Fusion Energy Sciences Program at LLNL

2020 FPA Meeting

Harry S. McLean
Program Leader, Fusion Energy Sciences Program
Associate Division Leader, PLS/Physics

December 16-17, 2020

LLNL-PRES-817811

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

The Fusion Energy Sciences Program (FESP) at LLNL is the POC for two DOE Offices: SC/FES and ARPA-E/Fusion.

Along with programmatic work for some areas of NNSA, FESP's broad engagement is a key benefit to all sponsors both for our scientific depth and our flexibility in adjusting to budget fluctuations

- **Fusion Science and Plasma Physics:** core competencies and disciplines essential to LLNL's mission-based science from both NNSA and SC perspectives.
- **S&T for HEDS:** The SKAs underlying Burning Plasmas is central to LLNL's HEDS applications space.
- **Partnering within LLNL:** shared capabilities with **LLNL Engineering** on pulse-power driven fusion devices (DPF, "other" areas and sponsors)
- **Partnering with other DOE Labs, Academia and Industry:** LLNL has experimental and theoretical collaborations with all major DOE FES facilities as well as PI and co-PI roles in multi-institutional fusion centers.

Fusion delivers mission science, discovery science, and workforce development

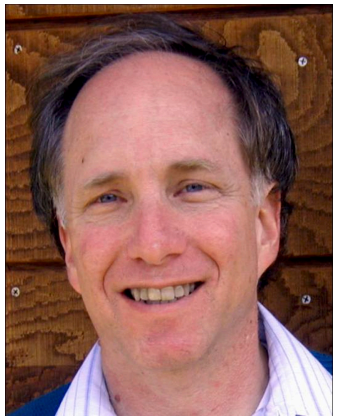
LLNL FES Program and Discipline FY20 Organization

Harry McLean
FES Program Leader
ADL PLS/PHYS

National Security Applied Plasmas
John Barnard

Pulsed Power Fusion Plasmas
Andrea Schmidt (APL)

Theory & Modeling
Alex Friedman



DIII-D
Steve Allen

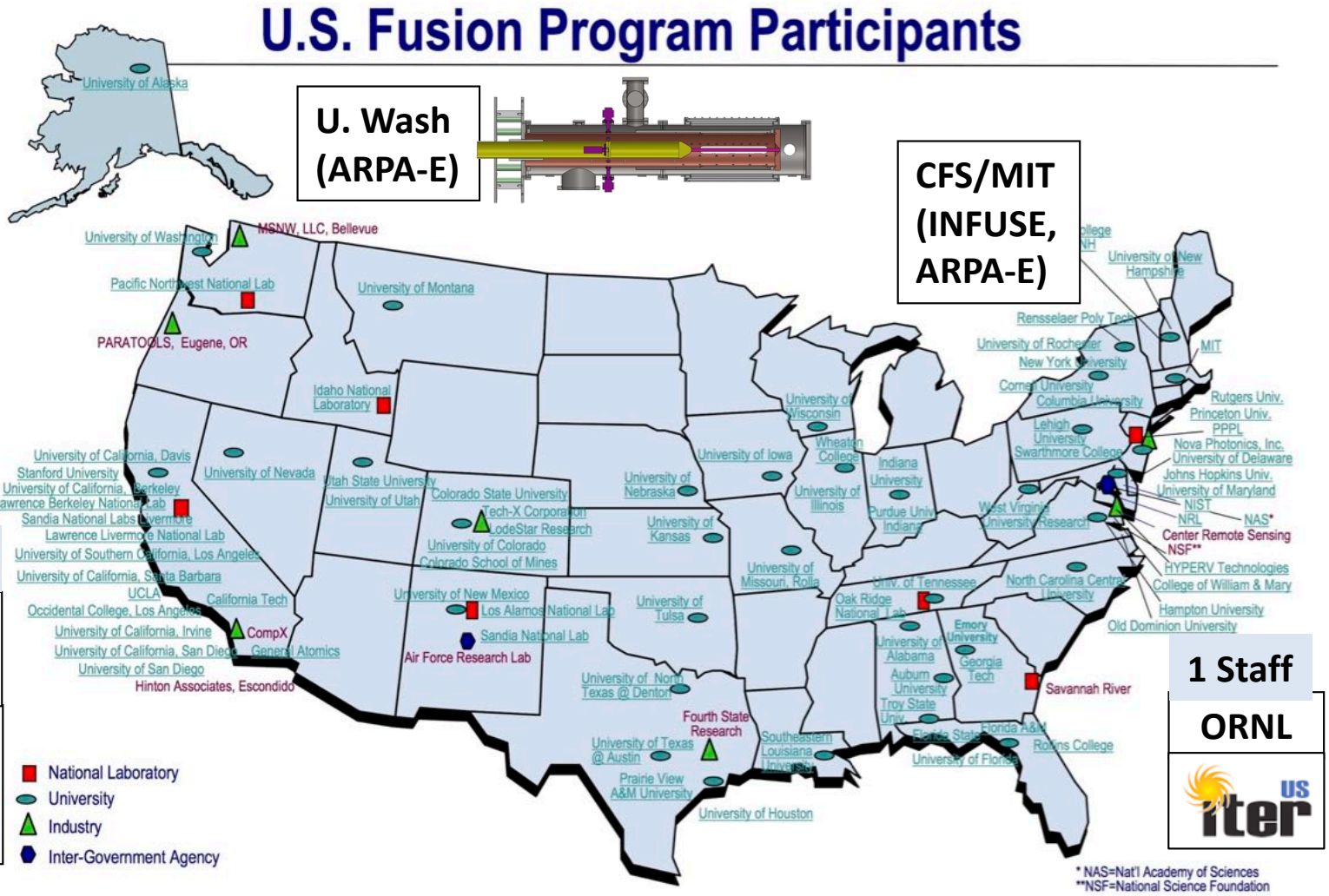
NSTX-U
Vlad Soukhanovskii

Mat'ls & Technology
Tom Rognlien

HEDLP/LaserNetUS
Tammy Ma

ITER Magnets
Nicolai Martovetsky

LLNL/FESP participates at the primary US MFE Facilities

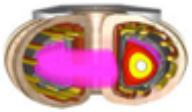


30 Staff

LLNL

10 Staff

General Atomics



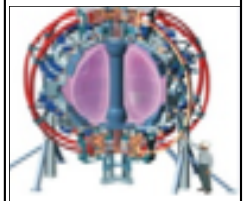
DIII-D

U. Wash (ARPA-E)

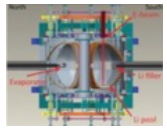
CFS/MIT (INFUSE, ARPA-E)

2 Staff

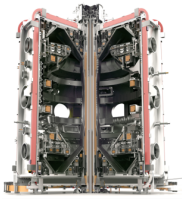
PPPL



NSTX-U



LTX-β



Mast

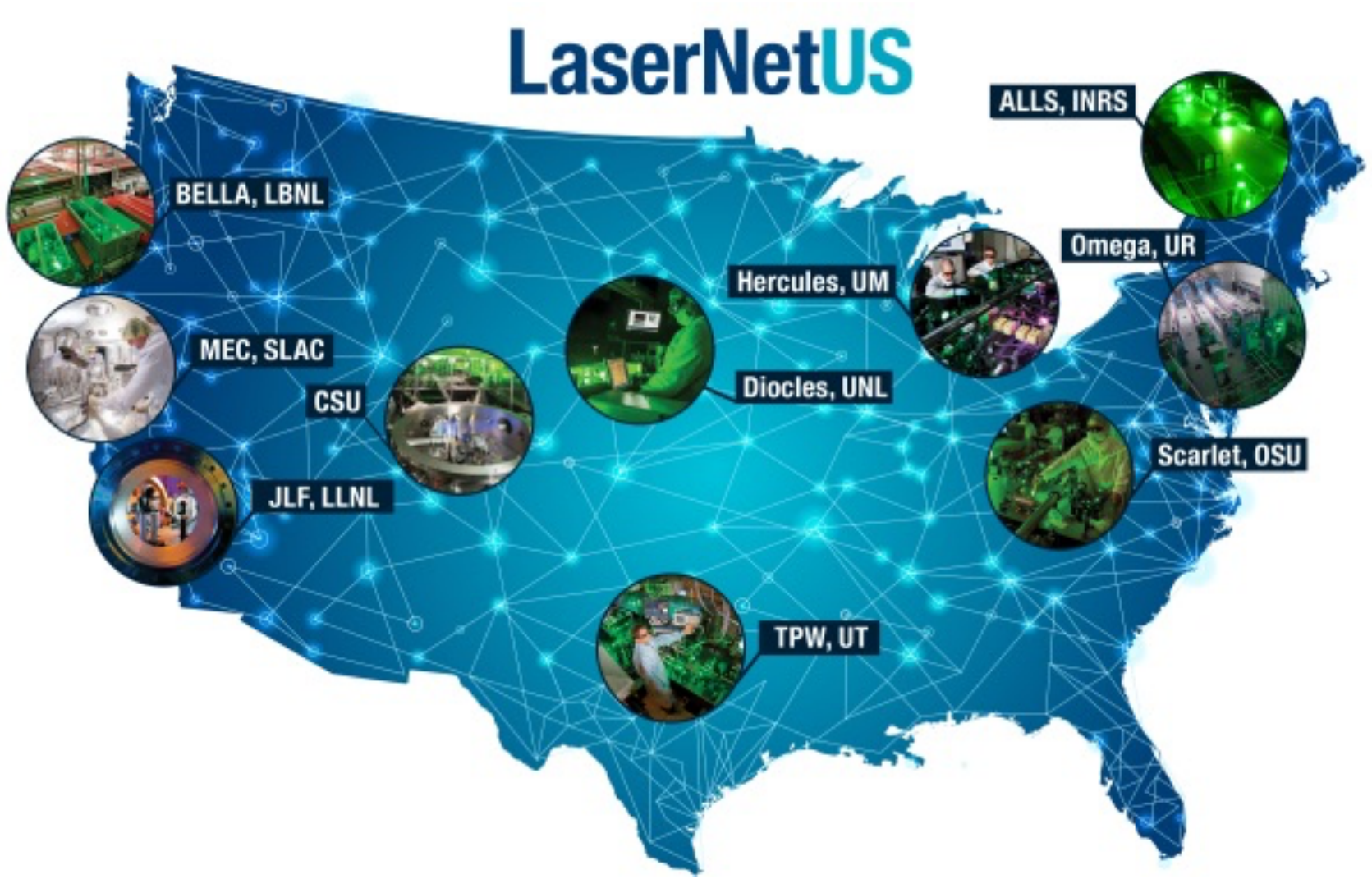
1 Staff

ORNL

ITER US

National presence is boosted by having permanent LLNL staff in residence

LLNL/FESP also participates at LaserNetUS and other HEDLP Sites

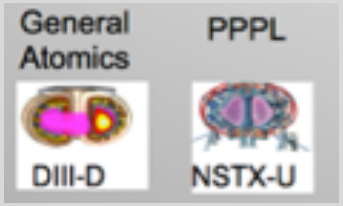


LLNL helps manage procurements and other needs to execute experiments

LLNL's Fusion Energy Sciences Program (FESP) has funded activities in all SC FES research categories

SC FES FY20 (671 M$)

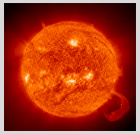
- **Foundations (280M)**
  - MFE Experiments
  - MFE Theory



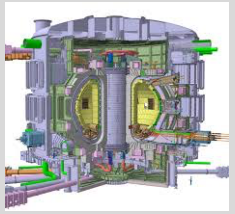
- **Long Pulse (70M)**
  - Superconducting Tokamaks
  - Stellarator Experiments
  - Materials
  - Technology


EAST (China)

- **Discovery Plasma Sci. (84M)**
  - General Plasma Science
  - Measurement Innovation
  - HEDLP: Expts at JLF, NIF, SLAC/LCLS, LLE/OMEGA



- **ITER + MEC (257M)**
  - US-ITER Project Office
  - ITER Organization
  - MEC ~ 15 M

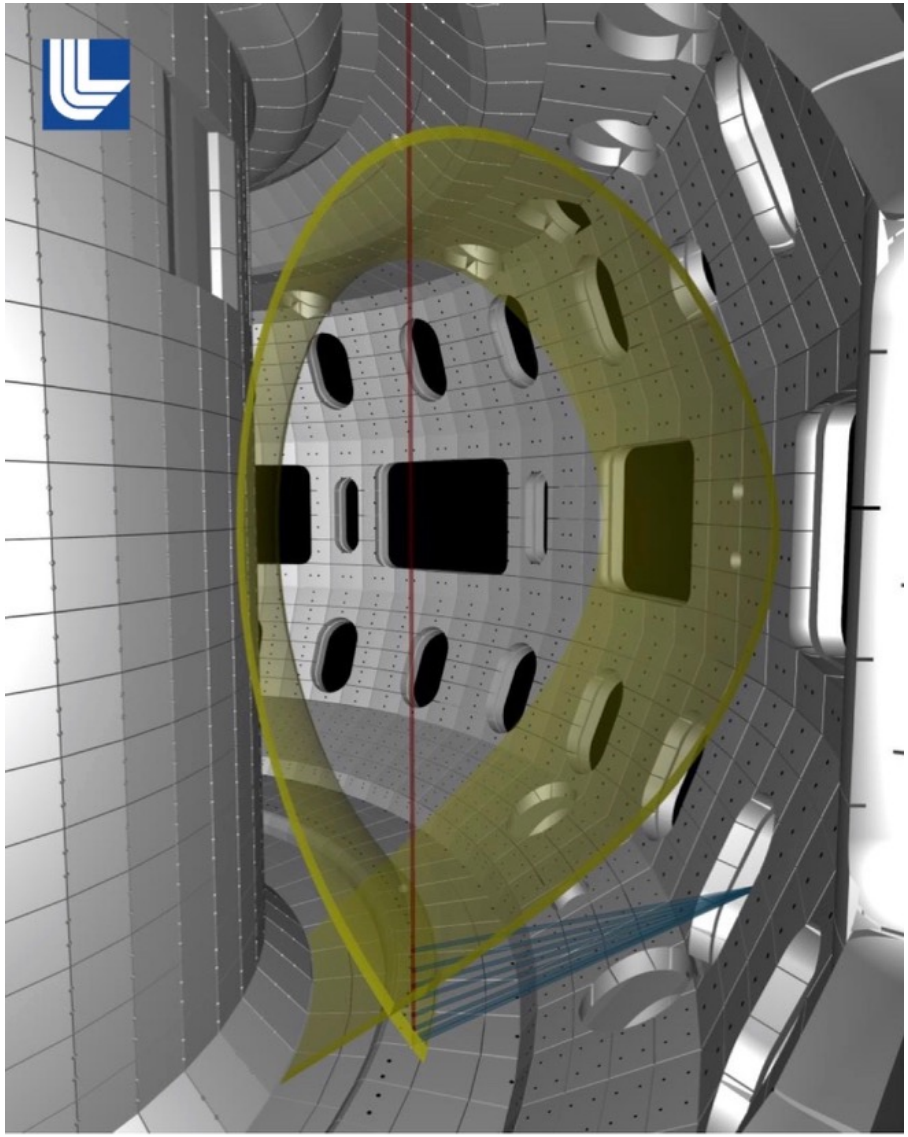

ITER (France)

LLNL FES Program

- **Foundations:**
  - DIII-D collaboration at GA, 10 LLNL staff in residence
  - PPPL, MAST (UK) collaboration, 2 staff in residence
  - Theory & Modeling + SciDACS, 16 Staff
  - HED Machine Learning
  - INFUSE
- **Long Pulse**
  - International: EAST (China)
  - Materials and Fusion Nuclear Science
- **Discovery Plasma**
  - Gen. Plasma Sci: Sheath, flux tube physics
  - Measurement Innovation
    - Quantum Calorimetry
    - High-Rep HEDLP Diags
  - HEDLP: Expts at JLF, NIF, SLAC/LCLS, LLE/OMEGA
    - FES Early Career (3 FY19, 4 FY20, 3 FY21)
    - LaserNetUS (experimental support)
  - QIS
- **Construction: ITER (1 FTE)**

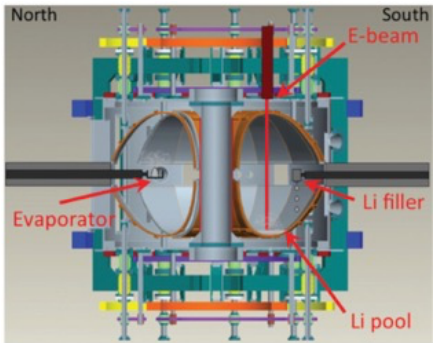
LLNL at DIII-D is active in both Divertor Science and Advanced Tokamak (Steady-state operation) Research

1. **Divertor Research: new measurements / modeling**
   - EUV spectroscopy, Infrared imaging, divertor T_i
   - UEDGE modeling, including plasma flow effects
   - Snowflake joint project: DIII-D, LLNL Theory, NSTX
2. **Advanced Tokamak program and Scenario Development**
   - Long-pulse Dynamics & Control
   - Core measurements
   - International Collaboration with EAST
3. **EUV spectrometer- Tungsten campaign**
   - Joint with LLNL/PLS/Physics
   - Similar to instruments fielded by FESP on NSTX
4. **Collaboration with Universities**
   - Tungsten Source Rates
   - Flow measurements via Coherence Imaging diagnostic
   - Diagnostic development on Auburn device



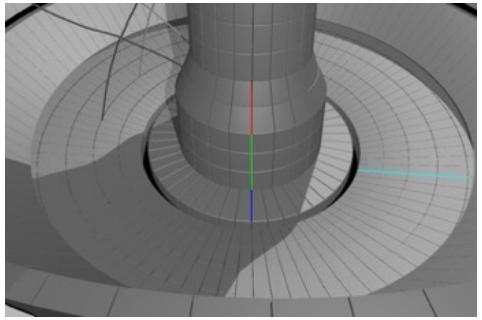
LLNL Experimental Research at PPPL is focused on Spherical Tokamak Program: LTX, MAST-U, and some NSTX-U Recovery/Physics Planning

1. **Boundary Physics Research on Spherical Tokamaks**
   - Lithium Tokamak Experiment (LTX)–beta
     - SOL turbulence and plasma-surface interactions with liquid lithium and tin
   - Mega-Ampere Spherical Tokamak Upgrade (MAST-U) in the U.K.
     - Divertor detachment and snowflake divertor studies
     - Fielding Diagnostics
     - First plasma achieved 29 Oct 2020

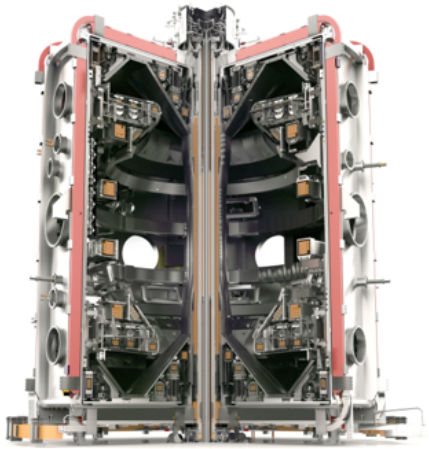


Lithium Tokamak eXperiment Beta in Princeton Plasma Physics Laboratory, Princeton, New Jersey

2. **NSTX-U collaboration research**
   - Contribute to NSTX-U Program activities (e.g., PAC, JRT)
   - Develop preliminary concepts for PFC monitoring system
   - Contributions to machine, PFC and diagnostic design, engineering, and assessment



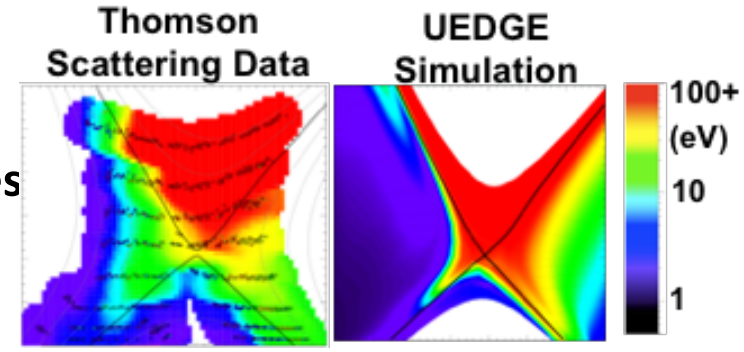
Conceptual view of PFC monitoring system viewing NSTX-U divertor



Mega-Ampere Spherical Tokamak Upgrade in Culham Centre for Fusion Energy, Culham, United Kingdom

LLNL/FESP's Theory, Modeling, SciDAC research focuses on tokamak edge physics and integrated modeling/MHD

- **Mission: Advance theoretical understanding and predictability of fusion plasmas**
  - Two main research focus areas: Edge Physics and Integrated Modeling
- **We pursue innovation in areas such as:**
  - advanced divertor design and operation
  - understanding, control, and mitigation of instabilities
  - predictive and whole device modeling
  - advanced algorithm development
  - advanced computing through SciDAC, exascale, and QIS other initiatives



- **We prioritize research with strong connections to experimental physics:**
  - Provide theoretical support for planning, analysis and modeling of experiments on DIII-D, NSTX-U, MAST, EAST, KSTAR, …, and many others
  - Provide scenario development tools for ITER and CFETR
- **Efforts are strengthened by connections to NNSA and SC computational mathematics:**
  - LLNL Center for Applied Scientific Computing (CASC)
  - LBNL Applied Numerical Algorithms Group (ANAG)

International collaborations with China and South Korea are a part of reciprocal relationships

FESP Staff go to China several times a year

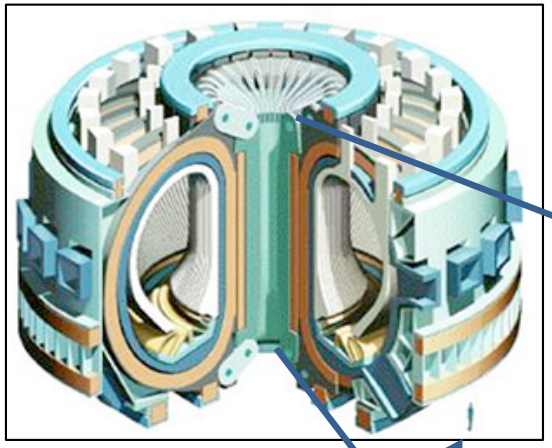
- Whole device modeling
- Advanced Tokamak experiments and remote control

FESP host at LLNL 4-6 Chinese faculty, post-docs, and students

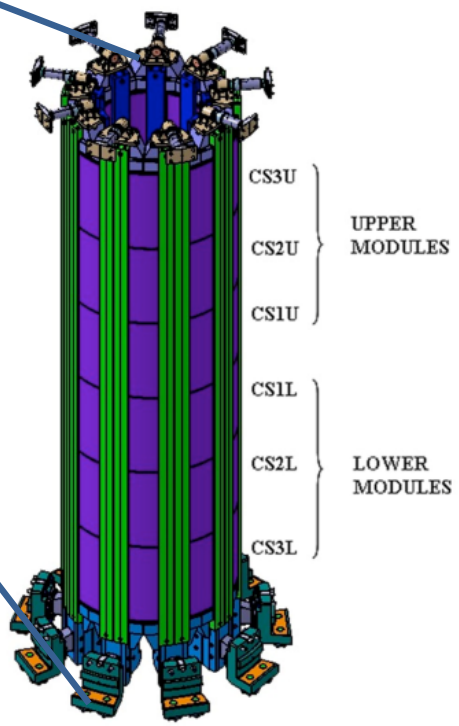
- Plasma-edge physics
- Boundary-turbulence modeling
- Yearly BOUT++ Workshop
- LLNL will Host 2020 MFE Workshop (Spring 2021)

U.S.- and China-based magnetic fusion scientists in the control room of the DIII-D tokamak in San Diego

FESP staff: R&D for design, fabrication, and testing of ITER Central Solenoid, will expand to include HTSC work in FY21 (SNS-STS, CFS)

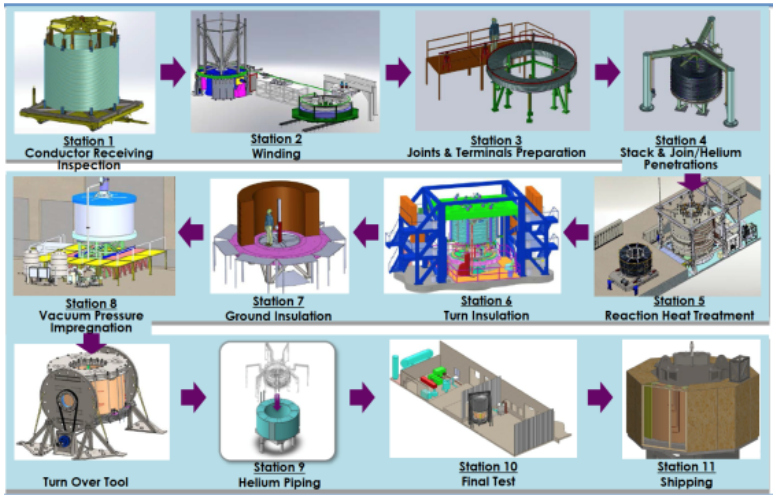


Worlds largest pulsed superconducting magnet



Nicolai Martovetsky:
Chief engineer for US ITER magnet systems, assigned off-site at ITER-US at ORNL.

Fabrication process developed and qualified

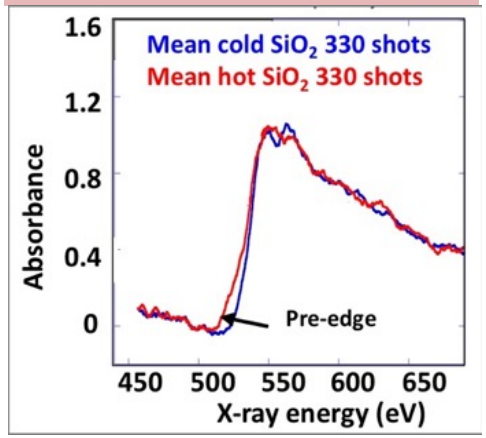


Discovery Science/HEDLP: enhanced by FES-ECRP awards

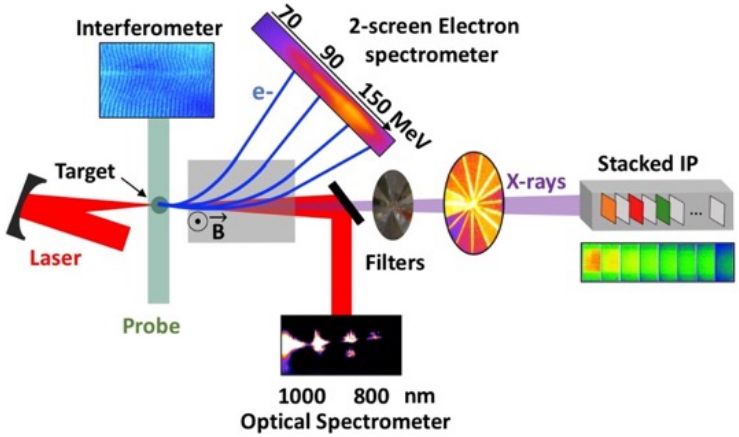
Example: Félicie Albert leads laser driven x-ray sources.

- Goal: Use x-rays from laser-plasma accelerators to probe high energy density science experiments using spectroscopy and imaging techniques
- Accomplishments in FY19-20 include sources, diagnostics, analysis
  - Multiple new publications (not complete):
    - "Ultrabroad-band, inverse Compton scattering source using a picosecond laser-driven plasma accelerator," N. Lemos et al, PRL (2019)
    - "Single-Shot Multi- keV X-Ray Absorption Spectroscopy Using an Ultrashort Laser-Wakefield Accelerator Source," B. Kettle et al, PRL (2019).
    - "X-ray sources using a picosecond laser driven plasma accelerator," N. Lemos et al, Phys. Plasmas (2019)
    - "X-ray analysis methods for sources from self-modulated laser wakefield acceleration driven by picosecond lasers," RSI (2019)
  - Multiple Invited Talks
    - N. Lemos, EPS 2019, "Hard X-ray sources using a picosecond laser driven plasma accelerator"
    - F. Albert, CERN Accelerator School on high gradient wakefield accelerators 2019, "Radiation from laser wakefield accelerators"
    - F. Albert, HEDS/OPIC 2019, X-ray sources driven by self-modulated laser wakefield acceleration
- Experiments in FY19-20-21 include multiple facilities
  - LCLS-MEC experiments
  - OMEGA-EP experiments
  - JLF/Titan experiments
  - NIF experiments
  - Astra-Gemini (RAL)
  - LMJ-PETAL (FY21)
  - LaserNetUS and ELI Facilities (Planned)

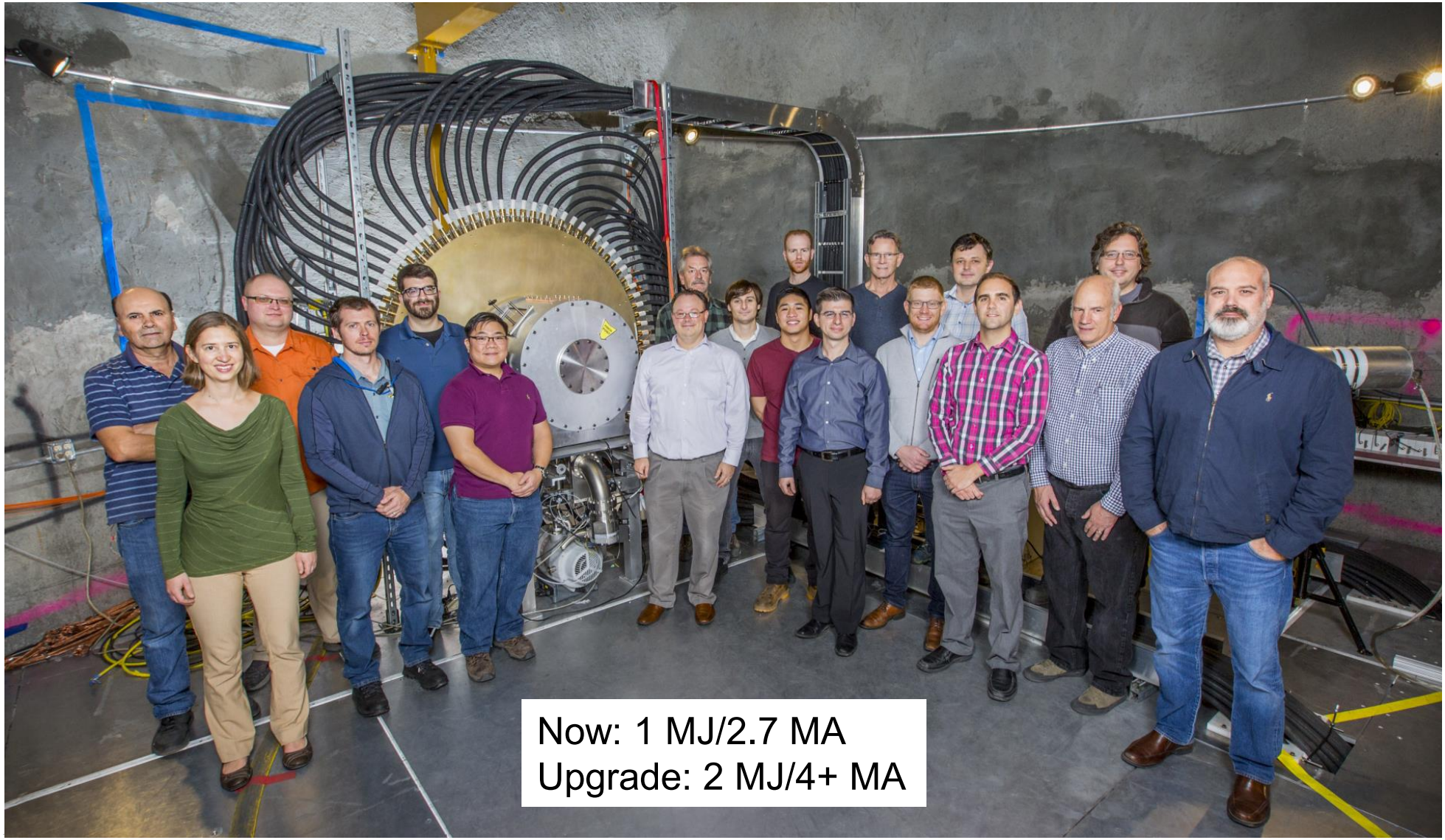
O2 K-edge spectra with LCLS betatron source



Platform for betatron experiments with picosecond lasers

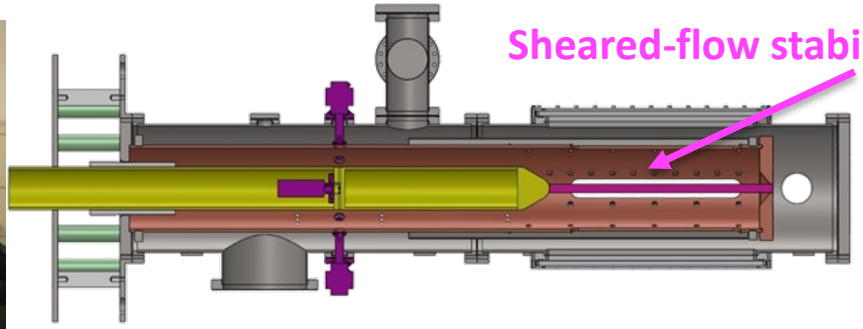


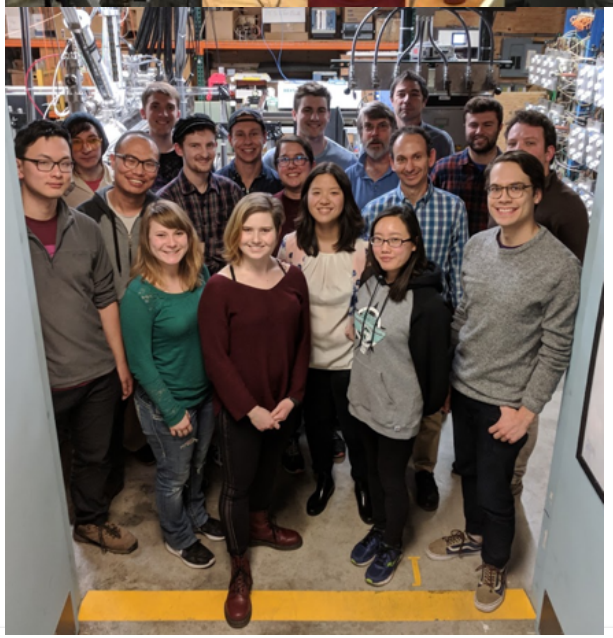
Pulsed Power Fusion Group has installed a multi-MJ DPF in the NOVA Laser Facility building for National Security Missions

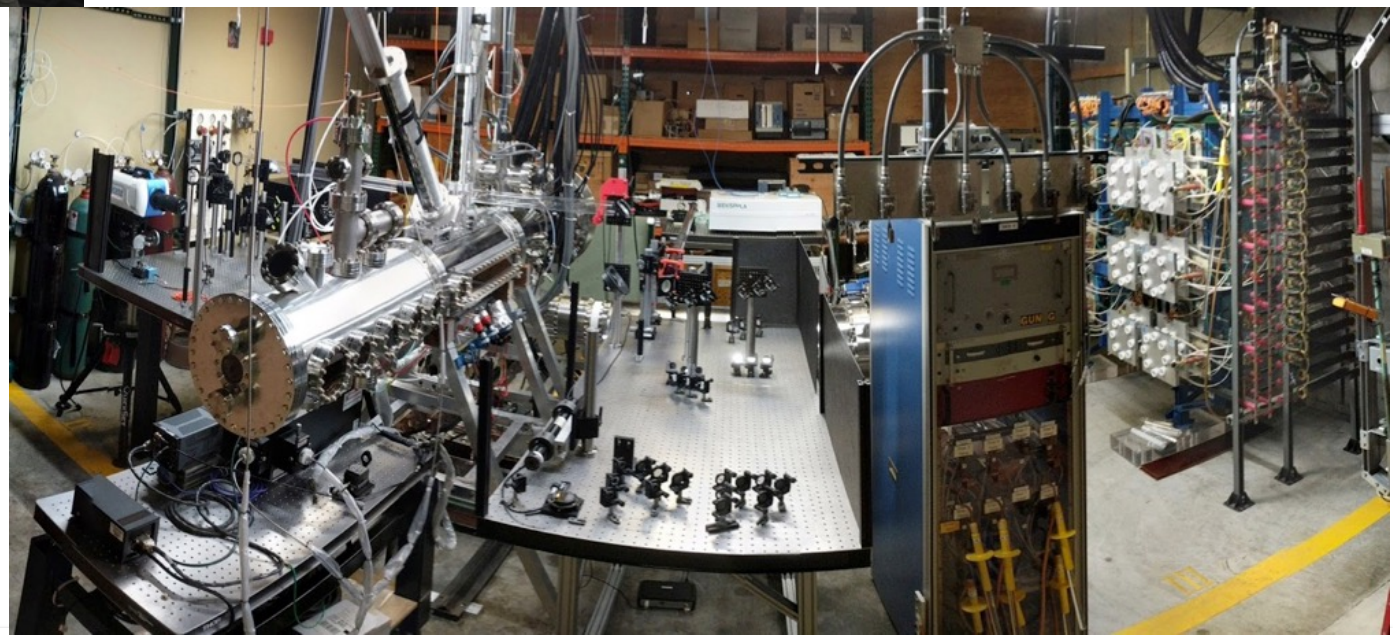


ARPA-E: Experimental, diagnostic, and computational efforts have grown beyond FuZE sheared-flow stabilized Z-pinch concept to include multiple projects

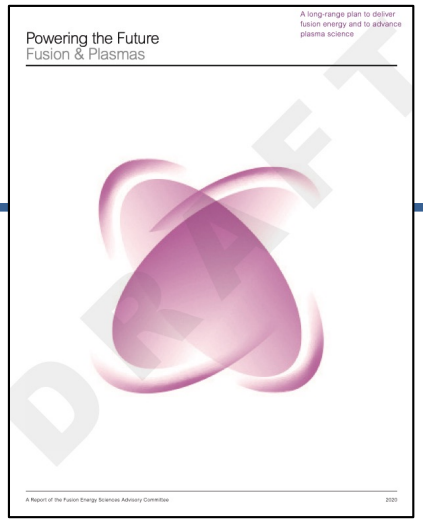
- 2015 University of Washington / LLNL partnership initiated for FuZE Project (ALPHA)
- 2019: Neutron Production/Spectroscopy and Portable Thomson Scattering (Fusion Diagnostics)
- 2020 HTSC CS for CFS, Tungsten Additive Manufacturing, (BETHE, GAMOW/FES)







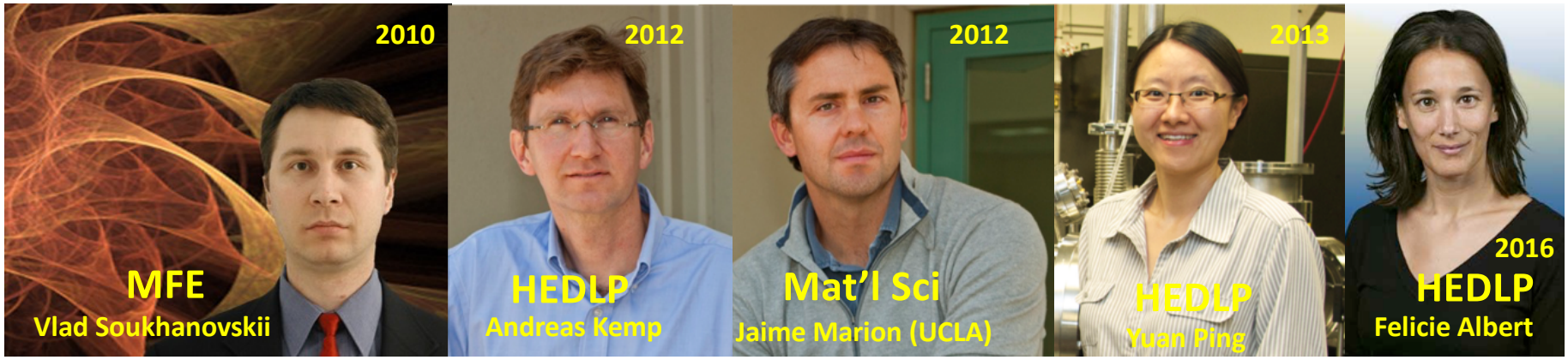
Overall LLNL FESP Outlook for 2020's for all sponsors will be guided by the new FESAC Report



- **Continue MFE experimental and theoretical research:**
  - National research (DIII-D, NSTX-U, LTX-β)
  - International research (MAST-U, EAST, KSTAR)
  - Preparations for ITER and the burning plasma era
  - Expand partnerships with ARPA-E and Private Industry
- **Pursue advanced computing relevant to predictive whole-fusion-device modeling**
  - Leverage partnerships within LLNL between FESP (SC-FES) and CASC (SC-ASCR)
  - Expand collaborations beyond LLNL with other SC-FES and SC-ASCR supported institutions
  - SciDAC Engagement, QIS explorations, machine learning
- **Expand Fusion Materials and Technology Efforts**
  - PFC model validation, advanced design studies to include liquid metals/liquid walls
  - Predictive modeling of material behavior (LLNL Material Science Division)
  - Additive manufacturing of tungsten (LLNL Material Science Division)
- **Foster Discovery Plasma Science, HEDLP, IFE**
  - Leverage NNSA facilities for SC-FES HEDLP experiments and modeling (ECRP's)
  - Astrophysical plasmas and Basic Plasma Science
  - Respond to user-needs on mid-scale facilities
  - Steward existing activities and foster new opportunities in LaserNetUS: LCLS (BES), JLF/NIF (NNSA), and BELLA Center (HEP)
  - Re-initiate appropriate IFE activities as guided by 2020 FESAC Report

Additional planning activities, reports, and studies…

Impact: LLNL Researchers have earned 8 DOE Office of Science Early Career Research Program Awards through FES



U.S. DEPARTMENT OF ENERGY
Office of Science
Early Career Research Program

*J. Marion left LLNL for UCLA in 2014, reducing his last 2 yrs to 150k/yr

Each ECRP provides $500k/yr x 5 Years. FES investment total of $19.3M*

Lawrence Livermore
National Laboratory