LLNL capabilities for Fusion

LLNL INFUSE POC: goyon1@llnl.gov

LLNL capabilities spans multiples Core Challenge Areas listed in the latest U.S. Department of Energy's (DOE) Fusion Science & Technology (FS&T) Roadmap - some selected areas suitable for INFUSE are showcased here

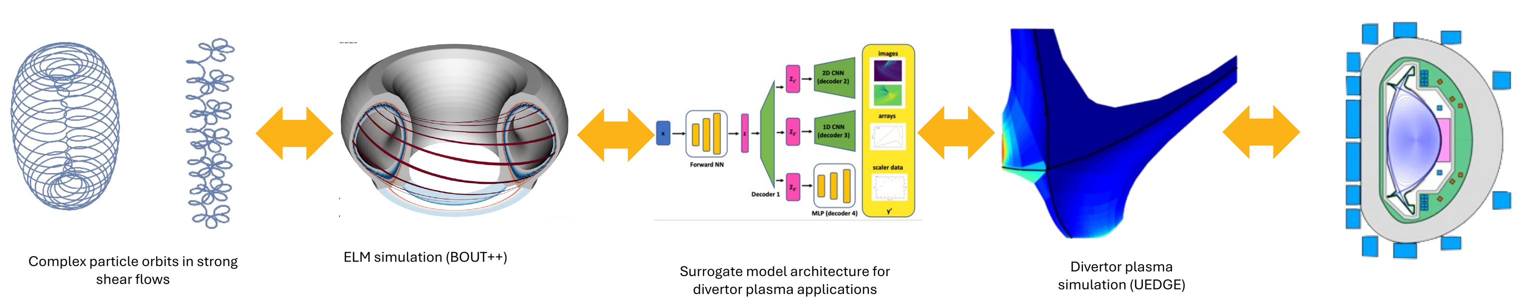
Advancing Confinement Approaches

The MFE team develops key physics capabilities to understand experiments and design a fusion pilot plant (FPP) applicable to tokamaks and stellarators

Experiment, Theory and Modeling Leadership

Capabilities

Analytic theory	High-fidelity models Advanced algorithms	Reduced models	Experimental validation	FPP design

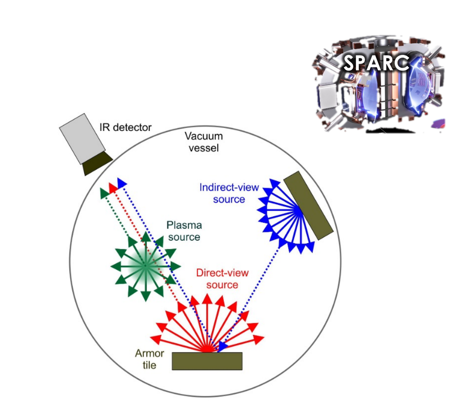


Examples

- Extend model validity to FPP regimes with University collaborations
- ➢ UEDGE-edge fluid/neutrals, BOUT++
  ➢ edge turbulence, Cogent
  ➢ Gyrokinetics, and CORSICA - core plasma scenarios
  See B. Zhu's poster Hermes-3: A Versatile Modeling Tool for Magnetically Confined Plasma
- See B. Zhu's poster ML-assisted Exhaust design and Control in MFE Systems
- Interpret and plan experiments and support core-edge tokamak integration:
  ➢ Edge plasma modeling validation
  ➢ Advanced core scenario design
- ➢ CORSICA predictions of ITER operation
  ➢ Divertor plasma interpretation and design of divertor hardware upgrades

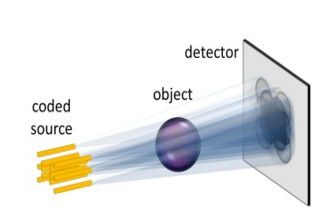
Diagnostics spanning from MFE to IFE

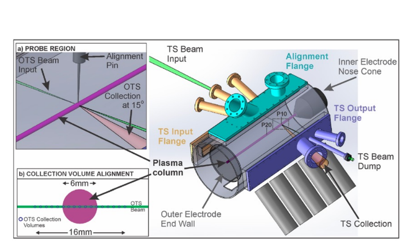
- Design, fielding and operation of key MFE diagnostics for:
  - Edge plasma diagnostics: *multi-channel EUV, VUV, visible, and NIR spectrometers (WISE, Divertor SPRED), filtered imaging cameras (IRTV, Tang TV), Coherence Imaging Spectroscopy*
  - Plasma-surface interaction: *multi-channel UV, visible, and NIR spectrometers, filtered imaging cameras, IR cameras, AXUV diode arrays*
  - Plasma turbulence: *fast framing filtered visible cameras*
  - Core plasma diagnostics: *Motional Stark Effect (MSE) and VUV spectrometers (SPRED)*



Implementation of Multiband Infrared and Interpretive Techniques for SPARC

- Expertise with gold-standard fusion diagnostics
  - Neutron Imaging systems:
    - INFUSE project to look at coded apertures Z-pinches with Pacific Fusion
  - Thomson scattering
    - Portable Thomson scattering system for Sheared Flow Stabilized Z-pinch (Goyon *et al., Phys. Plasmas* 2024)
    - Tokamak Thomson system (P. Schroeder *et al., Rev. Sci. Instrum.* 2023)
  - For more examples of NIF/ICF diagnostics, please see: J. D. Kilkenny *et al., Phys. Plasmas* 2024





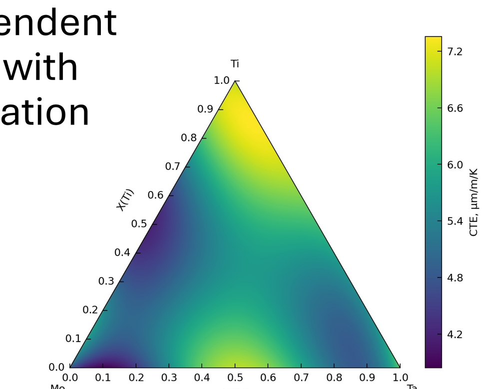
Plasma-Facing Components and Plasma- Materials Interactions

Design of Complex High-Performance Armor Materials

The Materials team can rapidly design new alloys to enhance the realization, safety, and cost effectiveness of fusion power plants. For instance, an ARPA-E *Chadwick* project will employ an integrated, high-throughput modeling and experimental framework to create new materials by thoroughly exploring the complex composition space offered by low-activation elements. LLNL's project will also use industrial laser technology to improve the surface of the new material to increase the chance of survival in a fusion power plant.

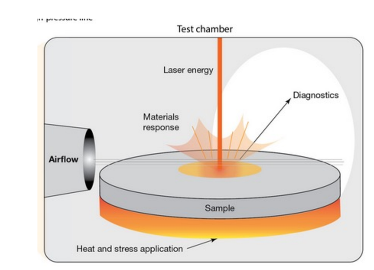
HIGH-THROUGHPUT EXPERIMENTS & SCALE UP

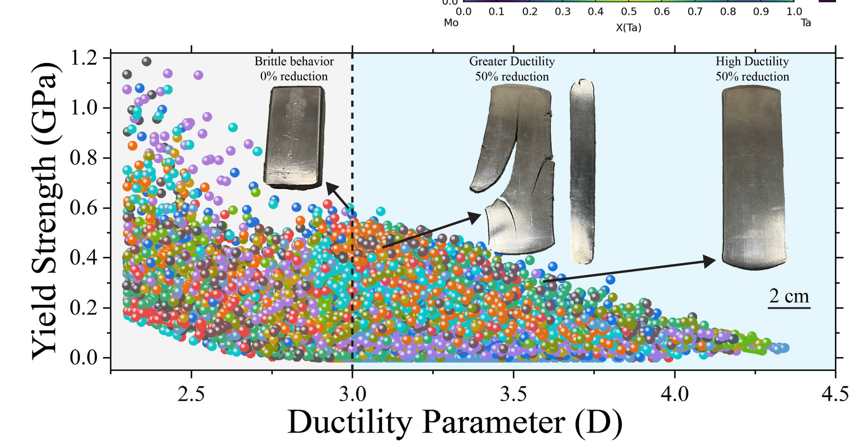
The MAP is an extensible computational framework that enables combining composition-dependent materials models with advanced optimization engines for alloy design

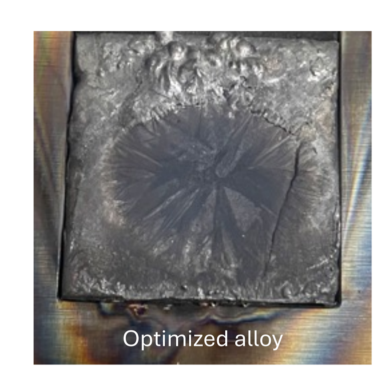


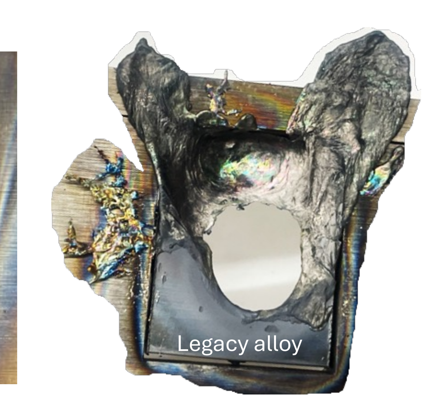
EXTREME CONDITIONS RESISTANCE

The Energy Matter Interaction Tunnel can simulate extreme aerothermodynamics









Divertor testing and FIRE collaborative

Divertors must dissipate exhaust power, remove helium ash and impurities, and maintain plasma detachment without degrading confinement. Divertor geometry and magnetic configuration define operating limits. Advanced designs, such as long-leg, snowflake, and liquid-metal divertors, aim to expand this space.

Areas we work in:

- snowflake and long-leg divertor studies at MAST-U
- liquid-wall experiments on LTX-b
- experiments and measurements for liquid-metal divertors on NSTX-U
- participate in FIRE Collaborative "Advancing the maturity of liquid metal plasma facing materials and first wall concepts"

Fusion Plant Engineering & System Integration

The LLNL Integrated Process Model (IPM) is a full-plant optimization framework, leveraging both technical and economic considerations

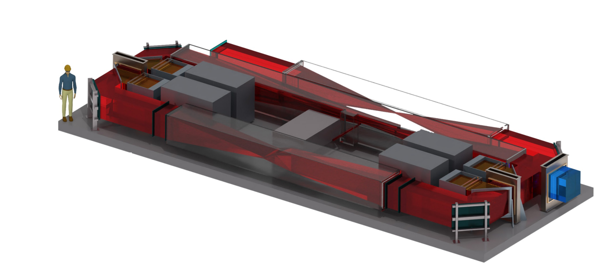
- Developed over the last 15+ years as part of LLNL's pioneering efforts on IFE
- Initial focus on DPSSL indirect-drive self-consistent integrated test facility
- First step towards optimization with AI/ML
- The IPM is a full-plant optimization framework, leveraging both technical and economic considerations

Identify Risks
⇒Inconsistencies
⇒R&D gaps
⇒Supply chain
⇒Costs

The integrated tools development serves as a guide for foundational R&D investments at LLNL

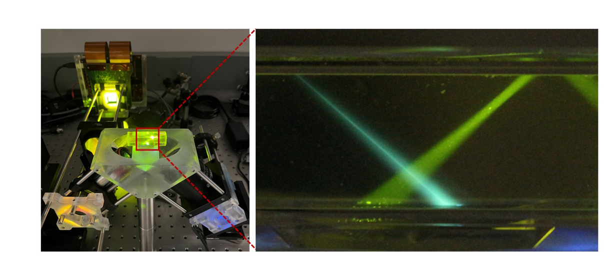
I. Investments aligned with LLNL core competences for fusion:
- Laboratory Directed Research and Development (LDRD) on Diode Pumped Solid State Lasers

DPSSL architecture for IFE



- ➢ DPSSL design compatible with ID and DD using benchmarked modeling tools (VBL++, AmpSim,...)
- ➢ innovative laser concepts for increased efficiency and reduced size

- STARFIRE effort on target design and fabrication



Viable fuel configuration scalable to mass production

- ➢ 2Photon Polymerization foam printing techniques with LVAM and LFOV
- ➢ Target Injection design with FIRE collaborative led by GA

II. Partnerships with experts to include and validate subsystems:
- Partnership with SRNL on tritium breeding
- Collaboration w/ manufacturers for laser diode pump characterization
- CRADAs investigating physics of irradiation damage

- ➢ LLNL has launched the Livermore Institute for Fusion Technology (LIFT) to support the burgeoning fusion energy ecosystem
- ➢ LIFT is a portal to provide scientifically backed, impartial, up-to-date information on fusion science and engineering to inform industry and investors. This portal will also facilitate partnerships with dedicated and knowledgeable staff, and new mechanisms for agreements.

lift.llnl.gov

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