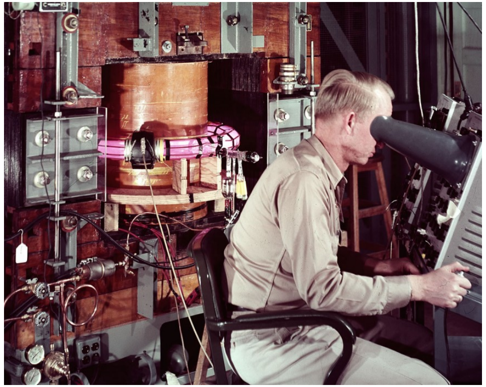
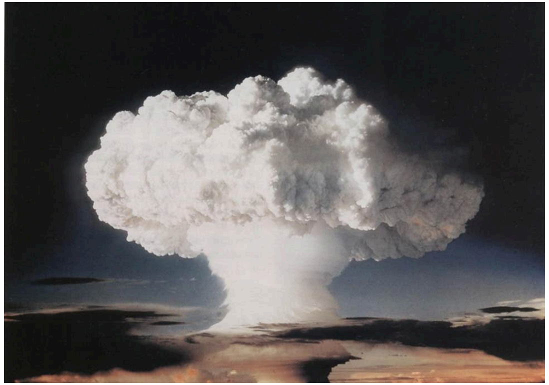
LANL Fusion Capabilities

INFUSE workshop Jan 22-23, 2019

Los Alamos has a long history of fusion research

James Tuck,
Perhapsatron, 1953





Ivy Mike, 1952

- Today magnetic and inertial fusion work resides in the Physics Division, Theory Division, and X Division (Weapons). There are also related capabilities in detectors, radiation damage, and tritium handling.
- Dr. John Kline (jkline@lanl.gov) is the present Fusion Energy Sciences (and Inertial Fusion) program manager, and a point-of-contact.

LANL FES Priorities for FY20 & FY21

- **Core Program Priorities**
  - **Burning Plasma Science: Foundations**
    - Theoretical and computational work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes, including validation experiments.
    - Enabling R&D needed to support the continued improvement of the experimental program in the area of diagnostics.
  - **Burning Plasma Science: Long Pulse**
    - The LANL collaboration on W7-X in Germany provides an opportunity to develop and assess 3D divertor configurations for long-pulse, high-performance stellarators.
    - Materials & Fusion Nuclear Science supports the development, characterization, and modeling of structural and plasma-facing materials used in the fusion environment.
- **Program Priorities for Term Grants**
  - **Discovery Plasma Science**
    - Supports research that explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications.

FRC's were developed in Russia and Los Alamos

Field Reversed Theta Pinches at Los Alamos

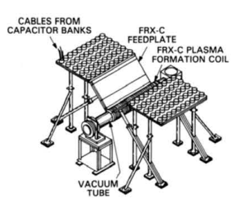
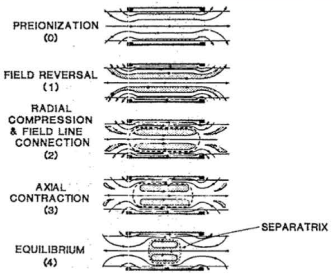


Fig. 3. Schematic of the FRX-C field-reversed theta pinch.



Phases of FRC formation in a field-reversed theta pinch

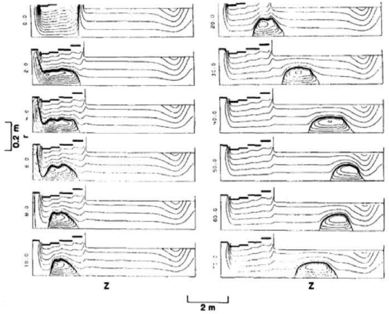
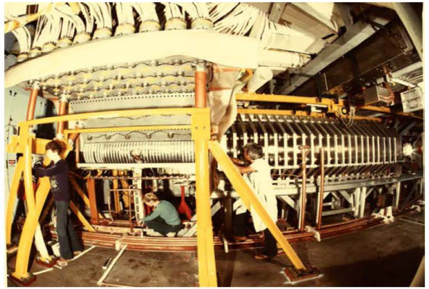


FIG. 11. Time evolution of the poloidal flux contours as predicted from 2-D MHD simulations of FRC translation in FRX-C/T for the low-compression, 5 mTorr puff mode with $B_0 = 2.5$ kG and $R_M = 2.5$.

MHD simulation of poloidal flux for FRC translation



LANL FRX-C/T theta pinch (left) and dc magnet coils surrounding the translation chamber (right)

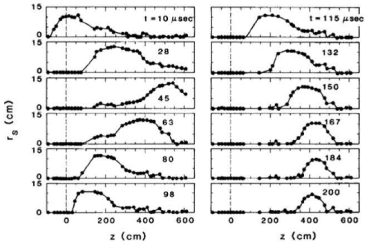


FIG. 2. Time evolution of the FRC separatrix radius profile $r_s(z)$, as inferred from excluded magnetic flux measurements. These data are from a single FRX-C/T discharge at the low-compression, 5 mTorr puff mode with $B_0 = 2.5$ kG and $R_M = 2.5$.

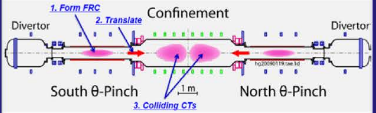
Experimental measurements of excluded magnetic flux for FRC translation

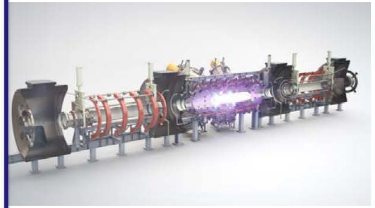
FRC's are high beta plasmas, with many interesting features

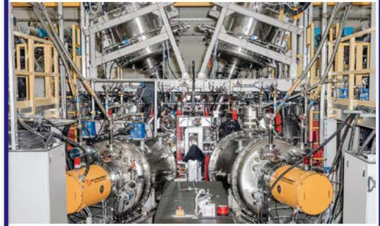
Today FRC plasmas are still being explored

Fast forward to 21st Century: Resurgence of FRCs through private investments

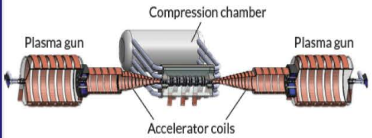
Tri-Alpha Energy, Inc
Foothill Ranch, CA

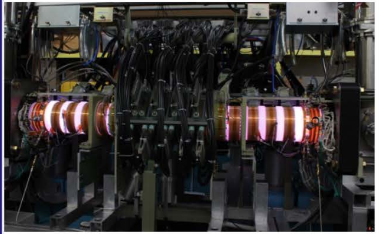




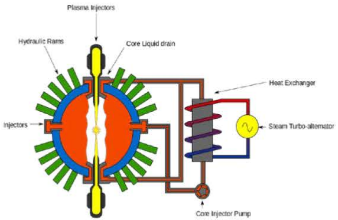


Helion Energy
Redman, WA

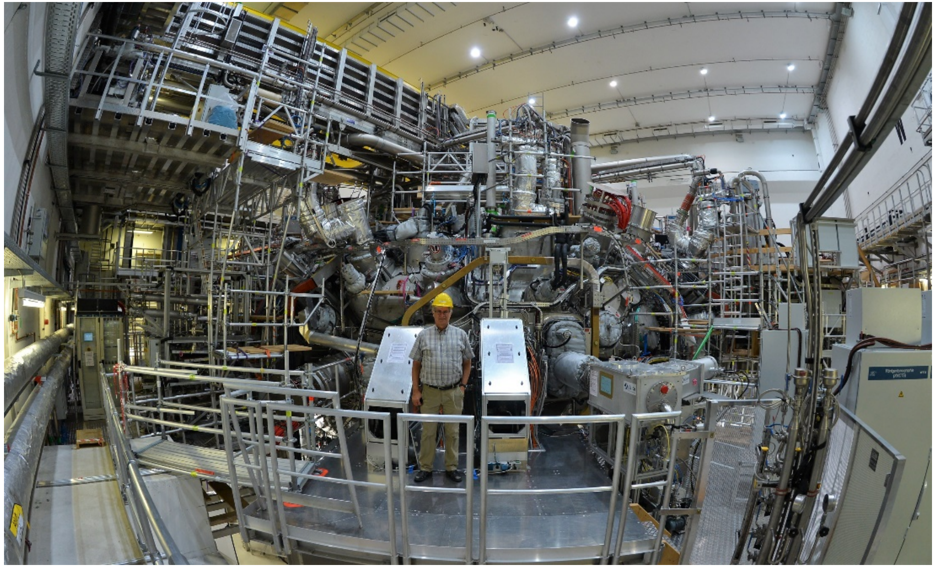


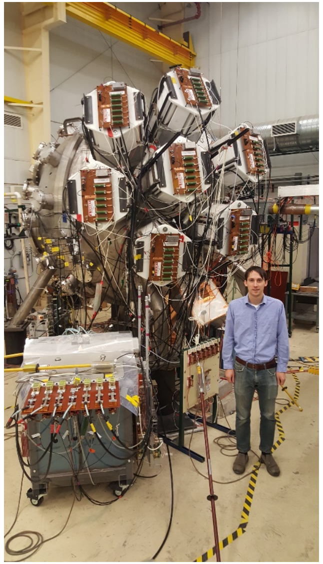


General Fusion
Burnaby, BC



Magnetized Plasma Team in P-24 Plasma Physics



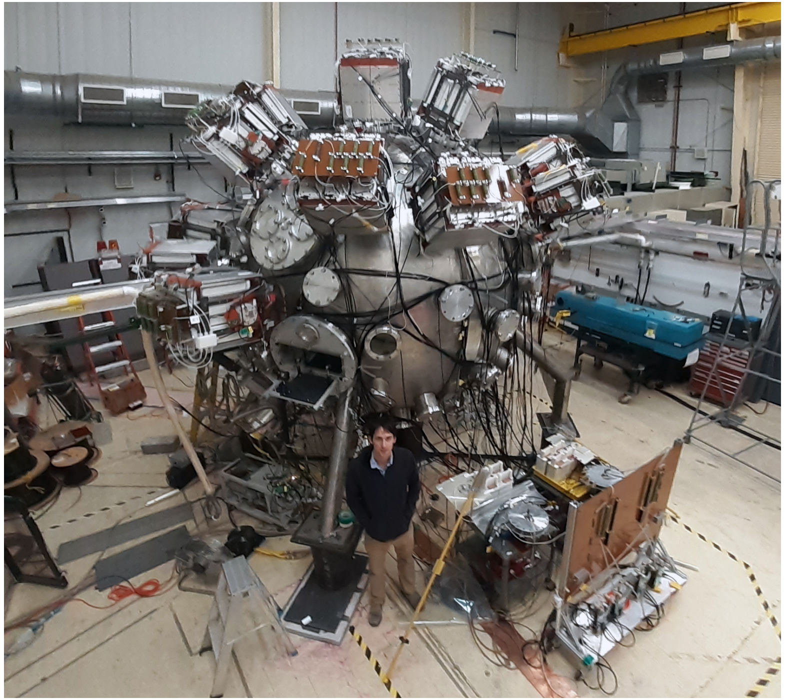


We do experimental plasma work for FES, APRA-E, and NNSA sponsors, with national and international partners, including small businesses. We use our knowledge of plasma diagnostics, pulsed power expertise, and HED plasmas in the areas of fusion energy, weapons support, and basic plasma science.

Team Leader: Glen Wurden (wurden@lanl.gov)
Staff: Hsu, Weber, Langendorf, Dunn, Shimada
Postdocs: Tom Byvank, Kevin Yates, John Boguski
Student: Chris Roper (Summer)

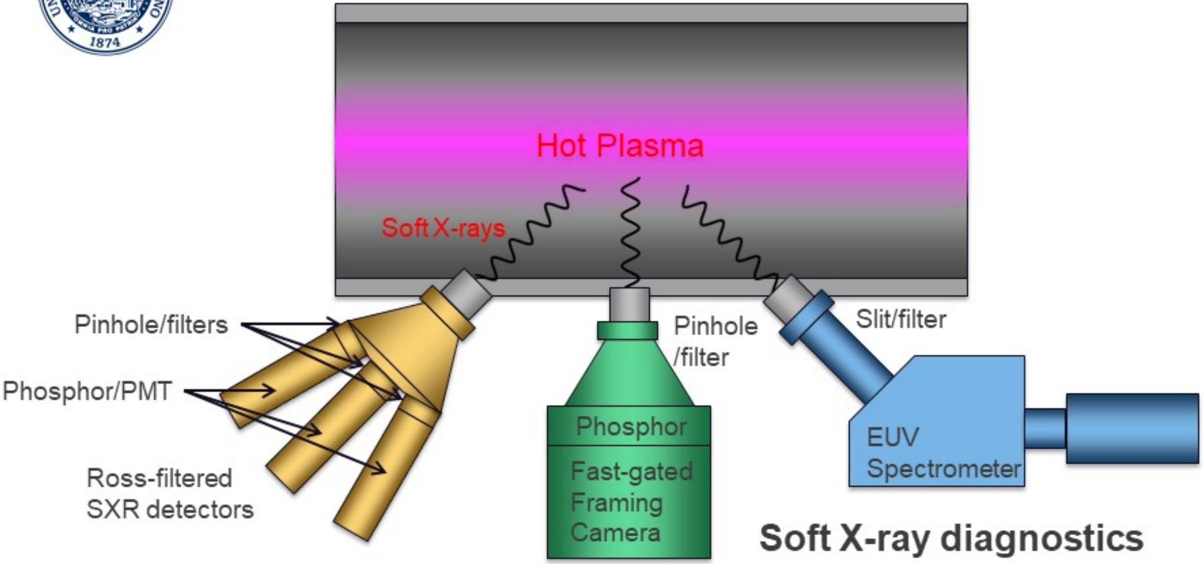
The Plasma Liner Experiment at LANL

- This was an ARPA-E “ALPHA” project.
- Presently PLX has18 plasma guns in a hemispherical geometry, on a 2.75 m diameter chamber.
- It is being used to study the merging hypersonic plasma jets.
- Later in 2020, it may be upgraded to a full set of 36 guns.
- PI: Sam Langendorf, Samuel.langendorf@lanl.gov



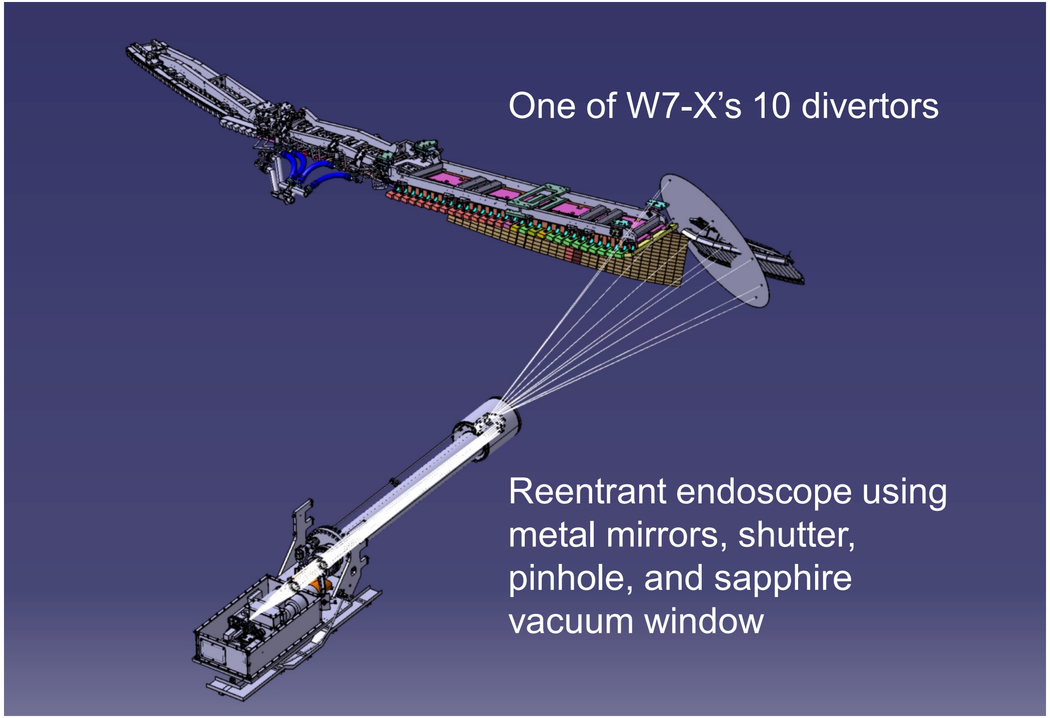
LANL leads an ARPA-E "capabilities" team

LANL and the University of Nevada, Reno will be providing three soft x-ray diagnostics to one or more ARPA-E transformative fusion facilities, starting with FUZE and ZAP at the University of Washington in 2020. They will provide information on electron temperature, hot spots, and impurity radiation.



Soft X-ray diagnostics

High resolution imaging on the W7-X stellarator



Infrared, visible, and ultraviolet

- FLIR Infrared camera, 512 x 512 pixels @310 Hz, or 64x16 pixels @ 3kHz.
- PCO Edge 5.5 visible camera, 1 Megapixel useful image, 60 Hz frame rate at 10 msec exposure. 5 narrow-band filters.
- Ocean Optics QE65000 UV spectrometer, 225-345 nm, 20 msec per spectrum, sees 20 or so lines, including He II, B IV, O V, C II, as well as low charge states of test impurities, such as Fe, Mo, N, Ne.

We collaborate at national and international facilities

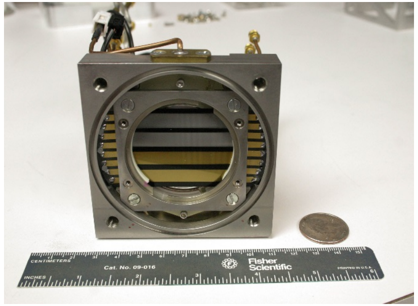
W7-X “One Team” in the control room,   Oct. 2018

LANL Advanced Diagnostics

What: A new type of diagnostic using laser inverse Compton scattering to measure soft x-rays generated from laser photons scattering off of runaway (relativistic) electrons in the DIII-D tokamak

Where we are: ($480k FY18) Multi-institution design study for Laser Inverse Compton Scattering (LICS) Diagnostic for Runaway Electron measurements on the DIII-D tokamak is in progress. Completion of reviews by early FY20. Present investment is $820k for design study (LANL/GA/UCSD/Woodruff), and $1.15M for SBIR Phase I and Phase II laser development effort (Voss Scientific).

Where we are going: In FY21, The LICS runaway electron diagnostic design for DIII-D will be ready to move to a construction and installation phase, contingent on DIII-D schedule, port negotiations, and funding.



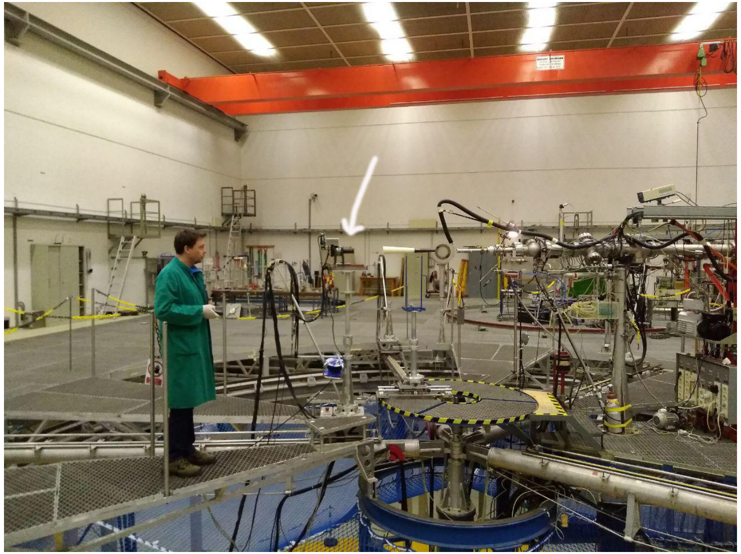
LANL 4 strip gated x-ray imager

Inside view of 105 tangential port on DIII-D

Voss Scientific prototype laser

We test our detectors at world class x-ray and neutron sources

- Argonne Advanced Photon Source (x-rays)
- Omega and NIF (x-rays, neutrons)
- P-24 soft x-ray sources
- Physikalisch-Technische Bundesanstalt (*PTB*) accelerator in Braunschweig, Germany (neutrons)
- Sandia Ion Beam Facility (neutrons)



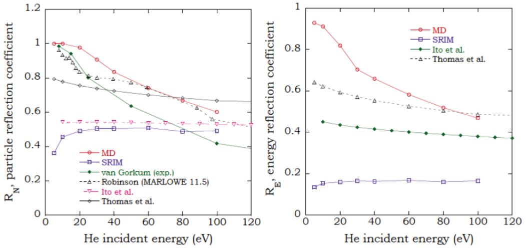
LANL Focus (i): Solution to Plasma Particle & Power Exhaust in Reactors

Where we are

- Identification of the plasma power exhaust challenge aggravated by light ion reflection by high-Z metal divertor/ wall surface
  - MD quantification of He reflection from W surface
  - Apply recent advances in sheath theory to tie ion power recycling to target plasma temperature.
- Fundamental advances in quantification of sheath energy transmission coefficients
  - Bohm speed (from Bohm criterion) is set by electron heat flux to the wall
  - Full kinetic simulations quantify sheath energy transmission
  - A fully kinetic sheath model for the collisionless sheath of a collisional plasma → tokamak regime
- Parallel transport along open field lines with magnetic trapping and varying collisionality

Where we are going

- Incorporate all relevant atomic processes to understand
  - Radiation cooling near & detachment at divertor
  - Impurity upstream transport and radiative cooling in the scrape-off layer
  - Radiation cooling near & inside the magnetic separatrix, and impurity screening



$$u_{\text{Bohm}} \equiv \sqrt{\frac{3k_B\left(T_{i\|}^{se} + Z\beta T_{e\|}^{se}\right)}{m_i} - Z\beta\frac{m_e}{m_i}\frac{j^2}{\left(en_e^{se}\right)^2}},$$

How we are going to do it

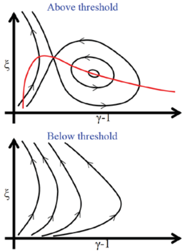
- Two complementary approaches
  - Incorporating discrete atomic processes in VPIC kinetic code (a prototype is in place-FY20-21)
  - Coupling plasma multi-fluid solver to collisional-radiative model (a light-weight CR module is in place – FY20; collaborating with SNL on multi-fluid solver (FY20-21) ← SciDAC & ASCR)

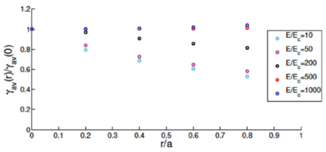
Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

LANL Focus (ii): Understanding Runaway Generation, Transport, & Dissipation

Where we are

- Physics picture of runaway vortex defines what runaways means in a tokamak
  - Runaway electrons are really run-around electrons in momentum space: cyclic acceleration and deceleration in the presence radiation damping and pitch angle scattering
  - Topological transition to runaway vortex → avalanche threshold; geometry of runaway vortex → avalanche growth rate
- The essential role of partial screening in mitigated disruption by high-Z impurities
  - Increased runaway amplification potential via avalanche process → make the matter worse
  - Increased runaway spatial transport + Ware pinch → impact the spatial distribution of runaway avalanche
- Toroidicity has surprising effect on runaways in the large E field regime, as required by current ITER DMS design





Where we are going

- Incorporate more accurate description of the atomic processes in the presence of a runaway component
  - QED corrections in the relativistic limit can significantly modify the cross sections: large angle collision and excitation due to free-bound electron collisions.
- Account for the full toroidal geometry plus 3D magnetic fields
- All known runaway seeding mechanisms

How we are going to do it

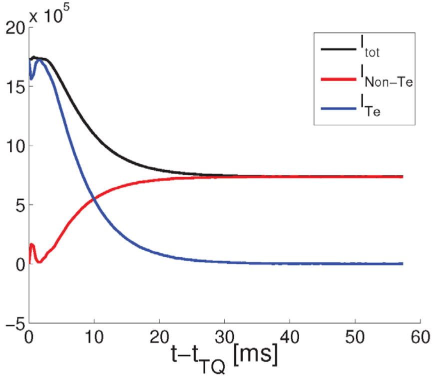
- Sophisticated collisional-radiative model accounts for relativistic electron component (a working prototype is producing intriguing results – FY20)
- Bringing various cross sections directly into relativistic Fokker-Planck solver FY20-21
- Full geometry and 3D fields in both continuum (FY-21) and particle (FY20) solvers

Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

LANL focus (ii): Integrated Modeling of Disruption Dynamics

Where we are

- MHD and extended MHD (PIXIE3D) modeling of the onset of tokamak disruption through major MHD instabilities
  - Reconnection & post-thermal quench current spike
- Multi-fluid (Drekar, TDS-SNL) modeling of neutral gas and plasma interaction
  - Gas and injected pellet assimilation
- Boundary plasma kinetic modeling by VPIC
  - Understand the PMI in disrupting plasma (with halo current) and set boundary condition for integrated modeling using quasi-neutral plasma models
- Gyro-fluid (BOUT++, TDS-LLNL) modeling of edge transport and turbulence and resulting disruption-induced transient particle and power load on PFC.
- Gyrokinetic (GTS, TDS-PPPL) modeling of thermal quench in the presence of 3D fields and hot tail formation (or not)
- Self-consistent E & B field evolution with runaway electrons in an axisymmetric tokamak undergoing rapid radiative cooling



McDevitt is taking the lead to acquire an ITER contract on DMS

Where we are going

- First step: integrate runaway electron dynamics into self-consistent electric field evolution to follow the macro-dynamics of a disrupting plasma.
- Second step: integrate plasma macro-dynamics that accounts for the runaway electrons with transport models that describes the seeding mechanisms as well as the thermal bulk.

How we are going to do it

- First step: a self-consistent electromagnetic field solver + runaway drift kinetic solver in a full torus, initially assuming toroidal symmetry (FY20), later including 3D fields (FY21)
  - Include partial-screening, Dreicer flux, avalanche, Ware pinch
- Second step: TBD depending on what we learn.

Los Alamos NATIONAL LABORATORY EST. 1943

Whole Device Modeling for Disruptions and other Transients

UNCLASSIFIED

U.S. DEPARTMENT OF ENERGY Office of Science Fusion Energy Sciences

NNSA National Nuclear Security Administration

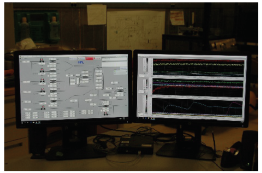
Los Alamos NATIONAL LABORATORY EST. 1943

Fusion Nuclear Science Highlights and Plans

- **The HPL is a pilot scale gas handling and metal hydride storage bed system that can be used for experimental, design and validation studies for tritium processing. The benefit of the HPL is that by using hydrogen instead of tritium the safety design and overhead cost associated radioactive processing can be reduced by using the hydrogen isotope as a surrogate for tritium.**

- **The Tritium System Test Assembly (TSTA) database has completed the initial upload of documentation.   FES and LANL are currently assessing export control requirements to determine the best process to open the database to open access.**

- **The Liquid Metal / Plasma Facing Components (LM/PFC) Working Group has been tasked with studying the impact of this type of a first wall concept to FNSF. LANL is assisting with a design assessment for a tritium plant to support this design.**



Current / Future Research Details (FY18/19)

- Completed upgrades to HPL data acquisition and control system. Control and data collection has been validated. Testing of PMR for comparison with previous reported data for ITER TEP design is planed for later this year
- Export control issue resolution to allow for transfer TSTA Database to open server for tritium community
- Participate in FESS for tritium plant modeling and support of B/TP program

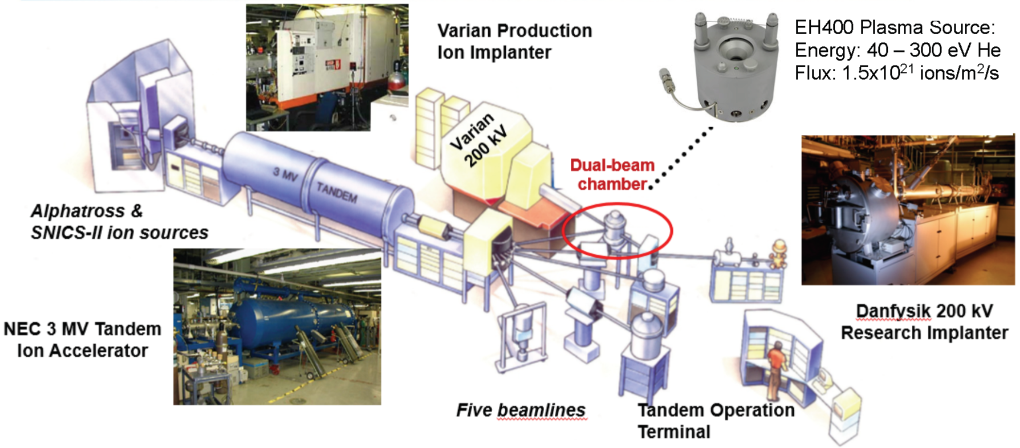
- **Recent Reports / Presentations**
- *W. Kirk Hollis, et at.*, LM PFC Meeting, LM PFC Working Group Meeting. FES Germantown, August 2018
- Hollis, W. Kirk, et at. Plant-wide tritium flow and control, definitions and modeling

New Start: Coupled plasma - irradiation PMI capability at LANL (Y. Wang)

The facility allows to examine dynamics of displacement damage and/or He effects on D transport (trapping, diffusion, and release) when defects and He are concurrently produced in PFM under various target temperatures.

Ion Beam Materials Laboratory

IBML Los Alamos



LANL FES Vision for Existing & Future Programs

Los Alamos contributes to the National Fusion Energy Sciences Program 10-year strategy, building upon and exercising unique LANL capabilities in magnetic fusion energy and discovery science theory, modeling, simulation, experiments, and technologies. As a DOE multipurpose National Lab, we are in the vanguard of deploying new and novel methodologies, instrumentation, and analyses aligned with the FES Ten-Year Perspective, including tokamak transient control, collaborations on the world-leading stellarator, plasma-material interactions, tritium science, and basic plasma physics discovery.