Lithium Experimental Application Platform (LEAP): Advancing Liquid Lithium Technologies for Fusion

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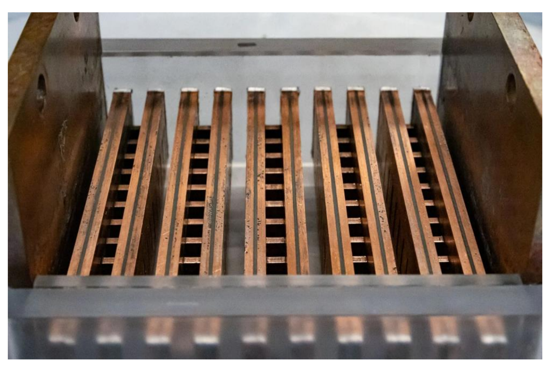
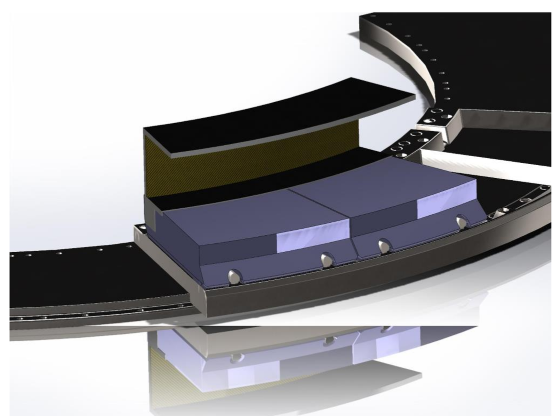
1:PPPL
2:ANL

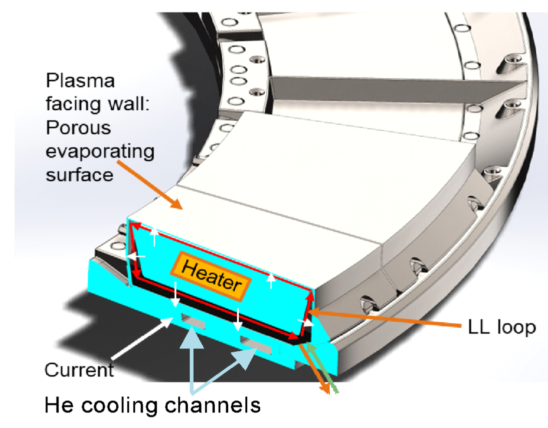
Liquid Metal PFCs and Fuel Cycle Require a Testing Platform



Divertorlets: J×B flows Li in row of vertical cascades. Tested experimentally in GaInSn and gram level at DIII-D.



Lithium Vapor Cave: Design and simulation



Capillary Porous System w. Flow (CPSF): Design and simulation

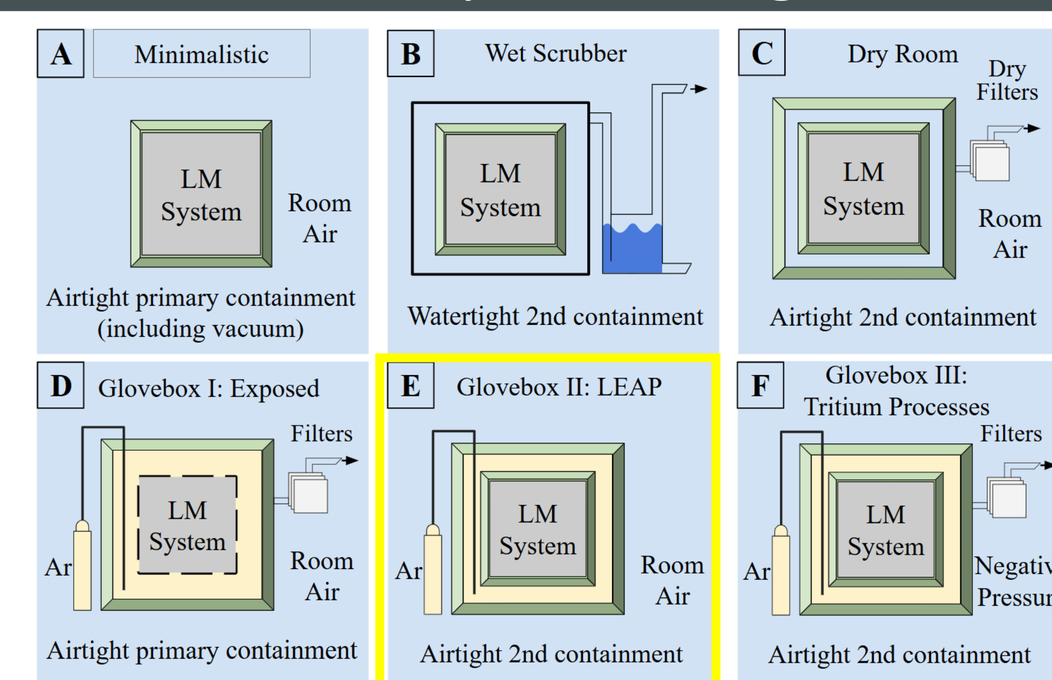
Various liquid lithium divertor designs need tile-scale experimental validation

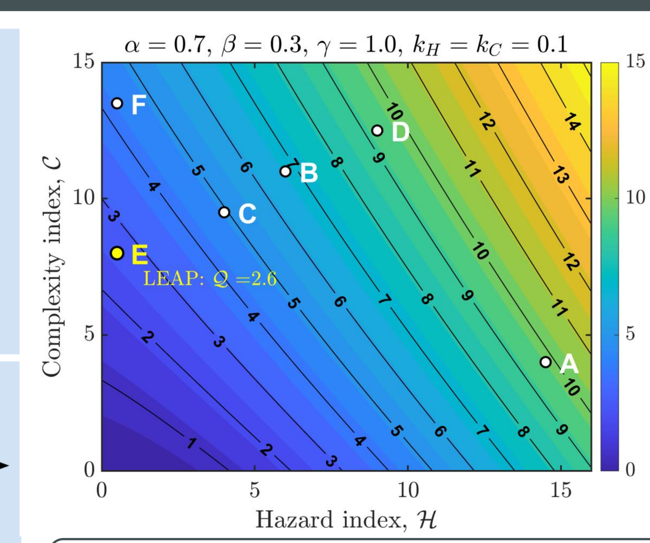
- Need subcomponent prototyping with liquid lithium
- Fast-flow designs, liquid metal flow through a strong magnetic field
- Fuel recovery requires large lithium flow rate, isotope extraction, and impurity removal

Integrated fuel processing

- A circulating test bed enables evaluation of pumps, diagnostics, separation, and isotope-extraction technologies as a connected system before fusion-device integration.

System Design Down-selection





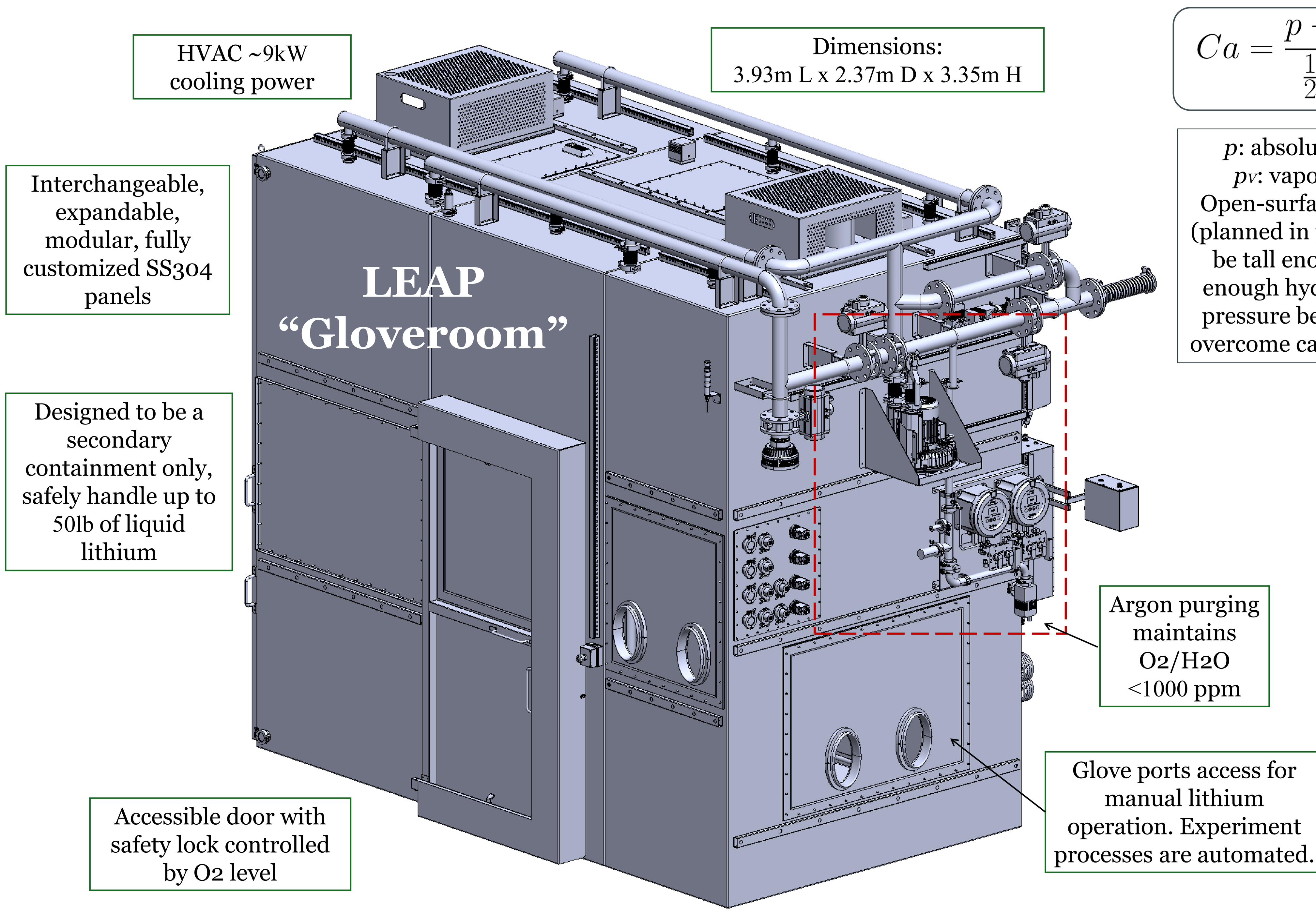
$$Q = \alpha\mathcal{H}\,(1 - \gamma_{\text{eff}}) + \beta\mathcal{C}$$

$$\gamma_{\text{eff}} = \gamma \exp\left(-k_H\mathcal{H} - k_C\mathcal{C}\right)$$

"effectiveness"

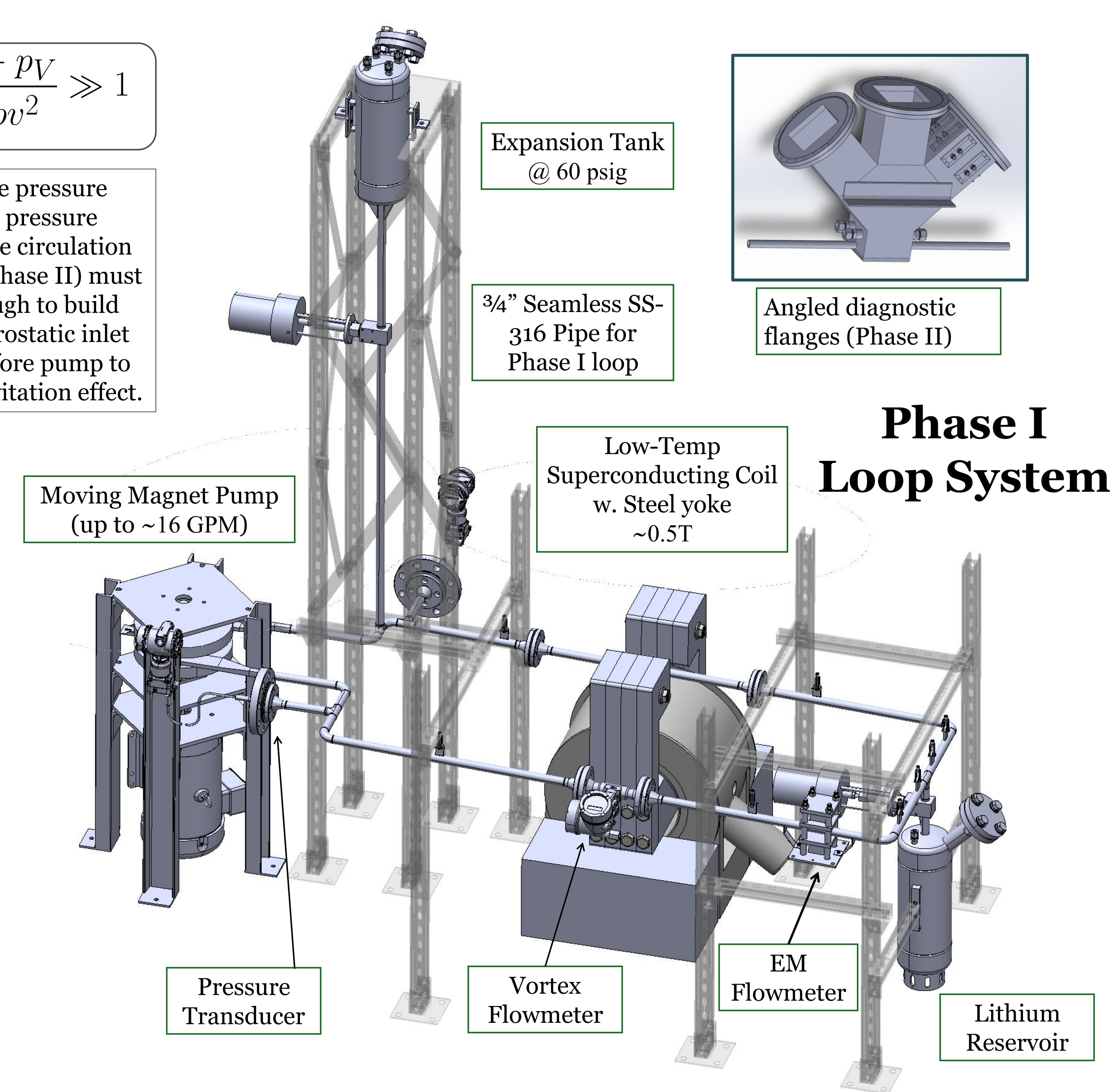
Hazard-complexity metrics: Defined hazard and complexity indices to balance lithium exposure hazards against infrastructure and operational requirements.

Selected configuration: Scenario E (airtight, argon-filled secondary enclosure without active scrubbers) achieves the lowest design penalty, Q ≈ 2.6, among the evaluated options under the specified model parameters.



$$Ca = \frac{p - p_V}{\frac{1}{2}\rho v^2} \gg 1$$

p: absolute pressure
p_V: vapor pressure
Open-surface circulation (planned in phase II) must be tall enough to build enough hydrostatic inlet pressure before pump to overcome cavitation effect.

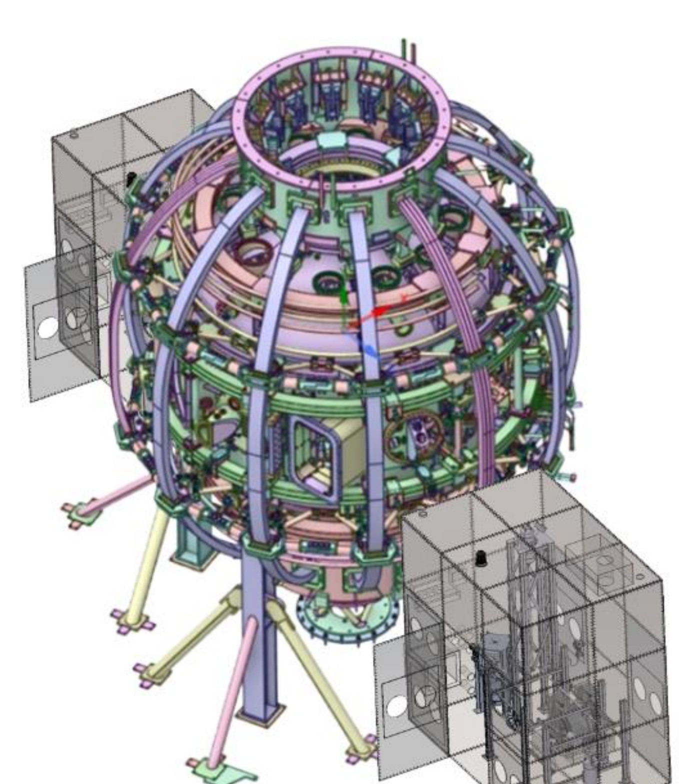


Current Status

- Final design reviews complete for the Phase I lithium system and gloveroom secondary containment
- Facility installation, system fabrication and assembly underway

ESAT building housing LEAP
Roof renovation in Sep 2026

New concrete pad with required smoothness for gloveroom support



LEAP integration concept with NSTX-U

Phase I (FY26-27)

Fully enclosed circulation loop, operates at 5lb.

- Demonstrate fast flow (~1L/s) through strong magnetic field
- Characterize pump behaviors & diagnostics
- Measure MHD pressure-loss and heat-transfer scaling.
- Erosion tests.

Phase II (FY27-28)

Open-surface component testing operates at 5-50lb.

- Test performance of heated porous and open-surface lithium components
- Investigate flow stability, heat transfer, and Li conditioning.

Phase III (FY28+)

Fusion-device integration

- Develop interfaces with fusion devices such as NSTX-U
- Connect Li supply and return circuits through vacuum-tight interfaces.
- Enable integrated plasma-facing component testing with external Li processing

Takeaway Messages

- **Lithium Experimental Application Platform (LEAP)** provides an integrated, versatile, and safe testbed for prototyping liquid metal PFC/first-wall and fuel cycle technologies. Three phases are planned to progressively address physics and engineering challenges with flowing liquid lithium systems.
- **Supports future integration with fusion reactors**
  - LEAP is a real-size fusion for flowing liquid metal circulation in fusion devices
  - Modularized panels can be modified to interface with fusion device
  - Multiple glovrooms decentralize lithium distribution with added redundancy

Dimensional operation parameters (Phase I):

Magnetic Field	Volumetric Flow Rate	Velocity	Temp.	Pressure/diff	Cooling Power
0.5T	~0-3 L/s	~0-5m/s	~200-400°C	~60psig/10psid	Up to 10kW

Scan to learn more about LEAP!

Xu et al. "Lithium Experimental Application Platform (LEAP) Part 1: Secondary-Containment Architecture and Downselection Framework for Flowing Liquid Lithium Fusion Systems." *Journal of Fusion Energy, in review.*

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Liquid lithium has broad potential applications in fusion energy, from improving plasma performance and managing heat and particle exhaust to supporting fuel-cycle technologies. An integrated, safe testing facility containing lithium circulation and interfaces with fusion devices is required and aligns with DOE's Fusion Science and Technology Roadmap. Princeton Plasma Physics Laboratory is developing the Lithium Experimental Application Platform (LEAP) with LDRD support to address this capability gap. Designed to accommodate lithium inventories up to approximately 23 kg in later phases, LEAP will expand U.S. experimental capabilities for liquid lithium component development and fusion device integration. The platform combines modular lithium circulation, an argon gloveroom for secondary containment, and customizable vacuum-tight interfaces. Initial experiments will characterize pumping and magnetohydrodynamic pressure loss at approximately 1 L/s in a 0.5 T magnetic field, establishing operating constraints for subsequent porous and open-surface lithium experiments. The modular architecture accommodates multiple component concepts and diagnostics while providing a pathway toward integration with fusion devices such as NSTX-U. Final design reviews are complete for both the Phase I lithium system and the secondary containment strategy. Fabrication and assembly are underway. Through staged development and early integration of containment requirements, LEAP demonstrates how LDRD investment facilitates rapid advancement of an emerging research direction into a versatile experimental facility supporting DOE's mission toward future fusion reactors.

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