LLNL Collaboration on NSTX-U in 2021-2025: Integrating high core performance with the attractive boundary

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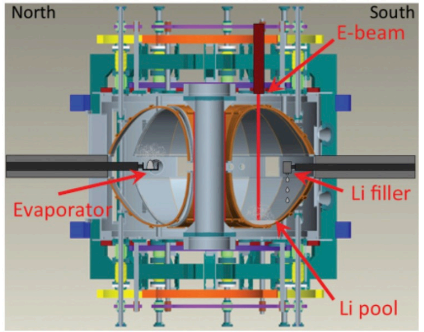
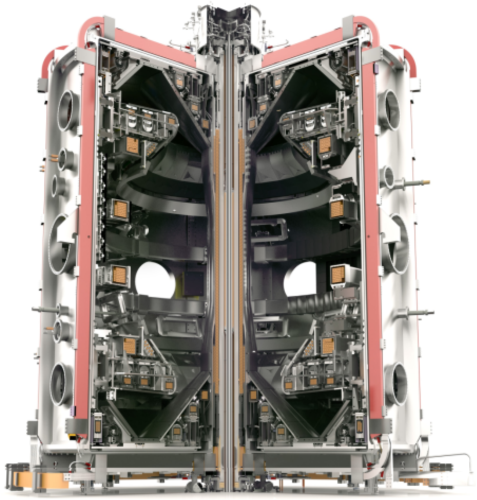
LLNL group at PPPL presently conducts research in several Boundary Physics areas on three spherical tokamaks

- **Boundary Physics Research on Spherical Tokamaks**
  - Lithium Tokamak Experiment (LTX)–beta
    - Scrape-off layer turbulence
    - Plasma-surface interactions with liquid lithium
  - Mega-Ampere Spherical Tokamak Upgrade (MAST-U)
    - Divertor detachment, Lyman radiation transport, and snowflake divertor
- **NSTX-U Research and Recovery**
  - FY2018 - supported several Recovery tasks
  - FY2019 – NSTX-U contribution to JRT2019 on pedestal fueling
  - FY2020 – NSTX-U contribution to JRT2020 on impurity transport



PPPL LTX-β



NSTX-U Program to focus on three high-level research goals in the first 5YP 2021-2025

1. Demonstrate **high-performance steady-state non-inductively sustained regimes** at large bootstrap fraction (f_{BS} > 0.7), large Greenwald density fraction (f_{GW} > 0.7) and β_N values surpassing typical conventional-A scenarios with sufficient stability margin for low disruptivity

2. Investigate if a **strong scaling of confinement and stability improvement with reduced collisionality** in regimes dominated by electron thermal transport at high-β and low-A persists at lower collisionality

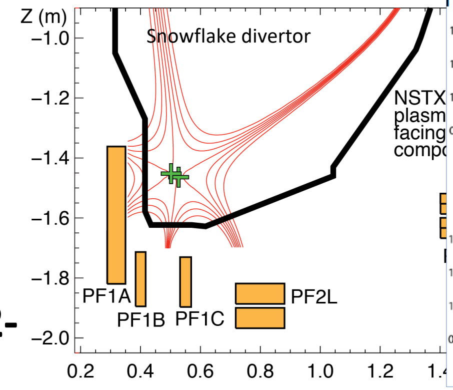
3. Develop and evaluate **conventional and innovative power and particle handling techniques** to optimize plasma exhaust in high performance scenarios

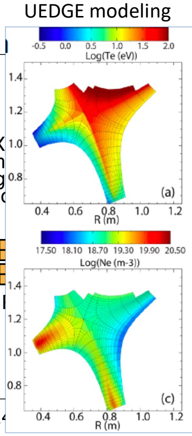
Objective 3: Develop and evaluate conventional and innovative power and particle handling techniques to optimize plasma exhaust in high performance scenarios

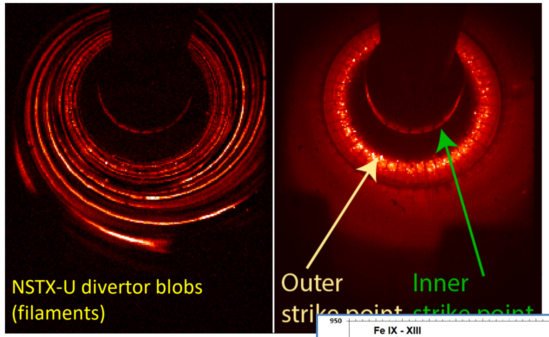
- (3.1) Assess performance and lifetime of new NSTX-U plasma-facing components, and establish the physics and engineering basis to enable future PFC/divertor upgrade(s)
- (3.2) Develop and evaluate power exhaust techniques for mitigating high projected NSTX-U heat fluxes
- (3.3) Investigate the sustainability of particle exhaust and PMI control via lithium pumping for density and impurity control consistent with integrated scenarios
- (3.4) Develop and understand techniques to mitigate/eliminate edge transients and the associated enhancement of PMI, and combine them with an attractive core scenario

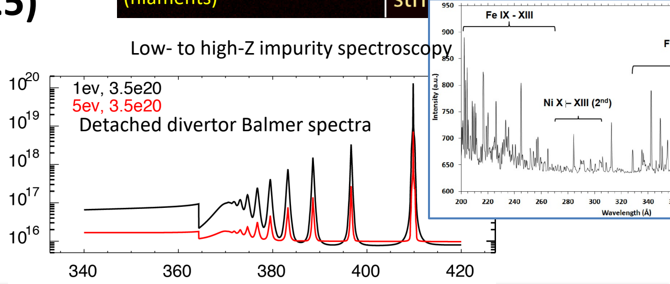
Proposed LLNL research addresses three high-level research objectives in the NSTX-U 5YP

- **Assessment of new plasma facing component performance (2022-2025) Obj. 1, 2, 3**
  - Recycling, carbon and lithium erosion fluxes, asymmetries, edge effects, connect to core carbon densities, study carbon “blooms”
- **Pedestal fueling and particle transport in high performance H-mode plasma scenarios (2023-2025) Obj. 1, 2**
  - Study low-Z and high-Z impurity transport, neoclassical transport modeling, high-Z accumulation and transport actuators
  - Study pedestal structure and fueling due to transport and ionization, neutral density, supersonic gas jet fueling, UEDGE and DEGAS 2 modeling
- **SOL transport and Divertor heat flux mitigation with established and novel techniques (2022-2025) Obj. 1, 3**
  - Study transport, turbulence and radiation in snowflake divertors in experiments and with UEDGE
  - Establish heat flux mitigation with radiative divertor using D_2 and impurities, identify and test real-time feedback control diagnostics
  - Contribute to assessment of lithium-based divertor modules
- **Plasma-surface interactions and material migration (particle control) (2024—2025) Obj. 1, 2, 3**
  - Study divertor and wall recycling and pumping with various conditioning techniques (lithium, boron, evaporation, dropped)
  - Study divertor and wall erosion and migration of intrinsic or dropped impurities, mixed-material interactions (B, Li, C, O)
- **Integrate particle and heat flux control with low-ν* H-mode scenarios, support operations (2022-2025) Obj. 1, 2, 3**
- PPPL support for collaborator interface (2021-2025):
  - Re-install Supersonic Gas Injector (SGI)
  - Re-install existing diagnostics (EUV Spectrometers, EIES, LADA, VIPS2, ENDD, DIMS, DIBS, TWICE, DivCam)
  - https://nstx.pppl.gov/DragNDrop/Program_PAC/Collaborator_research_plans/FY2016_2018_diagnostics/Meeting_1/Soukhanovskii-LLNL-diagnostics-FY16-18.pdf









Planned LLNL collaboration staffing in 2021-2025

- Vlad Soukhanovskii, Group Leader, experiment and modeling
- Staff Physicist, experiment
- Staff Physicist or Postdoc, modeling
- New postdoctoral researcher, impurity transport and plasma-surface interaction studies
- New postdoctoral researcher, divertor and plasma-surface interaction studies
- Will seek graduate students, thesis topics available

LLNL collaboration to support a number of edge and core diagnostics on NSTX-U to enable divertor, plasma-surface interaction and impurity transport studies

Diagnostic	Status in 2016
1. EIES (Edge Impurity Emission Spectroscopy, aka Filterscopes)	✓
2. EUV spectrometer (MonaLisa, 60-220 Å region)	✓
3. EUV spectrometer (LoWEUS, 220 - 400 Å region)	✓
4. EUV spectrometer (XEUS, 5 - 60 Å region)	✓
5. LADA (Lower divertor radiometer AXUV diode array)	✓
6. UV-VIS survey spectrometer VIPS2	
7. ENDD (Edge Neutral Density Diagnostic) camera	✓
8. UV-VIS divertor imaging spectrometer DIMS (Lower divertor)	
9. UV-VIS divertor Balmer spectrometer DIBS (Lower divertor)	
10. Duo-chromatic divertor imaging radiation-hardened cameras TWICE (two CIDTEC cameras, lower divertor)	✓
11. Divertor imaging cameras (three PPPL Phantom, Lower divertor and Upper divertor)	✓
12. Divertor Turbulence and Control Camera (LLNL Phantom, lower divertor)	✓

LLNL diagnostic implementation plan addresses NSTX-U plasma operations and Physics Program priorities

- Day 1 LLNL diagnostics on NSTX-U (requested by NSTX-U)
  - Three EUV spectrometers: impurity assessment for operations support
  - EIES (filtered visible diodes): plasma-surface interaction assessment for operations support
- First campaign LLNL diagnostics (Year 1)
  - Edge neutral density diagnostic (ENDD): fueling, pedestal studies, TRANSP
  - VIPS 2 wall conditioning survey spectrometer: H/D ratio (water), oxygen, impurity monitoring
  - LADA: lower divertor radiometer array for divertor radiation and PMI studies
- First to second campaign diagnostics (Years 1-2)
  - DIMS imaging divertor spectrometers for divertor, detachment, and lithium studies
  - DIBS imaging divertor spectrometers for divertor, detachment, and lithium studies
  - Filtered divertor cameras for divertor, detachment, and lithium studies (move to earlier?)
  - Fast divertor cameras for turbulence studies

Summary: LLNL is planning a new 5Y research program on NSTX-U

- LLNL 5YP proposal includes novel research in the pedestal, SOL, divertor and plasma-surface interaction areas
  - Proposed experimental research is to be supported with (mostly) previously implemented diagnostics and numerical modeling
  - Some research subtopics are similar in scope to our previous NSTX-U proposal (2014)

- The proposed LLNL 5Y research program is complementary to the on-going research program on LTX-beta and MAST-U
  - Plasma-surface interactions with liquid lithium in LTX-beta
  - Divertor detachment and snowflake divertor physics in MAST-U

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