Fusion Power Program at LANL

Courtesy Dr. Mike Campbell

John Kline

Los Alamos National Lab

FES program manager

ICF program manager

Fusion Power Associates Meeting

Washington, DC

Dec 16th, 2021

Thanks to: G. A. Wurden, B. Uberuaga, & J. Dumont

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LHD NIFS

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tokamak energy

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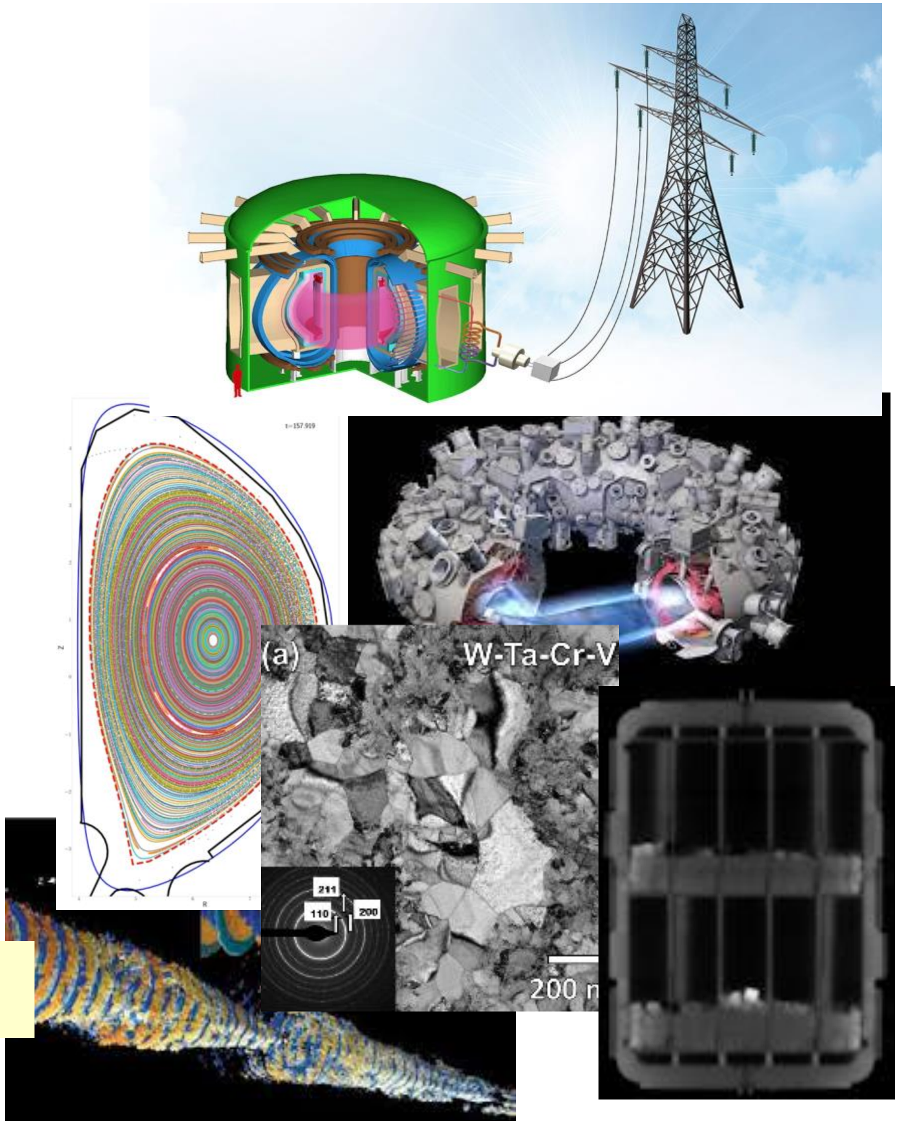
NNSA National Nuclear Security Administration

LA-UR-22-20009

LANL's program focuses on plasma theory/diagnostics, fusion materials, and tritium processing tapping into the vast lab's resources

- **Continue a strong program contributing to advancing fusion plasma theory to solve problems for future tokamak power plants, as well as novel diagnostics to validate our understanding**
- **Develop a strong program to support the advancement of fusion materials needed to realize a fusion prototypical power plant in the 2040 time frame**
- **Build capability to support the communities' need to utilize tritium for both proof-of-principle, scientific facilities, and future power plants.**
- **Develop public-private partnerships to advance commercial fusion using the lab's capabilities**

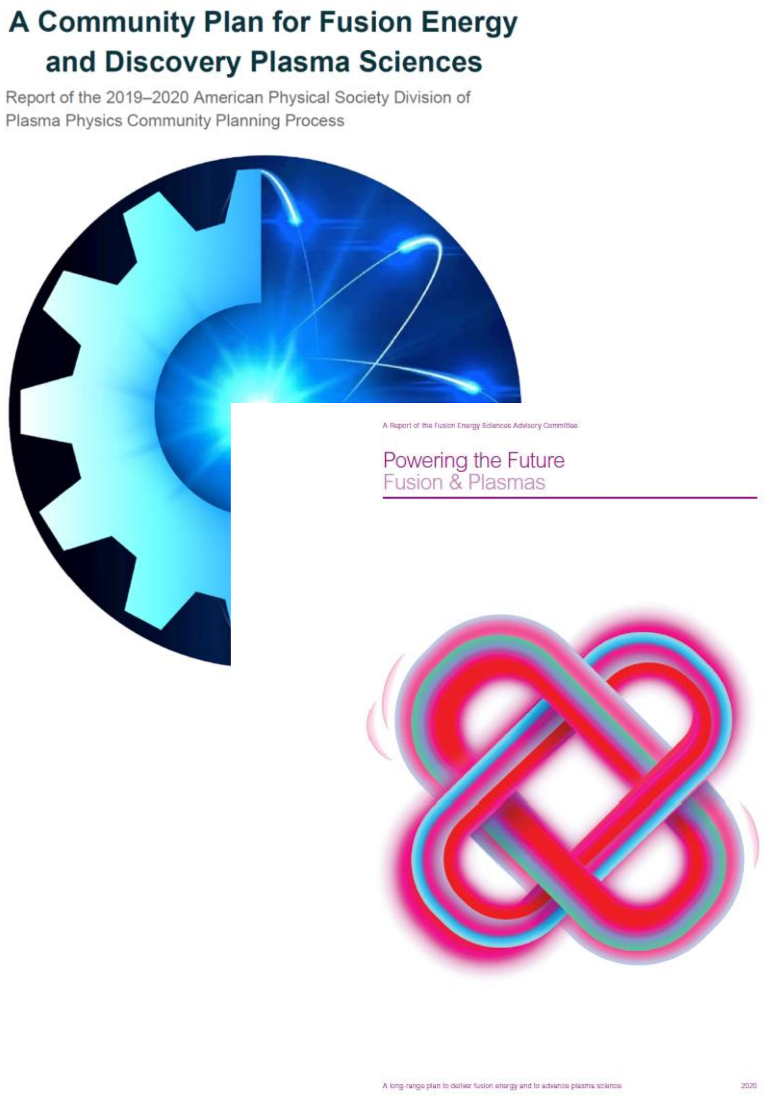


We want to continue LANL's long fusion research legacy

LANL is poised with its capabilities to support the key recommendation from the 2020 FESAC report

FESAC report :

- **Pivot** the research and development focus **toward fusion materials and technology**
- **Immediately establish the mission need for an FPNS** facility to support development of new materials suitable for use in the fusion nuclear environment, and pursue design and construction as soon as possible
- **Significantly expand** blanket and **tritium research** and development
- **Close fusion pilot plant design gaps** by utilizing research operation of DIII-D and NSTX-U, and **collaborating with other world-leading facilities**
- **Expand existing and establish new public-private partnership programs** to leverage capabilities, reduce cost, and accelerate the commercialization of fusion power and plasma technologies
- **development of innovative ideas** that could lead to more commercially attractive fusion systems and address critical gaps with entirely new concepts



LANL continues to contribute novel diagnostics for fusion experiments

- **Provide key diagnostic measurements to the FuZE stabilized z-pinch experiment at Zap Energy.**
  - Electromagnetic and Particle Diagnostics for Transformative Fusion Energy Concepts
    - *Providing neutron yield immediately after each pulse, at levels of 1x10^5 or higher neutrons per shot.*
    - *Identify impurity content via visible spectroscopy.*
    - *High-speed multi-frame x-ray movies of the plasma to study instabilities and plasma motion.*
  - Portable Soft X-Ray Diagnostics for Transformative Fusion-Energy Concepts
    - *X-ray emission from the tail of the electron distribution can be used to estimate the time history of the central electron temperature.*
    - *High-speed visible and multi-frame x-ray movies of the plasma to study instabilities and plasma motion.*
    - *Extreme ultraviolet emission spectroscopy identify plasma impurities, from key spectral lines.*

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Portable Soft X-Ray Diagnostics for Transformative Fusion-Energy Concepts

Early Research Highlights:

- Plasma motion complicated our first attempt with four filtered PMT's mounted on opposing sides of the FuZe machine.
- Switch to compact 7-detector "XUV7"silicon detectors, all mounted on the same port. We now have good signals from all seven foils, with excellent S/N ratios.
- High speed visible imaging shows development of the plasma at the time of peak x-ray and neutron emission.

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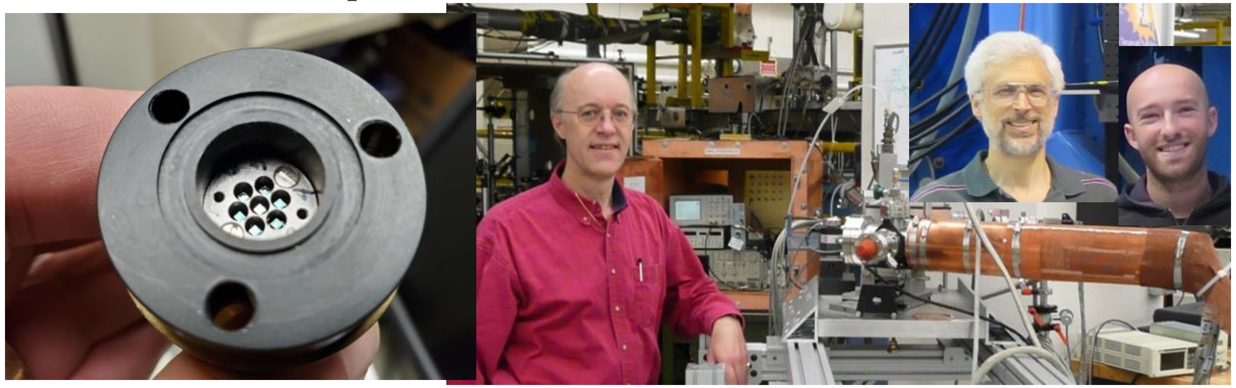
Next Steps:



- The EUV spectrometer is being checked out at Reno, and modified for FuZe's challenging vacuum environment, and will be fielded in 2022.

For more information:

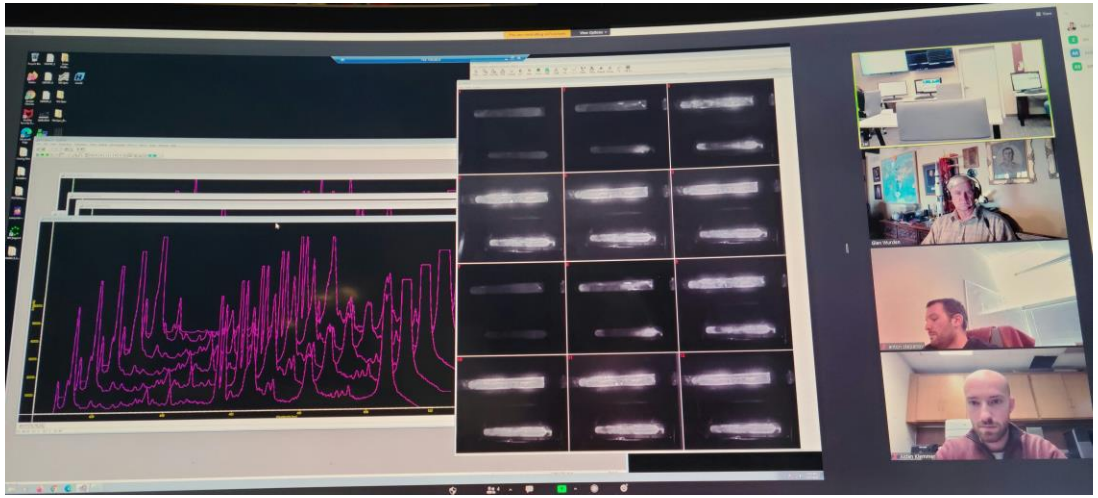
Contact: Dr. Glen Wurden, wurden@lanl.gov

Also, there will be a poster at the upcoming APS-DPP meeting, Nov. 2022

Electromagnetic and Particle Diagnostics for Transformative Fusion Energy Concepts

Research Highlights

- **First data was obtained in Dec 2021, at the U of Washington via Zoom from Los Alamos. Then FuZe and the diagnostics were moved to Zap Energy's new lab in Everett, Washington.**



- **Now data runs are being made both in person, and via Zoom (linking New Mexico, Nevada, and Washington).**

Next Steps:

- LANL's Arsenic neutron activation system is operational at FuZe, and being used on each pulse.
- LANL's visible spectroscopy is also operational at FuZe, and taking data.
- The solid state multi-frame x-ray imager from Germany has been delayed into 2022 (largely due to Covid impacts).

For more information:

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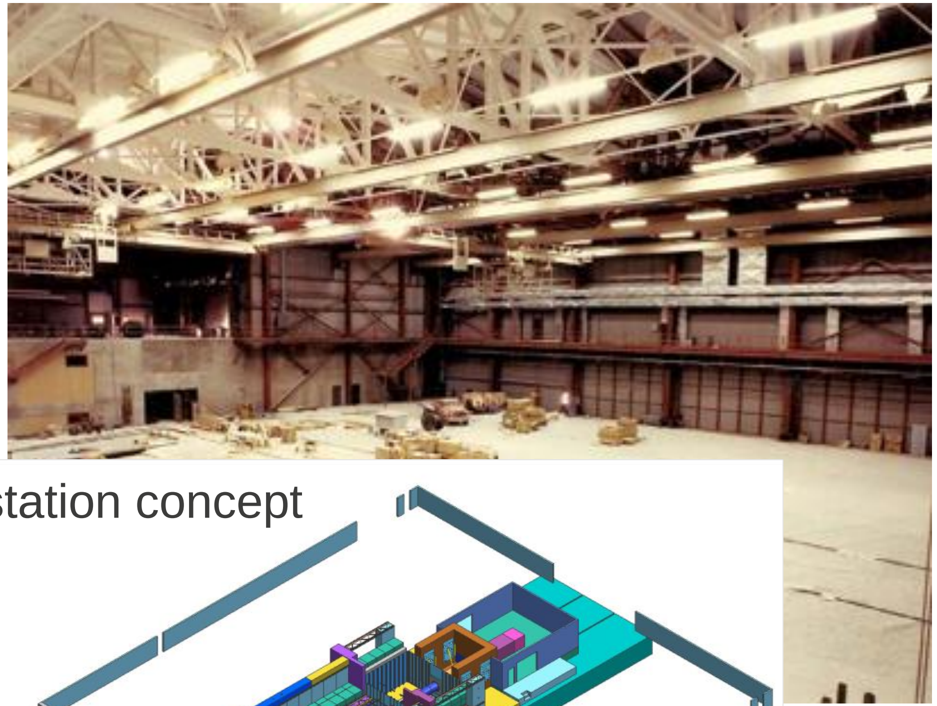
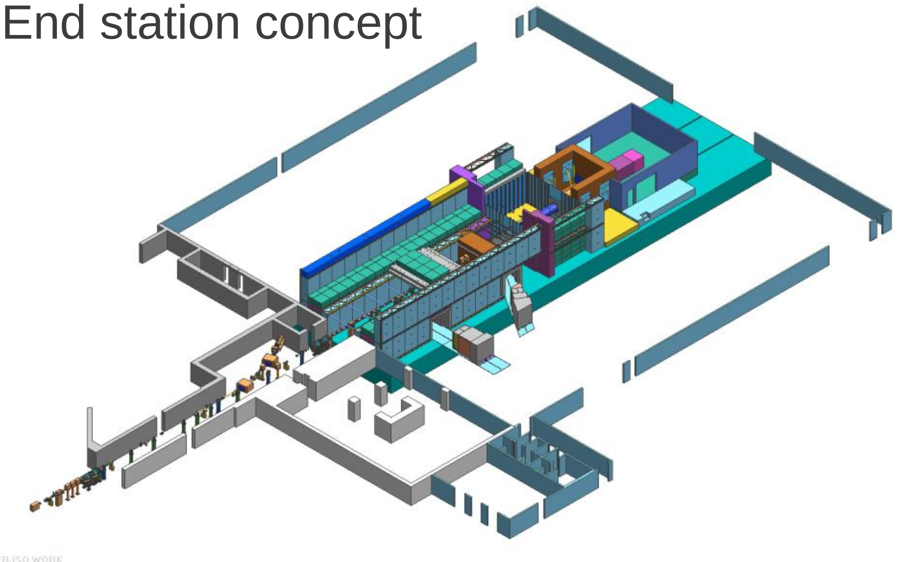
We continue to evaluate the use of LANSCE to drive a Fusion Prototypic Neutron Source (FPNS)

- **Our efforts this year focus on addressing concerns raised for a beam driven source using LANCE:**
  - *Reliability and run time for FPNS*
  - *Beam time/ space sharing with other programs*
  - *Effects of spallation tail for surrogacy*

Current activities at LANL:

- *We will hold a workshop to discuss surrogacy of a spallation source for fusion neutrons*
- *We are evaluating the thermal loading of the target*
- *We are examining designs that will support both FPNS and isotope production missions*





End station concept

Team: E. Pitcher, Phil Ferguson (ORNL)

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The project benefits from NNSA's investment in a new accelerator front end for LANL

To get to a demonstration fusion power plant requires developing materials that last under harsh DT reaction environments

FPNS needs compared with applications

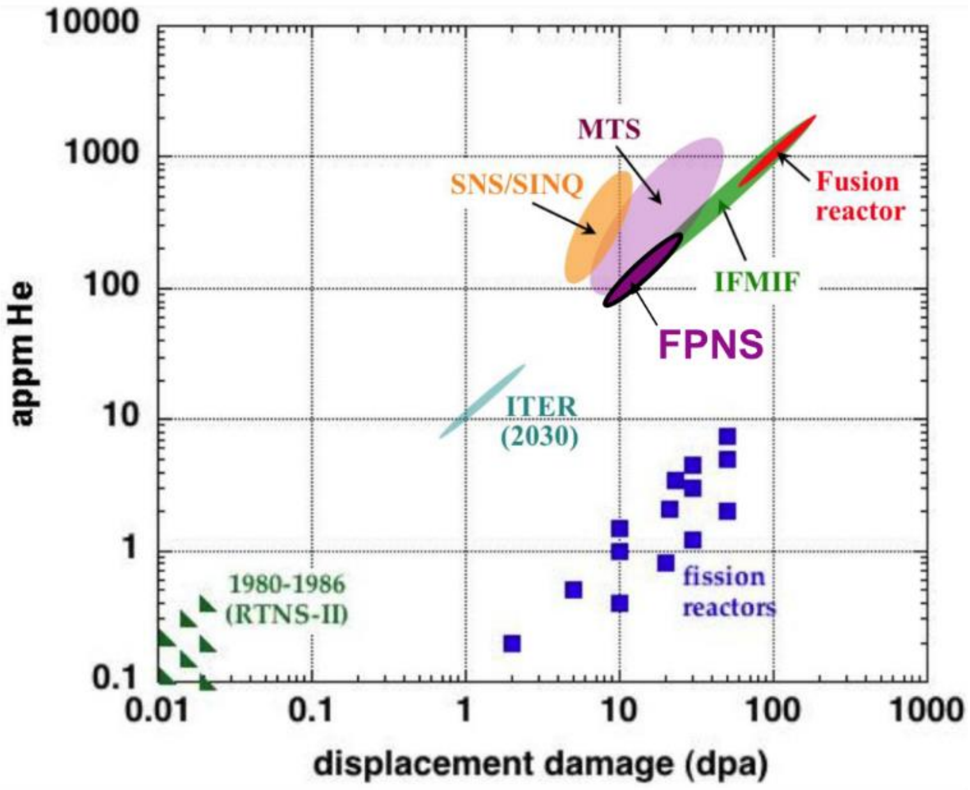
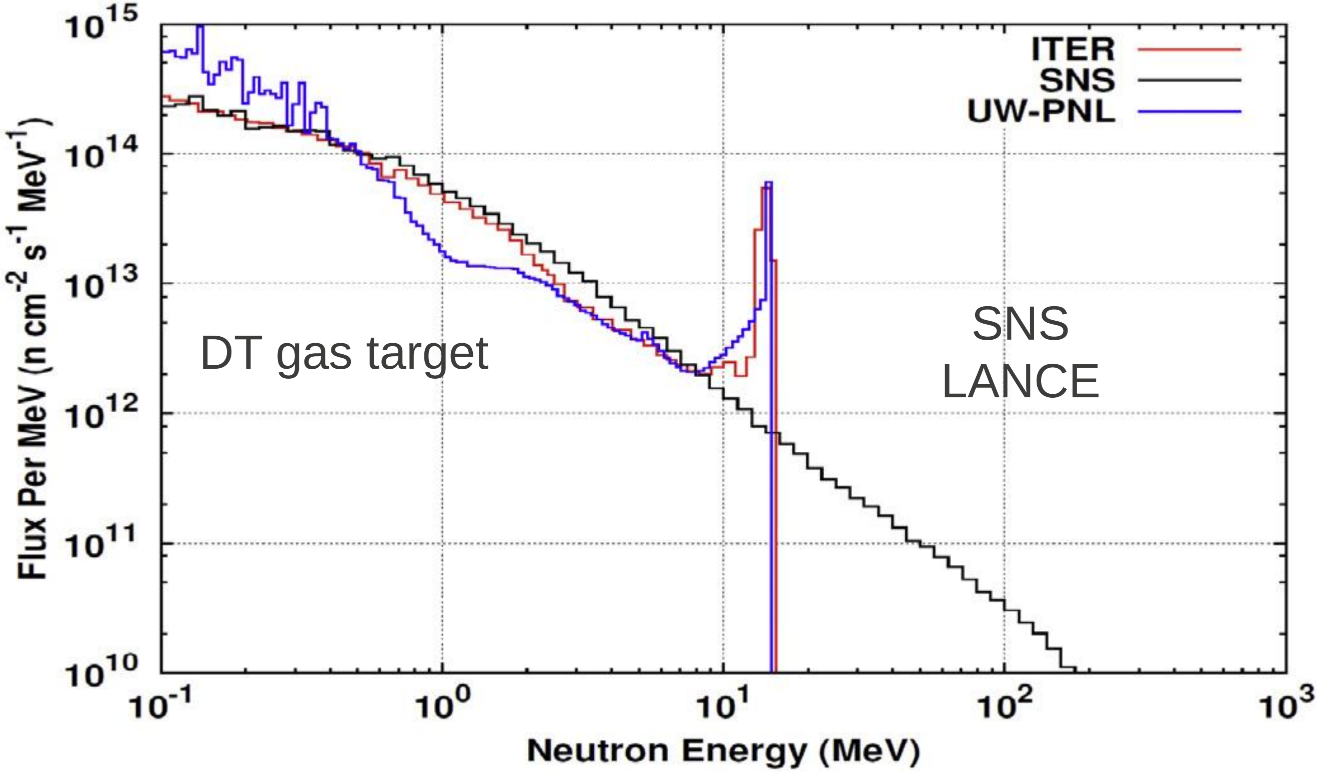


Figure adapted from FESAC Report DOE/SC-0149, February 2012.

Predicted neutron energy spectrum



B. Egle, et al. “Fusion Prototypic Neutron Source for near-term fusion material testing”, APS-DPP Nov 9th 2020

We are focusing on High Energy Alloys (HEA) as a path to fusion materials taking advantage of synergies with NNSA needs

HEAs are a new material formation targeted for maintaining strength under extreme radiation conditions

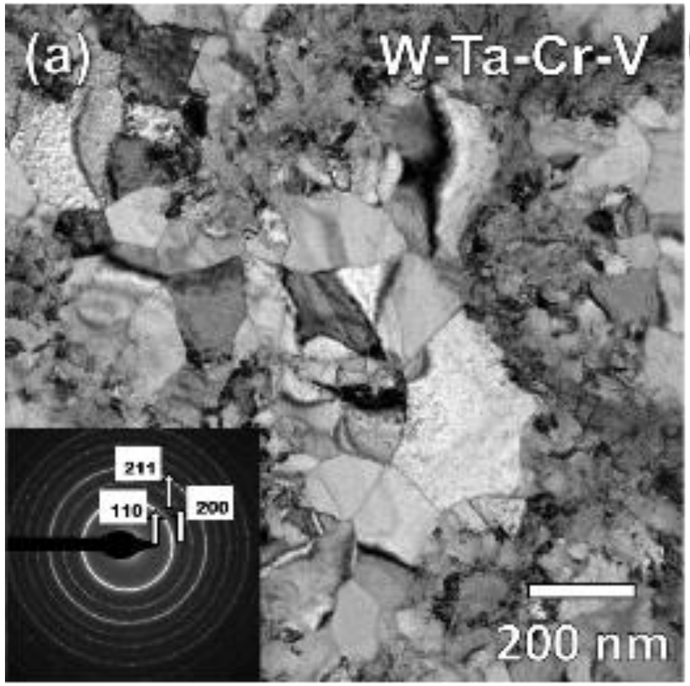
- Investigating single phase refractory high entropy alloy (W-Ta-Cr-V) of nanocrystalline grain size is alternative to pure W
- high hardness to high radiation tolerance under heavy ion irradiation at room temperature or very high temperatures.

HES are important because Significance and Impact

- This alloy showed no loop formation after heavy ion irradiation up to 8 dpa at RT and 1050 K.
- alloys are suitable for bulk production coupled with the exceptional radiation resistance

LANL owns the capability to

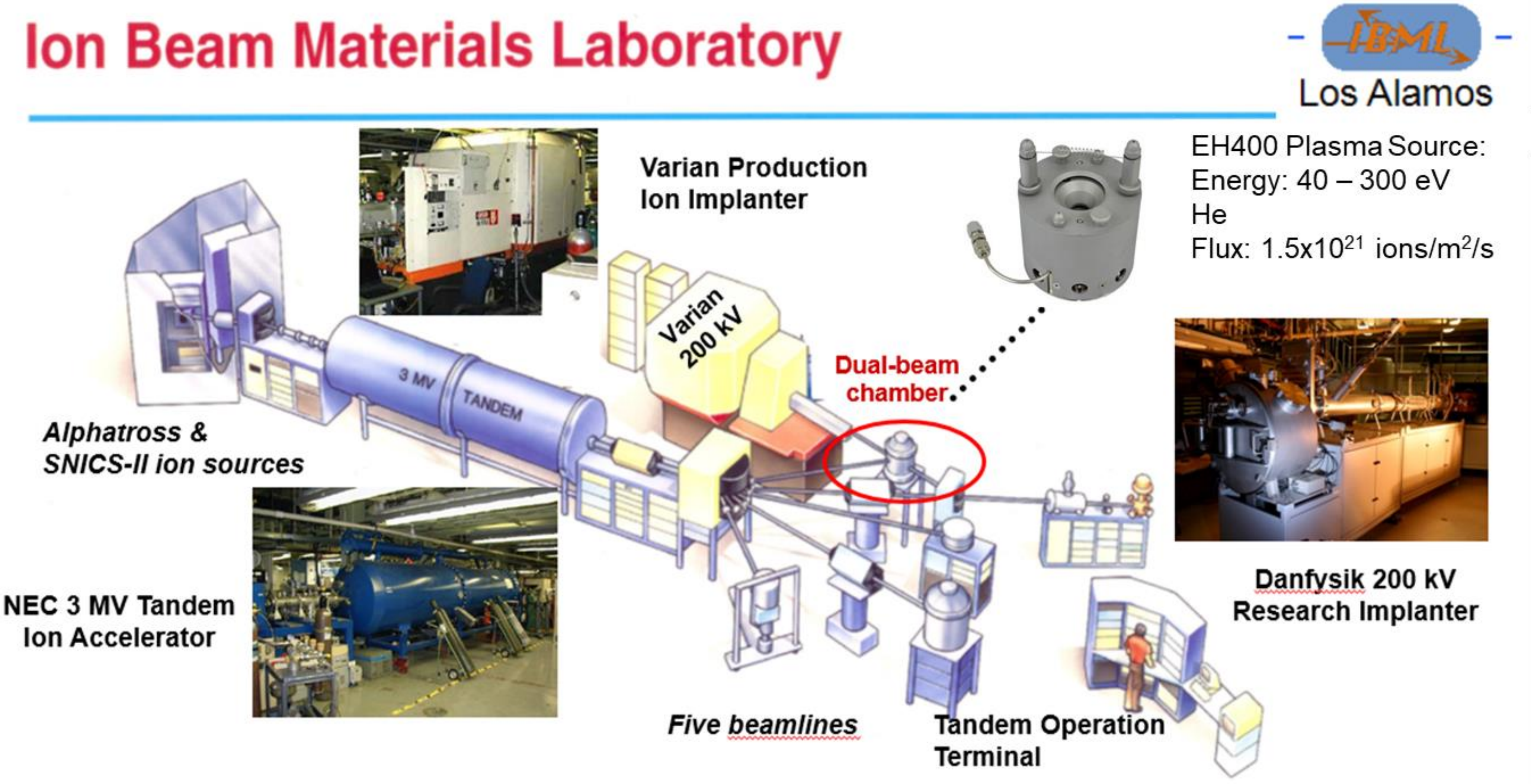
- manufacture Nanocrystalline W-Ta-Cr-V was prepared via PVD.
- Test using local facilities
- Theory capability DFT and Monte Carlo simulations were in remarkable agreement with the experimental result.



SEM of HEA

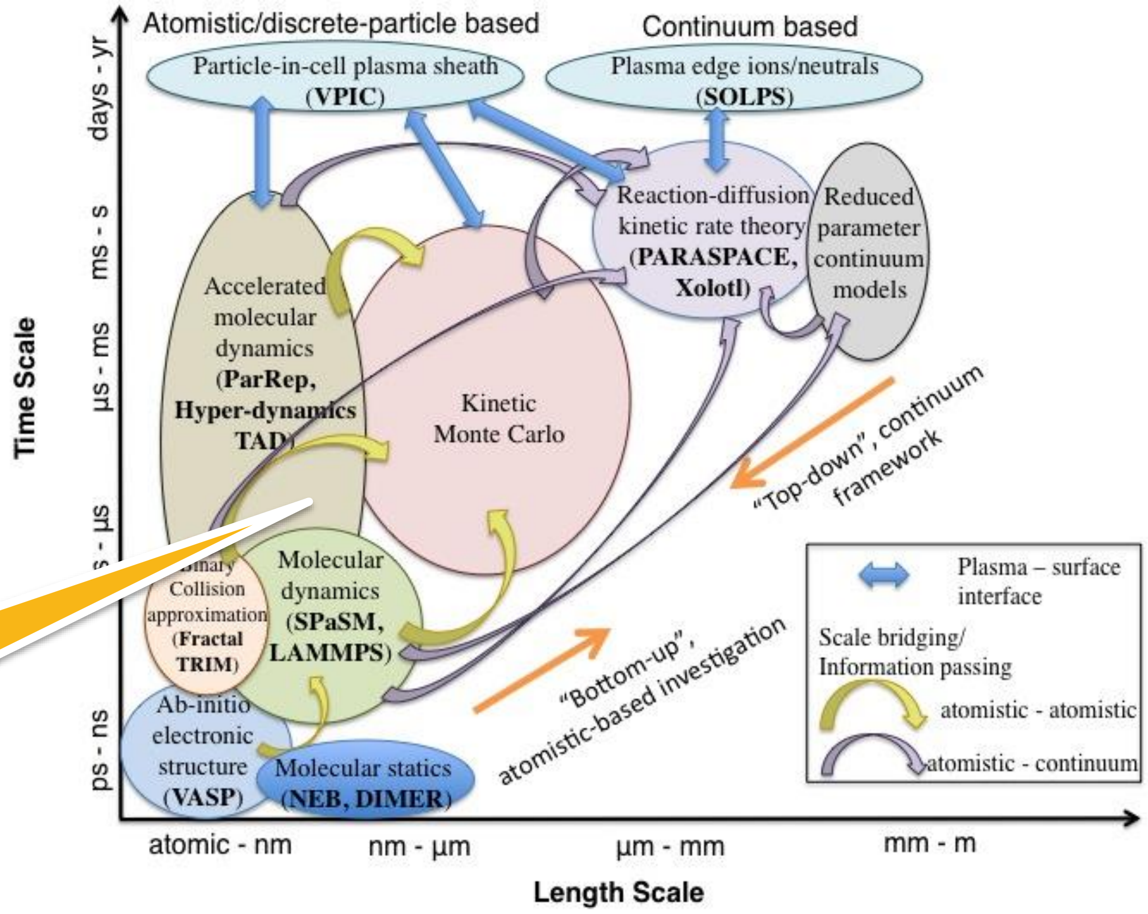
HEAs research has synergies with NNSA's needs enabled FES to leverage a larger body of research

Collaborations with the ion beam materials laboratory provides additional unique fusion materials testing with fission reactor research synergies



LANL modeling efforts support the development of a multiscale paradigm where atomistic insight informs larger-scale models to reach experimental time scales[1]

- **We are developing a multiscale paradigm where atomistic insight informs larger-scale models to reach experimental time scales – *PI Brian Wirth***
- **Goal: Discovery science to identify mechanisms of He/H evolution and Be intermixing**
- **LANL's role: Discovery science at the atomistic scale to identify mechanisms that may govern the evolution of the material**

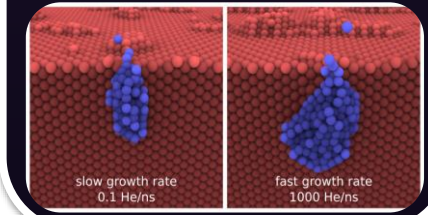


Work supported by SciDAC

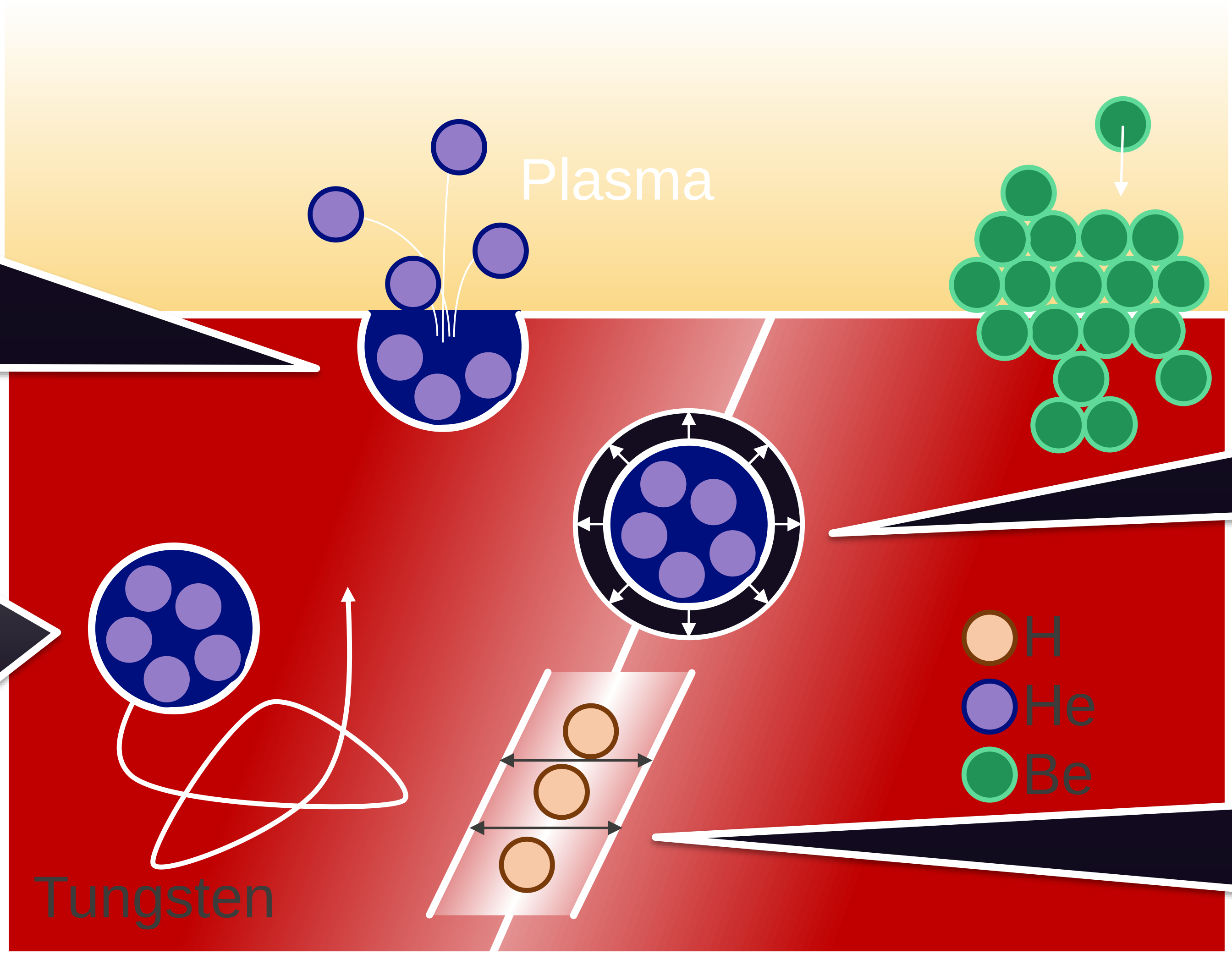
[1]BD Wirth, et a., "Challenges and Opportunities of Modeling Plasma Surface Interactions in Tungsten using High Performance Computing, *Journal of Nuclear Materials* (2015)

Several contributions to the understanding of materials for fusion reactors have been made to date

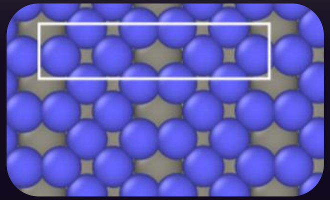
Bursting rates and morphologies depend on He arrival rate



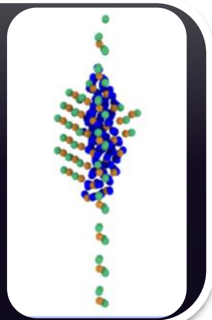
He bubbles can move remarkably fast, changing He retention predictions



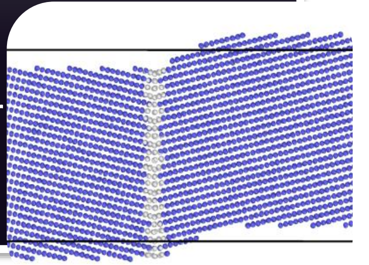
Be overlayers have complex structures that depend on density



He bubble growth very different at GBs than in bulk



H has complex impact on GB mobility, depends on GB character



LANL continues to understand key aspects for tritium processing often built on imperial models developed in the lab

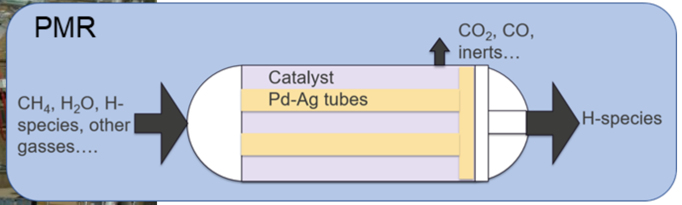
We use the Hydrogen Processing Lab to develop and validate models for tritium processing design

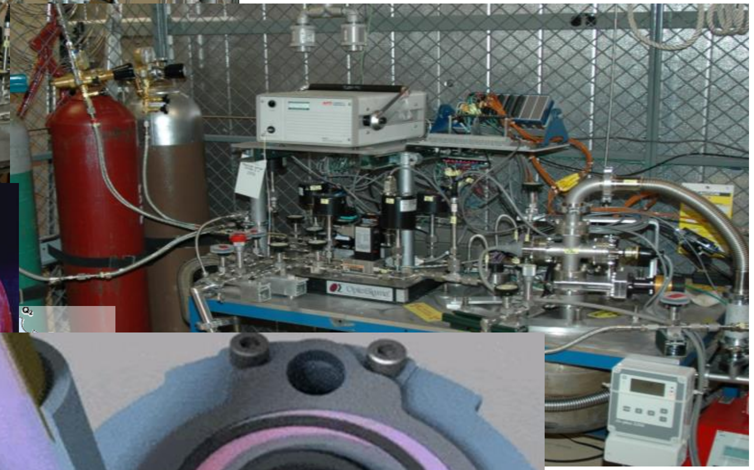
- *Component models of empirical*
- *Permeator & separator work for chemical processes*
- *Tritium pumping and storage*

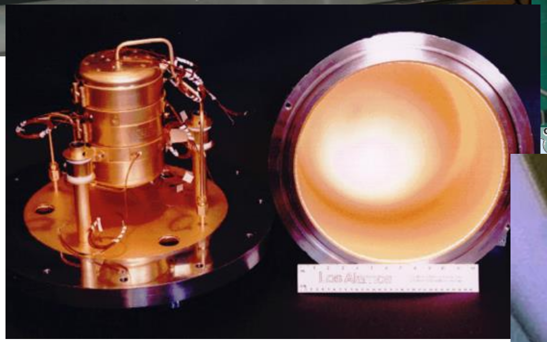
- **Recently, we have evacuated scroll pumps for Air Squared for operations in a hydrogen environment**
- **Gene, we are working on opportunities to use Tritium as opposed to hydrogen and deuterium.**

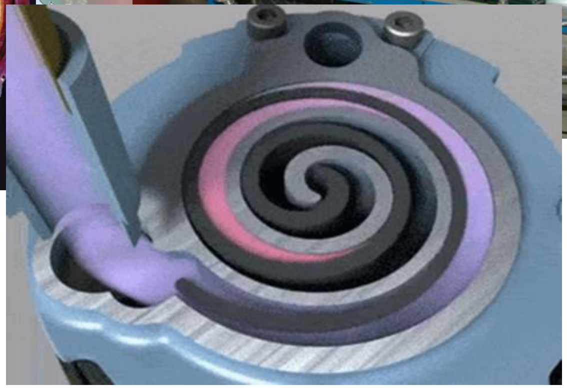
Hydrogen Processing Laboratory (HPL)

Palladium membrane reactor (PMR)









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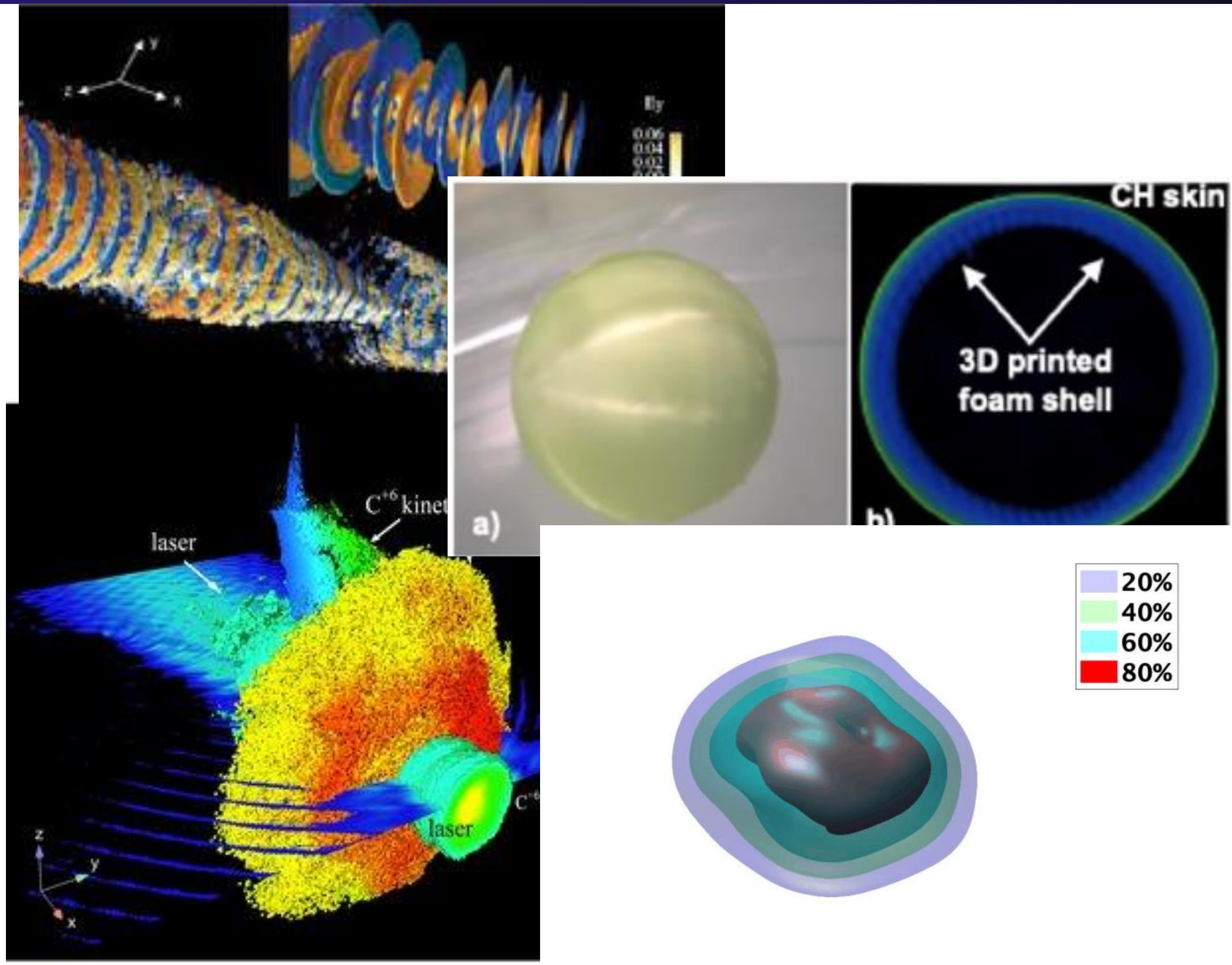
LANL engaging in inertial fusion energy activities as part of a national workshop, as well as looking to team with the private sector

- **Major ICF design lab with computing resources and experimental experience**
- **LANL strengths for IFE include:**
  - *Strong Laser Plasma/Matter Interactions research capabilities for 3D modeling*
  - *Leading the development of liquid layer targets for direct drive after demonstrating them for indirect drive*
  - *Past experience developing particle beam ion sources needed for ion fast ignition*
- **Unique computation capabilities for integrated 3D target simulations**
  - xRage Eulerian code
  - iFP Vlasov-Fokker-Planck code for kinetics
- **Expertise in nuclear fusion diagnostics with idea to deliver capabilities**



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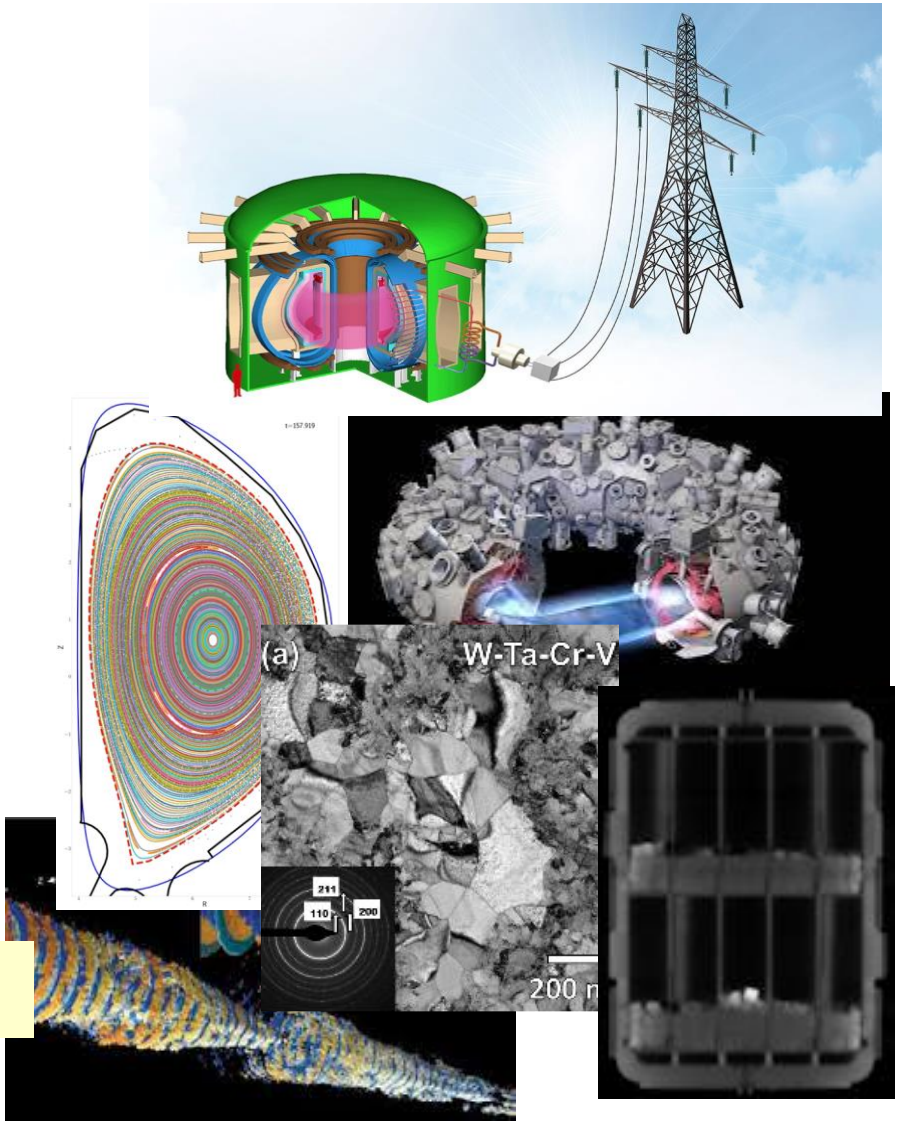

We want to continue LANL’s long fusion research legacy

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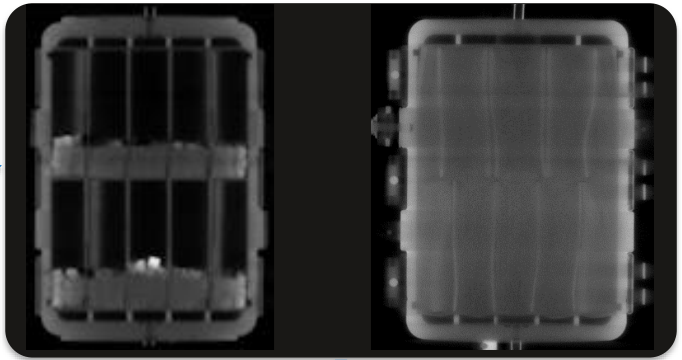
We are using the STACI bed to advance our modeling capabilities to build confidence for ITER and fusion power plant tritium handling

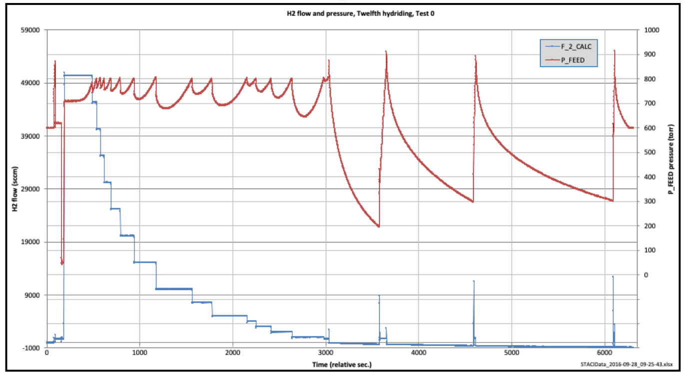
Experimental work
Hydriding/ dehydriding of Uranium

Materials characterization

X-Ray Computed Tomography

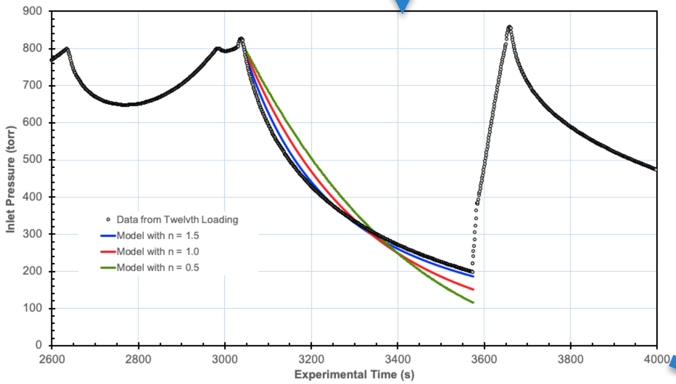


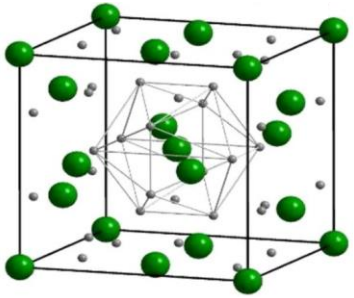
Experimental data

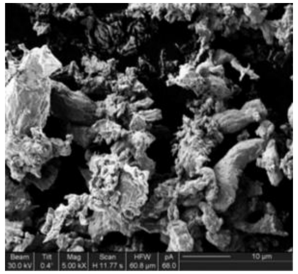


Kinetic model

$$r = \frac{k_o \cdot e^{-E_a/R\cdot T}}{s} \cdot \left(P^n_{Q_2} - \frac{1}{K_{eq} \cdot P^{3/2-n}_{Q_2}} \right)$$







Hypes et al., Uranium Bed Design Parameters for Tritium Plants Supporting Fusion Reactors, Fusion Science and Technology (ANS Winter 2020)

Information about material state, surface area, particle size