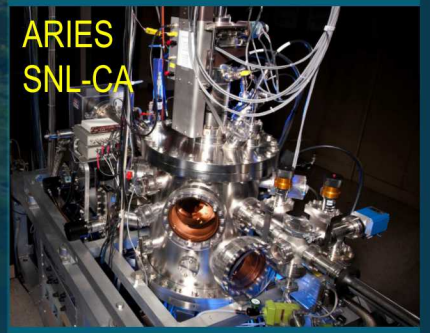
Sandia Fusion Energy Sciences Programs supporting

Burning Plasma Science
Discovery Plasma Science

Proposed baseline and new activities for FY22

SAND2020-4712PE



PRESENTED BY

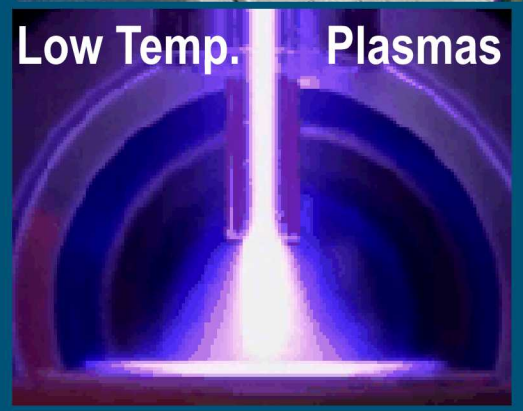
Dawn Flicker, Rob Kolasinski, and Ed Barnat
for the Sandia Fusion Team

SNL-CA: Jonathan Frank, Nils Hansen, Ryan Hood (PD), Chris Kliewer, Habib Najm, Alec Talin, Josh Whaley, and Tim Wong (PD)

SNL-NM: Mary Alice Cusentino (PD), Khalid Hattar, Matthew Hopkins, Richard Nygren, Aiden Thompson, Bill Wampler, and Ben Yee

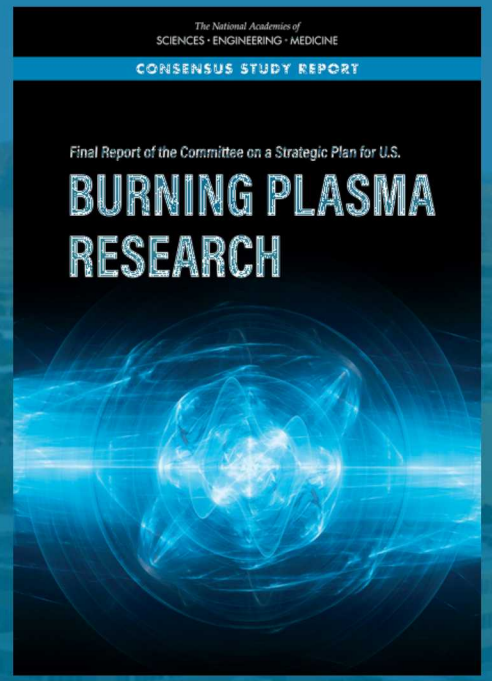
SNL @ GA: Jon Watkins and Dinh Truong (PD)

Our Vision: enable national goals of achieving fusion energy and transformative technologies by:



- Developing the science underlying plasma-wall interactions, boundary physics and fusion blanket designs.
- Understanding low temperature plasmas and sharing cutting edge capabilities through the Plasma Research Facility.
- Leveraging unique capabilities and expertise at Sandia built through complementary programs to address emerging needs of FES.
- Engaging in collaborations that maximize our scientific productivity.

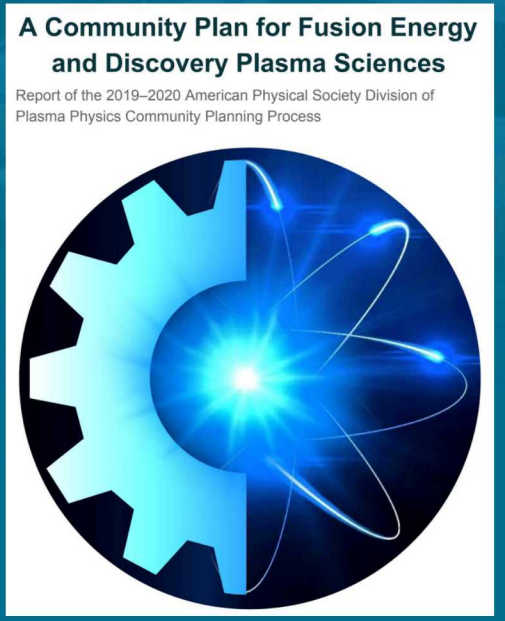
Fusion technology and plasma applications emphasized in the NAS report on Burning Plasmas and in the Community Plan



American Physical Society Community Report

Strategic and Cross-cutting Objectives:

- "Demonstrate solutions for managing high heat and particle loads sufficient to design **plasma-facing components (PFCs)** for a fusion pilot plant"
- "Develop the science and technology necessary to **breed, extract, and safely manage large quantities of tritium**"
- "**Advance the tokamak physics** basis sufficiently to design a low-cost fusion pilot plant."
- "**Advance the development of measurement and diagnostic techniques** for plasma science and fusion energy"
- "**Invigorate low temperature plasma research … enabling disruptive technologies …**"



National Academy of Sciences Burning Plasma Report

- Emphasis on compact pilot plant requires investment in technology
- Long-lifetime materials, advancement of tritium breeding and blankets

Sandia FES program maps well onto top priorities identified in the NAS report on Burning Plasmas and the CPP

Plasma-Facing Components PFC

Tritium Technologies TRIT

Advance Tokamak Physics Basis TOK

Advance the development of meas. & diagnostic techniques DIAG

Invigorate Low Temp. Plasma Rsch LTP

Burning Plasma Science: Long Pulse (ITER R&D) ($1.6 M)

- Materials & Fusion Nuclear Science PFC
  Plasma Surface Interactions and High Heat Flux Components
- Blanket & Tritium Fuel Cycle TRIT
  H permeation and surface analysis

Burning Plasma Science: Foundations ($0.6 M)

- Advanced Tokamak PFC TOK DIAG
  Boundary Physics Program at DIII-D
- Theory & Simulation PFC
  Plasma Surface Interactions SciDAC program, UTK lead

Discovery Plasma Science ($1.5 M)

- Low Temperature Plasma Research Facility DIAG LTP
  Advanced characterization and plasma science DIAG LTP
- General Plasma Science
  Highly Collisional Plasmas Science Center, UM lead
- Measurement Innovation DIAG
  H-microsensors for charge-exchange erosion

Our priorities exploit Sandia strengths and address issues of importance to FES

Top priorities: Core R&D areas emphasized for program growth

1. Plasma/Material interactions
   Folding Plasma Materials ECA scope into the program
2. DIII-D Boundary Physics
3. Low Temperature Plasma Collaborative Research Facility
4. Blanket and Tritium Fuel Cycle

Critical supporting roles outside of core R&D emphasis

5. Plasma-surface interactions SciDAC program
6. Hydrogen microsensor development for charge-exchange erosion
7. Highly Collisional Plasma Science Center

Realigned with higher-priority activities

8. High Heat Flux Component Design and Testing (realigning resources to Ion Beam Laboratory Initiatives and Dynamic PMI/Diagnostics)

Sandia encourages FES support of ZnetUS

Proposed new and expanded activities to address imperatives from national planning

- Capability, experiments & material characterization @ Sandia's Ion Beam Lab for studies of H/He effects on materials
  (redirecting current High Heat Flux funds if necessary in a flat budget)
- Dynamics of metal-plasma interaction
- Increase productivity and through-put at the Plasma Research Facility
- Additional DIII-D support for extended run time & automation
- Expand work in tritium fuel cycle and blankets
- Elucidate fusion metal degradation via in-situ electron microscopy (IBL) and coupled modeling
- Increase role of theory/simulation (within existing $)

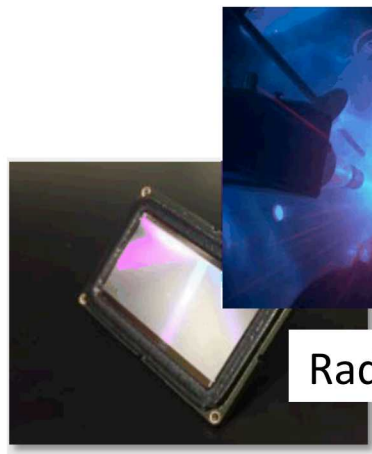
Detailed summary of Sandia FES Field Work Proposals (FY19-21)

	Sandia PI	DOE PM	FY19	FY20	FY21
Burning Plasma Science: Long Pulse (ITER R&D)					
Hydrogen and Plasma-Material Interactions Science	R. Kolasinski	D. Clark	$435 K	$435 K	$435 K
High Heat Flux / DIII-D Materials / Advanced Manufacturing	R. Nygren	D. Clark	$325 K	$350 K	$350 K
Ion Beam Laboratory Plasma-Material Interaction Studies	W. Wampler	D. Clark	$75 K	$50 K	$50 K
Tritum Fuel Cycle and Blanket Research	R. Kolasinski	G. Shaw	$250 K	$250 K	
Early Career Award Program	R. Kolasinski	D. Clark	$500 K	$500 K	$500 K
Burning Plasma Science: Foundations					
DIII-D Boundary Physics Base Program	J. Watkins	M. Lanctot	$429 K	$429 K	$429 K
Plasma-Surface Interactions SciDAC	H. Najm	J. Mandrekas	$300 K	$150 K	$150 K
Discovery Plasma Science					
Low Temperature Plasma Research Center	E. Barnat	N. Podder	$1.1 M	$1.1 M	$1.1 M
Highly Collisional Plasma Research Center	E. Barnat	N. Podder	$113 K	$113 K	$113 K
Charge Exchange H flux sensor	A. Talin	C. Bolton	$330 K	$330 K	
TOTAL			**$3.8 M**	**$3.7 M**	**$3.1 M**

Sandia has untapped resources to address FES challenges

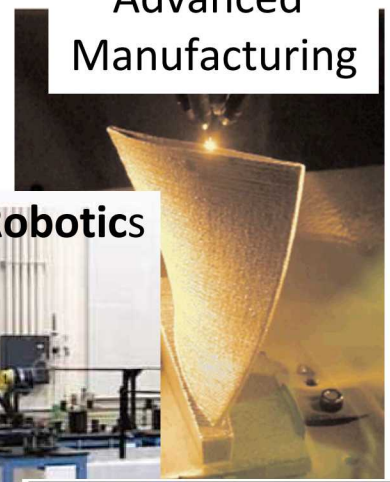
Reactor relevant considerations

- Heat, radiation & particle fluxes
- Corrosion, stress
- Compatibility
- Waste disposal
- Balance of Plant, remote handling, safety systems
- Automation
- Structural /functional materials



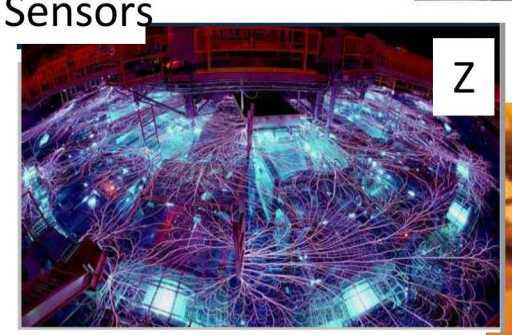
High-performance Computing

Advanced Manufacturing



Robotics

Rad Hard Sensors



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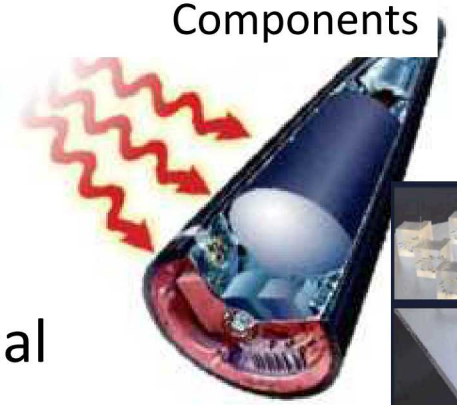
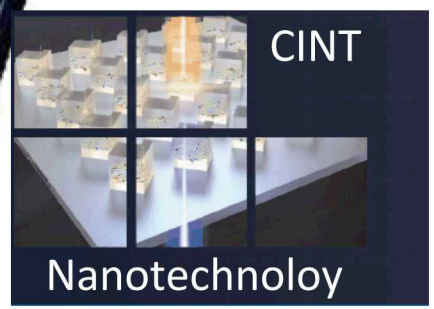
Radiation Hardening & Components





CINT

Nanotechnoloy

MESA – μ–electrons & Fab

Safe Reactor Design and Operation

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Discussion?

Fusion Materials & Technology R&D
DIII-D Boundary Physics Program

- Proposed baseline activities for FY22
- New efforts with increased FY22 budget

Principal Investigators:

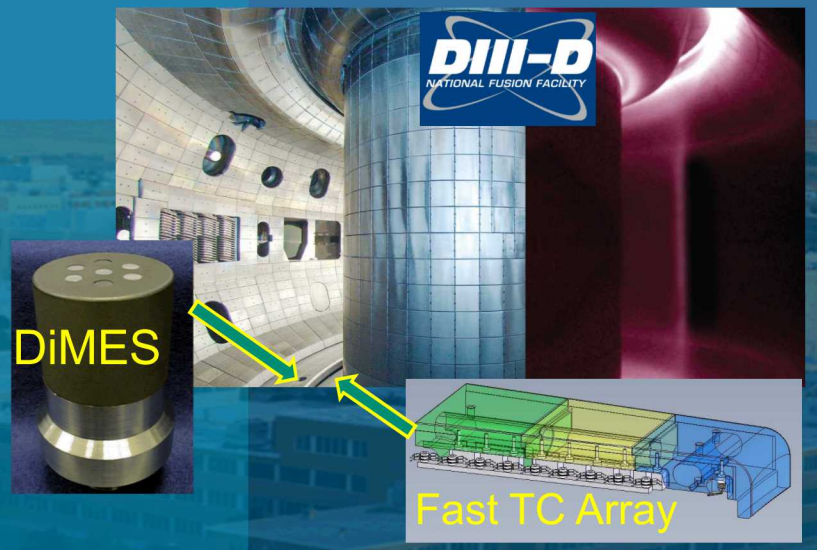
Rob Kolasinski, Jon Watkins, Bill Wampler, Khalid Hattar, Habib Najm, Alec Talin, and Richard Nygren

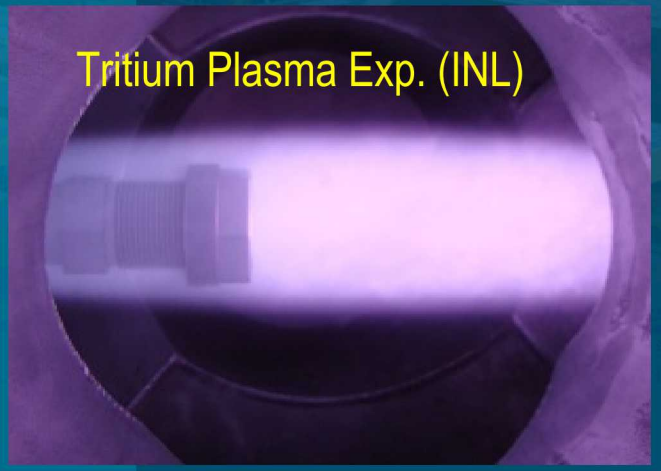
Team Members:

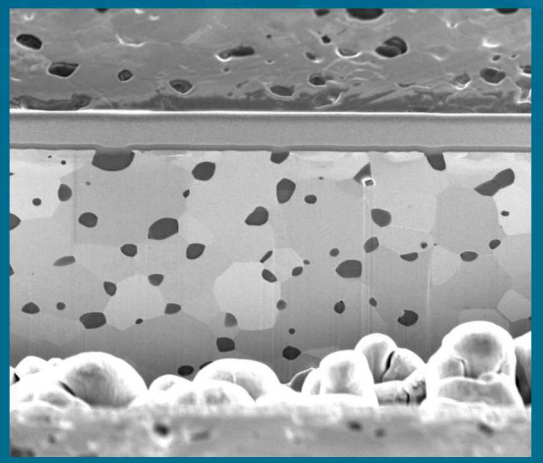
Trevor Clark, Mary Alice Cusentino, Ryan Hood, Aidan Thompson, Dinh Truong, Josh Whaley, Mitch Wood, and Tim Wong

The magnetic fusion energy work at Sandia has a significant impact and supports a wide range of collaborations

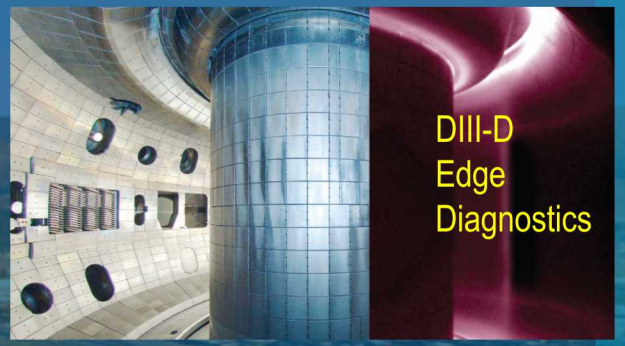
- SNL Langmuir probe array is a critical DIII-D diagnostic
  - requested on 60% of shots
  - data in 15% of DIII-D publications
- Ion Beam Lab provides critical support for both DIII-D and the fusion materials program
  - DiMES sample preparation and analysis
  - Material migration studies in DIII-D, ORNL, UTK, EAST
- Fusion Materials Program R&D reveals the effects of plasma exposure on materials, hydrogen transport & trapping, recrystallization effects

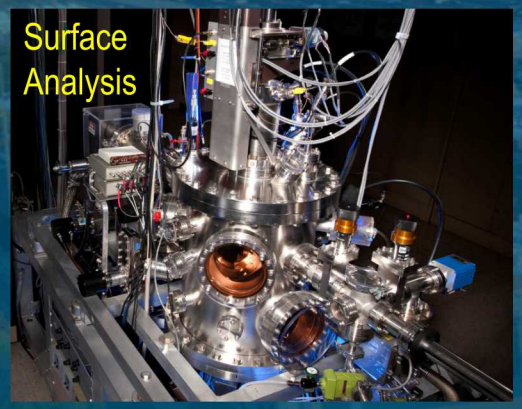






Advanced W materials
Collaborators: Penn State, Utah, Sony Brook Univ., UCSD-PISCES





R&D priorities in FY22 emphasize cutting-edge science on urgent problems identified by the research community

DIII-D Boundary Physics Program

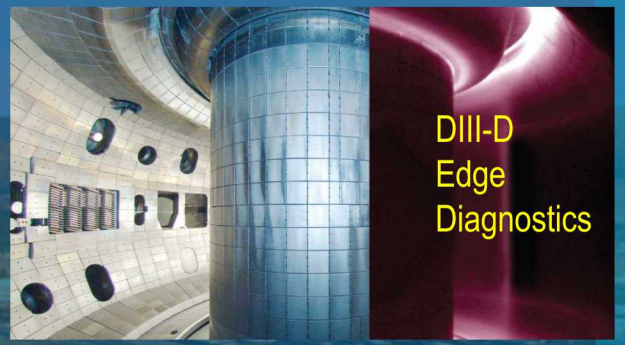
- Support and diagnose the SAS 2 advanced slot divertor
- Provide key benchmark data for plasma model simulations
- Support experimental programs with custom Langmuir probes, TCs, and surface analysis measurements for DIMES, Helicon, Lower hybrid, negative triangularity shapes, detachment control, the wall interaction test station (WITS)

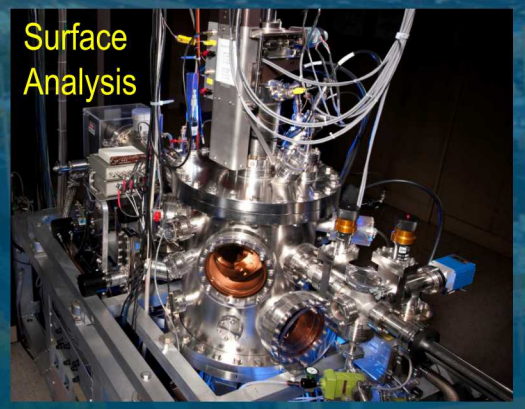
Plasma-Material Interactions and Fuel Retention

- Study effects of implanted **impurities** on surface structure / composition
- Determine mechanisms governing H transport and trapping in **advanced plasma-facing materials**

New Emphasis:

- Expanded support for studies of hydrogen effects on materials and erosion/re-deposition at Sandia's **Ion Beam Laboratory**





Additional resources would enable us to apply unique Sandia capabilities to critical R&D problems for FES

Dynamic measurements of H/He effects plasma-exposed materials

- Add new high-flux RF **plasma source**, new **diagnostics** to ion beam analysis end station
- Ongoing support for **in-situ TEM** studies

Enhance the capabilities of DIII-D edge diagnostics

- New Langmuir probes (LPs), thermocouples (TCs) for the SAS2 divertor and on the outer wall for negative triangularity shapes
- New LPs, TCs, neutral flux sensors and surface TCs (with UTK) to study the main chamber wall erosion with the wall interaction test station (WITS)

Hydrogen in Metals / Surface Analysis for an Expanded Tritium Fuel Cycle & Blanket Program

- Physics of permeation, surface-bulk H transport
- Develop advanced diagnostics for characterizing surface chemistry/corrosion

Rad-hardened electronics are also an area of Sandia expertise

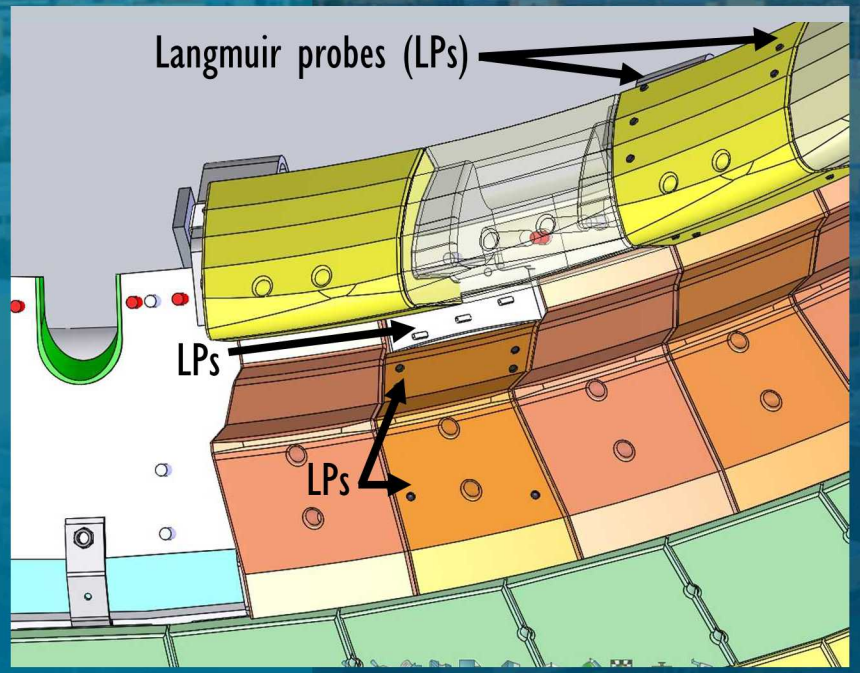
Sandia's Boundary Physics Program at DIII-D provides critical diagnostic support and boundary physics expertise

Baseline FY22:

- Expand Langmuir probe arrays with more active probe measurements,
- **increase automation** for improved data quality, enhanced capability, and faster analysis
- Develop more advanced feedback **control using LP data for DIII-D detachment control** through smart gas puffing
- Extend capabilities for ELM measurements and ELM effects in slot divertors

FY22 Increase:

- LP program needs 1 additional FTE for LP extended operations in FY 21 (2-->3 FTE = post-doc or contractor)
- Incremental needs: surface analysis and feedback control
- New probes, TCs for **SAS 2** advanced slot divertor
- New Langmuir Probes for lower outer baffle for the **negative triangularity campaign**



DIII-D relies on Jon Watkin's expertise and leadership in plasma facing components and edge diagnostic measurements including for the small angle slot (SAS) divertor

Fusion-relevant materials testing and development at DIII-D takes advantage of unique capabilities of DiMES platform and Sandia characterization tools

FY22 Baseline Plan:

Support DiMES program for divertor materials studies

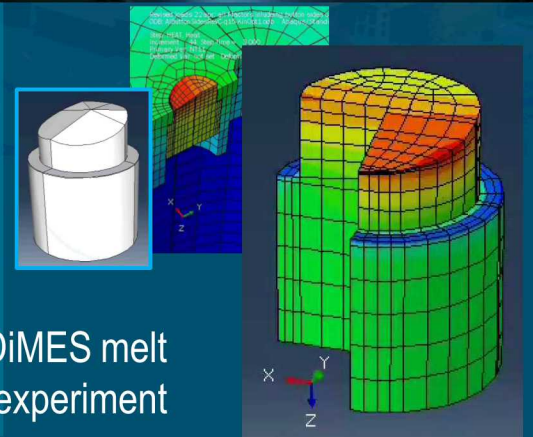
- Evaluate erosion, transport and deposition, surface structure changes, and recrystallization in W materials
- Analysis of DiMEs samples, vessel tiles, and collector probes for erosion and re-depostion measurements.
- Thermal analysis on heat exhaust for DiMES

Angled DiMES specimens for testing at combined high-heat/particle flux

Sandia thin film lab prepares sputter-deposited DiMES coatings

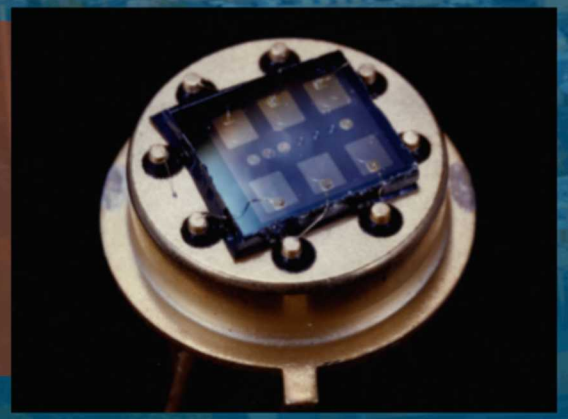
FY22 Increase:

- Study **main chamber wall conditions** with the Wall Interaction Test station (**WITS**)
- Additional post-doc support (with W. Wampler) to augment throughput



Model of ITER DiMES melt experiment

Unique hydrogen neutral flux sensors design can provide unprecedented insight into wall erosion



Current Funding: Measurement Innovation Program

Pd Metal Oxide Sensor (Pd-MOS) development:

- Provides critical information needed to predict wall erosion
- Planned diagnostic for Wall Interaction Test Stand (WITS) in DIII-D
- Leverages Sandia's microelectronics expertise & MESA-Fab facility
- Complete Pd-MOS sensor development at Sandia / DIII-D testing

FY22 Follow-on Activity:

- Extend to SiC-based sensors that can withstand high temp. bake

Emphasis on effects of plasma impurities on near-surface material structure and composition

What mechanisms govern defect nucleation and growth during low energy plasma exposure?

Effects of plasmas containing D_2^+, N_2^+, and B not well studied, complex surface chemistry

Ongoing Core Activities:

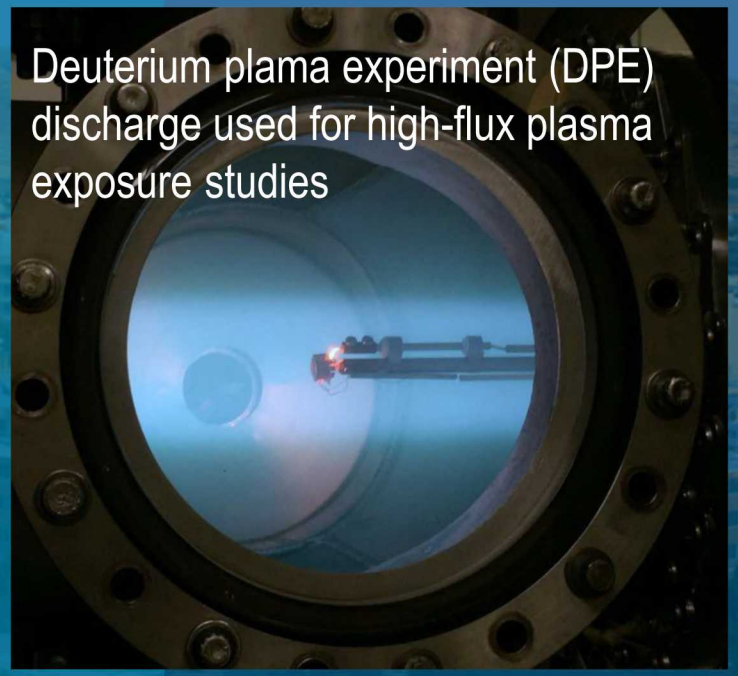
- D and He effects on polycrystalline W (different microstructures)

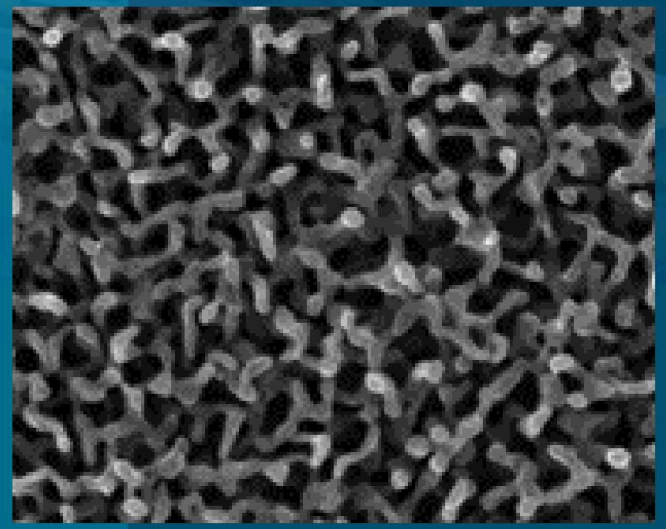
Baseline Work (FY22):

- Expand focus to include more complex impurities (N_2, B)
- Collaboration with UTK with complementary modelling

FY22 Increase:

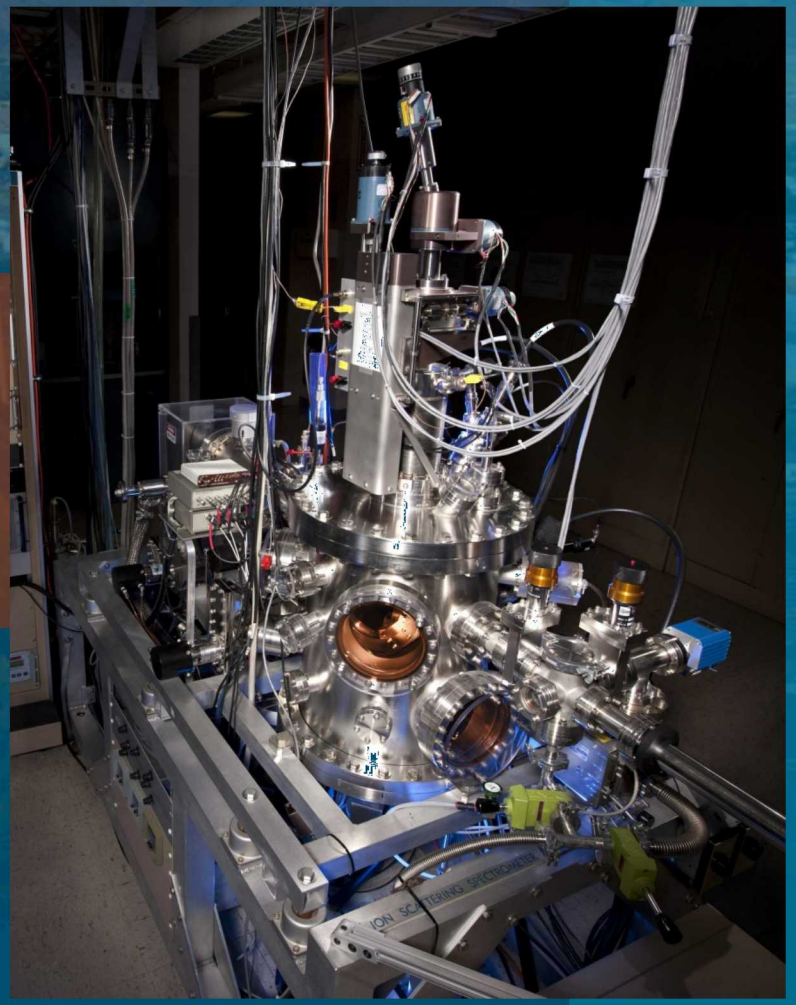
- Facility modifications to add plasma diagnostics (optical spectroscopy), load lock, high sensitivity TDS ($100 K)





Effects of He plasma on W

Sandia has unique surface analysis capabilities can be applied to decipher surface chemistry in a H environment



Enhancements to our unique surface analysis capabilities have been funded through LDRD

How do chemisorbed and implanted impurities affect H uptake?

Previous work: H chemisorption, He channeling

Baseline work (FY22):

- Surface chemistry of reactive species (O_2, N_2, B)
- Fundamental measurements hydrogen chemisorption, ion reflection, recombination
- Effect of impurity species on H uptake
- Segregation of impurities during heating

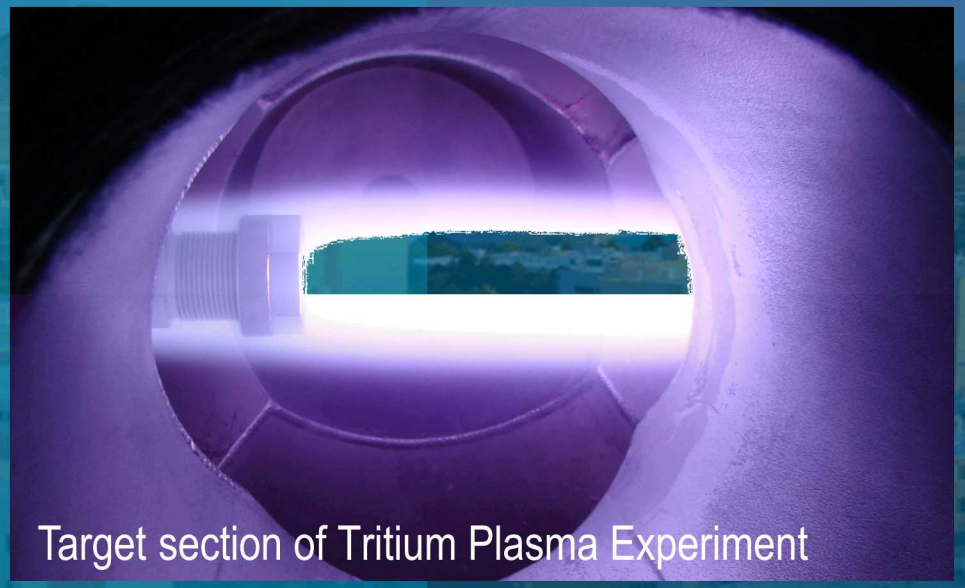
Similar mechanisms relevant to Blanket activities (discussed later)

Support of FRONTIER program and studies of neutron-irradiated materials

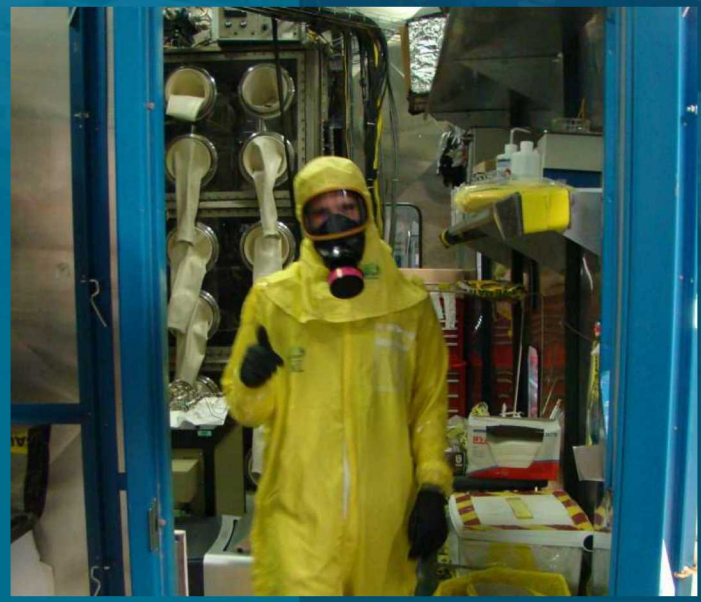
How do defects produced by 14 MeV neutrons affect tritium retention and permeation?

FY22 focus:

- Retention/defect evolution (D_2 / D_2+He plasmas)
- SNL-supplied W single crystals for PHENIX irradiations in HiFIR (now available.)
- FRONTIER matrix: dispersoid-strengthened W
- Ion Beam Laboratory performs depth profiling
- Exposure of ion-damaged materials performed at Sandia-Livermore



Target section of Tritium Plasma Experiment

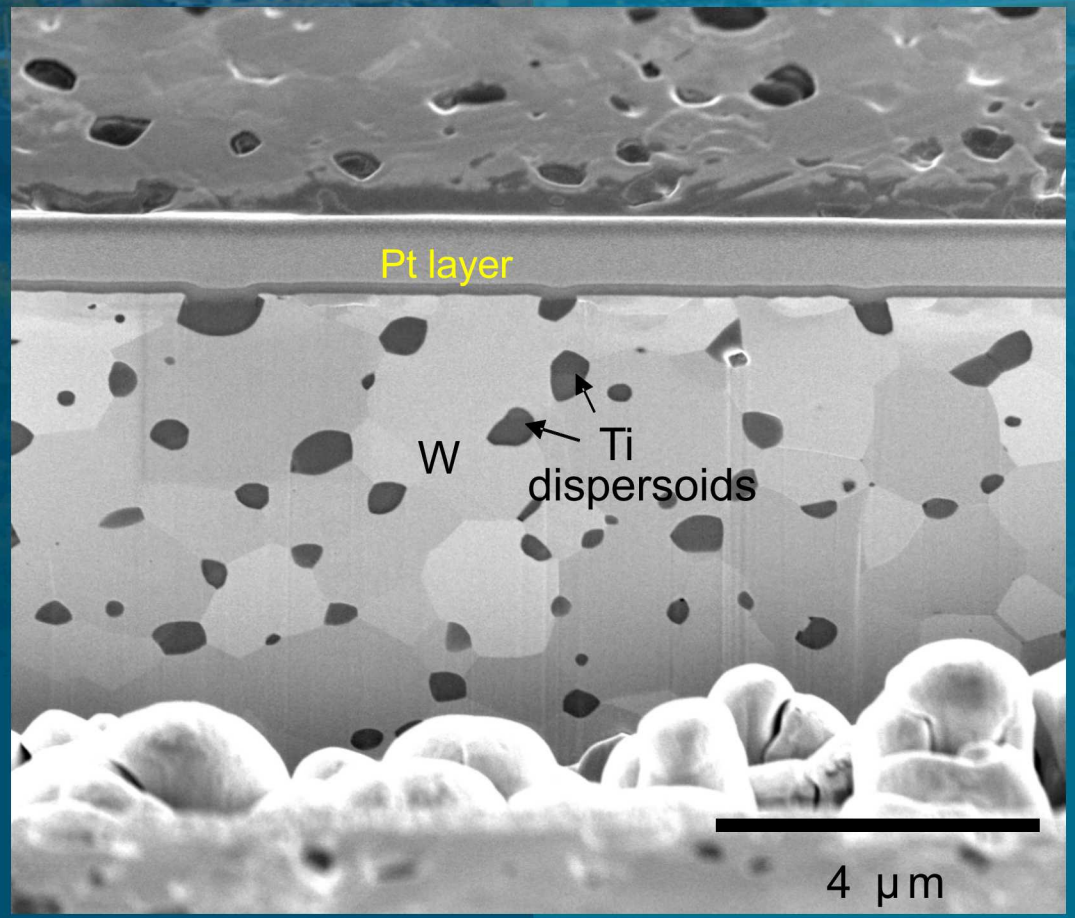


Long-standing collaboration with INL on the Tritium Plasma Experiment

Testing of new tungsten materials enables fundamental mechanisms underlying hydrogen trapping in complex materials to be understood

How does microstructure affect defect growth?

What trade-offs are made in W alloys optimized for thermo-mechanical performance?



Novel materials and advanced manufacturing methods

[PMI Community Report emphasis]

FY22 Focus:

Testing new W materials:

- Dispersoid-strengthened Univ. of Utah (Z. Fang), Penn State (J. P. Allain)
- Ultra-fine grained (Stony Brook)

Response to plasma **unknown**

- Initial scoping studies: permeation tests, exposure to plasma
- Exposure to **DIII-D** H-mode plasmas in DiMES

Expanded effort at Sandia's Ion Beam Laboratory will provide unique opportunities for fundamental studies of H/He effects on metals

Sandia's Ion Beam Laboratory is a world-class facility for materials analysis supported by a wide range of programs ($4.5 M / yr operating budget.)

Key FES Diagnostics:

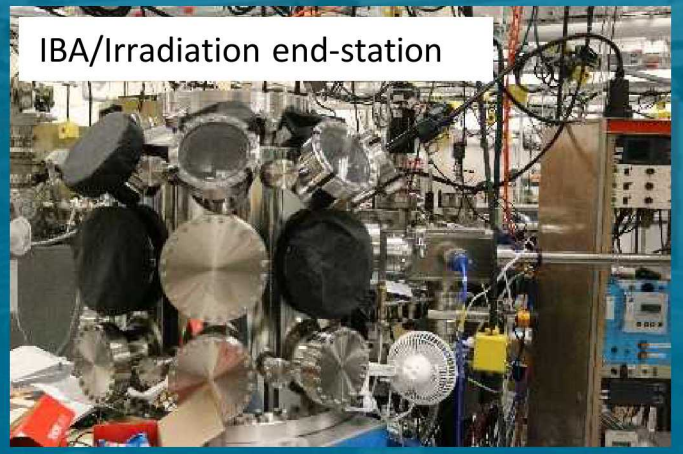
- Rutherford Backscattering (RBS)
- Nuclear Reaction Analysis (NRA)

FY22 Baseline (Existing Funding): $300 K / yr

- Retention at displacement damage
- DIII-D erosion and re-deposition measurements
- Characterization of neutron irradiated specimens (FRONTIER program)

New Effort: Dynamic retention studies using in-situ ion beam analysis combined with high-flux plasma exposure

Combine SNL existing strengths into one system allowing for in-situ Ion Beam Analysis (IBA), Ion Beam Irradiation for damage studies, relevant plasma exposures and in-situ plasma diagnostics for FES applications



New end station enables us to study:

- Dynamic concentration of H in solution during plasma-exposure
- Hydrogen recombination at surfaces
- Hydrogen isotope retention at displacement damage during plasma exposure
- Test-bed for low temperature plasma diagnostics

Non-resonant RF source coupled with plasma/surface diagnostics provides an economical means of adding a high-flux plasma capability to an beam-line end station

$500 K total: $250 K hardware + $250 K labor

New Effort: Elucidating Fusion W-Alloy Degradation via in-situ electron microscopy and coupled modeling

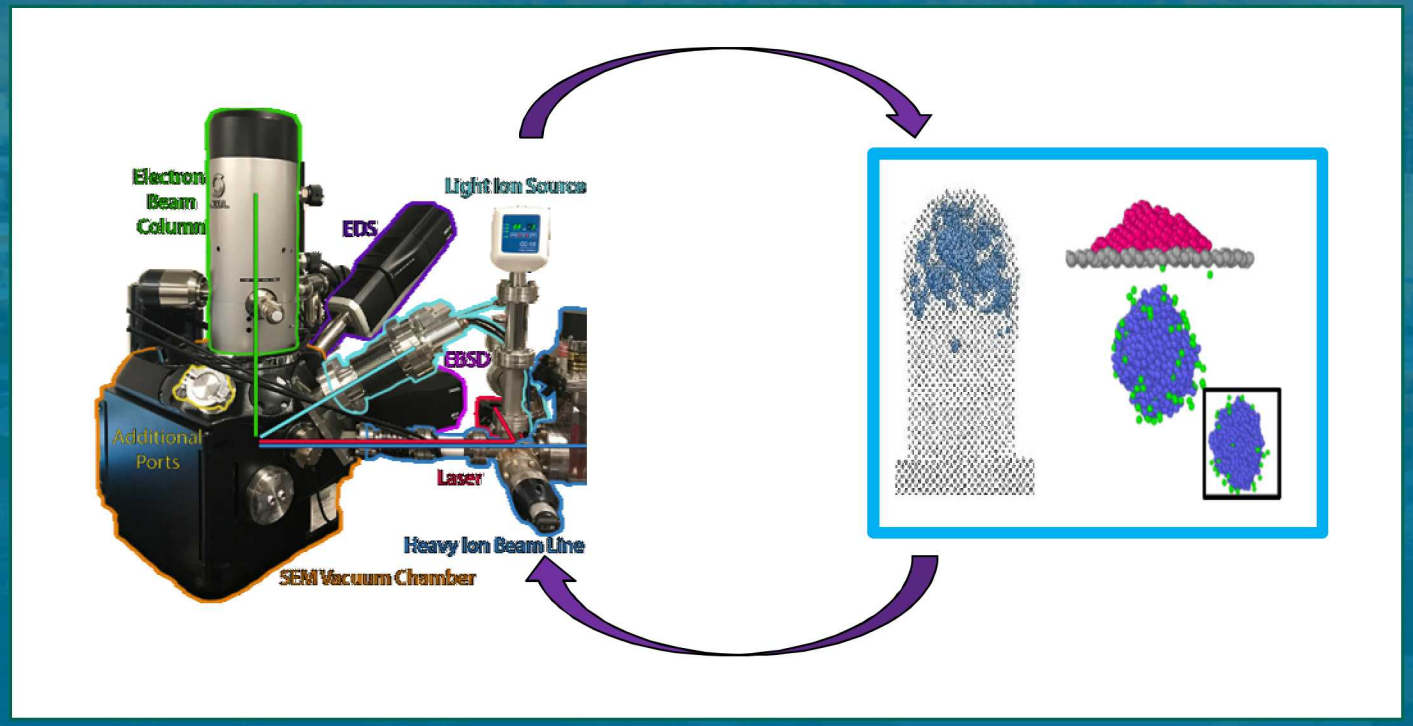
What underlying physics dominates the helium bubbles formation and degradation mechanisms that result in complex structures as blistering and nano fuzz?

FY22 Baseline:

- Collaborative effort with Prof. Jason Trelewicz (SBU) and others on characterizing effects of ion irradiation advanced W materials

FY22 Increase: $100 K

- Expanded parameter space for low energy He studies (temp., flux, displacement damage.)



New Effort: Hydrogen in Metals / Surface Analysis for an Expanded Tritium Fuel Cycle & Blanket Program

APS Report emphasizes small-scale and bench-top experiments near-term priorities

Current Work: Surface analysis and permeation studies for super-permeable membranes $250 K / yr (through FY21)

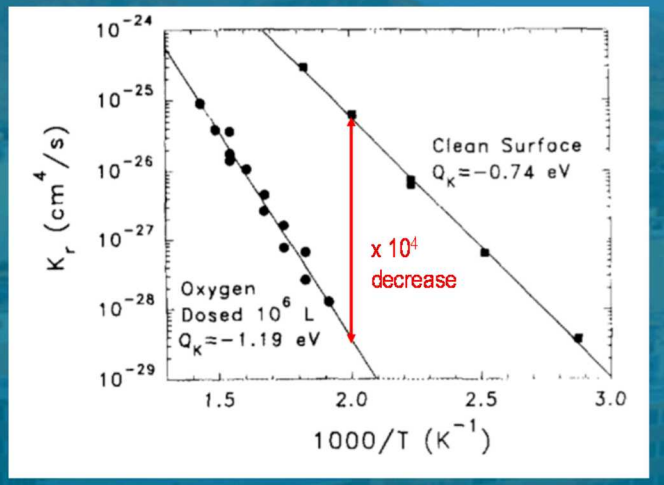
Follow-on: $400 K / yr (Ion Beam Laboratory and Sandia-Livermore)

Surface to bulk transport and permeation of H through blanket/fuel cycle materials

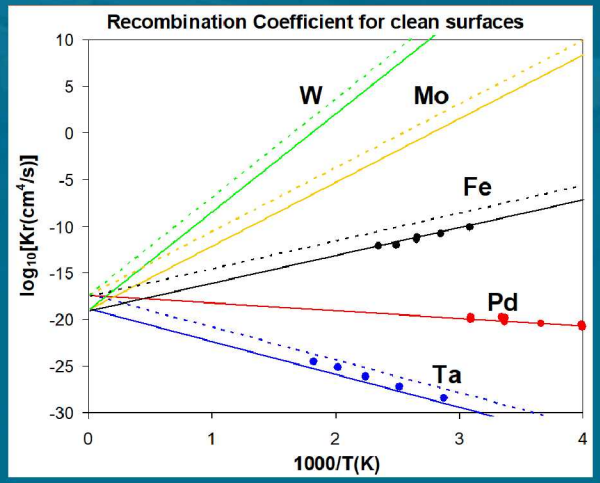
H uptake is sensitive to surface impurities

Proposed FY22 Work:

- Recombination meas. at IBL following dosing with impurities
  using refurbished end station described previously
- Complementary H chemisorption studies (ion scattering), surface-sensitive thermal desorption



K_r for O-covered and clean Ta surface
Wampler, JVST 1991



Wampler, J. Appl. Phys. 1990

New Effort: Hydrogen in Metals / Surface Analysis for an Expanded Tritium Fuel Cycle & Blanket Program

Proposed FY22 Work (Continued):

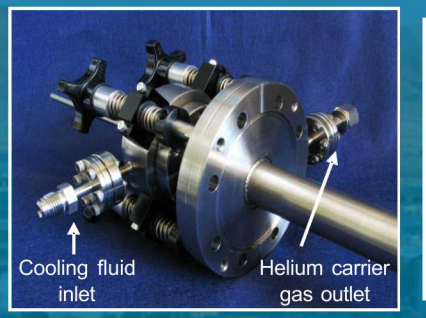
Hydrogen permeation studies

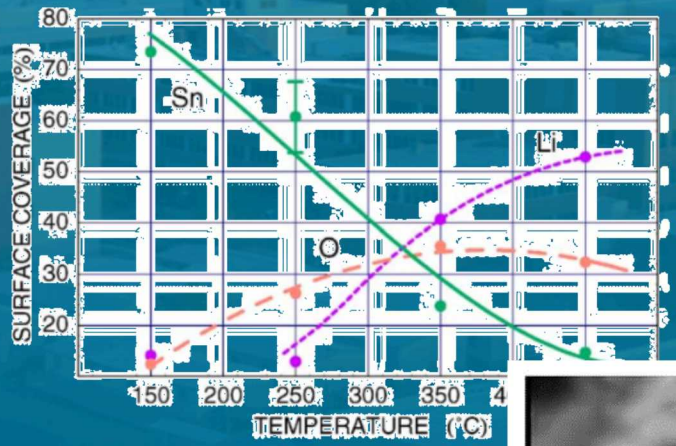
- Gas-driven permeation for blanket structural materials
- Plasma-driven permeation studies for super-permeable membranes

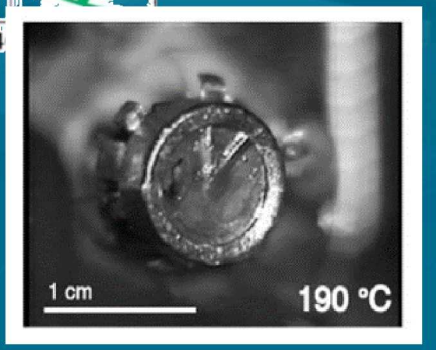
  use previously-developed in-situ diagnostics, permeation system

Characterization of liquid metal + surface interactions

- Key materials compatibility information for liquid breeder concepts, vacuum permeator
- Apply surface science and ion beam analysis to study interface buried beneath thin liquid metal films







Example: Measurement of liquid $Sn_{0.8}Li_{0.2}$ alloy segregation during *in-situ* heating, D dosing

Advanced Manufacturing (AM): Sandia has championed advanced manufacturing and has led characterization and testing

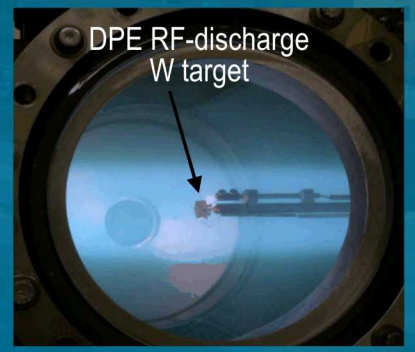
AM+ for fusion

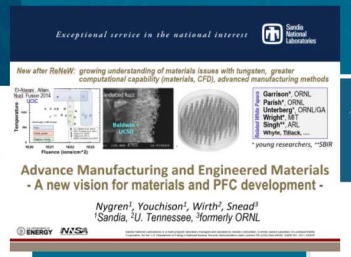
decade

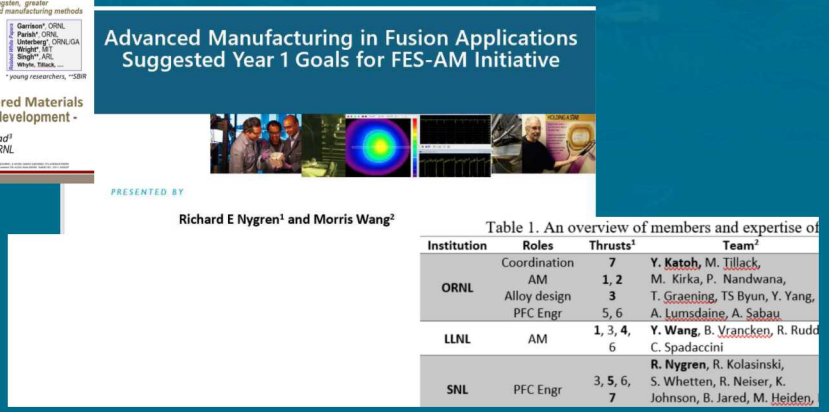
- Invited papers at ISFNT12&13
- Report and white papers for TEC/NAS/FESAC/FES-NatPlanWkshp
- 2020 FES 4-Lab white paper
- 2021 ARPAe white paper
- Internal SNL discussions on AM+; (rejected) 2021 LDRD proposal on crack propagation in AM tungsten

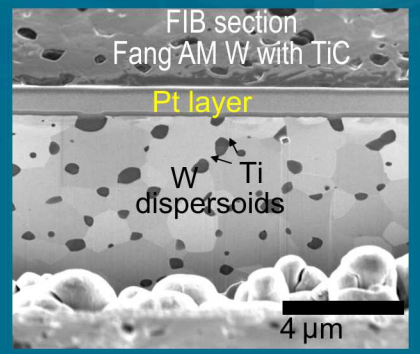
AM+ tungsten in experiments

- DiMES W buttons (Fang/Barton)
- PISCES/DPE/Permeation (Fang/Kolasinski)
- Polaronyx collaboration (Liu/Nygren)





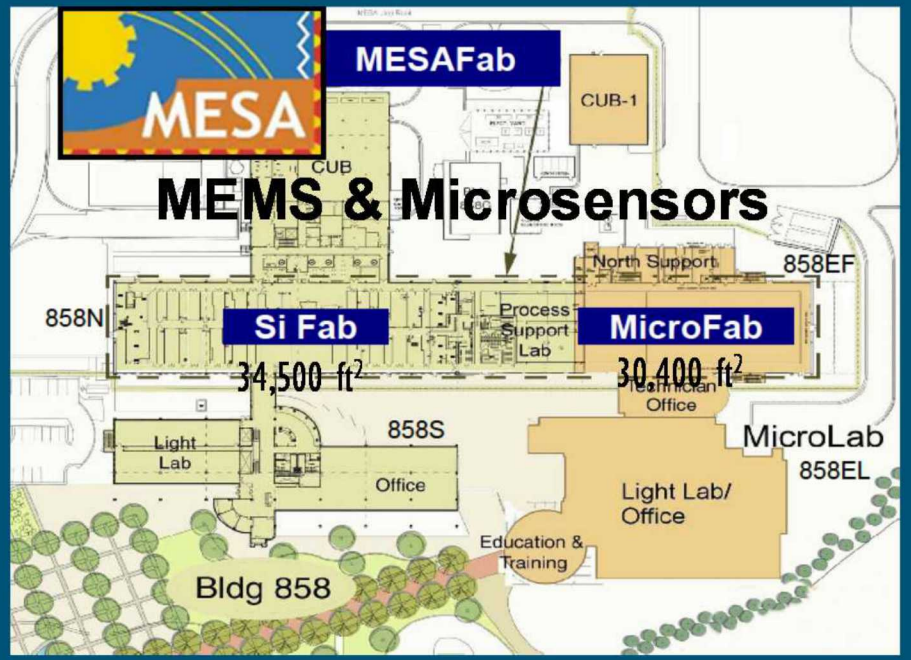


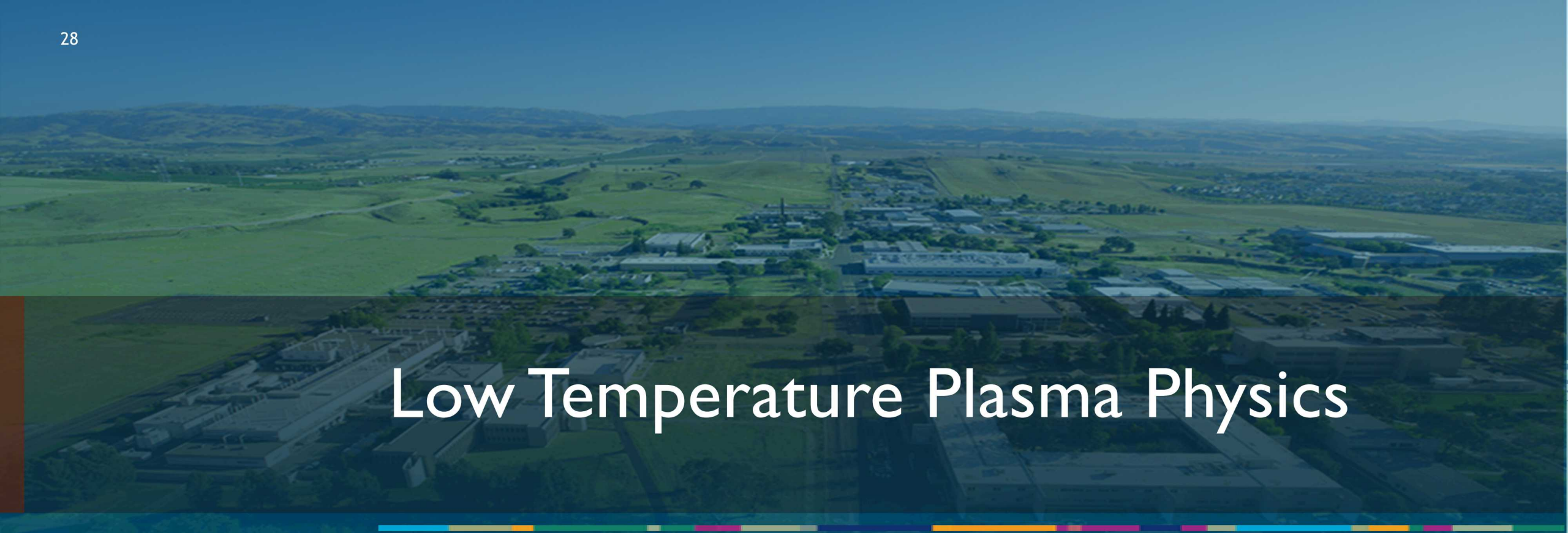


Sandia expertise in radiation-hardened electronics could be used to support reactor-relevant instrumentation

Sandia core mission: design, fabricate and qualify electronics for use in radiation environments for US national defense programs.

- Experimental facilities for testing
- Modeling and simulation of devices and effects of displacement damage and ionization
- MESA facility for fabrication of rad-hard electronic components.





Low Temperature Plasma Physics

Plasma Research Facility Lead: Ed Barnat

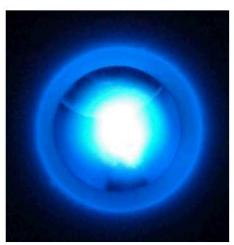
Principal Investigators:

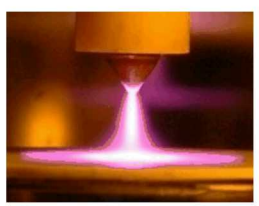
Ed Barnat, Jonathan Frank, Chris Kliewer, Matthew Hopkins, Nils Hansen, Ben Yee

Overview: Low Temperature Plasma Science

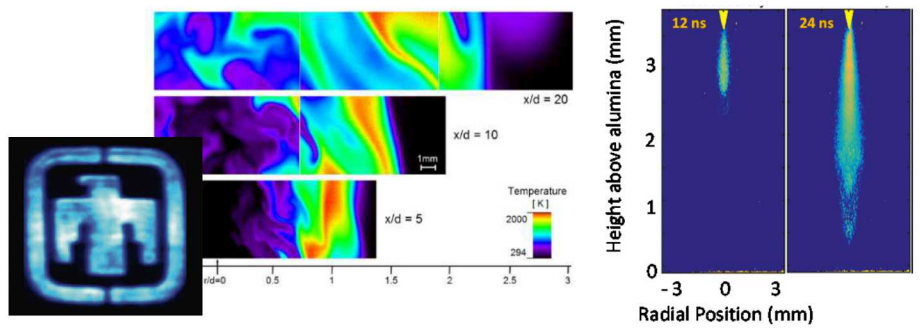
- Low Temperature Plasma (LTP) Science is diverse and complex field.
  - Many research areas: Materials processing, combustion, catalysis, biomedical, controlled EM interactions...
  - Unique challenges: Length scales (nm to m) and time scales (ps to s) and complex (unknown) chemistries.
- Unifying grand challenge of LTPS: Obtaining predictive control over energetic particles in plasma environment.
  - LTP can be considered a means of converting electrical energy to chemical energy.
  - “Making electrons do our bidding to benefit food, water, health, {energy} and economic {national} security”
- Research needs to address frontier science challenges in LTP[1]:
  - Designated user facilities (DUF) are needed to enable high risk, high reward research.
  - Form dynamic exploratory clusters, short time frame, high risk teams of expertise.

Plasma generation

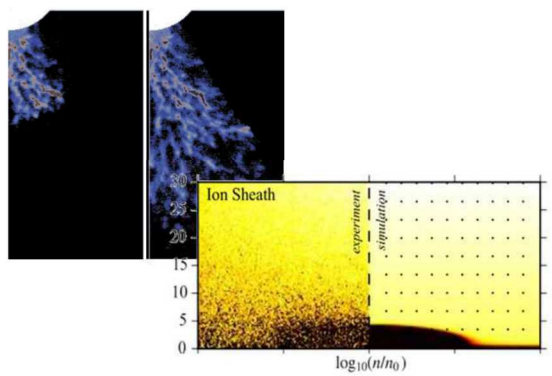




Diagnostic Development



Modeling and simulation



Ion densities for plasma-anode system

Sandia is working with FES and the LTP community to address these research needs.

[1] 2016 Frontiers of plasma science workshops report

Low Temperature Plasma at Sandia

- Current FES efforts in low-temperature plasma science.
  - Center on Plasma Interactions with Complex Interfaces.
  - Low Temperature Plasma Research Facility.
- We have assembled a team of six experts to support our plasma research facility
  - Ed Barnat (PI): Multi-dimensional interrogation of atomic species, electron densities and electric fields.
  - Jonathan Frank: Imaging and gas-phase spectroscopy for high-speed, multi-dimensional measurements in plasmas and plasma-assisted reacting flows.
  - Nils Hansen: Interrogation of chemistries in reactive environments using high resolution mass spectroscopy.
  - Matthew Hopkins: Computational modeling and simulation of non-equilibrium plasma phenomena.
  - Christopher Kliewer: Ultrafast non-linear gas and surface phase spectroscopies.
  - Benjamin Yee: Electrical characterization and spectroscopy.
- Composition of this team enables us to ensure facility best serves the broad challenges the community offers.

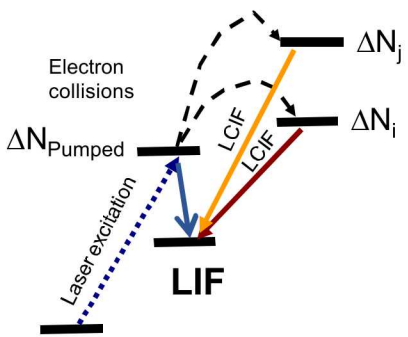
PICI DOE Plasma Science Center
Plasma Complex Interfaces

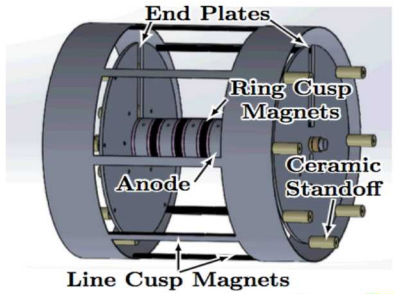
This team highlights the strength Sandia offers to further FES and LTP science:
(Why Sandia)

Standing up Plasma Research Facility

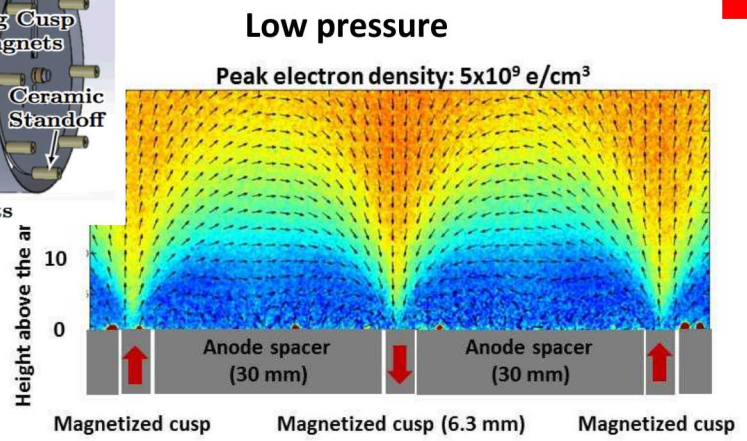
- We are preparing for challenges offered by plasma community.
  - Have accepted 9 proposals (6 experimental, 3 computational).
  - Have waiting list of ~ 6 proposals (Experimental).
- We are basing our efforts on past experiences in interacting with colleagues in LTP
  - Hosted over 15+ collaborations during 10 years of participation in plasma science center (PSC) and general plasma science (GPS) programs .
  - Each offered unique challenges, each required considerable planning to ensure successful interaction.

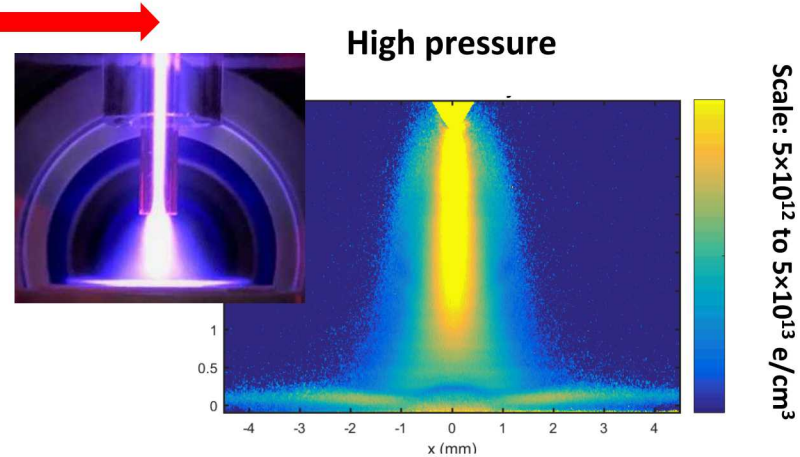
LCIF Concept





Implementation



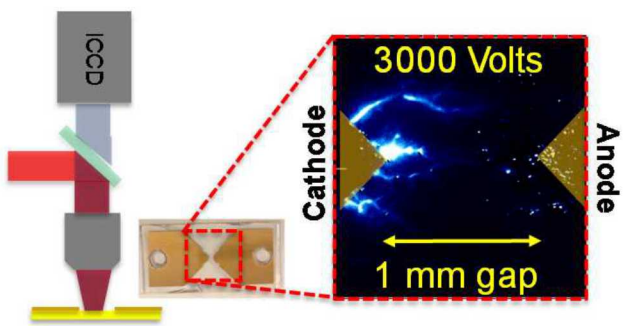


Our team is continually engaging collaborators to ensure success.

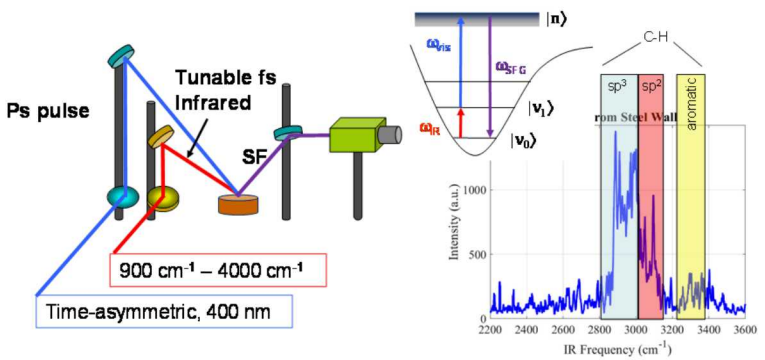
Long Term Goals for LTP at Sandia

- Our PRF also is tasked with ensuring that we are doing transformative and enabling research
  - Maintain new and unique capabilities to advance plasma science
  - Continue to engage plasma community to ensure we are addressing relevant questions.
- We are developing new diagnostic capabilities and models to access the plasma state
  - Fast (< 1ns) and ultrafast (< 1ps) pump-probe techniques for accessing highly collisional environments.
  - Non-linear spectroscopies for accessing plasma-surface interfaces
  - New capabilities to detect small signals in challenging environments.
  - Kinetic simulations that incorporate photon transport.

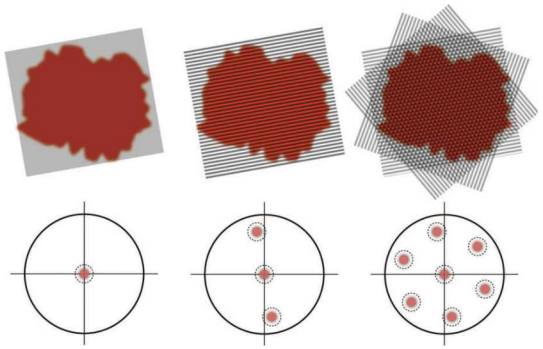
2D Second Harmonic Generation



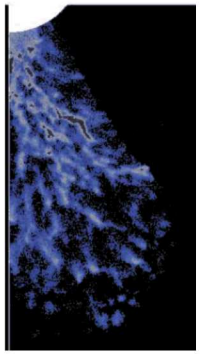
Sum Frequency Generation



Multiplexed imaging



Photon transport



These investments will ensure that we address Frontiers Report by staying dynamic, exploratory and able to collaborate with the low-temperature plasma community

PRF is High SNL Priority

- Sandia wants to partner with FES to build on this central mission theme.
  - Invest in skills and capabilities that add flexibility to what SNL can offer.
  - Leverage capabilities and opportunities that are unique to national laboratories environment.
- Budget Decrease would lead to loss of PI and capability
- Budget increase would be used enable PRF team to be more productive.
- Leverage investment to target new challenges that emerge in plasma science.
  - Gas phase and surface phase reactions in plasma catalysis
  - Interface between plasma and solid-state physics
  - Efficient Plasma aided combustion
  - Plasmas interacting with complex, multi-phase interfaces
- Team with MFE efforts to further extend LTP impact into other FES programs.
    - Identify similarities in questions and discuss synergistic activities.
- Start working with PPPL and the community to initiate LTP-net

Augmented support would expand tools and expertise that could help realize vision called out in Frontiers of Plasma Science Report

Wrap-up

Budget Scenarios for FY22 strengthen/protect deliverables to the national strategy

	FY22 base	FY22 +25%	FY22 -10%	Comments
Burning Plasma Science: Long Pulse (ITER R&D)				
Hydrogen and Plasma-Material Interactions Science	$585 K	$660 K	$435 K	Emphasis -dynamic PMI & diagnostics
High Heat Flux / DIII-D Materials / AM	-	-	-	
Ion Beam Laboratory Plasma-Material Interaction Studies & Initiatives	$250 K	$400 K	$100 K	New capability and increased support of program
Tritium Fuel Cycle and Blanket Research	$250 K	$400 K	$250 K	Increasing importance
Burning Plasma Science: Foundations				
DIII-D Boundary Physics Base Program	$429 K	$525 K	$429 K	Increase support; post-doc
Plasma-Surface Interactions SciDAC	$150 K	$150 K	$150 K	
Discovery Plasma Science				
Low Temperature Plasma Research Center	$113 K	$113 K	$113 K	
Highly Collisional Plasma Research Center	$1.1 M	$1.4 M	$1.1 M	Increase though-put at PRF
TOTAL	**$2.9 M**	**$3.6 M**	**$2.6 M**	

ECA ends in FY21; HHF funds ($400K) redirected to IBL & PMI

Supplementary Slides

DIII-D incremental requests

items	FY21	FY22
Surface analysis for DIMES	$25K	$25K
Upper LP arrays (SAS1V, SAS)	$25K	$25K
Power supply/auto feedback control	$20K	$10K
Lower hybrid Langmuir probes	$25K	
Negative triangularity probes		$37K
Total	$95K	$97K

Another Post doc for extended OPS	$150K	$150K

Sandia supports the FES ZnetUS Consortium

- Association of HEDP research scientists in academia, the national labs, and industry to support decades of growth and enable collaborative research in pulsed-power science and technology.
- Core Purpose:
  - Provide broad access to two user facilities at SNL, Mykonos and Thor.
  - Facilitate the development and technology guidance for an intermediate-scale facility that bridges the gap between 1-MA drivers at universities and the Z Facility (~25 MA).
  - Provide an enhanced network for existing research efforts ongoing in pulsed power science and technology today in academia, government and industry
- Benefit to OFES is a more coordinated national pulsed-power community to identify and develop critical skills and key technologies that advances fundamental understanding and innovation in HEDP science.

Radiation-hardened electronics at Sandia

A core mission of Sandia National Laboratories is to design, fabricate and qualify electronics for use in radiation environments for US national defense programs.

Sandia has broad and deep technical expertise in this area, which includes:

1. Experimental facilities for testing:
   - Fission neutrons – Annular Core Research Reactor
   - DT Fusion neutrons – IBL 14 MeV irradiation facility
   - Energetic ions and ionizing radiation - IBL
   - X-rays and Gammas – Hermes, Saturn, GIF
2. Modeling and simulation of devices and effects of displacement damage and ionization,
3. MESA facility for fabrication of rad-hard electronic components.

Rad-hard electronics is not presently required for MFE, but may be for ITER or DEMO.

Sandia can provide guidance on rad-hardened electronic systems for MFE if needed.

Examples of recent work:

1. Gain change from neutron displacement damage in III-V HBTs.
2. Stuck bits and single-event upsets in highly-scaled CMOS SRAMs
3. Neutron damage in Si photodiodes
4. Photocurrent in GaN high-voltage diodes

Sandia's Fusion Program enhances and strengthens core FES activities

Vision

Beyond FY22

Sandia will:

Lead critical areas of fusion materials and technology with key personnel in the national effort (design team, technology center) to design a pilot plant.

These include: PMI and surface effects in PFCs, blankets and tritium handling systems; power exhaust and plasma boundary physics; and diagnostics that extend facility capabilities (DIII-D and lab plasmas, surface probes)

Produce outstanding technical results and serve the nation utilizing SNL's unique capabilities and expertise to advance fusion and plasma science.

Sandia has outstanding scientists, engineers and technologists in materials science, plasma physics, diagnostics and other areas, and facilities such as the Ion Beam Laboratory, Low Temperature Plasma Facility, MESA (micro-machines), CINT, Z-machine, ACCR (reactor), and Advanced Manufacturing labs.

Maximize our creative output and advance the FES program by networking across MFE, HEDP and DPS in SNL and strategic partnerhsips with others.

Sandia has well-established networks for collaborations in MFE, HEDP, DPS and other programs such as ..... Diagnostics and damage to materials are among many themes that cross these areas.

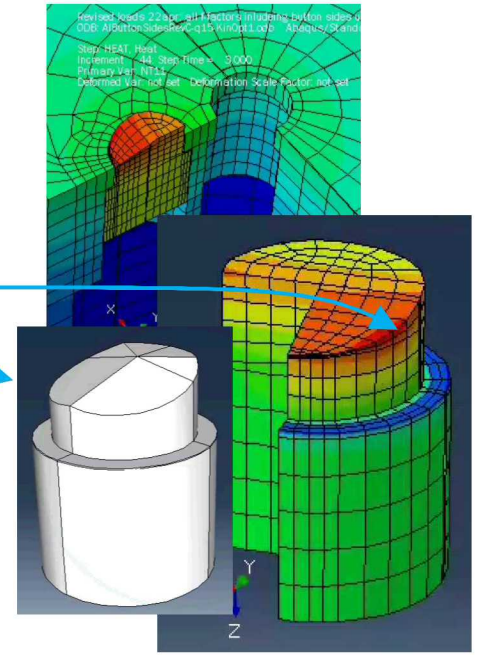
The FES NM Base Program (HHF) has redirected effort: power exhaust in DIII-D, AM+ PFCs and novel PFCs (heat pipes).

DIII-D support:

- Thermal analysis on heat exhaust and for DiMES experiments

  Example - DiMES Al melt experiment for ITER: *Model indicates edge would melt first due to heat on sides by $q_{parallel}$. Alternate 2-bevel shape recommended.*

- Sample preparation and thermal analysis for tungsten experiments
- Participation in design reviews for experiments such as the SAS, WITTS and DiMES where Sandia has strong interest.



AM-based fusion materials, and particularly W-based

- SNL PI for AM ARPAe proposal by ORNL, SNL and others (2021+)
- Collaboration with Polaronyx on W and W alloys (restart 2021)
- Exploring SNL capabilities and non-fusion work (ongoing)

Ongoing interest in novel PFCs

- Collaboration with CCFE/WarwickTech/DIFFER (ongoing)
- ARPAe proposal (Gray/ORNL PI) heat pipe for Tokamak Energy

Incorporation of Early Career Award activities into Sandia/CA base program

Characterizing the dynamic response of surfaces to plasma exposure

Main Accomplishments:

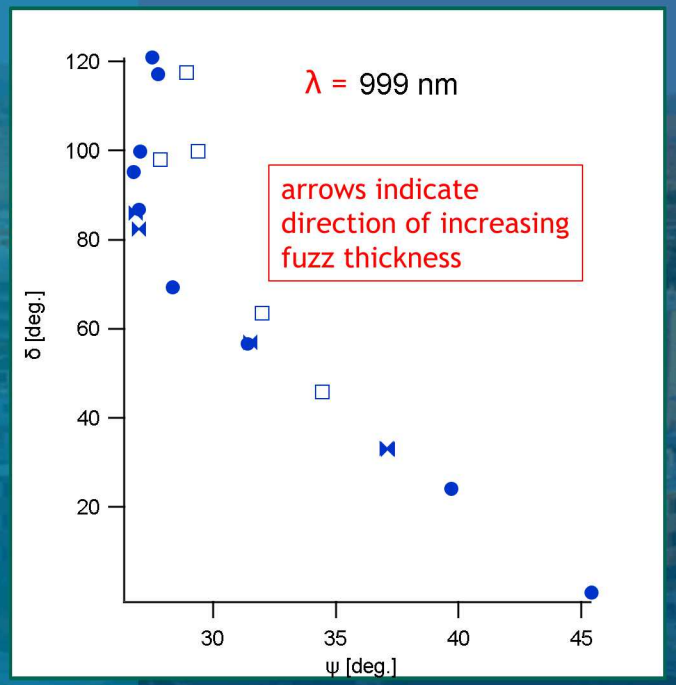
- **In-situ diagnostic**: spectroscopic ellipsometry
- **He ion channeling** in surfaces (near-surface defect formation, H binding)
- Analysis of **near-surface stresses** during plasma exposure (in progress)

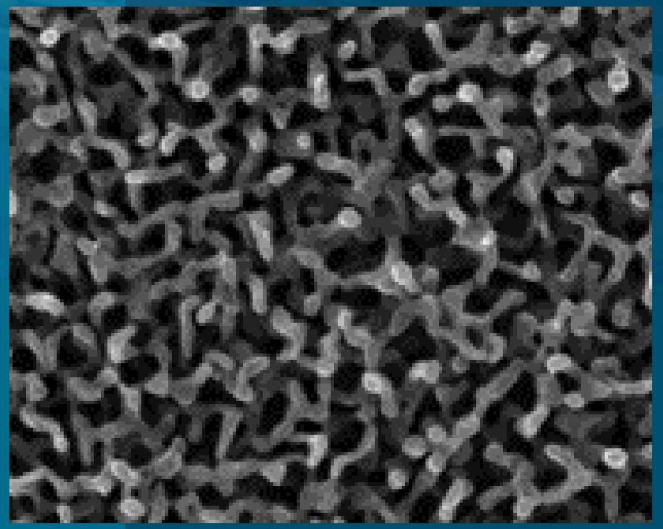
New Capabilities:

- High flux RF source as a test platform for diagnostic development, high-temperature TDS, TOF spectroscop

Collaborations:

- University of Tennessee (B. Wirth), Penn State (J. P. Allain), U. C. Berkeley (F. Allen)





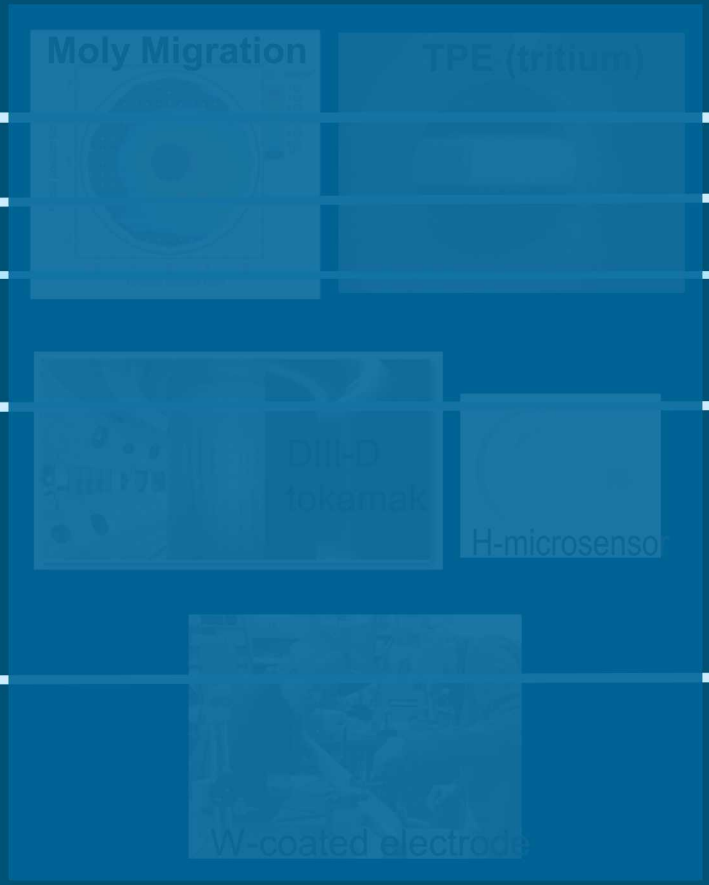
Effects of He plasma on W

OUR WORK SUPPORTS THE FES STRATEGIC PLAN

Fusion research exploits SNL program strengths and synergies.

SNL capabilities & the INL-SNL TPE are unique elements of the fusion program.

- Transportation Energy & Nuclear Weapons
- Materials Science Research Foundation & Non-proliferation (Neutron Source Development)
- Nanodevices & Microsystems Research Foundation
- Grand Challenge LDRD (Hostile Environments)
- Radiation Effects & High Energy Density Science Research Foundation (Pulsed Power, EM & Resistive-MHD models)



- Behavior of H & He in materials and on surfaces
- Micro-scale atomic H detection & smart tiles
- Disruption mitigation by radiation from injected compact toroids

CAD-scale detailed 3-D neutronics modeling for FW/ blankets, EM modeling of disruption loads (past)

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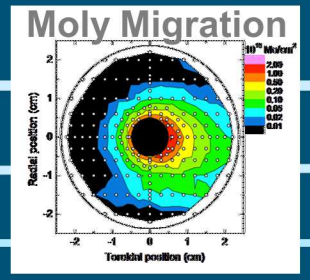

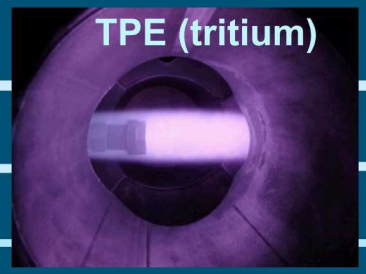

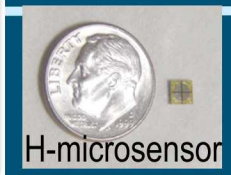

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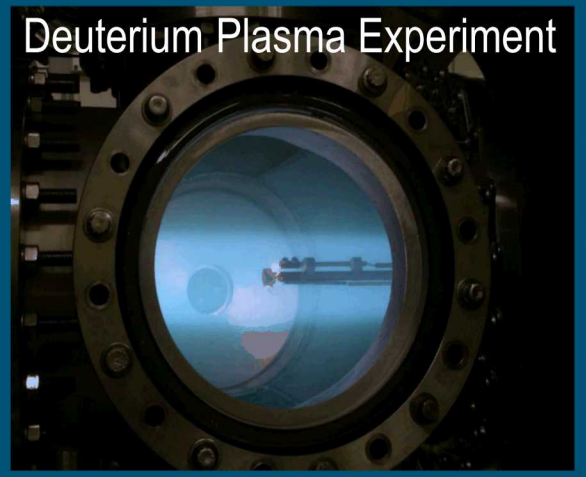
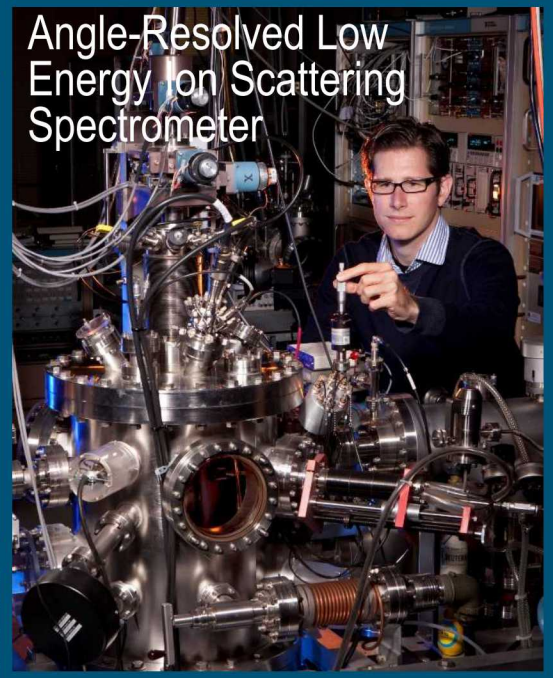
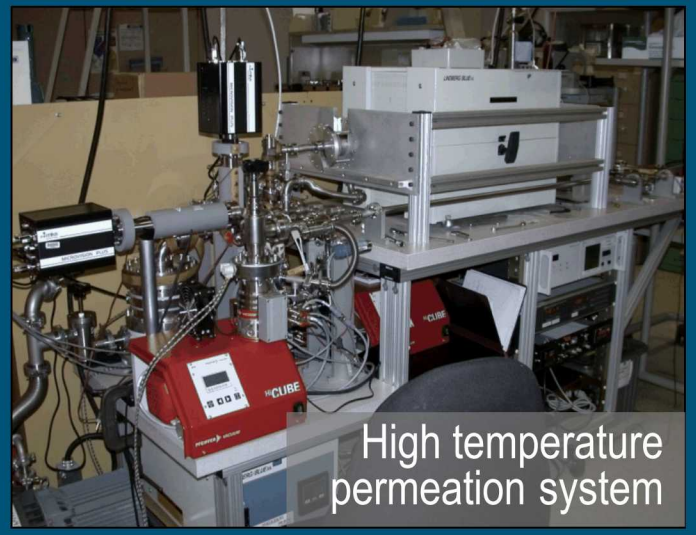
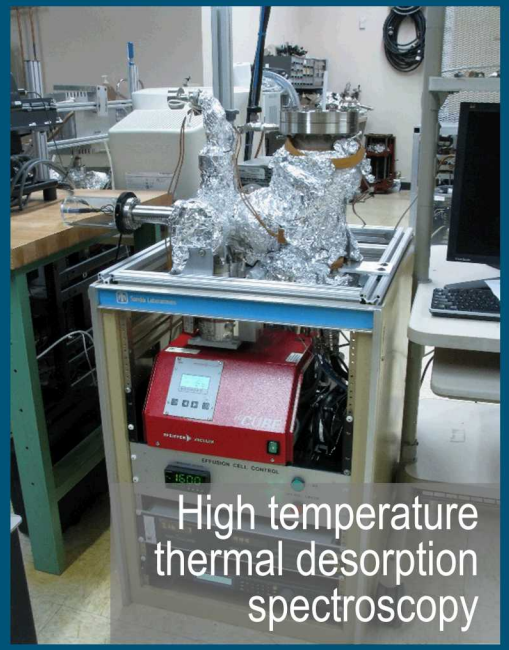
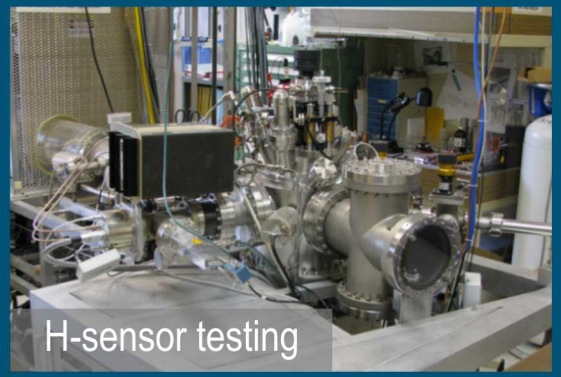
SNL CAPABILITIES WITH FULL/PARTIAL OFES SUPPORT

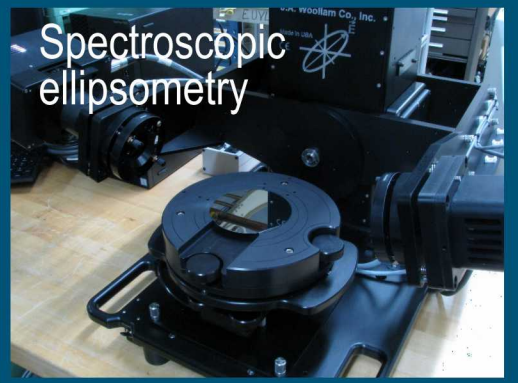








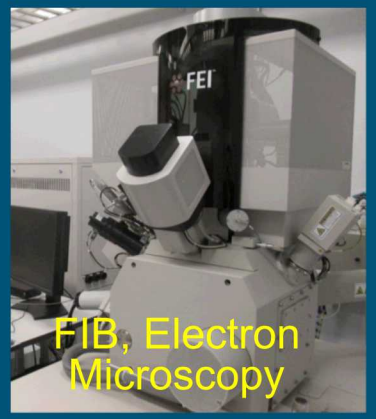




These lab facilities are at the Livermore site.

OTHER (LEVERAGED) SNL CAPABILITIES

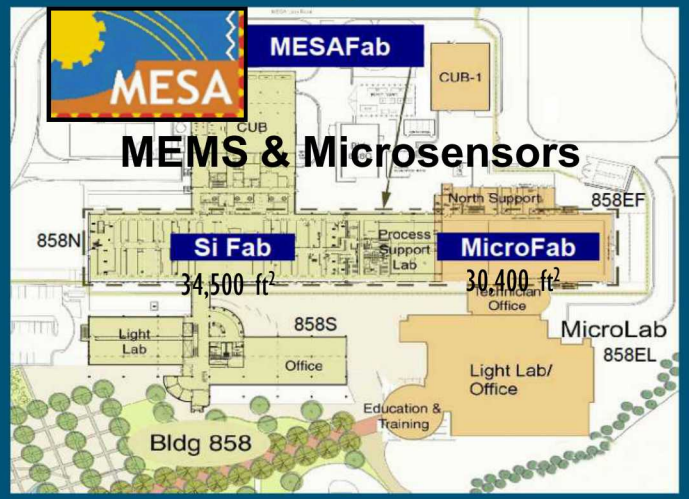
Livermore site

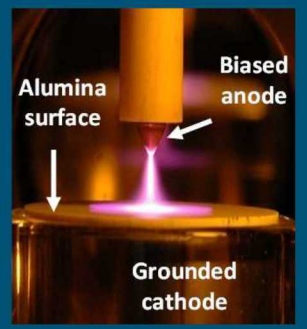


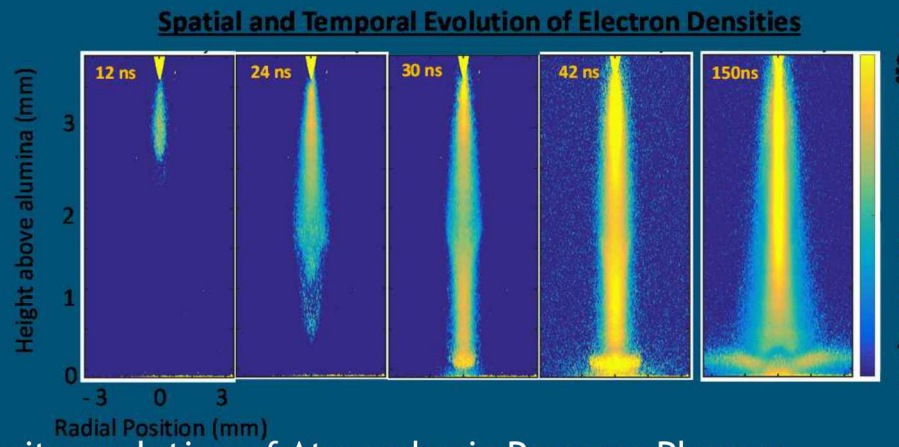
ABQ site

Coatings, Surface Analysis for DIII-D DiMES experiments

Microsensors, AM and heat pipes) are R&D topics of interest.
Our leverage to SNL expertise enables effective limited effort.







Plasma density evolution of Atmospheric Pressure Plasmas

SNL COLLABORATIONS

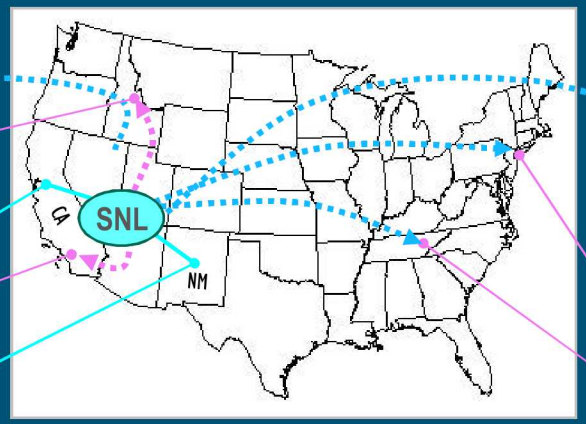
Japan, China, Korea, India

INL

Livermore

DIII-D *GA*
La Jolla

Albuquerque



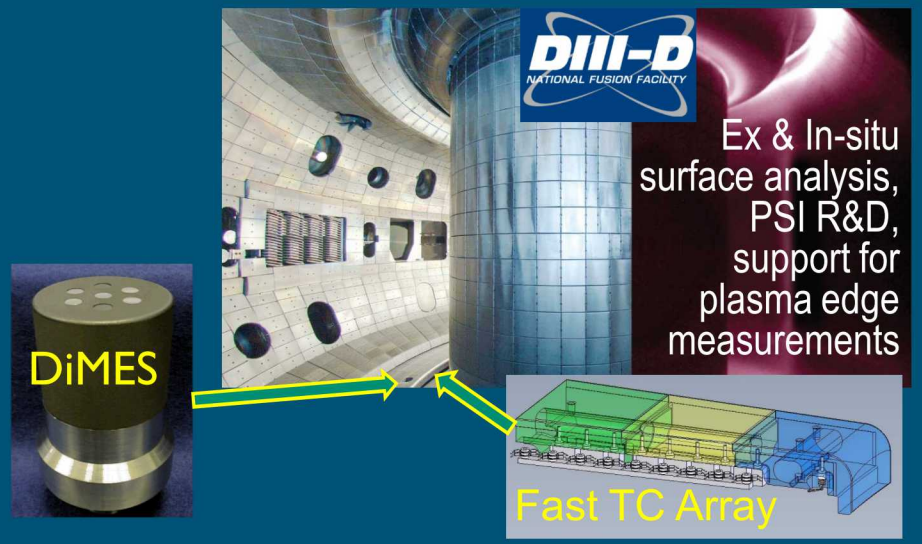
ITER, CEA, Others in EU

NSTX-U *PPPL*
Princeton

ORNL

Strategy

- *TARGETING R&D THAT SERVES FES OBJECTIVES*
- *PARTNERING IN PRODUCTIVE COLLABORATIONS THAT FURTHER OUR MISSION*
- *WORKING WITH YOUNG RESEARCHERS AT SANDIA AND OTHER INSTITUTIONS*



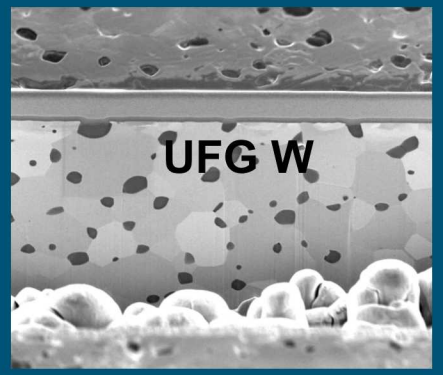
Tritium PSI

2013-2018
PHENIX
JAPAN-US JOINT PROJECT

INL Idaho National Laboratory

Tritium Plasma Experiment
TPE at INL

OTHER SNL COLLABORATIONS



UCSD

Characterization of tungsten

- Russ Doerner, Matt Baldwin - Nano-structured W (PISCES)
- Profs. Zak Fang (U. Utah) & Yasushi Oya (Shuizuoka U.)
  - Ultra Fine Grain Tungsten

MD simulations of LEIS: H sites

- Prof. Brian Wirth (UT/DIII-D/MPEX)

PMI diagnostic development

- Prof. David Donovan (UT/DIII-D/MPEX, former SNL post-doc)

DIII-D NATIONAL FUSION FACILITY

OFES- Other synergistic with fusion materials

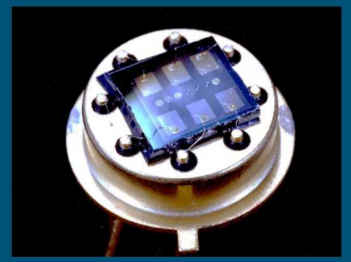
- DIII-D Langmuir probe and thermocouple arrays*
- Measurement Innovation: H sensors (testing on DIII-D*)
- ITER/EAST* (erosion/redeposition for ITER FW)
- DIFFER/CCFE/Aavid-Thermacore (Li heat pipe*)
- NSTX-U - Li safety/handling, liquid PFC development

He plasma
Li-Ta heat pipe
Magnum PSI,
DIFFER

DIFFER Dutch Institute for Fundamental Energy Research

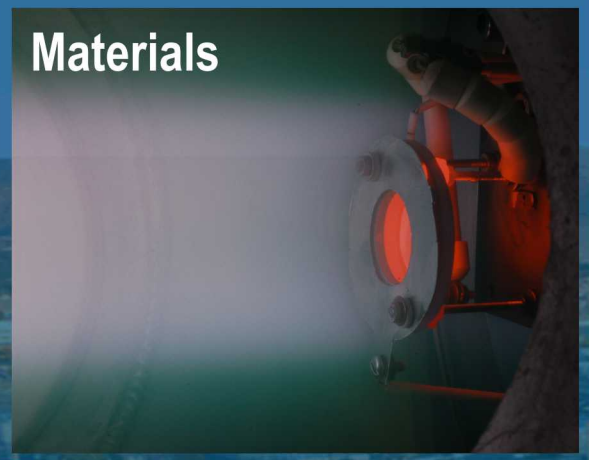
PPPL PRINCETON PLASMA PHYSICS LABORATORY

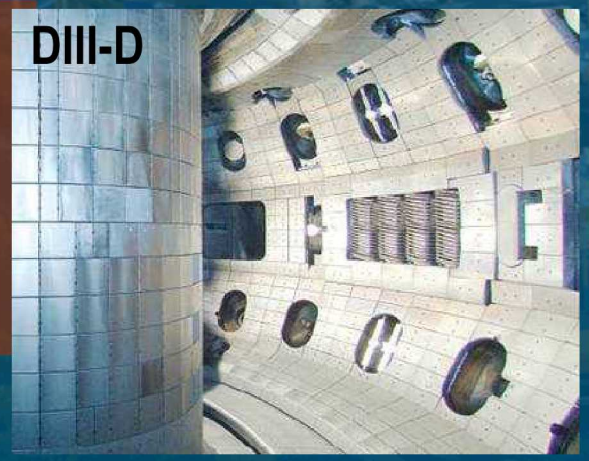
PRINCETON PLASMA PHYSICS LABORATORY

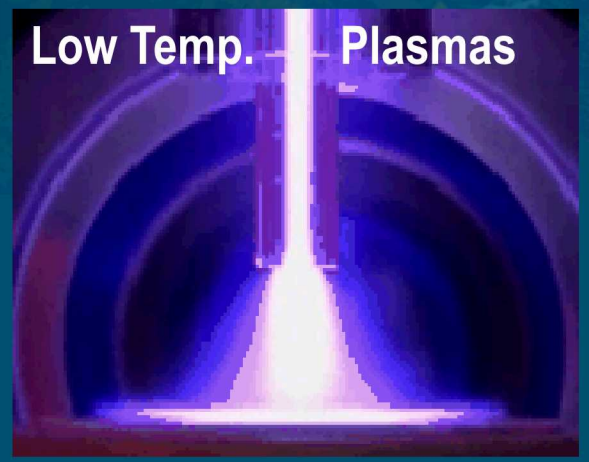


chip with 6 neutral H sensors

*OFES/Clark







Program Overview: Fusion Activities at Sandia Cover All Three FES Initiatives

12 FWPs
$3.8 M in FY20

Burning Plasma Science: Long Pulse (ITER R&D) ($1.6 M/2.1 FTE)

- Materials & Fusion Nuclear Science
  Plasma Surface Interactions and High Heat Flux Components
- Blanket & Tritium Fuel Cycle
  H permeation and surface analysis

Burning Plasma Science: Foundations ($0.6 M/.95 FTE)

- Advanced Tokamak
  Boundary Physics Program at DIII-D
- Theory & Simulation
  Plasma Surface Interactions SciDAC program, UTK lead

Discovery Plasma Science ($1.5 M/2.3 FTE)

- Low Temperature Plasma Research Facility
  Advanced characterization and plasma science
- General Plasma Science
  Highly Collisional Plasmas Science Center, UM lead
- Measurement Innovation
  H-microsensors for charge-exchange erosion

Instructions from FES Office

With your opening viewgraphs (max 5 VGs), please consider the following five bullets:

- What is your vision for your existing programs, both for FY 2022 and beyond FY 2022? What are your thoughts for new activities?
- What are your thoughts about the direction your program needs to go starting in FY 2022 and beyond and how that fits in with the community/FESAC long-range planning activities?
- How are your programs addressing the recent NAS reports on Burning Plasma and Intense Ultrafast Lasers?
- What are the priorities of your institution as well as your FES programs? Everything cannot be top priority. Please prioritize. Make choices. You should prioritize not only within a program area (e.g., theory), but, even more importantly, across all program areas that are being presented. Please let us know what areas you are willing to reduce in order to either start something new or increase effort in existing areas of research.

The next VG should be a budget table that summarizes total funding for your program areas (e.g., Theory, Materials, HEDLP, etc.) in FY 2019, 2020, and 2021

The next set of VGs will identify your FY 2022 priorities within and between program areas for base/ +25%/-10% cases