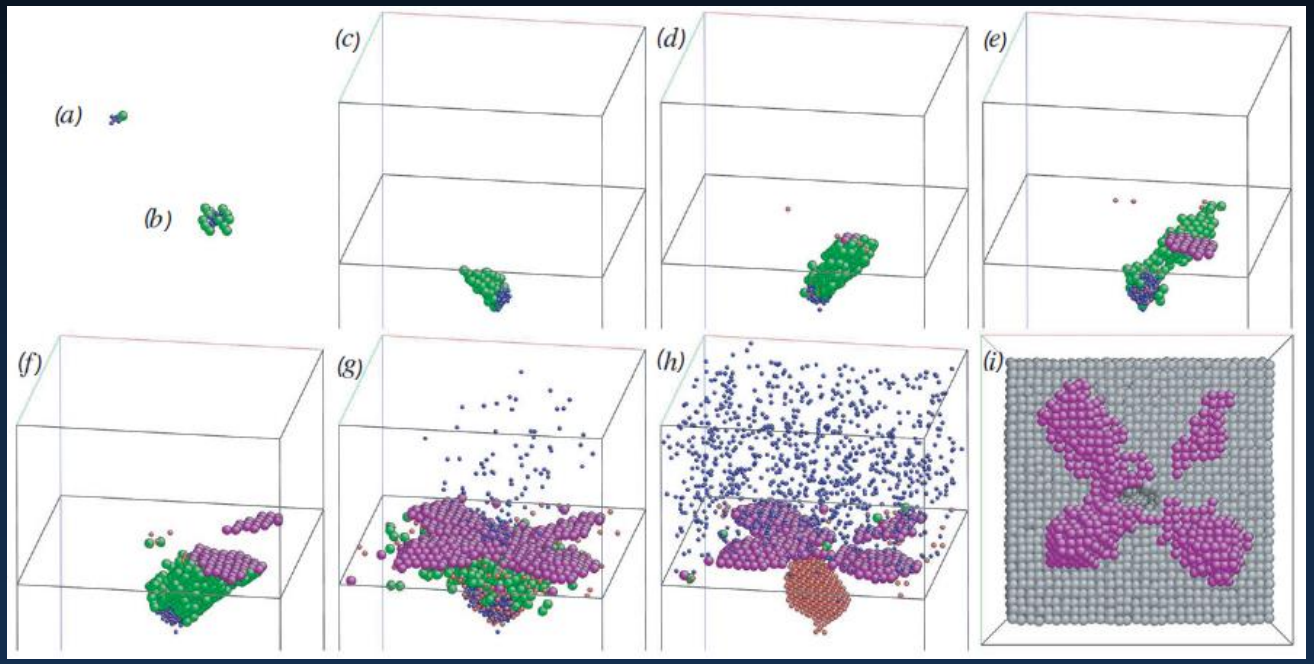


See next talk by J. Rapp (S1).

University of Tennessee

Key Activities: PSI Science Center and SciDAC PSI

- MD simulations provide insight into He bubble nucleation, and tungsten nano-structure growth.
- New H-W, W-W potentials developed



Evolution in time of helium bubble, tungsten interstitials, and surface adatoms during growth of He bubble below W(100) surface.

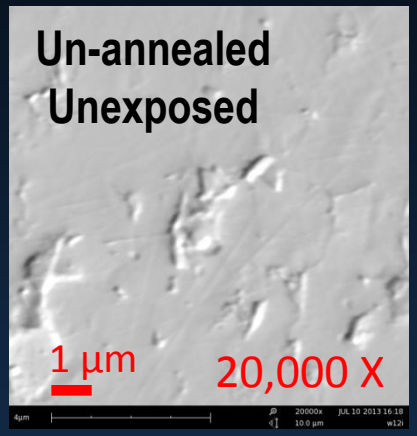
See later talk by B. Wirth (S2), recent paper: Nucl. Fusion **53** (2013) 073015

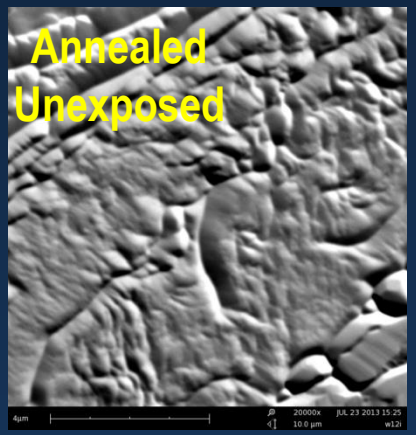
Sandia – Livermore: Initial Fuzz Growth Studies

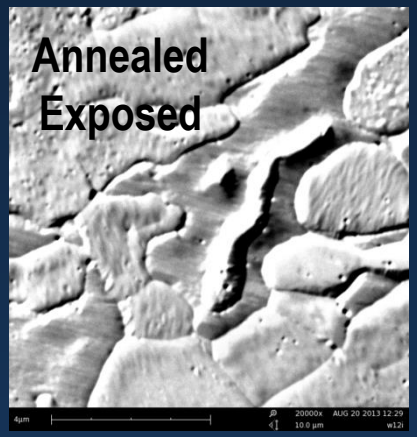
ITER-grade W samples exposed to low-flux ECR plasma

- Annealing created raised grain boundaries.
- No fuzz growth; bubbles evident.
- AFM reveals bubbles up to 150 nm in dia., 40 nm high
- Vented bubbles up to 15 nm deep.

W Sample Exposure Conditions	
Sample Temperature	1000 °C
Ion Temperature	60-80 eV
He Ion Flux	2.5×10^{19} m^{-2} sec^{-1}
Total Fluence	3.2×10^{24} m^{-2}
Sample Bias	-20 V







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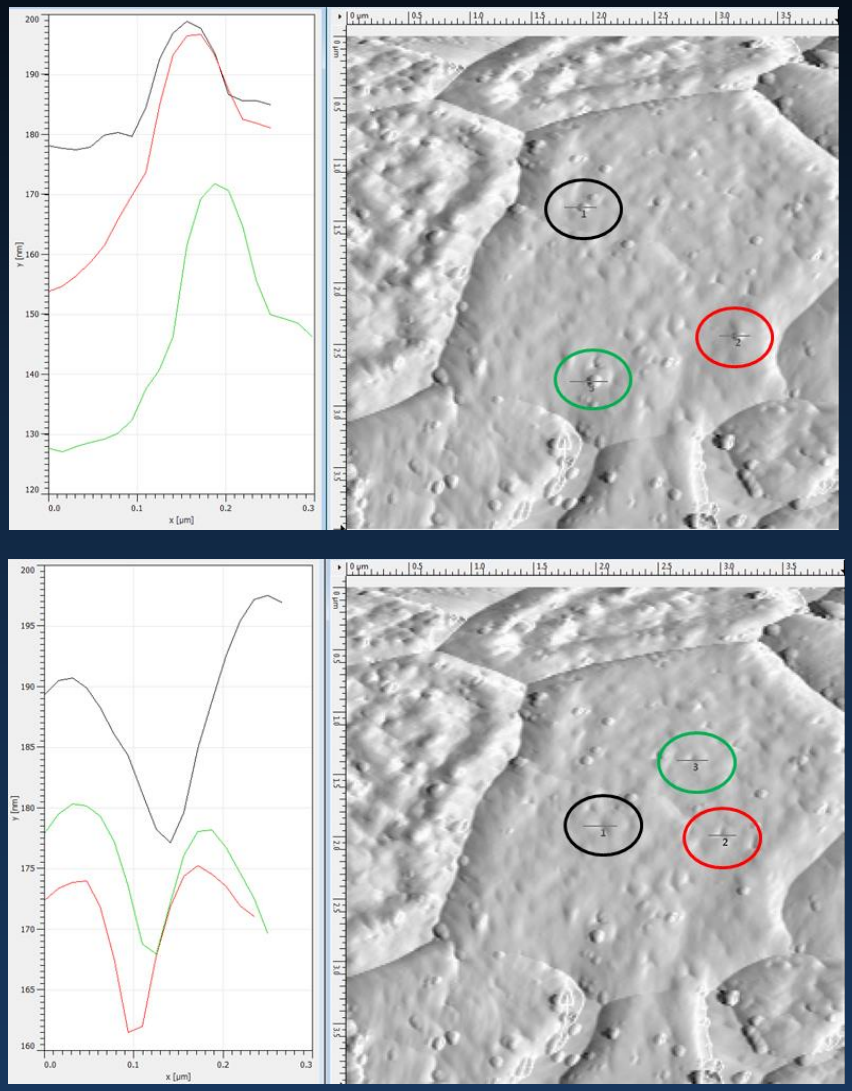
AFM Results

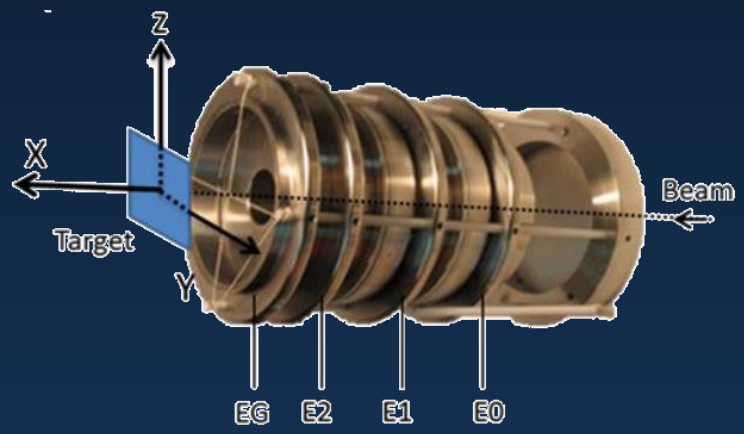


Oak Ridge: Physics Division

OAK RIDGE National Laboratory

Systematic studies of He-induced nano-structure

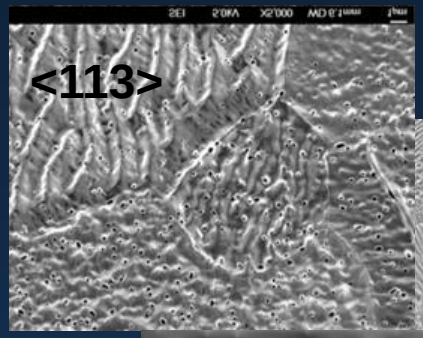
- New high-current ion beam deceleration system developed
- Provides intense (0.3 – 1 mA) He^+ beams from 50 eV to 12 keV

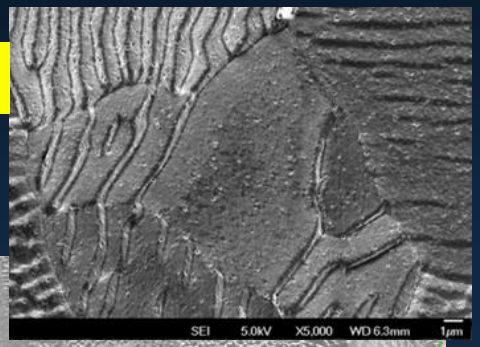


H Hijazi, and F W Meyer, *Rev. Sci. Inst.* 84, 033305 (2013)

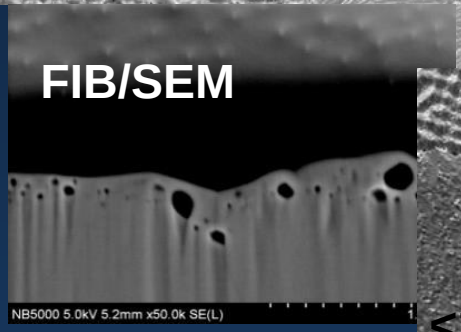
Below critical flux, organized surface morphology changes occur that vary with the grains' crystal orientation

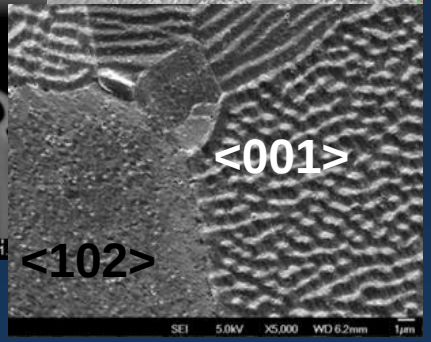
T~1130 °C, F=5x10^{24}/m^2





SEM

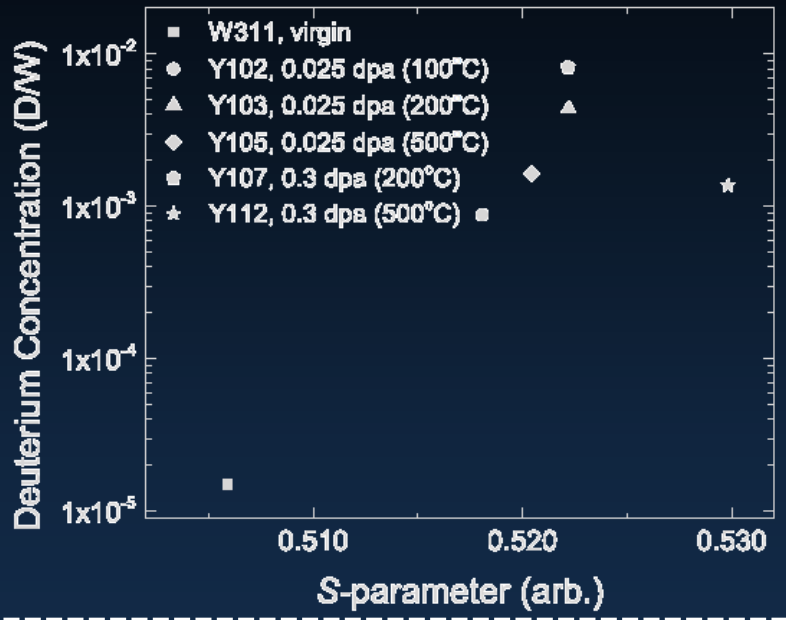


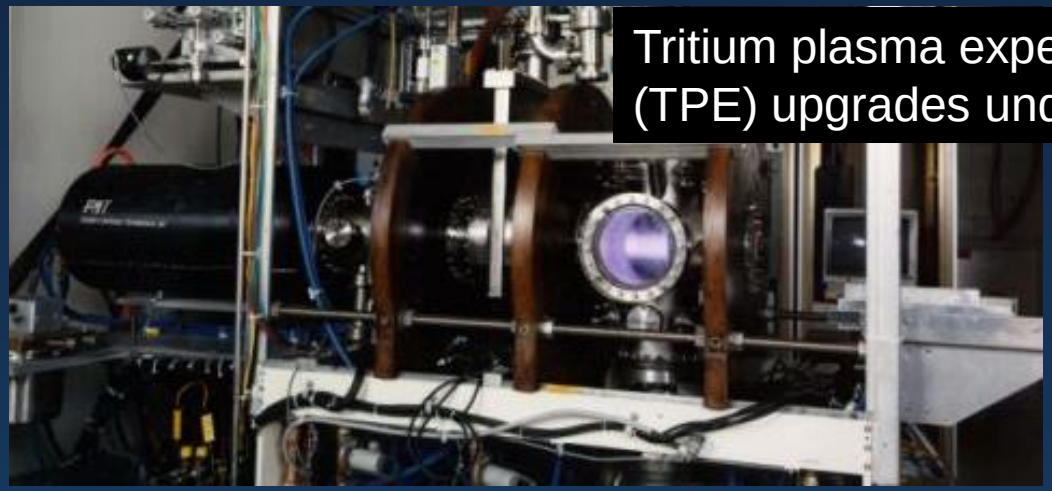


Idaho National Laboratory

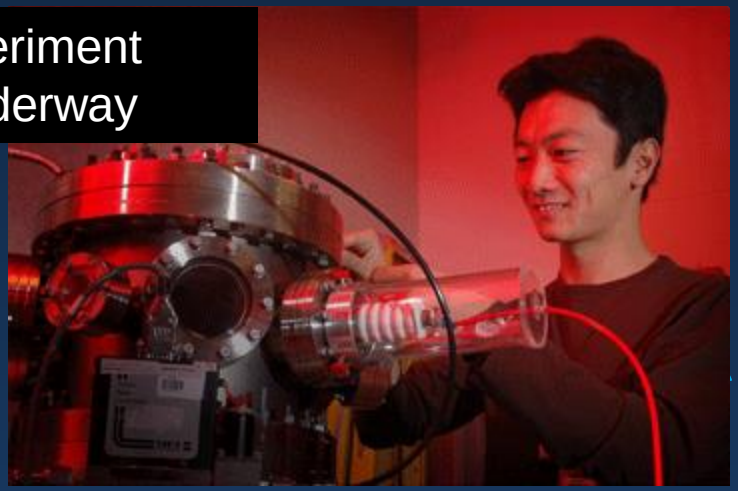
Doppler-broadening PAS for n-irradiated, plasma-exposed tungsten

- 200 μm-thick W samples:
  - Damage: 0.025 and 0.3 dpa
  - TPE exposure: 100 °C, 200 °C, 500 °C
- PAS source:
  - ^{68}Ge (bulk) and ^{22}Na (shallow)
  - Plasma-exposed and back surfaces characterized.





Tritium plasma experiment (TPE) upgrades underway



Concluding Remarks

- NSTX-U set for beginning of operations later this year.
- Recent DIII-D PFC activities include DiMES erosion/redeposition, Langmuir probe / TC meas.
- Collaborations to study tungsten nano-structure growth, He precipitation
- Unique aspect of U.S. research: emphasis on liquid metals as PFC materials.

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