Richard Nygren
Sandia National Laboratories
Analytical Materials Science Department

SAND2013-8101P

Program Review
Sandia's MFE Activities in
Plasma Wall Interactions & Development of PFCs

1:00	Introduction	Nygren
1:10	Plasma-wall interaction and tritium science studies at SNL-CA	Kolasinski
1:35	Hydrogen and PSI Collaborations at SNL-CA	Buchenauer
1:50	EAST/MAPES Material Migration Experiment	Wampler
2:05	Sandia's PFC Development & HHF Research	Youchison
2:30	End	

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Program Review
Sandia's MFE Activities in
Plasma Wall Interactions & Development of PFCs

Included here

- PSI experiments & collaborations
- TPE experiments with INL
- DiMES collaborations
- DIII-D edge probe array support
- PSI Science Center
- PHENIX
- compact toroid with UCD
- DIII-D fast thermocouples
- W armor (He-cooled PFCs, SBIR/CRADA)

excluded

These provide great leverage that benefits SNL and FES.

- DIII-D edge probes
  Watkins
- NSTX-U
  Nygren/Youchison
- ITER – Task Agreement
  Ulrickson/Youchison/Nygren

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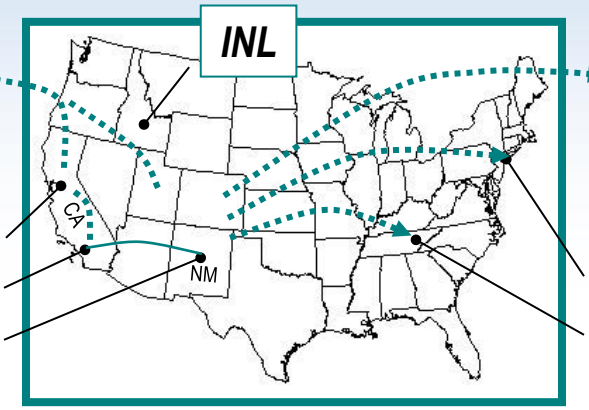
Magnetic Fusion at Sandia

Collaborations with Japan, China, Korea, India



IPO, CEA France

Other EU collaborations

Livermore
La Jolla
Albuquerque

NSTX, PPPL

IP-ORNL

Sandia National Laboratories

Livermore California

California Lab.

Albuquerque New Mexico

Science & Technology

Physical & Eng. Sci.

Phys., Chem. & Nano Sci.

Puls… Radiation Sciences

Hydrogen & Metallurgy Sci.
(Tom Felter, Mgr)

- PSI experiments
- TPE experiments with INL
- DiMES collaborations and probe support
- PSI Science Center
- PHENIX
- NSTX-U
- compact toroid with UCD
- DIII-D fast thermocouples
- DIII-D edge probes array – Watkins @ GA

Buchenauer
Kolasinski
Donovan
Whaley
Nygren-ABQ
(Youchison)

Rad.-Solid Int.
(Jon Custer, Mgr.)

- PSI experiments
- PSI collaborations
- Ion Beam Lab

Wampler
Van Deusen

Fusion Technol…

- ITER FW Design
- NSTX Liquid Li Div…
- W armor
  He-cooled PFCs
  many SBIR/CRADA
- PHENIX

Ulrickson, 1352
Youchison
Nygren
Youchison, 1353

Sandia National Laboratories

Senior Staff

Dennis Youchison

Nuclear Engineer, Prof. Eng
US Technical Leade ITER FW (new)
Field Coord., SBIR Program - PFCs
PFC Group Steering Committee
Past: Ch. IEEE Fusion Tech. Comm.
IEA NTFR Subtask Chair
SOFE General Chair
ReNew task group co-leader

Dean Buchenauer

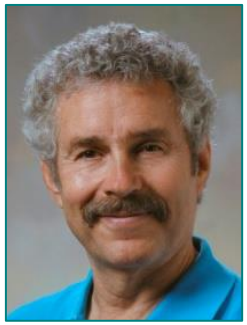
Plasma physicist
DiMES and erosion/redep experiments
Gas-driven permeation through barriers
PHENIX Co-leader Task 3
PI Compact Toroid Injection
PFC Steering Committee, Ch. Lab Exp.
Organizer: 2010 Int. Wkshp on H Isotopes
Past: DIII-D probe s GDC of W, TFTR tritium

Mike Ulrickson

Nuclear Engineer
US Technical Leader, ITER FW
ITER Coordinator, BIPT
PFC Group Steering Comm.
Past: US BPO Advisory Comm.
ReNeW leader (1 of 5)
FESAC subcommittee
Fusion Technology Editor
SOFE Tech Chair

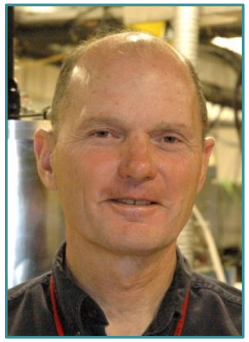
Jon Watkins

Plasma physicist
Designs, builds, operates probes
ELM suppression experiments
Collaborates with scientists worldwide to interpret plasma edge conditions
Past: TEXTOR, built reciprocating probes DIII-D



Richard Nygren

Materials Scientist
Deputy Dir. Virtual Lab for Tech.
IEA NTFR Subtask Chair
ARIES pathway study
Past: FNSPA Core Group
US BPO Res, Comm., Ch. Top. Grp.
FESAC Mat. Subcommittee
ReNew task group
ISFNT & ICFRM Comm.
ITER Design Review Chair



Bill Wampler

Surface scientist
Measures H, D, He, metals on surfaces
ITER C erosion experiments with EAST
C erosion/retention, DIII-D C^{13} experiments
Li deposition in NSTX
Collaborates worldwide on trapping/implantation

On contract to Sandia is
Charlie Baker (retired) – NAS IFE Panel, LANL PAC, FED Editor, past: ITER MAC, FESAC, US ITER Team

Sandia National Laboratories

Other Important Staff

Rob Kolasinski

Surface scientist
Young Career Award
H,D on surfaces
Angle resolved spectroscopy with ARIES
Tritium experiments with TPE (INL)
Host for US-Japan PMI/PFC Workshops

Josh Whaley

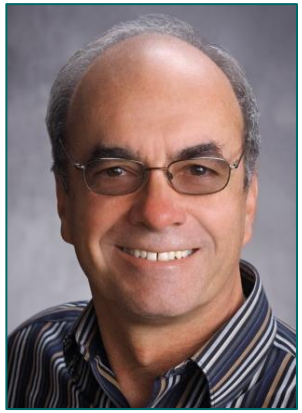
Technologist, CA-lab
DPE, ARIES, SEMs, permeation
DiMES and probes at DIII-D

David Donovan

Post-doc, Nuclear engineer
Active DiMES experiments
Support DIII-D probes & fast thermocouples
Tritium experiments with TPE (INL)
W fuzz incubation in DPE

Stuart Van Deusen

Technologist, Ion Beam Lab
Operation of accelerator-based surface probes, e.g., PIXIE, NRA, Rutherford backscattering, etc.



Tom Felter

Manager, Hydrogen & Metallurgy Science

Our history includes many successful national and international collaborations.

Foreign: JET, TEXTOR, Tore Supra, JT-60, LHD, KSTAR, Post-TITAN, PHENIX …

Domestic: DIII-D, NSTX, C-MOD, TFTR, PISCES, INL, UCD, Purdue, GIT ….

.. Sandia tests for JA, RU, EU, KO, CH, IN and many SBIRs

ITER
- US FW design, R&D
- BIPT coordinator
- Sandia tests Be, C, W (PFC options)
- Sandia/Boeing built divertor cassette
- ITER PFC costing & Design Reviews

DIII-D
- Sandia edge probe array; fast thermocouple array
- ELM control studies
- DiMES collaboration, erosion/redeposition studies

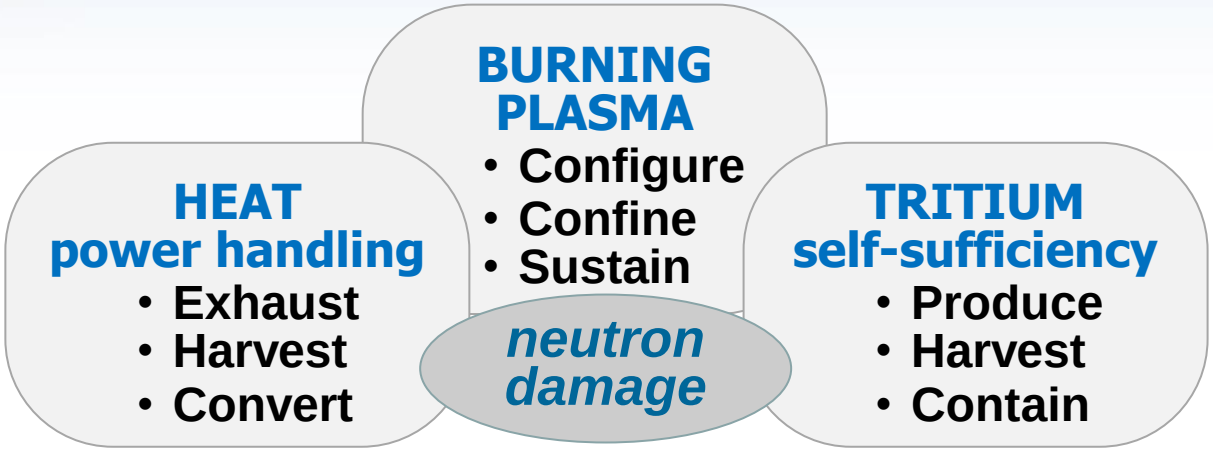
NSTX
- NSTX-U, thermal analysis of tiles, gas cooling
- Li jet test at SNL (NSTX divertor B field)
- Li measurements (no Li/D correlation)
- LLD divertor plates & heater control

EAST
- C erosion for ITER

Other
- PSI Science Center (funds post-doc)
- INL (tritium permeation/retention)
- PHENIX (Task 1 - US-J, Georgia Tech., ORNL; Task 3 - INL)
- UCD (compact toroid injection)
- UCSD (W fuzz, TPE sample holder, target cooling)
- Purdue (emissivity of lithiated surfaces)

**black are areas of current emphasis*

Basic requirements in fusion systems



HANDLE/HARVEST HEAT **and** ***BREED/PROCESS/TRACK TRITIUM***

PROTECT the PLASMA

ROBUST PLASMA FACING COMPONENTS

- **Mitigate ion & radiation damage**
- **Develop suitable materials**
- **Develop workable cooling systems**
- **Understand/predict system behavior including plasma-wall interactions**

VIABLE BREEDING BLANKETs

- **Demonstrated tritium breeding**
- **Develop suitable materials**
- **Viable integrated systems**
- **Understand/predict system behavior including tritium migration/retention**

****Solutions are the focus of Sandia's research for OFES.***

HEAT power handling

BURNING PLASMA

TRITIUM self-sufficiency

Plasma Edge

HANDLE/HARVEST HEAT

- Surface temperature
- Gradients: temp/stress

PROTECT PLASMA

Heat & Particles

ion damage

Morphology evolves!

He effects & neutrons

Surface

Bulk

- Material damage & modification
- T retention
- T permeation
- Cooling
- Pressure
- Thermal-hydraulics
- Thermal stress
- Cracking/failure
- Fab – Joining etc.

P F C

coolant

BREED/PROCESS/TRACK TRITIUM

- Impurity source
- Erosion/redep.
- D/T recycling

PFC
SNL R&D

We analyze and test PFCs.

We have designed, built and deployed PFCs.

And we develop fundamental data in the Engineering Sciences on fluids and heat transfer.

PMI
SNL R&D

We design, build and use probes and analyze tiles. We collaborate on plasma edge experiments.

With various facilities, we investigate trapping of D/T/He; permeation of D/T and growth of W fuzz.

Sandia has unique capabilities for research on PFCs.

Surface analysis for PWI

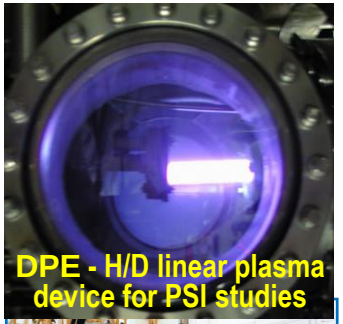
- Plasma sources for tritium studies: Deuterium Plasma Experiment (DPE) and Tritium Plasma Experiment (TPE) now at INL in Idaho.
- Low-energy ion beam probes for LEIS, DRS & SIMS
- MeV ion beam analysis of surface modification, T trapping and traditional analysis (Auger, Raman AFM, and XPS).

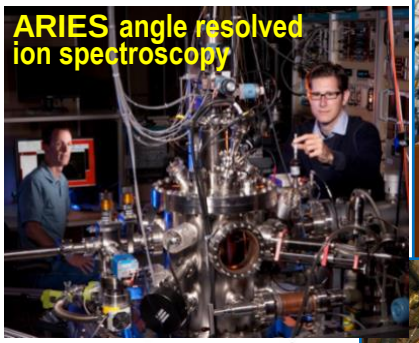
High Heat Flux Testing

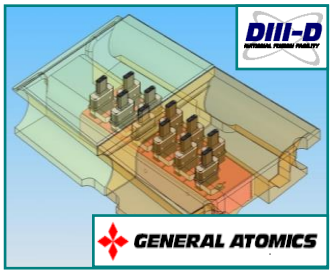
- Electron beams: EB60 & EB1200 (with Be handling)
- Coolants: high T & P water, He (largest closed loop in US)
- Diagnostics: IR, pyrometers, thermocouples, calorimetry
- Codes: magnetics, thermal/stress, CFD

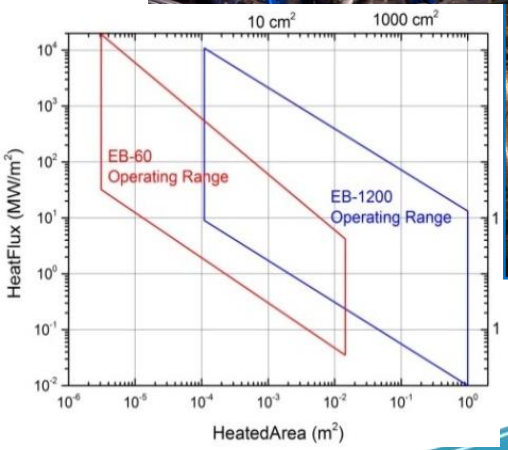
We are technology leaders,

- Hydrogen in metals
- Ion Beam Laboratory
- High heat flux tests, facility operation
- Enhanced heat transfer, two-phase flow, gas cooling (porous media, jets)
- Refractory alloys, high temperature heat exchangers









and active collaborators

Sandia National Laboratories

Richard Nygren
Sandia National Laboratories
Analytical Materials Science Department

Program Review
Sandia's MFE Activities in
Concluding Comments

- TRL levels (in guidance to reviewers)
- Concerns regarding staff and facilities
- Future plans
- Leadership
- Documentation (references)

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TRL charts, FESAC Mat'ls

PFC development

Major Science & technology issues: Plasma-Material Interactions

Facility	Plasma test stands	Non-DT confinement: inductive, low T	Non-DT confinement: non-inductive, low T	Non-DT confinement: non-inductive, high T	ITER: DT, inductive, low T	FNSF: DT, non-inductive, high T	DEMO
Divertor + Wall PMI							
Quiescent plasma heat/energy exhaust	1.-3. Sheath heat transmissio basica parallel plasma physic						
Transient plasma heat exhaust	1.-3. Surface response > 0.1 MJ/m2						
Erosion control	1.-3. Sputter yield + morpholo evolution						
Dust and redeposit control	1.-3. Response of redeposits plasma load, dust transport						
Tritium fuel retention	1.-4. Implantation & permeati						

Facility	Plasma test stands	Non-DT confinement: inductive, low T
Divertor + Wall PMI		
Quiescent plasma heat/energy exhaust	1.-3. Sheath heat transmission, basica parallel plasma physics	3.-5. Non-stationary T, but possible high parallel power loading at small size
Transient plasma heat exhaust	1.-3. Surface response > 0.1 MJ/m2	4.-5. Disrupt

density W/S~1.5 for one year

PWI issues

Facility | test sta anc design s

Device Requirements for PFC Development

Understand power flow, predict heat loads — 2 edge moc development

Relevant divertor size (area ratio to FW)

DEMO relevant disruption mitigation

Representative e flux)

Solid PFC Config

Relevant high te

DEMO relevant l

W-based divertc

W-based limiters high temp FW

Understand PFC

Demonstrate ac

Demonstrate ac

Liquid Divertor (Demonstrated h

Integrated op., a

Qualified PFC Su ply

Develop/qualify vertor fabrication process

Develop/qualify miter fab process

Solid PFC Config

Relevant high te

DEMO relevant l

W-based divertor

W-based limiters, recessed or highly-shaped high temp FW

Understand PFC failu

Demonstrate accept

Demonstrate accept

	experiments	performance	wrong edge plasma
W-based divertor	2-3 design studies, HHF experiments	4 HHF mockups; W tiles, hot wall (C-MOD); W div EAST	5 W div East-U (higher power) & Satellites	4 W div in ITER H & D plasmas
W-based limiters, recessed or highly-shaped high temp FW	2-3 design studies, HHF experiments	4 improved models, HHF experiments	?5 deployed W lim & recessed FW	data from port plugs, FW modules

Input to FESAC Materials Subcommittee:

Many divertor and PMI issues could be studied by working first at low wall temperatures .. likely advance most of these issues to .. TRL 4-5.

Extending .. to high wall temperature in non-DT long pulse devices, combined with ITER experience, could advance .. most issues ..TRL 5-6.

Ultimately .. experiments in .. FNSF .. needed to advance to .. TRL 7-8

Similarly, .. liquid divertor and PFC materials qualification topics could advance through the TRL3-4 stage with test stands, design studies, ...

Solid PFCs & PMI - TRLs

2-3 test stands

3-4 upgraded test stands, short pulse confinement devices

typical

4-5 non-nuclear steady state toroidal device, no further change with ITER

7 FNSF

Sandia National Laboratories

Concerns in Sandia's current program

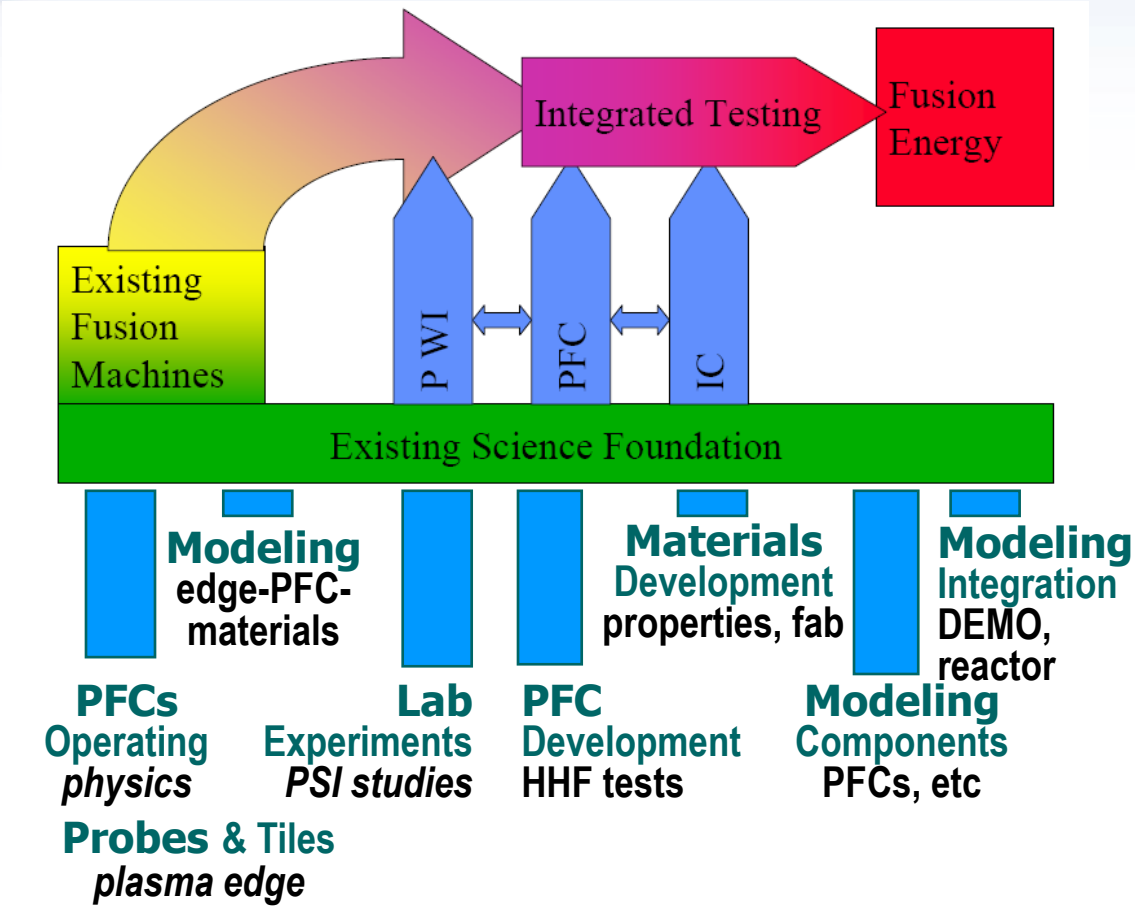
Staff

- **Wampler no funding 2014+**
  - **impact: lost from program** (0.1 of 0.1 FTE)
  - ***mitigation: FY2014 redirect base funds (Nygren/Buchenauer)***
  - ***FY2015 no solution yet identified, ?RFP2015***
- **Youchison limited coverage 2014+**
  - **impact: lost from program** (0.8 of 1.8 FTE)
  - ***mitigation: FY2014 increase ITER work, some NSTX effort***
  - ***FY2015 no solution yet identified, ?RFP2015***
- **1 staff, no funding 2015+** (end of ARRA – Plasma Sci. Ctr.)
  - **impact: lost from program** (1 of 2.2 FTE)
  - ***mitigation: FY2015 no solution yet identified, ?RFP2015***

Facilities

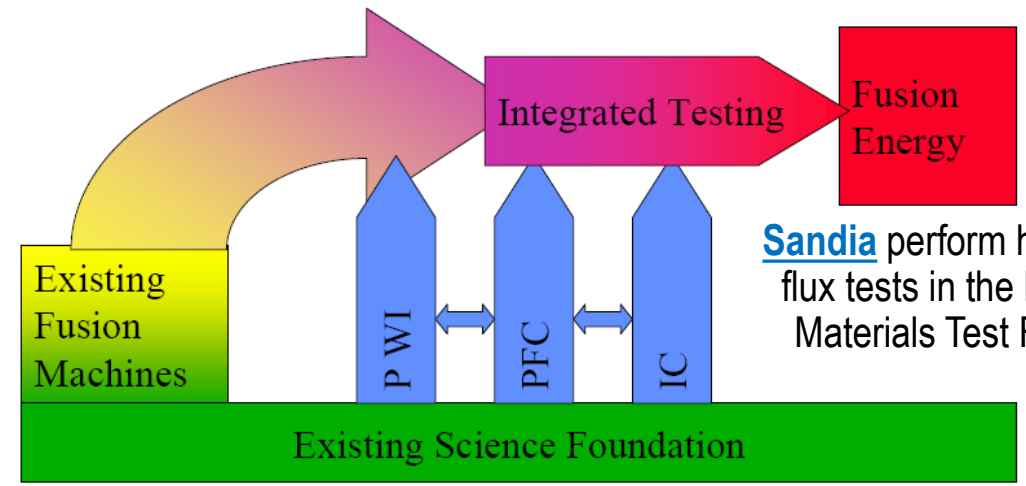
- **High Heat Flux Test Facility**
  - **status: cold standby (no base FES $$, SNL $$ cleanup)**
  - **impact: loss of US/world capability - HHF tests** (Be, high T&P He)
  - ***options: 1. Restart SNL – 5 year business plan*** *("big" customer)*
  - ***2. Relocate to other institution***
- **PSI Lab (CA)**
  - **status: relocation within SNL required**
  - **mitigation: move accomplished (redirected base + SNL$$), disruptive**

Future Plans

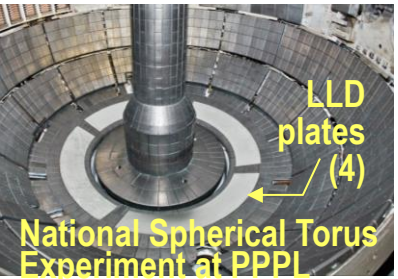


- **Build on experience, use expertise.**
- **Collaborate, engage US & other partners.**
- **Obtain support: FY2015 RFP, KDEMO, WEST, ITER**

Build on experience & expertise



Sandia built the plates for the NSTX liquid lithium divertor (LLD).



Sandia designs, builds and operates plasma edge probes in DIII-D.

Sandia perform high heat flux tests in the Plasma Materials Test Facility

Modeling edge-PFC-materials

PFCs Operating *physics*

Lab Experiments *PSI studies*

PFC Development HHF tests

Materials Development properties, fab

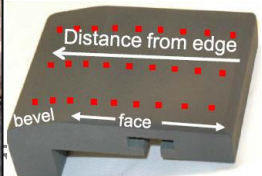
Modeling Integration DEMO, reactor

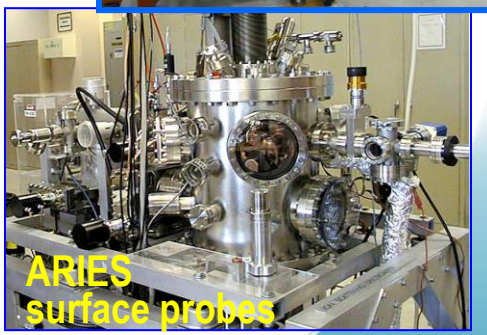
Modeling Components PFCs, etc

Probes & Tiles plasma edge

We measure H/D/He and metals in surfaces in **Sandia's** Ion Beam Lab and other facilities.

Measurements for ITER of carbon erosion in EAST tokamak (China)





Sandia National Laboratories

Leadership & Awards – 2008-2013

Dennis Youchison
US Technical Leader ITER FW (new)
Field Coordinator, SBIR PFCs
PFC Group Steering Committee
Chair IEEE Fusion Technical Committee
Guest Editor Trans. on Plasma Science
IEA NTFR Subtask Chair
ReNew Task Co-leader

Mike Ulrickson
US Technical Leader, ITER FW
ITER Coordinator, BIPT
PFC Group Steering Committee
US BPO Advisory Committee
ReNeW leader (1 of 5 US leaders)
FESAC subcommittee
Fusion Technology Editor
SOFE Tech Chair

Dean Buchenauer
PHENIX Co-leader Task 3
PFC Steering Committee, Ch. Lab Exp.
Organizer: 2010 International Workshop on Hydrogen Isotopes

Rob Kolasinski
Host for US-Japan PMI/PFC Workshops

Young Career Award
Rob Kolasinski

DOE Appreciation Awards *framed plaques from Ray Orbach*
Mike Ulrickson (ReNeW Leader)
Dennis Youchison (SBIR Coordinator)

2008 Nuclear Fusion Award
***Suppression of large edge localized modes with edge resonant magnetic fields in high confinement DIII-D plasmas*, NF 45 595-607,**
T.E. Evans, R.A. Moyer, J.G. Watkins, ...

Richard Nygren
Deputy Dir. Virtual Lab for Tech.
IEA NTFR Subtask Chair
ARIES Pathway Study (FY2014+)
FNSPA Core Group
US BPO Research Committee
BPO Chair Topical Goup, Eng. Sciences
FESAC Mat. Subcommittee
ISFNT & ICFRM Technical Committees
ITER Divertor CDR (Design Review) Chair
ITER FW-Diag. Port CDR participant

Publications – first author, last 5 years

1. **R. D. Kolasinski**, J. E. Polk, D. M. Goebel, and L. K. Johnson, "Carbon sputtering yield measurements at grazing incidence," *Appl. Surf. Sci.* **254** (8), 2506-2515 (2008).
2. **R. D. Kolasinski**, **J. A. Whaley**, and **R. Bastasz**, "Real space ion scattering maps of the Mg(0001) surface," *Phys. Rev. B* **79** (2009) 075416.
3. **D. Buchenauer**, **W. M. Clift**, R. Klauser, S. J. Howard, S. J. Brockington, R. W. Evans, and D. Q. Hwang, "Impurity production and acceleration in CTIX," *J. Nucl. Mater.* (2009), doi: 10.1016/j.jnucmat.2009.01.058.
4. **R. A. Causey**, R. Doerner, H. Fraser, **R. D. Kolasinski**, **J. Smugeresky**, K. Umstadter, and R. Williams, "Defects in tungsten responsible for molecular hydrogen isotope retention after exposure to low energy plasmas," *J. Nucl. Mater.* (2009), doi:10.1016/j.jnucmat.2009.01.300
5. **R. D. Kolasinski**, K. R. Umstadter, J. P. Sharpe, **R. A. Causey**, R. J. Pawelko, **J. A. Whaley**, **D.A. Buchenauer**, and M. Shimada, "The impact of specific surface area on the retention of deuterium in carbon fiber composites," *Fusion Eng. Des.* (2009), doi: 10.1016/j.fusengdes.2008.12.008
6. **R. D. Kolasinski**, M. Shimada, **D. A. Buchenauer**, **R. A. Causey**, T. Otsuka, **W. M. Clift**, J. M Shea, T. R. Allen, P. Calderoni, and J. P. Sharpe, "Characterization of surface morphology and retention in tungsten materials exposed to high fluxes of deuterium ions in the tritium plasma experiment," *Phys. Scr.* **T138** (2009) 014042.
7. **R. A. Causey**, **D. F. Cowgill**, R. Doerner, **R. Kolasinski**, **B. Mills**, **D. Morse**, **J. Smugeresky**, **W.R. Wampler**, R. Williams, and D. Huber, "Deuterium retention in tungsten at elevated temperatures," *J. Nucl. Mater.* **415** (2011) S672, doi:10.1016/j.jnucmat.2010.10.057.
8. **R. D. Kolasinski**, **D. F. Cowgill**, and **R. A. Causey**, "A continuum-scale model of hydrogen precipitate growth in tungsten plasma-facing materials," *J. Nucl. Mater.* **415** (2011) S676, doi:10.1016/j.jnucmat.2010.10.077.
9. **R. D. Kolasinski**, **J. A. Whaley**, **R. A. Karnesky**, **C. San Marchi**, and **R. Bastasz**, "Characterization of the Ne-Al scattering potential using low energy ion scattering maps," *Nuclear Instruments and Methods in Physics Research B* **269** (2011) 1229, doi:10.1016/j.nimb.2010.11.038.
10. **R. D. Kolasinski**, **N. C. Bartelt**, **J. A. Whaley**, and **T. E. Felter**, "Channeling of low-energy ions on hydrogen-covered single-crystal surfaces," *Phys Rev. B* **85** (2012) 115422-1, doi:10.1103/PhysRevB.85.115422.
11. **R. D. Kolasinski**, **D. F. Cowgill**, **D. C. Donovan**, M. Shimada, and **W. R. Wampler**, "Mechanisms of gas precipitation in plasma-exposed tungsten," *J. Nucl. Mater.*, **438** (2013) S1019-S1022; 10.1016/j.jnucmat.2013.01.222.
12. **D. Donovan**, **D. Buchenauer**, **J. Watkins**, A. Leonard, C. Wong, M. Schaffer, D. Rudakov, C. Lasnier, and P. Stangeby, "Experimental Measurements of the Particle Flux and Sheath Power Transmission Factor Profiles in the Divertor of DIII-D," *J. Nucl. Mater.*, **438** (2013) S467-S471; 10.1016/j.jnucmat.2013.01.095.
13. **D. C. Donovan**, D.R. Boris, G.L. Kulcinski, J.F. Santarius, and G.R. Piefer, "Measuring time of flight of fusion products in an inertial electrostatic confinement fusion device for spatial profiling of fusion reactions," *Rev. Sci. Instrum.* **84** (2013) 033501.
14. **R. D. Kolasinski**, **J. A. Whaley**, **R. A. Karnesky**, and **C. San Marchi**, "Interactions Between Gaseous Hydrogen and Aluminum Surfaces," presented at the 2012 International Hydrogen Conference, Jackson Hole, WY, 9/9-9/12, 2012. To be published in ASM International Conference Proceedings.
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