Virtual Laboratory for Technology
FES FY2017 Fourth Quarter Report

Phil Ferguson
for the VLT members

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Director's Corner

- FY17 has been a busy year for the VLT. We participated in the FES FY19 budget planning meeting, the FESAC Transformative Enabling Capabilities meetings, the community workshop in Madison, and made a presentation to the National Academy of Sciences committee for a Strategic Plan for Burning Plasma Research
- Bi-monthly teleconferences are continuing with good representation. Additional teleconferences are held as needed to prepare for whitepaper submissions, presentation discussions, etc. Most recently, the newest ECA winner, Jason Trelewicz, presented a short summary of his planned work.
- This and future highlights will continue to cover research highlights from recent VLT publications and the main VLT research areas:
  - Magnet Systems; Heating & Current Drive; Plasma Fueling/ ELM Pacing/Disruption Mitigation
  - Plasma Facing Components; Plasma Materials Interactions; Structural Materials
  - Design/Systems studies; Power Handling; Fusion Safety; Fuel Cycle Research; Blanket Technology; Vacuum System

If you have any questions on the information in this report, please don't hesitate to contact us.

VLT
Virtual Laboratory for Technology
For Fusion Energy Science

Ohmic Loss Calculation of Polarizers at 170 GHz for EC Heating in ITER

Scientific Achievement

Ohmic loss was calculated for miter-bend polarizers that convert a linearly polarized microwave beam into an arbitrary elliptically polarized beam for Electron Cyclotron Heating in ITER.

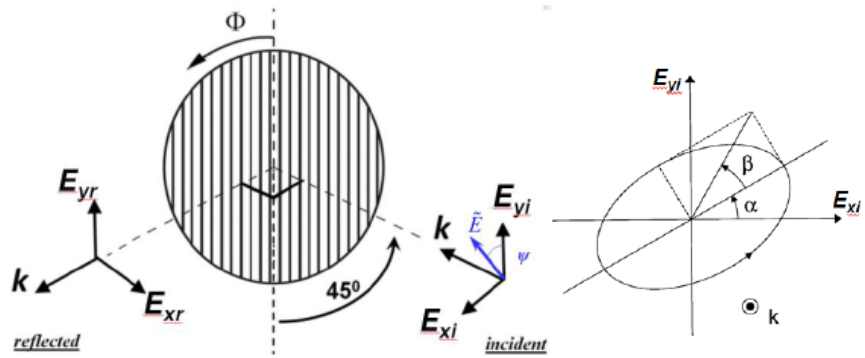
Significance and Impact

ECH power, transported through highly oversized corrugated metallic waveguides, must achieve > 95% transmission efficiency in order to have sufficient power to meet ITER needs.

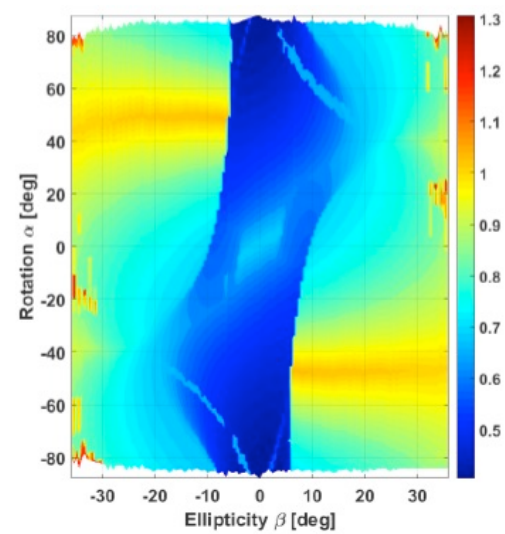
Research Details

- Ohmic loss was calculated as a function of the ellipticity parameters α and β (see figure).
- **Application**

  These results are critical to designing the ITER ECH transmission lines but also apply to all other ECH experiments.



Schematic of a polarizer and ellipticity definition



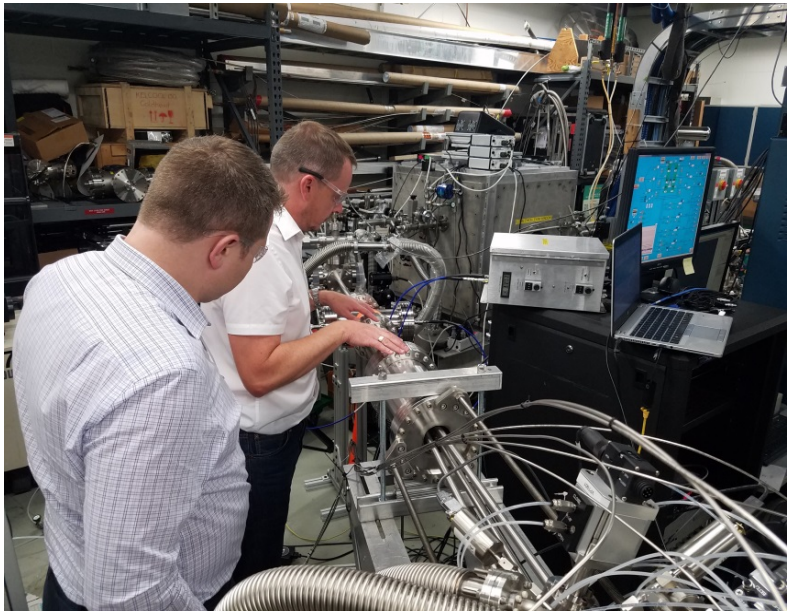
Calculated ohmic loss vs. ellipticity parameters α and β

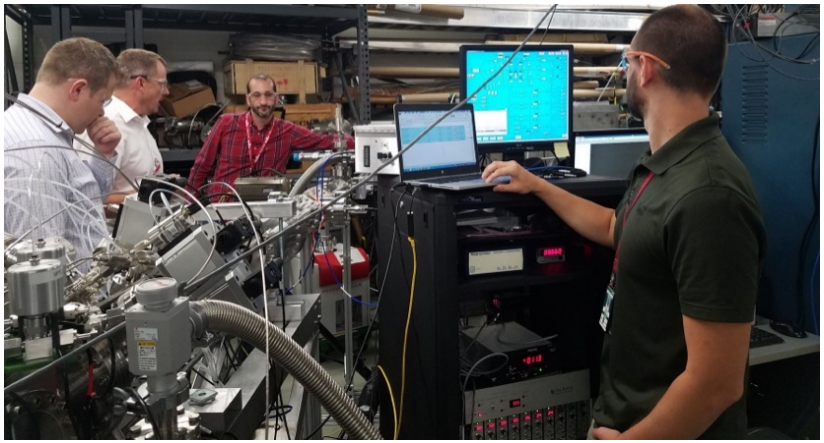
MIT: H. Hoffmann, S. Jawla, M. Shapiro and R. Temkin; G. Hanson, ORNL; supported by DOE VLT and US IPO

JET Staff Visit ORNL for In-Lab Commissioning of JET Shattered Pellet Injector

- JET-SPI fabrication and assembly completed with first cooldown 30Aug2017 to 5.6 K with no leaks.
- First pellets fired 12Sep2017
- JET Staff James Wilson, Alex Muir, & George Ellwood visited ORNL the week of 11Sep to assist with in-lab commissioning of the system

Photo: L-to-R: Baylor, Ellwood, Muir, Gebhart, & Wilson, Meitner kneeling





Steve Meitner,
Larry Baylor,
Trey Gebhart,&
Tam Ha

Work sponsored by
DOE Office of Fusion
Energy Sciences

Toward high-field compact fusion magnets: understand the electro-mechanical performance of REBCO conductors at high fields and elevated temperatures

Scientific status as of October 2017

We are validating an experimental setup to measure the critical current of REBCO tapes as a function of strain, magnetic fields (up to 15 T) and temperatures (4.2 – 50 K)

Significance and Impact

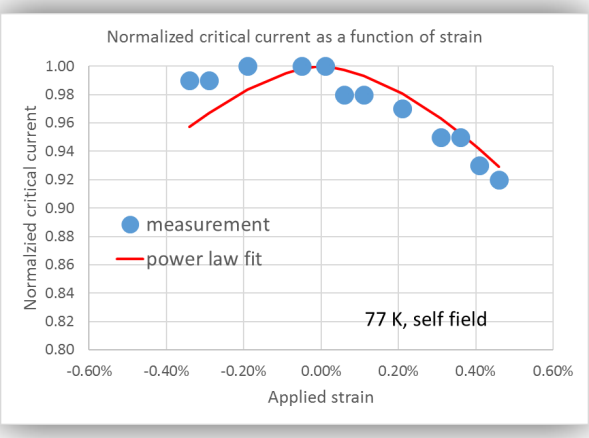
The current-carrying capability of REBCO tapes depends on applied strains. Beyond certain strain levels, permanent damage occurs and magnet performance degrades. The conductor will experience strains at various stages of magnet development, e.g., cabling, winding, cooldown, energization and quench. Understand the strain dependence at high magnetic fields and elevated temperatures (20 – 50 K) will provide significant insight into the design and optimization of high-current REBCO cables for high-field compact fusion reactor magnets.

Research Details

A new U-spring sample holder was developed and tested at 77 K. Obtained first results for the strain impact on latest commercial REBCO tapes. Observed 8% reversible reduction in I_c at 0.46% tensile strain, consistent with expectation and validating the setup. Next step is to test it in field up to 15 T, at 4.2 K and higher temperatures.

Testing the setup at 77 K (15 T magnet in background)

Instrumented U-spring sample holder



- First results on the I_c-strain dependence on the latest 2-mm wide, 30 μm thick substrate commercial REBCO samples.
- Observed 8% reduction in I_c with 0.46% tensile strain

U.S. DEPARTMENT OF ENERGY | Office of Science

BERKELEY LAB

Tufts UNIVERSITY

VLT Virtual Laboratory for Technology For Fusion Energy Science

In Situ Plasma Sputtering & Angular Distribution Measurements for Structured Molybdenum Surfaces (UCLA)

Research Highlight

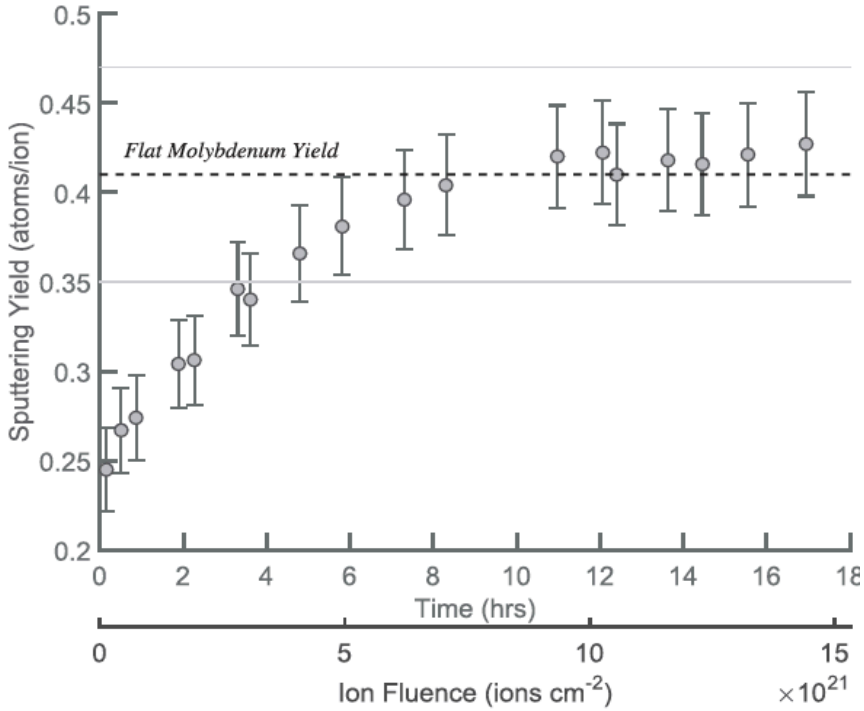


Figure 12. The time-dependent sputtering yield for 300 eV argon ions incident on micro-architectured molybdenum is shown converging to the flat molybdenum result. The gray lines signify error bars for the flat sample measurement.

Gary Z Li, Taylor S Matlock, Dan M Goebel, Christopher A Dodson, Christopher S R Matthes, Nasr M Ghoniem and Richard E Wirz, "In situ plasma sputtering and angular distribution measurements for structured molybdenum." Plasma Sources Sci. & Technol., April 2017.

Scientific Achievement

In situ sputtering yield measurements of the time-dependent erosion of flat and micro-architectured molybdenum samples in a plasma environment have been achieved. The measurements are performed using the plasma interactions (Pi) Facility at UCLA, which focuses a magnetized hollow cathode plasma to a material target with an exposure diameter of approximately 1.5 cm.

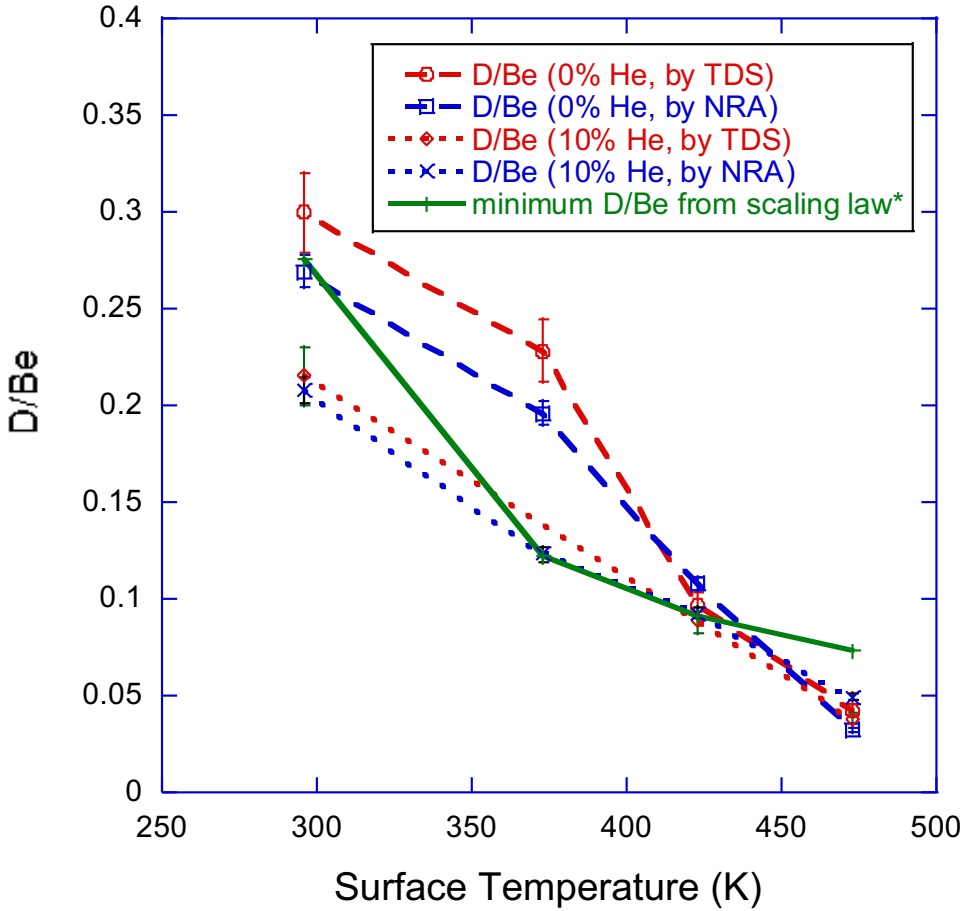
Significance and Impact

Development of resilient plasma facing materials will revolutionize the design and operation of divetors in fusion power systems.

Research Details

During plasma exposure, a scanning quartz crystal microbalance (QCM) provides angular sputtering profiles that are integrated to determine the total sputtering yield. The QCM is then used to obtain in situ measurements during a 17 h exposure of a micro-architectured-surface molybdenum sample to 300 eV incident argon ions. The time-dependent angular sputtering profile is shown to deviate from classical planar profiles, demonstrating the unique temporal and spatial sputtering effects of micro-architectured materials. Notably, the sputtering yield for the micro-architectured sample is initially much less than that for planar molybdenum, but then gradually asymptotes to the value or planar molybdenum after approximately 10 h as the surface features are eroded away.

Addition of Helium to Beryllium co-deposits during deposition does not increase Deuterium retention



*D/Be co-deposition scaling law prediction from G. De Temmerman et al., NF 48(2008)075008.

- Co-deposition with Be will dominate T accumulation in ITER
- T will only exist in the ITER plasma in conjunction with small amount of He ash
- D is used to simulate T behavior in laboratory plasma
- D+10%He plasma bombards Be targets in PISCES-B to generate Be co-deposits
- D content is measured by TDS (UCSD) and NRA (IPP-Garching)
- At low surface temperature He acts to reduce D content in Be co-deposits
- D content in Be co-deposits fall at the lower end of co-deposition scaling law predictions*

Inferred Si sputtering yields from silicon carbide (SiC) in DIII-D divertor are consistent with Si surface enrichment

Scientific Achievement

Measured silicon sputtering yields from a SiC-coated DiMES surface are consistent with a 5% Si enrichment of the SiC surface. Substantial Si sputtering observed at low T_e suggests that SiD_4 chemical erosion also occurs.

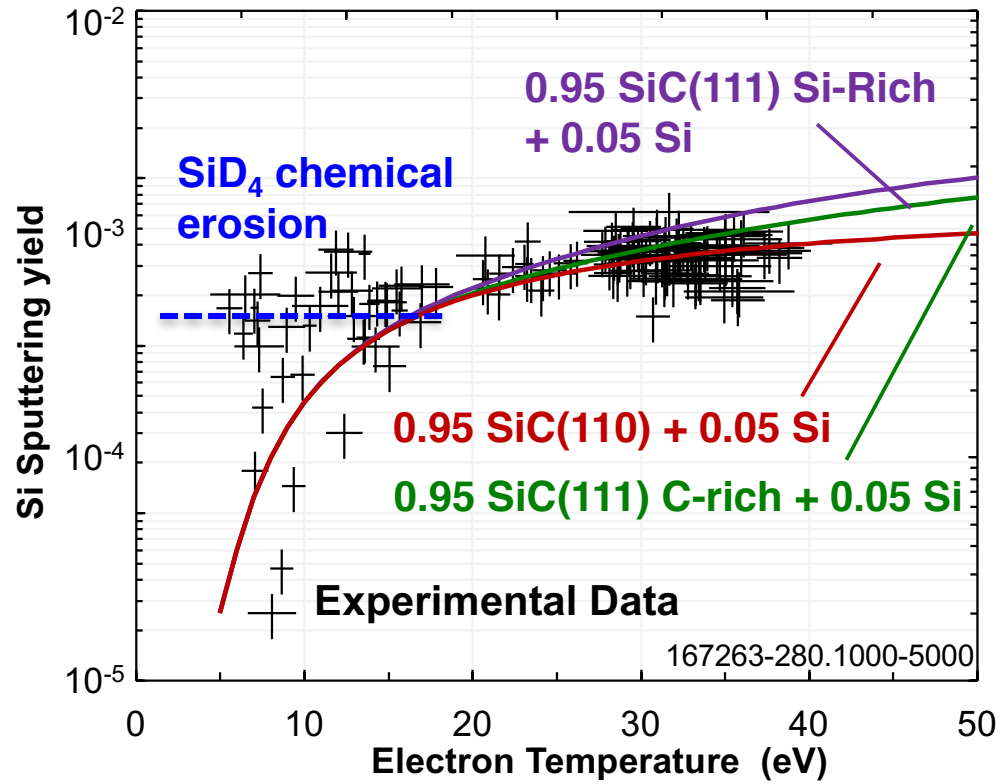
Research Details

- SiC-coated DiMES samples were exposed to H-mode plasmas in the DIII-D divertor with a range of electron temperatures.
- Si sputtering yield from the SiC surface was measured via Si II spectroscopy and the S/XB method, normalized to D ion flux obtained from divertor Thomson Scattering (DTS).
- Measurements tested against theoretical models for Si sputtering from SiC with different crystal orientations.
- Crystal orientation impacts the surface binding energy (SBE), which in turn affects the Si sputtering yield.

SBE and vacancy formation energies (Tersoff Phys Rev B 1994)

$SBE = E_x - V_x$

	E_{Si}(eV)	E_C(eV)	V_{si}(eV)	V_C(eV)
SiC(111) C-rich	26.06	11.34	7.85	4.22
SiC(111) Si-rich	21.89	15.32	7.85	4.22
SiC(110)	24.47	14.73	7.85	4.22
Si + C Mixture	4.72	7.37	--	--



Significance and Impact

Silicon carbide is an option as a plasma facing material due to its neutron damage resistance, low activation, and low T permeation, but limited testing has been performed on tokamaks. These tests suggest that preferential sputtering of C from SiC, previously observed in ion beam experiments, occurs in tokamaks.

T. Abrams, S. Bringuier, H. Khalifa, L. Holland

S. Bringuier et al., APS-DPP Conference, Oct 2017.

Ti_3SiC_2/SiC Joint Swelling Predicted by Dual-phase Finite Element Model

Research Highlight

Science Objective

SiC joining has been pursued for many years and several methods to create dual-phase or composite joints have been developed. Ti_3SiC_2/SiC joints are very strong but may fail during neutron irradiation due to differential material response.

Significance and Impact

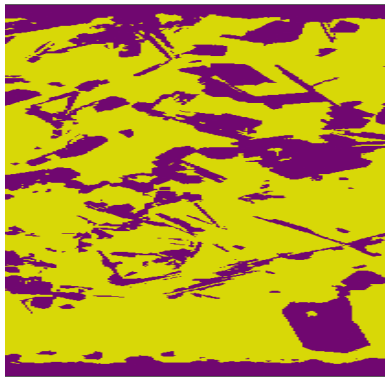
Accurate simulation tools can facilitate design of improved joints and can help understand complex materials response to thermal and irradiation environments. This model provides key insights into joint failure mechanisms following HFIR irradiation and indicates routes to making improved joints and joining methods.

Research Details

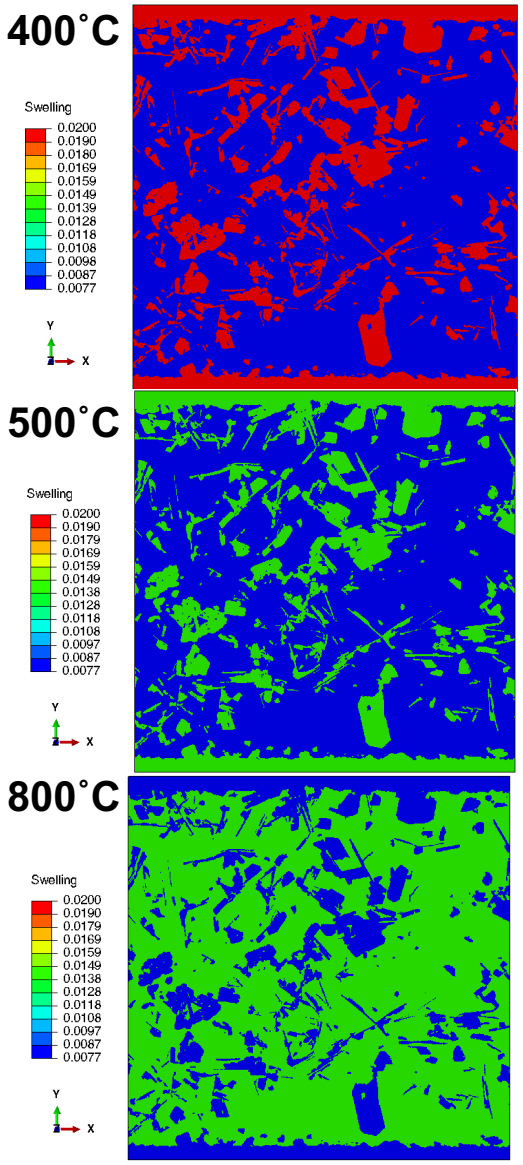
Finite element (FE) damage mechanics using dual-phase FE meshes created using OOF2 (NIST) software from real images of Ti_3SiC_2/SiC joints

B.N. Nguyen, C.H. Henager, Jr., R.J. Kurtz, Journal of Nuclear Materials 495 (2017) 504

http://dx.doi.org/10.1016/j.jnucmat.2017.09.011



Detailed FE discretization of Ti_3SiC_2/SiC joint region from SEM image. Joint is 10 µm thick. SiC is magenta, Ti_3SiC_2 is yellow



- Color images show swelling levels in SiC and Ti_3SiC_2 after simulated irradiation dose sufficient to saturate SiC swelling at the indicated irradiation temperatures
- Differential swelling is highest at 400˚C and is reduced at higher temperatures

Evolution of Nanoscale Interstitial Dislocation Loops Under the Coupled Effects of Stress and Temperature

Research Highlight

Science Objective

Explore the combined effects of applied stress and temperature on the stability of nanoscale self interstitial (SIA) dislocation loops in iron

Significance and Impact

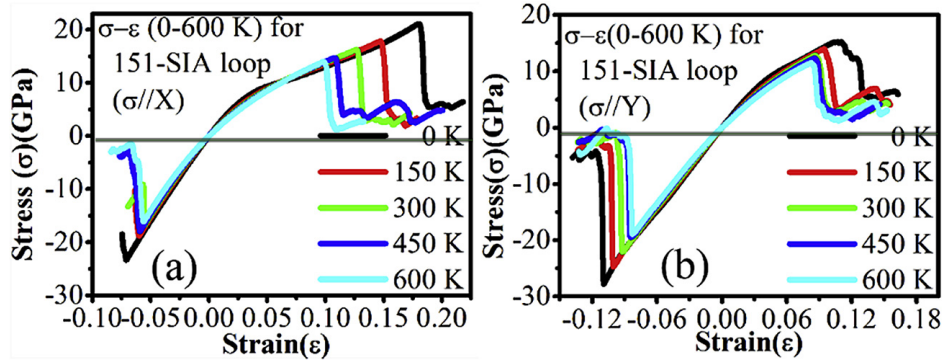
Irradiation with energetic particles creates clusters of SIAs and vacancies, which form dislocation loops and voids. Applied stresses and elevated temperatures could influence the microstructural evolution of these defects, which has implications for the mechanical response of an irradiated material (e.g. tensile strength, creep properties, fracture behavior, etc.)

Research Details

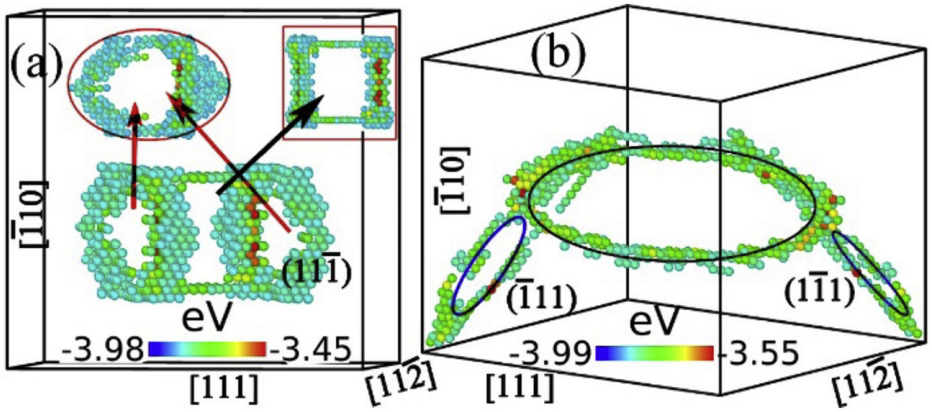
Atomic scale molecular dynamics models of SIA loops were loaded at constant strain rate in uniaxial tension or compression with the loading direction either parallel or perpendicular to the loop Burgers vector at temperatures ranging from 0 to 600 K

N.Gao, T. Shen, R.J. Kurtz, Z. Wang, F. Gao, Scripta Materialia 136 (2017) 64

http://dx.doi.org/10.1016/j.scriptamat.2017.03.008



Stress-strain curves for a model containing a 151 SIA loop at different temperatures with the stress application along the [111] direction in (a) and [112] direction in (b)



Loop configurations produced under (a) tensile and (b) compressive stress where the applied stress is perpendicular to the Burgers vector. In (a) the central loop changes from a circular to rectangular shape and two circular loops are emitted on a (111) plane. In (b) the elliptical shape remains for the central loop but two small loops are emitted, which are located on (111) and (111) planes.

Additive Manufacturing (AM) and Fusion Technology: Engage experts, understand potential applications and benefits, aim for US leadership

Scientific Achievement

- AM as a transformative enabling capability.[1-2] US fusion researchers recommend investment to confirm and understand fusion applications.
- US experts outside fusion are studying the underlying materials science in AM to improve the processes and predict the properties of AM parts. This is a relatively new area. Right now we lead the world.

Significance and Impact

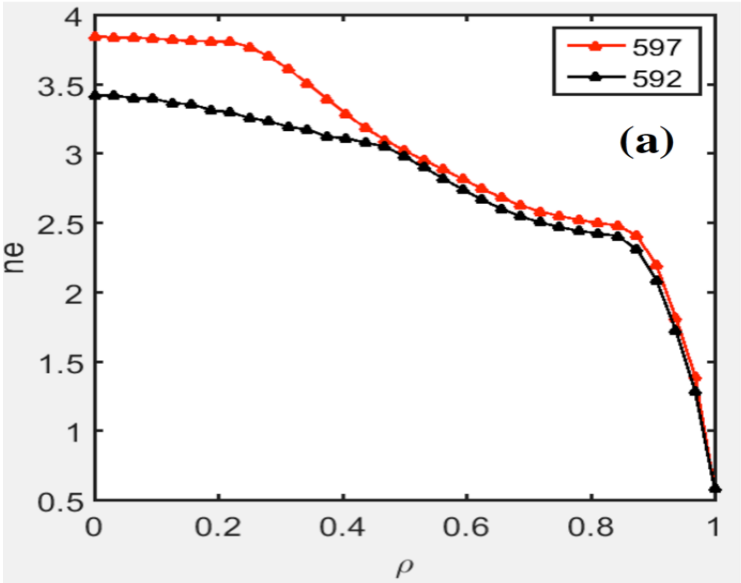
- AM's broad applicability is transforming manufacturing world-wide and createing new products. Fusion AM is readily adapted to complex shapes, open porous structures and materials architectures with graded transitions from one material to another or nano-particles that improve mechanical properties. Fusion is rich with potential applications.
- Nuclear heating in ITER or in a reactor will heat all components near the plasma. Coolant must reach all parts of these complex components to avoid melting. AM fabrication could enable continuous serpentine cooling channels that cannot be made in any other way.
- Understanding such AM applications can help us find new solutions for fusion technology that are grounded in practical aspects of advanced materials engineering being pursued outside fusion.

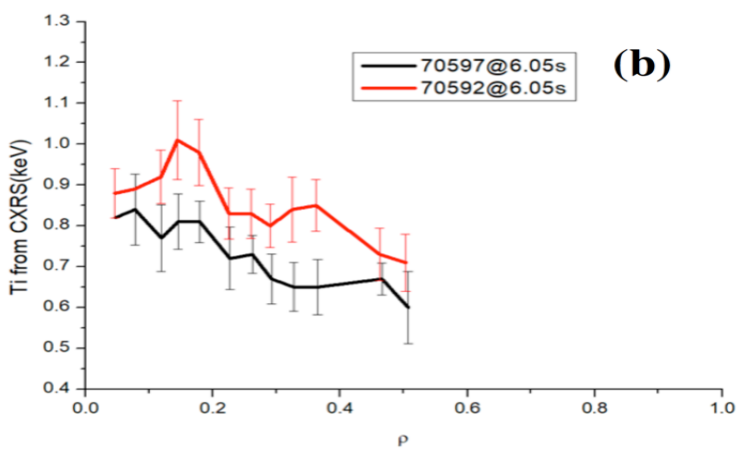
Research Details

AM makes objects from 3D models, usually building layer upon layer. AM processes melt materials with lasers, electron beams or other equipment, or rolling liquid layers or printing them by ink jets.

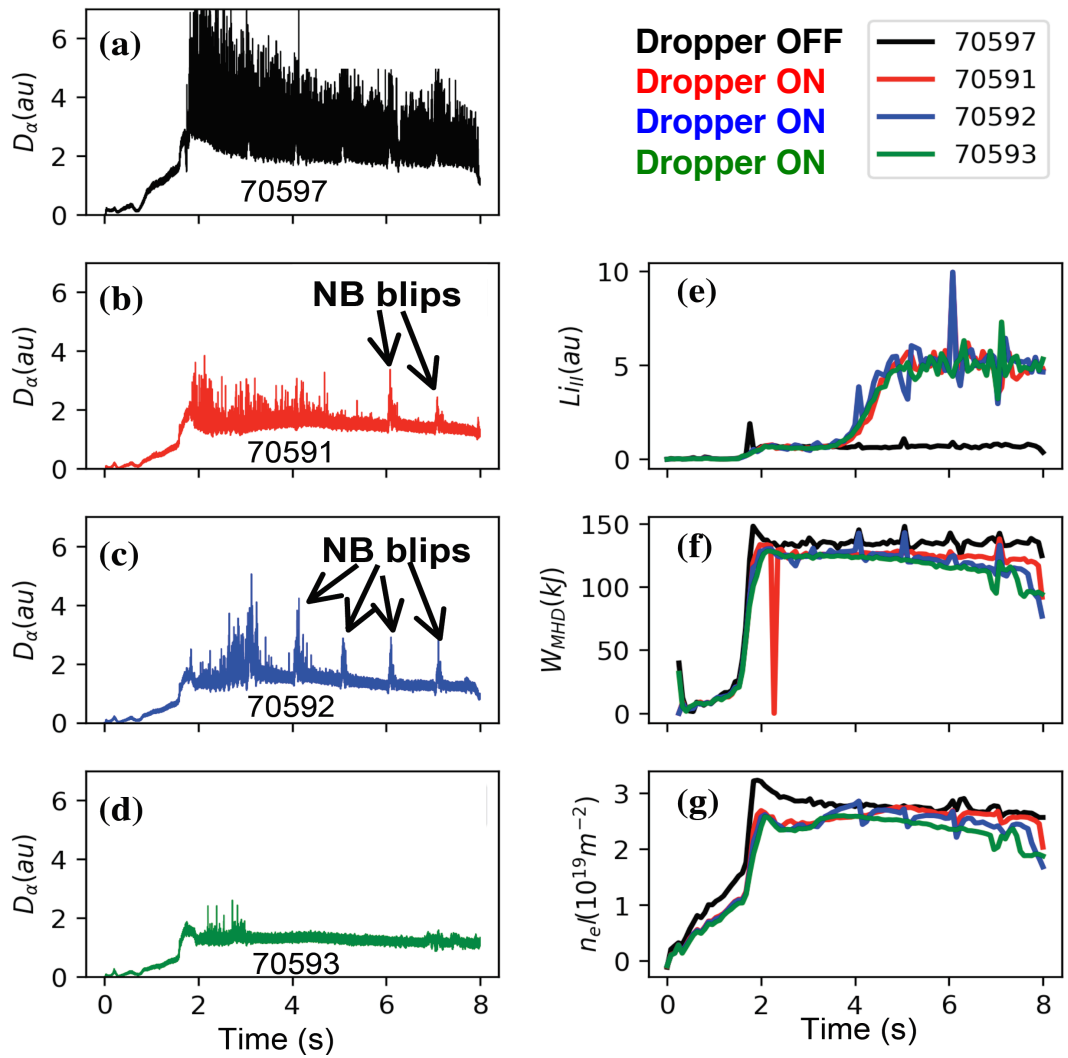
1. Advanced Manufacturing – A Transformative Enabling Capability for Advancing Fusion, RE Nygren et al., invited oral presentation ISFNT 2017 submitted Oct2017 for publication in FED
2. Advanced Manufacturing – A Transformative Enabling Capability for Advancing Fusion, R Dehoff et al, white paper input for 2017 National Academy of Science panel on burning plasmas.

Recycling & ELMs progressively reduced with constant Li injection rate in EAST, similar to NSTX Li evaporation





R. Maingi, Nucl. Fusion (2017) submitted



SOLPS analysis shows local divertor recycling coefficient drops by 20%
J. Canik, IEEE Trans. Plasma Sci. (2017) submitted

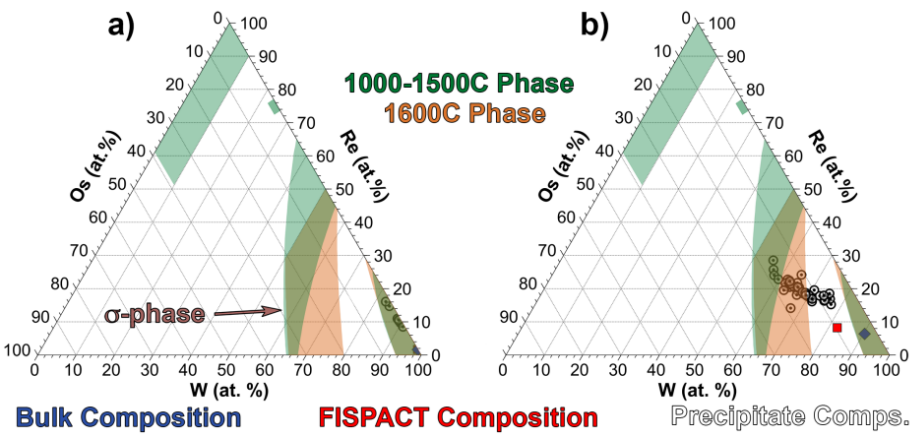
ASIPP PPPL PRINCETON PLASMA PHYSICS LABORATORY OAK RIDGE National Laboratory VLT Virtual Laboratory for Technology For Fusion Energy Science

Characterization of Second Phase Precipitates in Neutron Irradiated Tungsten

Research Highlight

Characterization

Atom probe reconstructions highlighting the radiation-induced second phase precipitation in the low-dose (a), and high-dose (b) condition. The clusters/precipitates are highlighted using concentration isosurfaces for Re & Os.



Neutron-inventory informed precipitate chemistry from the atom probe datasets for the low-dose (a) and high-dose (b) conditions. The high-dose precipitates are tending towards the sigma phase boundary.

Scientific Achievement

Understanding the composition of second phase precipitates that form in neutron-irradiated tungsten due to transmutation of the matrix elements is important in determining the mechanisms by which the precipitates form. We combine neutron-inventory calculations to correct the compositional analysis from atom probe data to obtain highly accurate, individual precipitate compositions.

Significance and Impact

Tungsten undergoes irradiation-induced precipitation due to considerable neutron-induced transmutation to Re and Os. Analysis allows us to understand what governs/dominates precipitate nucleation and growth mechanisms.

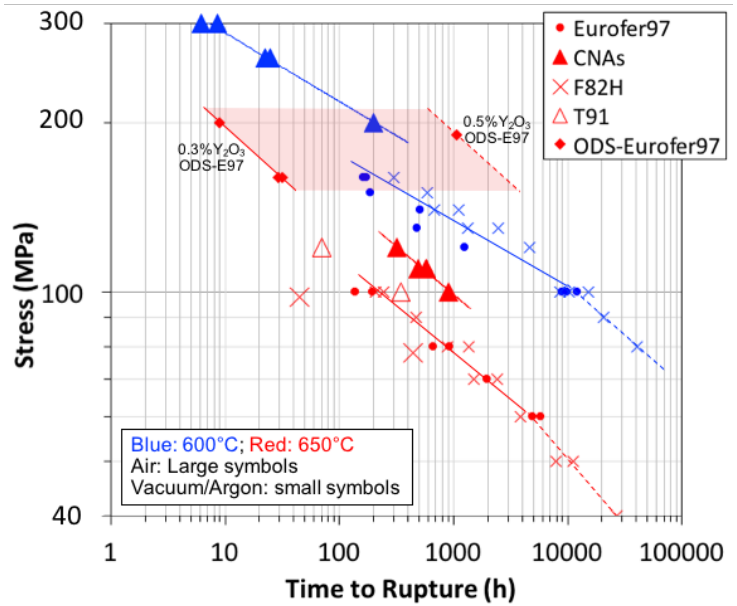
Research Details

Single crystal tungsten irradiated in HFIR to 0.1 and 1.8 dpa at ~700°C was analyzed using atom probe tomography. Neutron-inventory calculations based on the HFIR irradiations were used to deconvolve overlapping peaks in the mass spectrum to obtain the precipitate compositions.

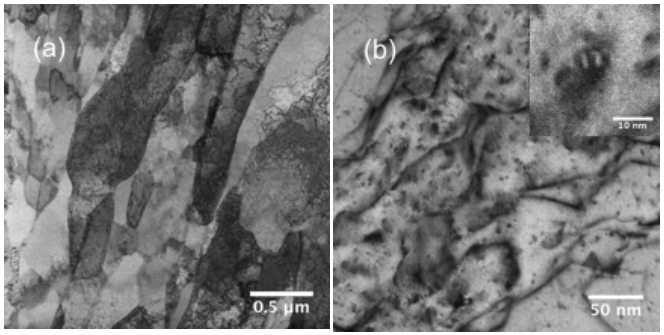
Application

Determination of accurate precipitate compositions will aid the mechanistic understanding of the nucleation and growth of second phase precipitates in neutron-irradiated tungsten.

Castable Nanostructured Alloys (CNAs) are the Next Generation RAFM Steels



- *Creep behavior of CNA compares favorably with other RAFM and commercial steels*



- *Fine lath structure and fine scale precipitates provide superior properties*

Scientific Achievement

Preliminary test results indicated that the creep resistance of CNAs is superior to the current RAFM (reduced-activation ferritic-martensitic) steels and comparable to the lower-bound of 9Cr-ODS (oxide-dispersion-strengthened) alloys.

Significance and Impact

Developing CNAs to have isotropic properties superior to the current RAFM steels and reaching ODS alloy properties will bridge the gap between the current RAFM steels and ODS alloys, advantageous for future fusion reactors and research facilities.

Research Details

Type SS-3 CNAs and commercial T91 alloy samples were creep tested in air at 600 and 650°C and compared to literature values. Bright-field scanning transmission electron microscopy (BF-STEM) images show the microstructures of the CNAs with fine lath and high densities of dislocations and ultrafine precipitates, contributing to the superior strength.

Ongoing Studies

Microstructural characterization of selected creep-ruptured samples and irradiation resistance screening of CNAs are in progress.

Computational Thermodynamics Lead to Novel Cu-Cr-Nb-Zr Alloys for Fusion

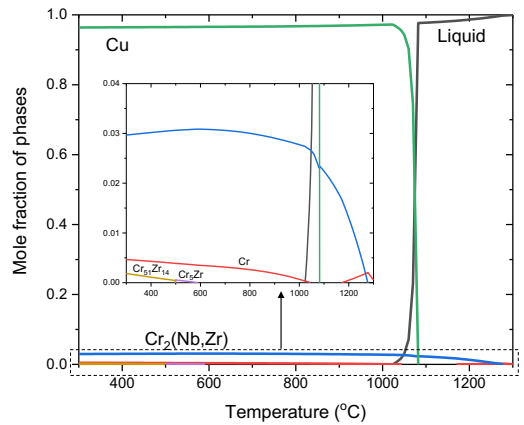
Scientific Achievement

- Developed thermodynamic database for the Cr-Cr-Nb-Zr quaternary system
- Used computational thermodynamics to designed novel Cu-Cr-Nb-Zr alloys with bimodal precipitate distribution
- Produced alloys by economical conventional ingot technology.
- Microstructures in the alloy validated predictions

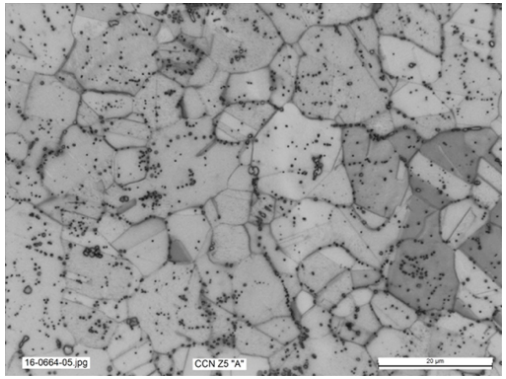
Significance and impact

- Bimodal distribution of ppts. in this novel alloy enables a balanced property combination of high temperature creep resistance, tensile strength, ductility and thermal conductivity, leading to a promising candidate for the high heat flux structures material in fusion energy systems.

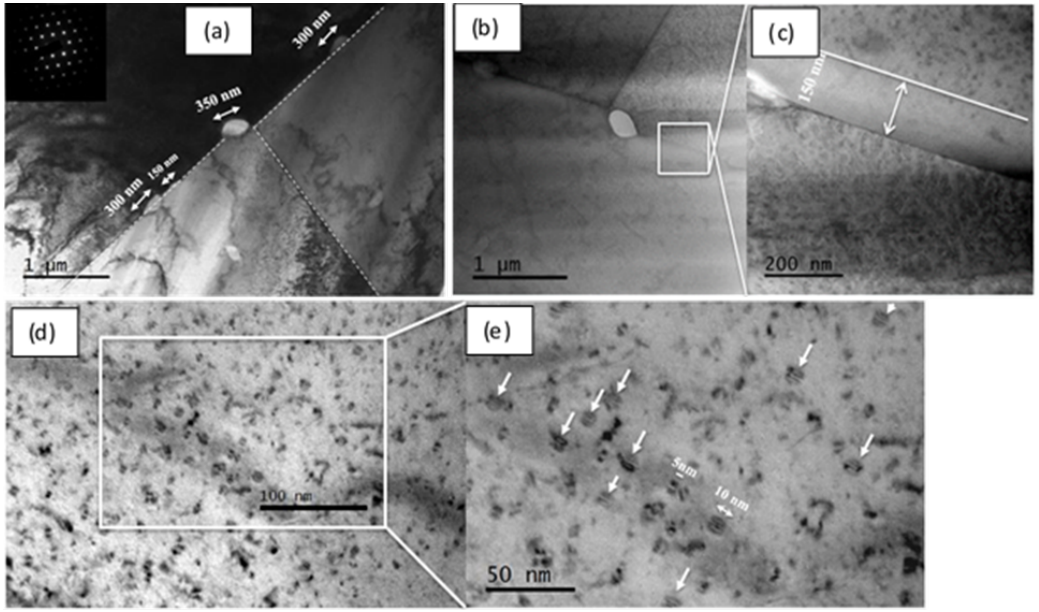
The predicted bimodal ppt distribution in designed alloys



Validated microstructure showing sub-micron ppts. at GBs and dislocations



TEM images show sub-micron size GB ppts and finer scale matrix ppts



Research Team: Ying Yang (ORNL), S.J. Zinkle (UTK), L.L. Snead (SBU)

Unraveling the mechanisms behind Re precipitation in irradiated W alloys using kinetic Monte Carlo simulations

Research Highlight

Scientific Achievement

We have carried out lattice kinetic Monte Carlo (LKMC) simulations of W-Re alloys under irradiation to study non-equilibrium Re precipitation. We have found that mixed-interstitial solute transport is responsible for initiating Re clustering at high temperatures.

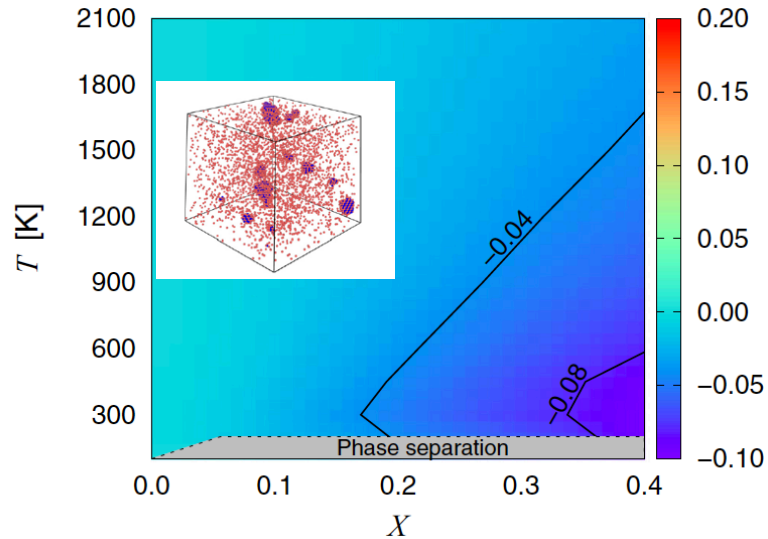
Significance and Impact

The precipitation of Re in irradiated W alloys gives rise to the formation of brittle intermetallics that lower the ductile-to-brittle transition temperature to untolerable levels. This precipitation often occurs homogeneously and so it doesn't't follow standard radiation-induced precipitation. We have found that special mixed interstitial structures give rise to the formation of precursor Re clusters.

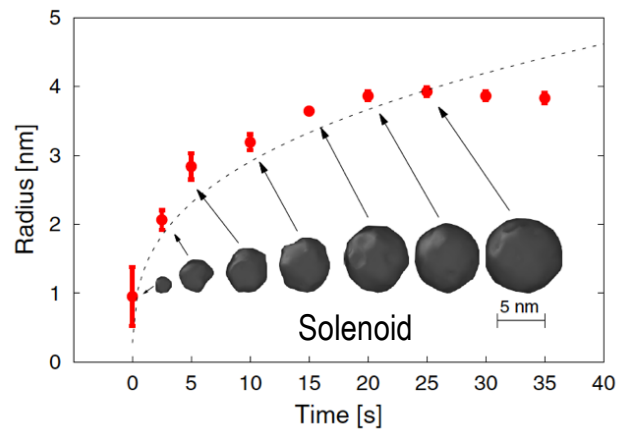
Research Details

We have developed a LKMC model parameterized with electronic structure calculations, including thermodynamic and kinetic information.

"Mechanism of nucleation and incipient growth of Re clusters in irradiated W-Re alloys from kinetic Monte Carlo simulations", C. H. Huang, L. Gharaee, Y. Zhao, P. Erhart, and Jaime Marian, *Physical Review* B 96, 094108 (2017)



Equilibrium phase diagram of W-*X*Re alloys as predicted by our computational methodology (inset: formation of V-Re clusters in oversaturated conditions). The plot shows short-range order parameter values.



Growth with time of Re clusters obtained in the LKMC simulations

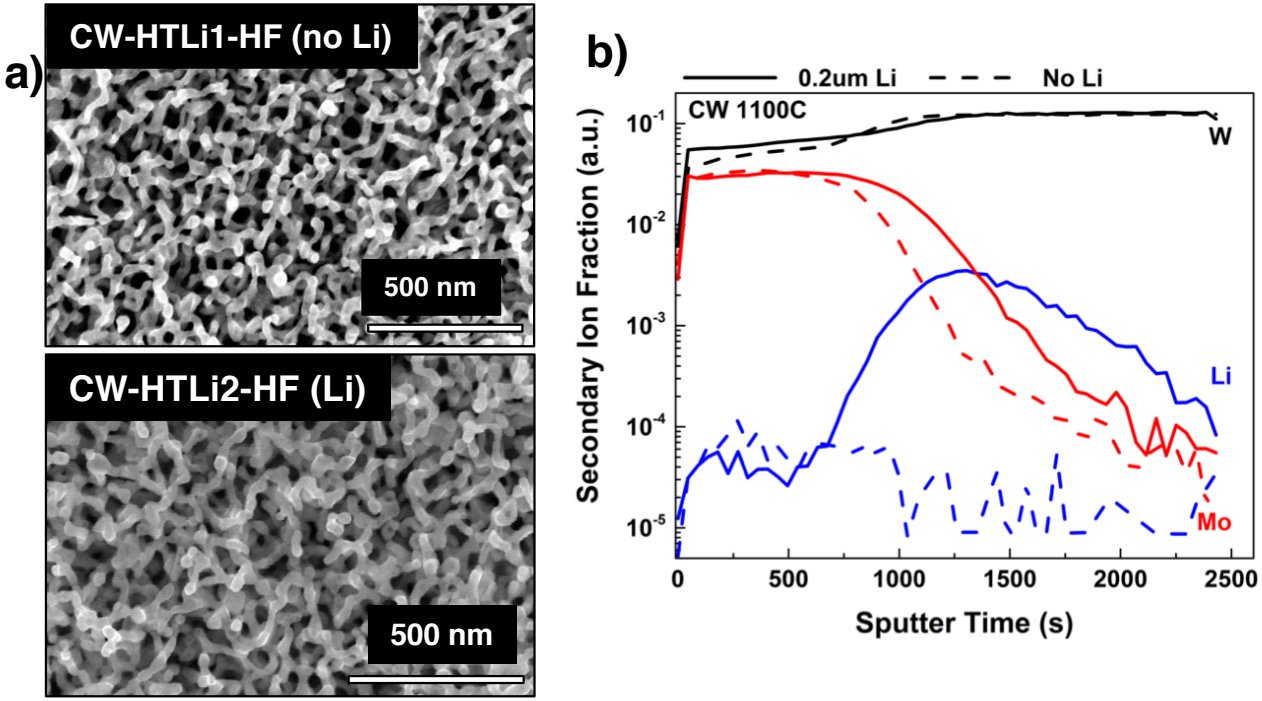
U.S. DEPARTMENT OF ENERGY | Office of Science

UCLA

VLT Virtual Laboratory for Technology For Fusion Energy Science

Elucidating low-Z thin film dynamics under high-fluence plasma exposure on nano-structured W

Coarse Grained W @ ~1373 K, Fluence ~4.0E26 m^{-2}



a) SEM micrographs of coarse-grained W, with and without a Li thin film deposited prior to exposure, showing formation of fuzz for both cases, b) Secondary Ion Mass Spectrometry depth profile of the same samples showing a trace of Li persisting on the surface.

- Irradiations were carried out in collaboration with T. Morgan at the Dutch Institute for Fundamental Energy Research.
- SIMS and SEM was carried out in part in the Frederick Seitz Materials Research Laboratory Central Research Facilities, University of Illinois.

Scientific Achievement

These results indicate that nano-structured fuzz still forms with Li present as a thin film and that the Li may not be removed from the surface.

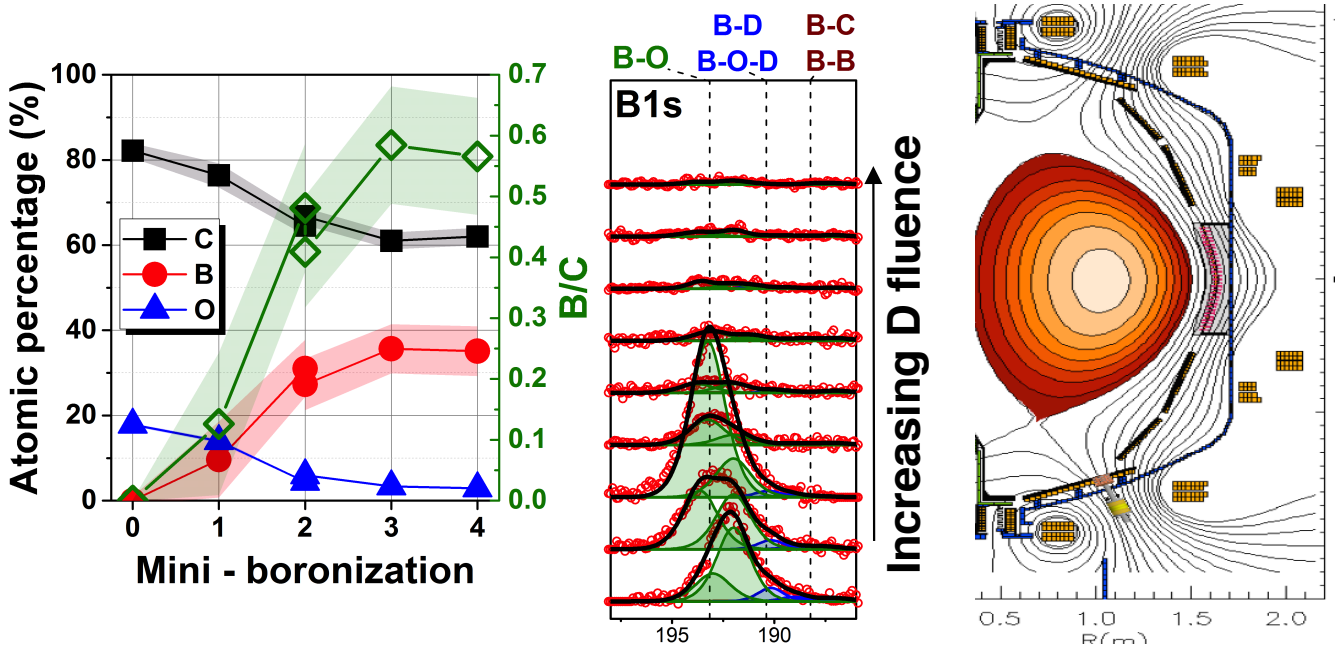
Significance and Impact

With the formation of fuzz in spite of the Li, indicates that fuzz would still form if Li coatings were used on W PFCs subjected to a He discharge in ITER. The reliance of the Li on the surface could be beneficial to prolong the fuel pumping capability of Li

Research Details

- Exposures of coarse-grained W with and without a Li thin film to He plasma at DIFFER at 1373 K at fluxes of 10^{24} $m^{-2}s^{-1}$.
- Secondary Ion Mass Spectrometry (SIMS) depth profiling using Cs ions at the sputtering species and Au as the analysis beam show Li persisting under surface of tendrils.

In-situ MAPP analysis of boronized ATJ graphite samples and comparisons to IGNIS UIUC data



(a) *(b)*

a) Atomic concentrations obtained using in-situ XPS in MAPP over four small-scale or "mini" boronizations with no exposure to plasmas, (b). Right panel is NSTX-U fiducial EFIT field lines near MAPP probe and Left panel data from in-situ XPS on irradiated boronized surfaces with D+ on ATJ graphite samples that mimic NSTX-U PFCs where the enhanced oxygen concentrations lead to retention of D at the surface until eroded away over time

F. Bedoya, Ph.D. Thesis 2017 *"Plasma-facing components conditioning techniques and their correlation with plasma performance in the National Spherical Torus Experiment Upgrade (NSTX-U)*

Scientific Achievement

This work leverages on the first *in-situ* PFC data collected in NSTX-U to compare boronization methodologies (full vs. mini) using complementary *ex-vessel* analysis at UIUC on the IGNIS platform. These results are helping elucidate mechanisms for D pumping

Significance and Impact

In this work the mechanisms that drive D retention on boronized vs lithiumized surfaces on graphite are being assessed.

Research Details

- *In-situ* XPS data with MAPP diagnostic and *ex-vessel* IGNIS experiments show the role that low-energy D irradiation can play on the equilibrium B and O concentrations that impact D pumping. Results show that boronized surfaces can start at high B-O concentrations that initially pump D effectively but lose this as both oxygen and boron layers are eroded.

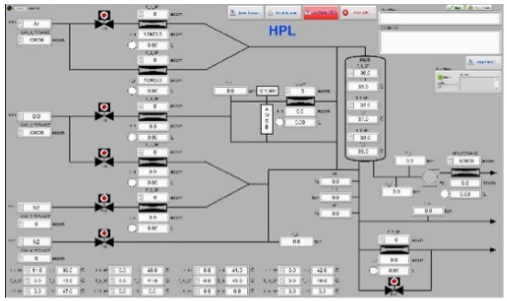
Tritium Processing Development for Magnetic Fusion at LANL

Application

Development and testing of tritium fuel cycle components and data-mining of TSTA historical documentation.

Scientific Achievement

Work continuing on upgrades of Hydrogen Processing Laboratory (HPL) test stand and replacement heater design for U-Bed. Participated in Liquid metal plasma facing component (LM-PFC) System Study.



HPL Software Interface

Heater Design

Significance and Impact

- HPL and U-Bed upgrades will allow for continued engineering design development of tritium fuel cycle for fusion processes
- Integration of fuel cycle design into LM-PFC development will strengthen design options and applications.

Research Details

- All materials for HPL upgrades have been received, old wiring has been removed and new instrumentation is being installed. Software interface design in process (see figure on left).
- Design for new heater (vacuum compatible) is continuing due to the identification of an alternative heater. We are trying to ensure the final design with be reliable and maintainable for future studies (figure on left).
- Presented LM PFC Tritium Fuel Cycle at second LM-PFC system study in Germantown. Presented a review of proposed LIFE and other tritium fuel cycle concepts/issues

Hollis, W. Kirk, LM PFC Tritium Fuel Cycle, A review of the proposed LIFE / Other Tritium Fuel Cycle Concepts/Issues, LM PFC Working Group Meeting. FES Germantown, June 2017

Volumetric heating simulation and its practicality on ceramic breeder thermomechanics study at UCLA

Research Highlight

Why it matters

Recreating breeder temperature profiles due to nuclear heating in the lab is a crucial step in advancing the scientific understanding of the stability and operation of solid breeder blankets and potentially exploring control mechanisms that maintain breeder temperature limits within the acceptable window dictated by tritium release requirements and heat extraction efficiencies.

Approach

Experimentally establish and validate the practicality of a volumetric heating technique for a representative breeder pebble bed configuration and study consequent thermomechanical stability and evolution

Result

Verified the ability of the proposed volumetric heating technique in recreating prototypical temperature profiles absent notable thermomechanical disruption

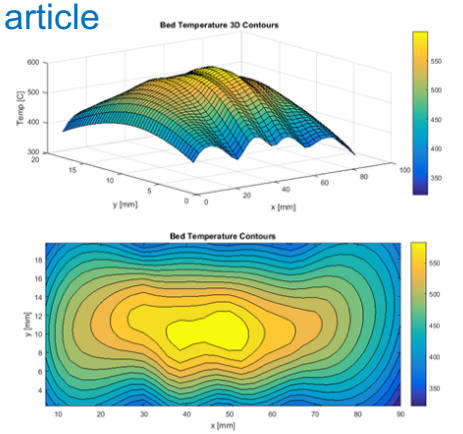
Publication

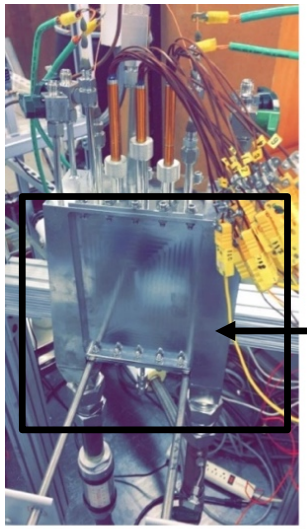
[1]Mahmoud Lotfy, Alice Ying, Mohamed Abdou, Yi-Hyun Park, Seungyon Cho, Study on the Thermally-Induced Stress and Relaxation of Ceramic Breeder Pebble Beds, FST Vol.72, No3, pp: 255-262, 2017.

Complex thermally-induced stresses arise in the pebble bed under typical operating temperature gradients[1]

Initial packing fraction γ (%)	σ_{pc} (MPa)	Meas. PC (μm)	Temperature diff. [a] ΔT (°C)	σ_{p1} [b] (MPa)	σ_{p5} (MPa)
63.2	0.1	--	288 [450-162]	0.25	0.005
63.5	1	366	300 [457-157]	0.98	0.03
63.1	2	446	311 [474-163]	1.8	0.82
63.2	3	597	318 [477-159]	1.92	1.85
63.3	0.1	--	391 [659-268]	0.54	0.04
63.3	3	580	402 [657-255]	3.1	2.89

Measured temperature profile in a Li_2TiO_3 pebble bed simulated by wire heater block in a preliminary test article





Test article fabricated at KAERI using Korean ARAA reduced ferritic steel through US/UCLA-KO/NFRI Task Agreement

Installed at UCLA cooling loop with wire heaters and TCs for further experiments

U.S. DEPARTMENT OF ENERGY | Office of Science

UCLA

VLT Virtual Laboratory for Technology For Fusion Energy Science

Tritium dynamic modeling tool development for permeation/inventory analysis & FW tritium ion implantation

Research Highlight

Why it matters

Better predictions of tritium inventory and permeation rate from test blanket system (TBS) coolant in ITER building/Vault are urgently needed for Connection Pipe design, DS requirement, safety, and maintenance assessments

Approach

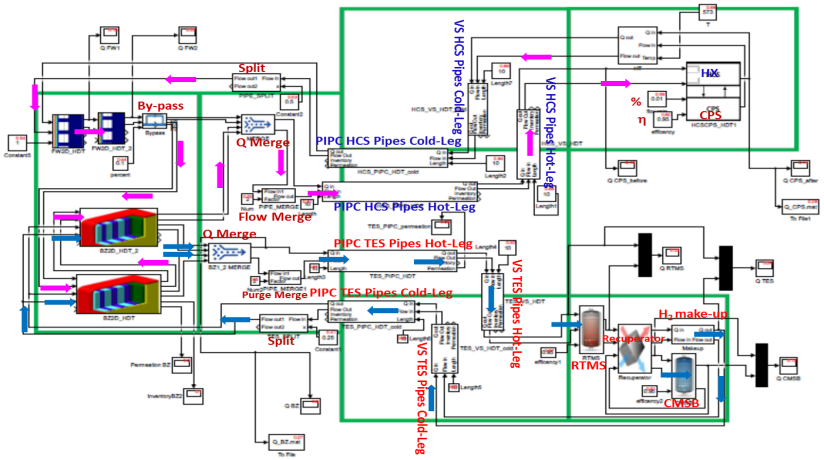
This task is conducted under UCLA-NFRI collaboration. The UCLA-NFRI collaboration facilitates the development and testing of US predictive tools on realistic blanket module designs and requirements, particularly through access to the ITER TBM designs. Incorporate detailed component model into a system level model for improved accuracy for answers to safety/licensing related questions and to the TES/CPS designs

Results

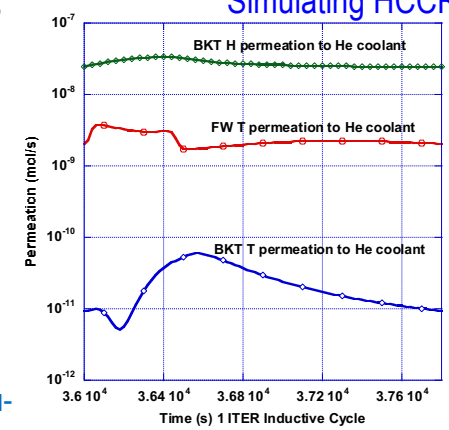
Dynamic, multi-physics simulation is necessary since the system equilibrium state is not governed by a single component. It provides more accurate information on the tritium-permeation characteristics for assessing tritium mitigation strategy and design

Invited talk & paper submission

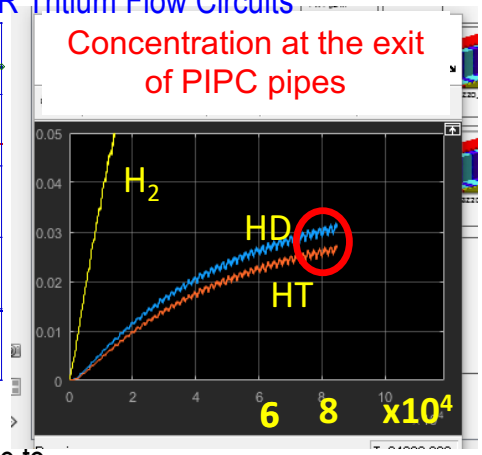
Invited talk at the ISFNT-13, Sep. 26, 2017 Alice Ying, Hongjie Zhang, Brad Merrill, Mu-Young Ahn, Seungyon Cho, TBS Design Implications on Tritium Transport and Permeation with High Tritium Ion Implantation: A MATLAB/Simulink, COMSOL Integrated Dynamic Tritium Transport Model for HCCR TBS (also paper submitted to Fusion Engineering and Design)



A Simulink/Matlab- COMSOL Dynamic Tritium Modeling Platform Simulating HCCR Tritium Flow Circuits



Tritium permeation to He coolant due to ion implantation is 80-100 times larger than that due to tritium bred in breeders



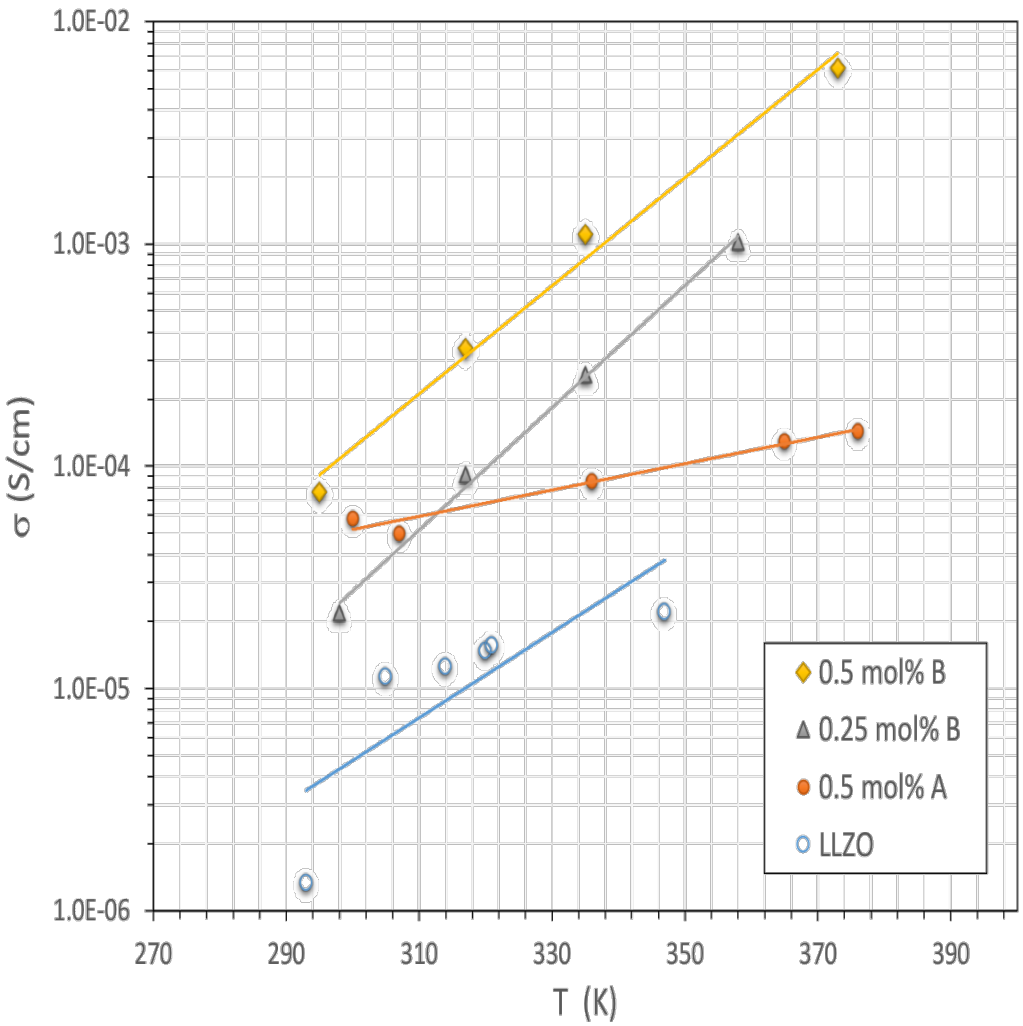
A quasi equilibrium tritium concentration state is being reached in HCS

U.S. DEPARTMENT OF ENERGY | Office of Science

Ucla

VLT Virtual Laboratory for Technology For Fusion Energy Science

Demonstration of Direct LiT Electrolysis using an Immersion Cell



Scientific Achievement

- Samples with Additive "A" and "B" were synthesized and tested to determine Li-ion conductivity at different temperatures
- The 0.5 mol% "B" sample had the highest conductivity and had a projected conductivity of significantly greater than the milestone of 0.5 mS/cm

Significance and Impact

The development of a revised synthesis method allows significant variation of LLZO electrolyte properties and can be used to increase conductivity and strength of the electrolyte

Research Details

- Methods were identified to prevent the formation of undesired phases that reduce conductivity
- One phase of LLZO increased with incorporation of up to 0.5 mol% of A and B
- Higher levels of Additive doping will be tested to further stabilize the desired LLZO properties

Modeling SOL Plasma/Neutral Interactions with PFCs in Present-Day Devices Validates Models

Research Highlight

Scientific Objective

Develop and validate simulation models of particle and heat fluxes to plasma-facing components (PFCs) on present-day devices and assess innovative divertor designs. Aid physics understanding of data.

Achievement

Continued 4D COGENT simulations of LTX to obtain first kinetic ion distribution at core edge and into the scrape-off layer. Provides details of hot ion distribution function striking PFCs in low-recycling LTX.

Continued support of snowflake divertor simulations for present-day devices including cross-field drifts.

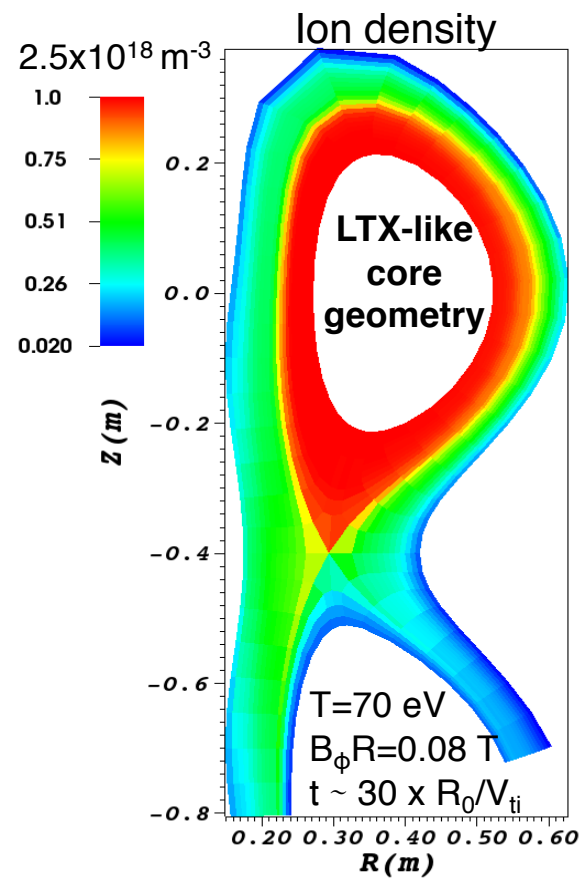
PPCF joint publication accepted: compares UEDGE/TCV-data on effects of ExB/magnetic drifts on PFC heat flux. Trends ok, details need work.

Why it matters

Predictive capability of particle and power loads on PFCs is very important to guiding safe and economical operation of high-power devices such as ITER and to design of future devices.

*N. Christen, C. Theiler, T.D. Rognlien et al., Plasma Phys. Contr. Fusion **59** (2017) 105004.*

COGENT simulation for LTX yields kinetic ion density & non-Maxwellian ion flux to PFC's



U.S. DEPARTMENT OF ENERGY | Office of Science

VLT Virtual Laboratory for Technology For Fusion Energy Science

Critical Issues for Liquid PFCs include Managing Power & Particle Fluxes and Shielding Vapor

Research Highlight

Scientific Objective

Predict edge-plasma properties that are compatible with manageable heat flux and core plasma operation for FNSF design when using of various liquid walls. Compare results with similar configurations that used solid walls to identify key issues and impact on overall fusion performance.

Achievement

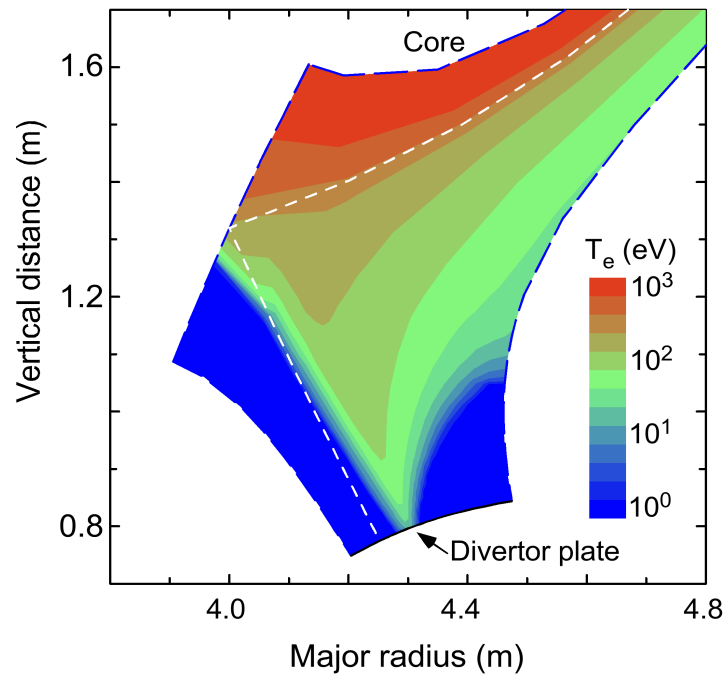
Obtained initial UEDGE Li/D/T simulations for the outer SOL/divertor in 2D FNSF geometry. Most of the input power is radiated by Li, which is injected from the side walls near the divertor plate to model a vapor-box-like configuration. Focus of ongoing work include obtaining steady-state solutions and preventing Li penetration to the core, where it serves to dilute the D/T fuel.

Why it matters

Flowing liquid walls could avoid the issue of wall erosion by ions and neutrals and could also lead to high-performance core operational modes through high-temperature edge conditions.

FNSF divertor electron temperature is 100's of eV in low recycling mode, but sufficient Li injection cools T_e by radiation

Electron temperature in FNSF outer divertor with strong Li injection from sidewalls near plate

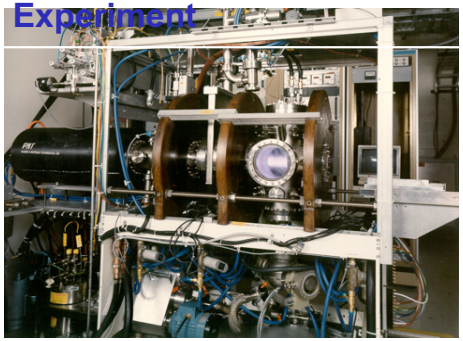
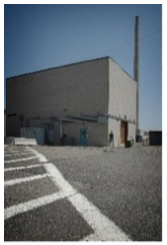
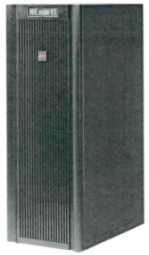
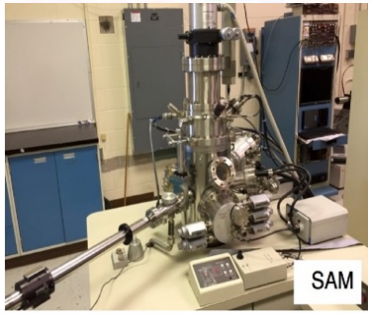
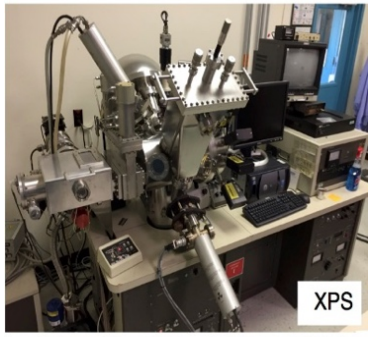
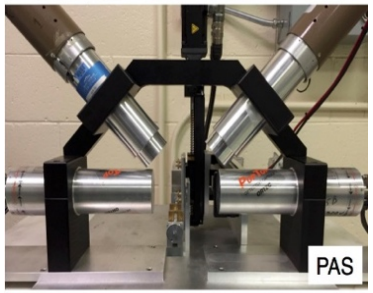


T.D. Rognlien, M.E. Rensink, *Fusion Eng. Design, pub. online.*

Recent Progress in Fusion Safety at INL

- **Fusion Safety Program's Mission**:
  - Assist the US fusion community in developing the inherent safety and environmental potential of fusion power by producing fusion nuclear and tritium licensing data at the Safety and Tritium Applied Research (STAR) facility and developing safety analysis computer codes and data
- **Recent accomplishments**:
  - MELCOR-TMAP development to combine thermal-hydraulic accident analysis with tritium migration to make a more complete analysis tool for licensing fusion facilities
  - Tritium Plasma Experiment (TPE) upgrade with a new plasma generator to improve plasma particle and heat fluxes
  - FSP has added a suite of surface science instruments to interrogate material composition, morphology, and defect structure
  - The STAR lab has also added standby power and additional tritium monitoring for added safety
- **Highlight STAR Publication**
  - B. J. Merrill et al., "Recent Accomplishments of the Fusion Safety Program at the Idaho National Laboratory," presented at ISFNT-13, Sept 2017.

Tritium Plasma Experiment



STAR bldg and new UPS