Results from, and plans for, the Lithium Tokamak eXperiment (LTX)

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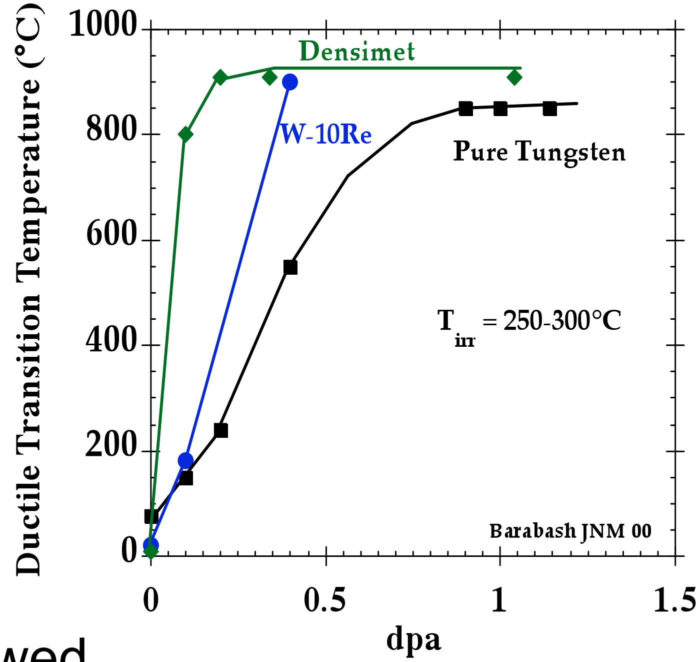
Outline

- Short recap - liquid metal plasma facing components
  - Solids (tungsten) vs. liquids
  - LTX and liquid metal PFCs
- LTX design for liquid lithium operation
  - Overview
  - Shell and heater systems
  - Recycling diagnostics
  - 2010 lithium evaporation system
- Results with evaporated coatings (2010)
  - Cold walls
  - Hot walls and discussion
- Near-term plans, and summary

Plasma-facing components (PFCs) for reactors

- Only candidate solid material considered viable for reactor-grade PFCs is tungsten
  - Ductile to brittle transition: 200 – 500 °C
  - Subject to radiation-induced embrittlement above a few DPA
    - » Require 100 – 200 DPA lifetime
  - Subject to surface damage under He fluence



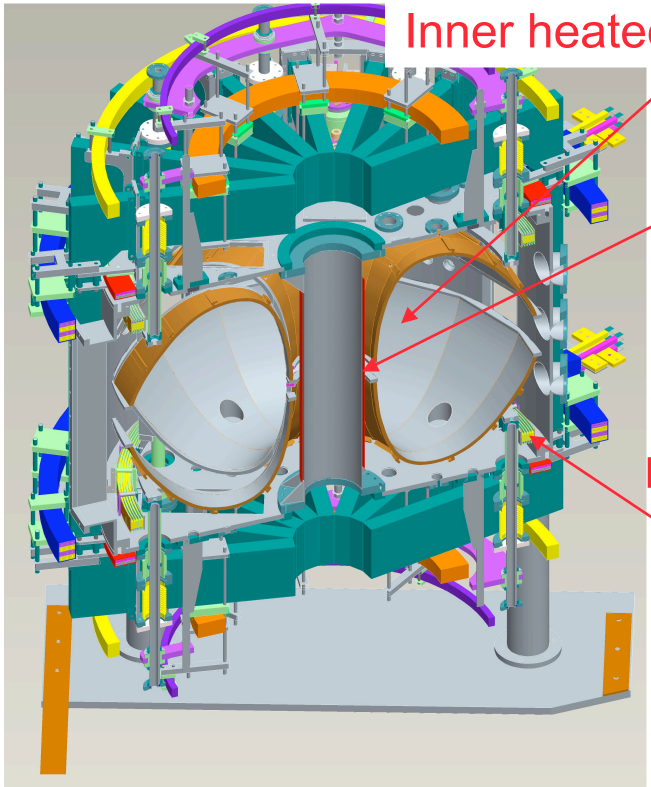
Liquid metal walls offer another PFC solution

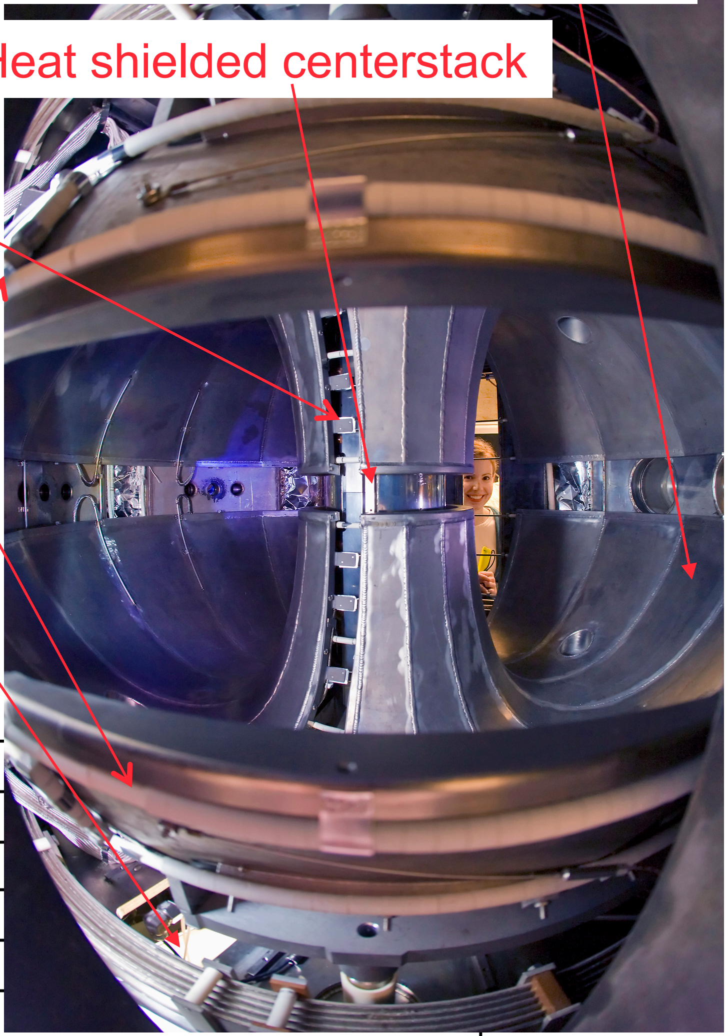
- Flowing liquid metal PFC is continuously renewed
- Neutron damage limited to supporting substrate
- Plasma-material interaction (PMI) limited to the liquid metal: sputtering + evaporation
- PMI issues and neutron damage issues are *separable* with liquid metal systems

Liquid metals and LTX

- LTX is the first confinement device designed to test a full, hot, liquid metal (lithium) wall
- Liquid lithium wall development relevant to all liquid metals
  - Gallium, tin, tin-lithium eutectics
- Lithium has a strong affinity for hydrogen
  - Forms a stable hydride
  - *Low recycling wall*
- Low recycling wall ↔ hot edge in a magnetically confined plasma
  - Power flux is carried by particles at the edge
  - Poor fueling efficiency (~5-10%) for recycled particles *guarantees* high particle density at the wall (for a high recycling wall)
  - For low recycling, *only* edge particles are those lost from the core
  - High recycling = low power/particle (low edge temperature)
  - Low recycling = high power/particle (high edge temperature)
- LTX combines development of liquid metal wall technology and a test of the physics consequences of low recycling liquid lithium walls

LTX has a full, 5 m^2 heated, conformal wall





Inner heated shell (explosively bonded SS on copper)

Heat shielded centerstack

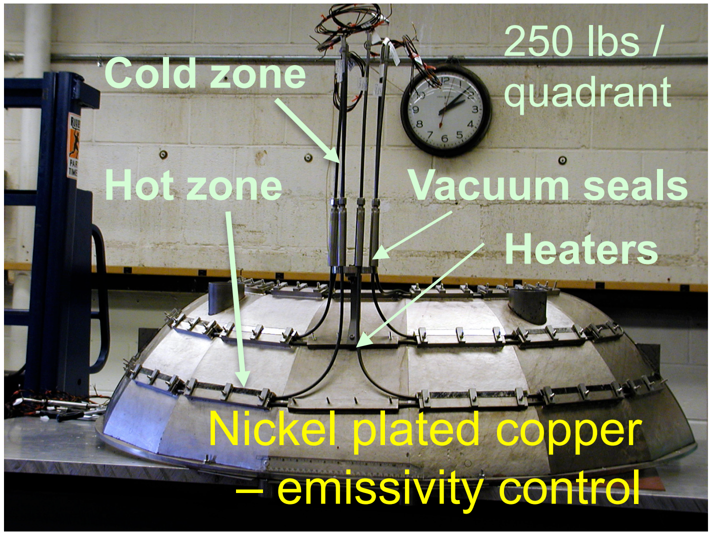
2-axis Mirnov coils

Flux loops

Fast, uncased internal coil

Parameter	CDX-U	LTX
Major radius	0.34 m	0.4 m
Minor radius	0.22 m	0.26 m
Toroidal field	0.21 T	0.34 T
Plasma current	100 kA	400 kA
Current flattop	5 ms	>100 ms
Ohmic flux	30 mV-s	160 mV-s (centerstack maximum: 225 mV-s)
Wall temp.	20 °C	400 °C now, ~ 600 °C future

Robust operation of LTX heaters to 300 °C demonstrated

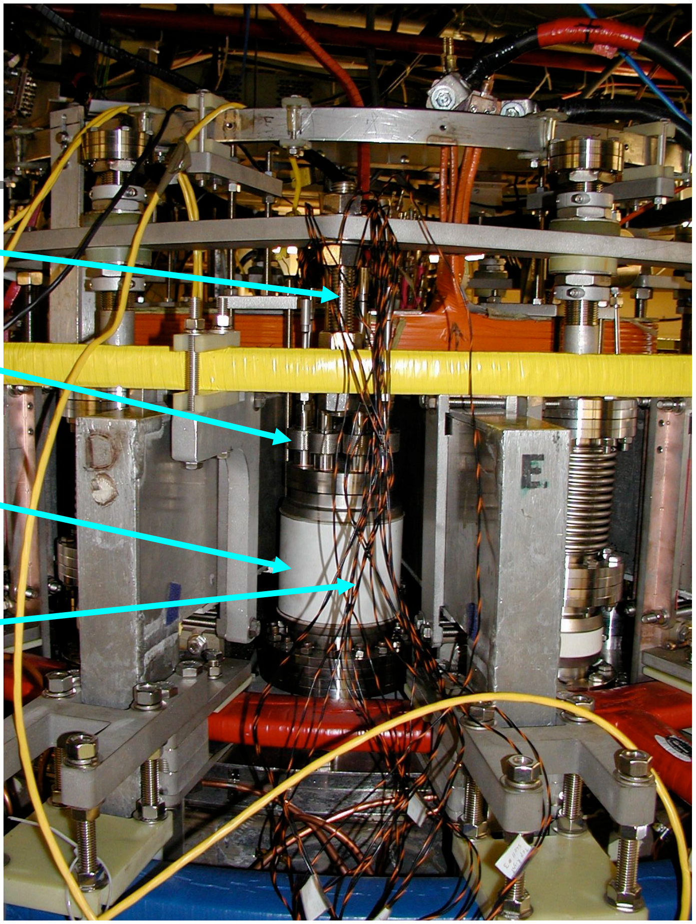


Heater cold ends

Swagelok + Kal-rez seal

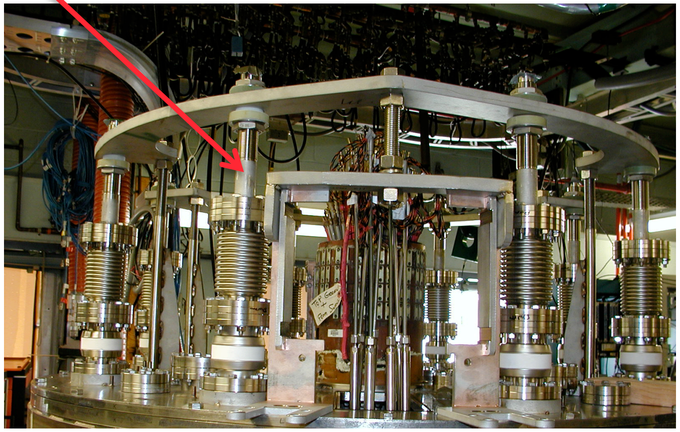
Ceramic break

External heater leads



- Cable heaters (Durex Corp.) Nichrome elements, compacted (swaged) MgO insulation, thermal transfer medium
  - But: Nichrome sublimates at operating temperature, in vacuum
  - Solution: re-entrant heaters ➔ Nichrome elements in air
  - No leaks, no heater failures in 3 years testing
- Bonus: no in-vacuum electrical feeds

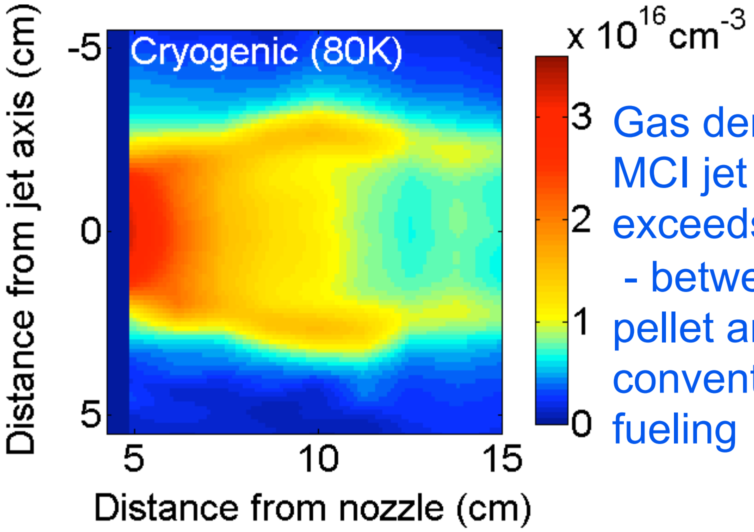
Support legs



- Shell “floats” in vessel; external supports

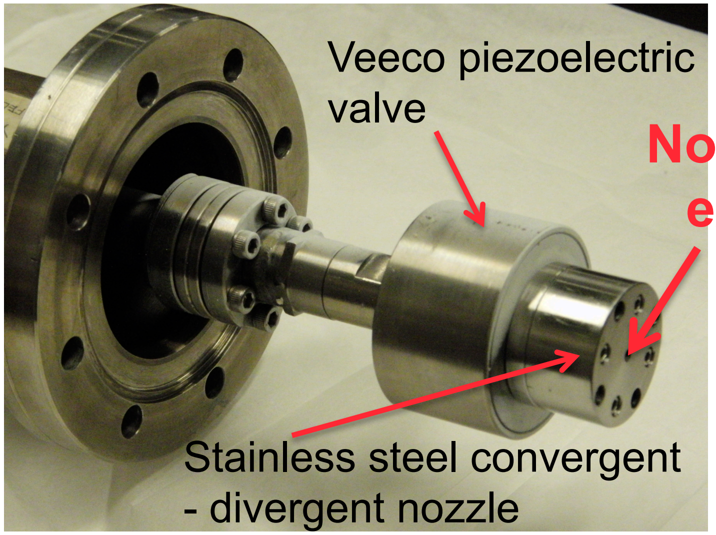
Recycling source being replaced by active fueling

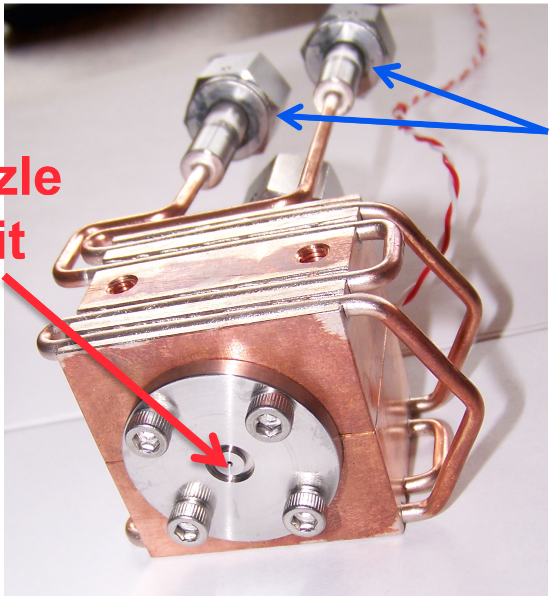
- Molecular cluster injector for LTX
  - Precooled (82K) gas condenses through nozzle exhaust
    - Forms clusters
  - Less expansion of jet
  - High fueling capability
  - Millisecond response
- Combined with existing supersonic gas injector



Gas density in MCI jet exceeds 10^{16} cm^{-3}
- between a pellet and conventional gas fueling

Supersonic Gas Injector

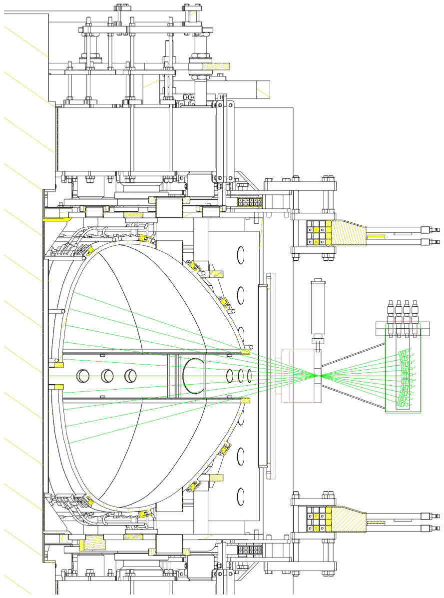


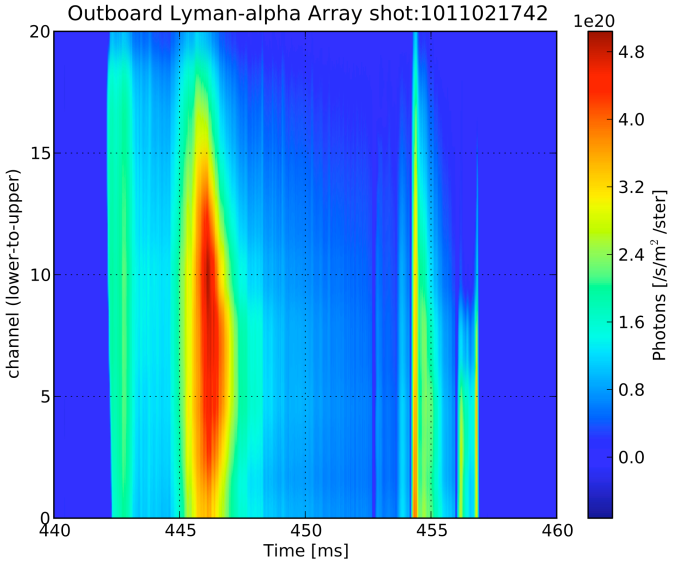


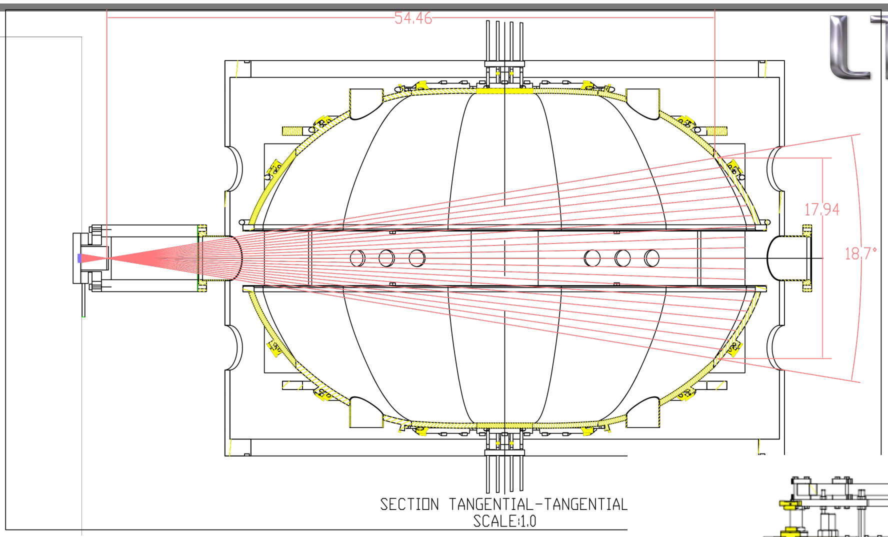
Molecular Cluster Injector

Recycling measurements employ Lyman-α arrays

- Lyman-α array viewing shell high-field (inner) side
- Replaced for upcoming run with a JHU-style detector set
  - Lower noise

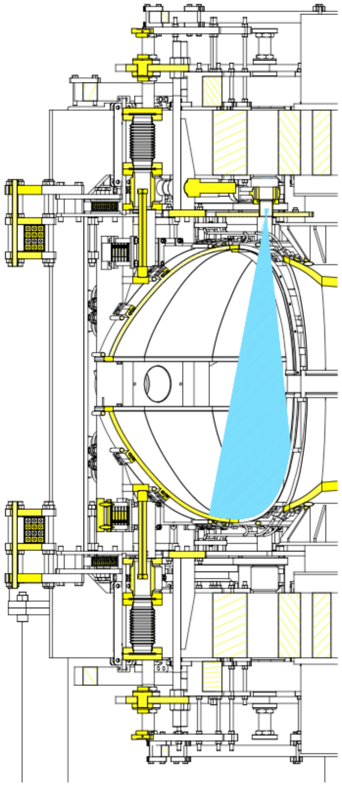




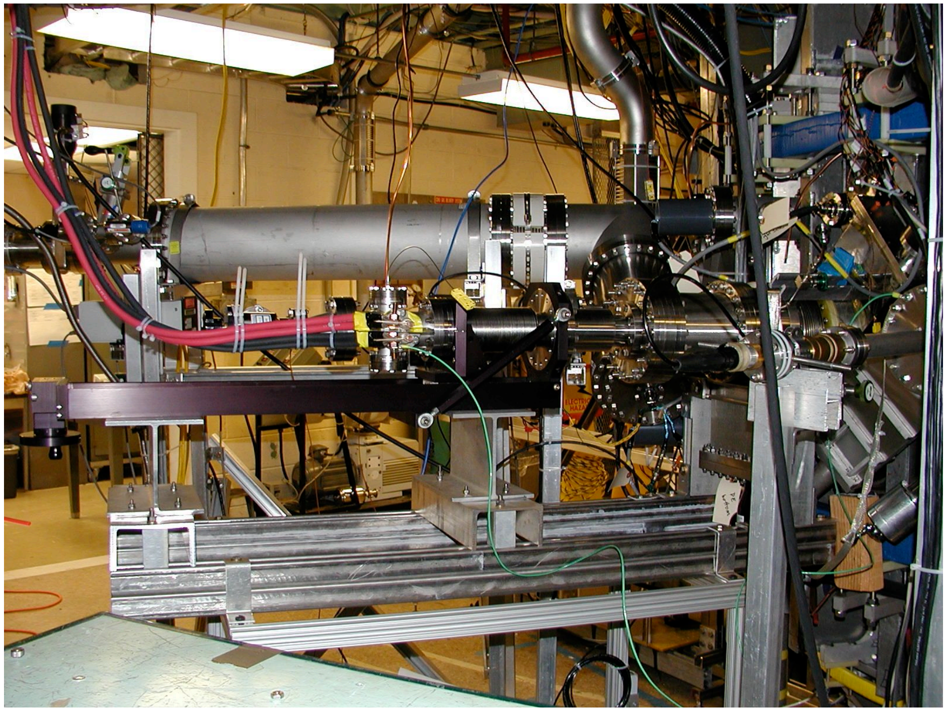


- View of shell low-field (outboard) side through tangential port (array developed by K. Tritz, JHU)

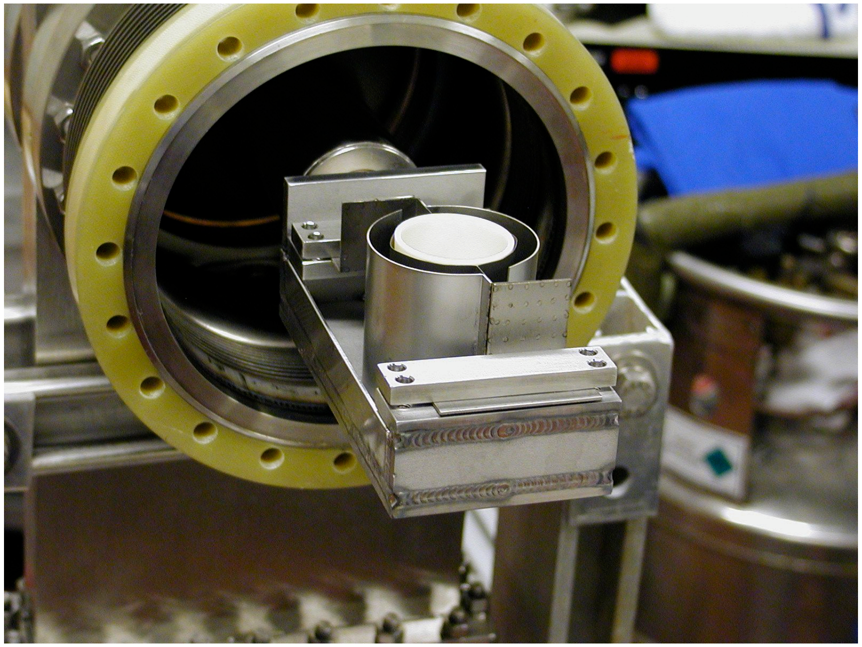
- View of lower molybdenum limiter in lower shell



New lithium coating systems developed for LTX



Evaporator (1 of 2) with linear motion stage mounted on LTX

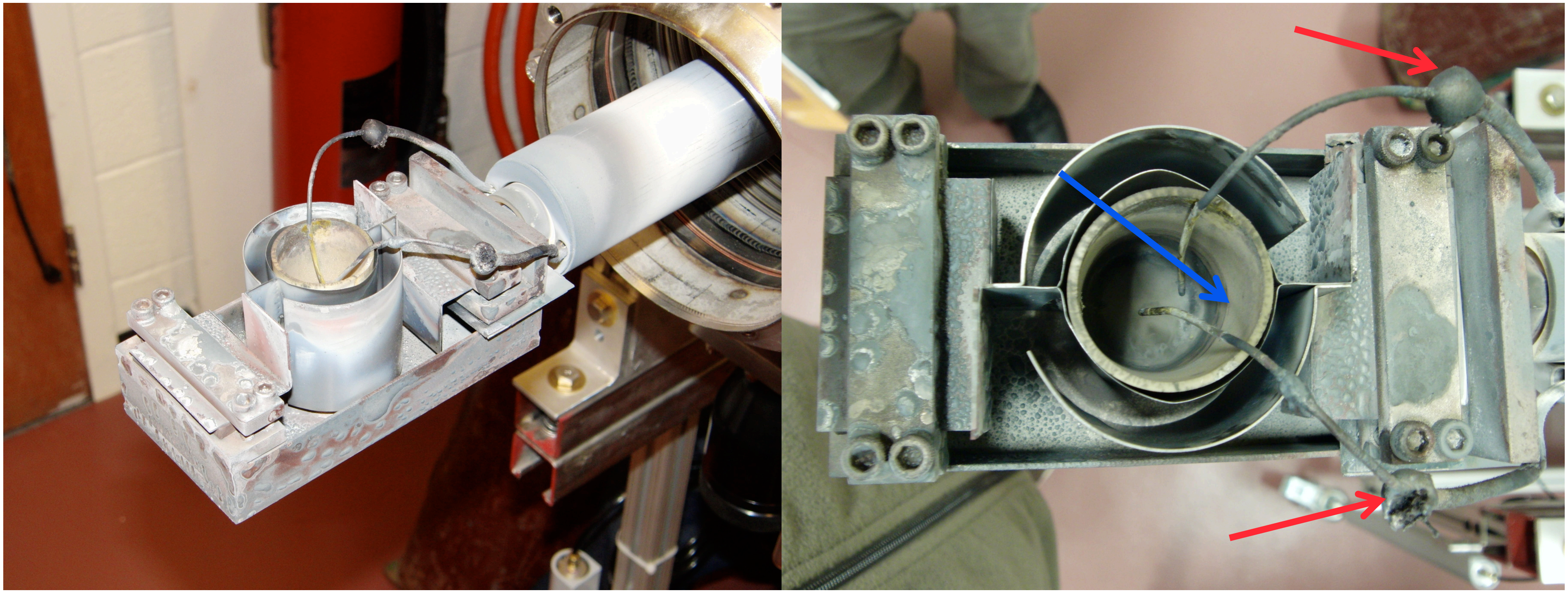


Y_2O_3 crucible, Ta heater

➢Tested to 700 °C

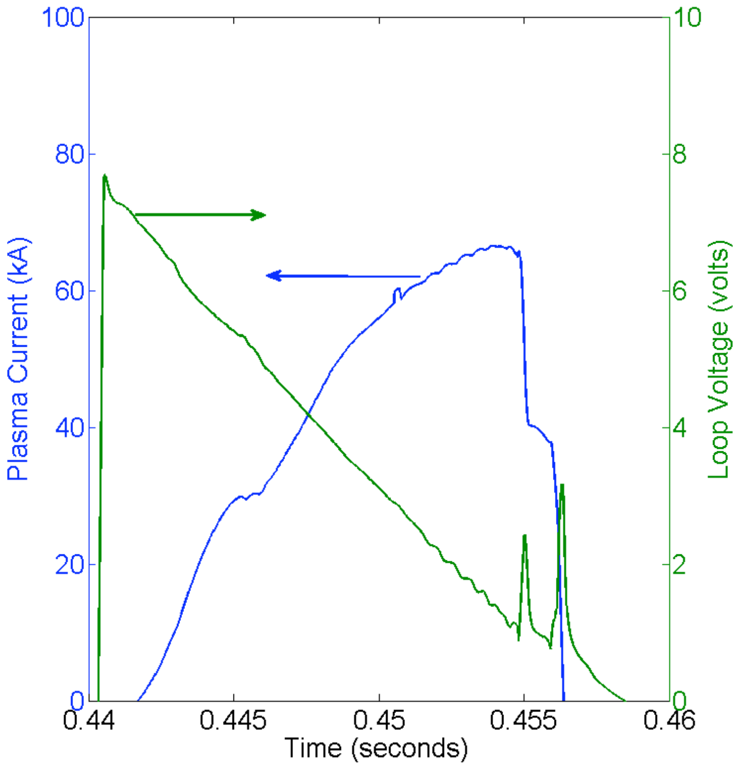
- Two evaporators installed
- LTX lithium experiments have begun
- Total of 10 g evaporated onto walls in first round
  - 44g total lithium evaporated in 2010
  - Sufficient for a 4 micron coating of the entire shell

Crucibles and heaters effective, simple, reliable

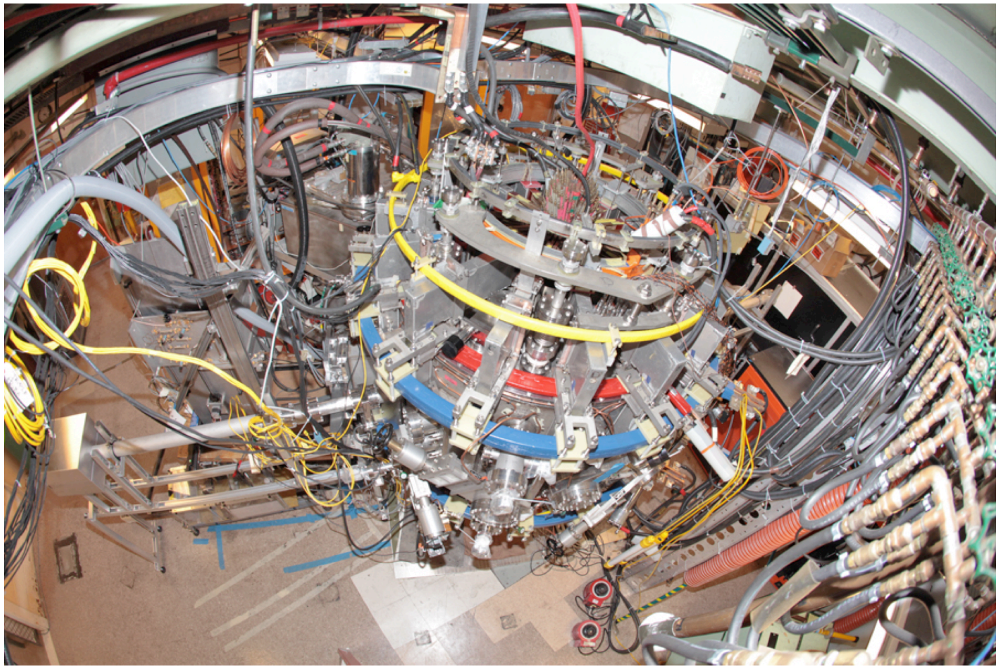


- Cleanup relatively straightforward
- No significant issues with yttria crucibles after 600C operations
  - Lithium did not wet the crucible
  - Thermocouple wetting provided an escape route

Current LTX status

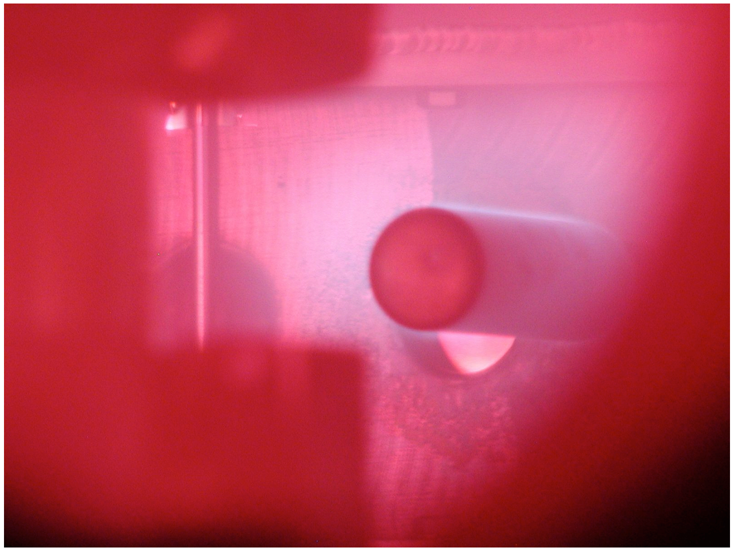


- (Almost) overhead fisheye view of LTX

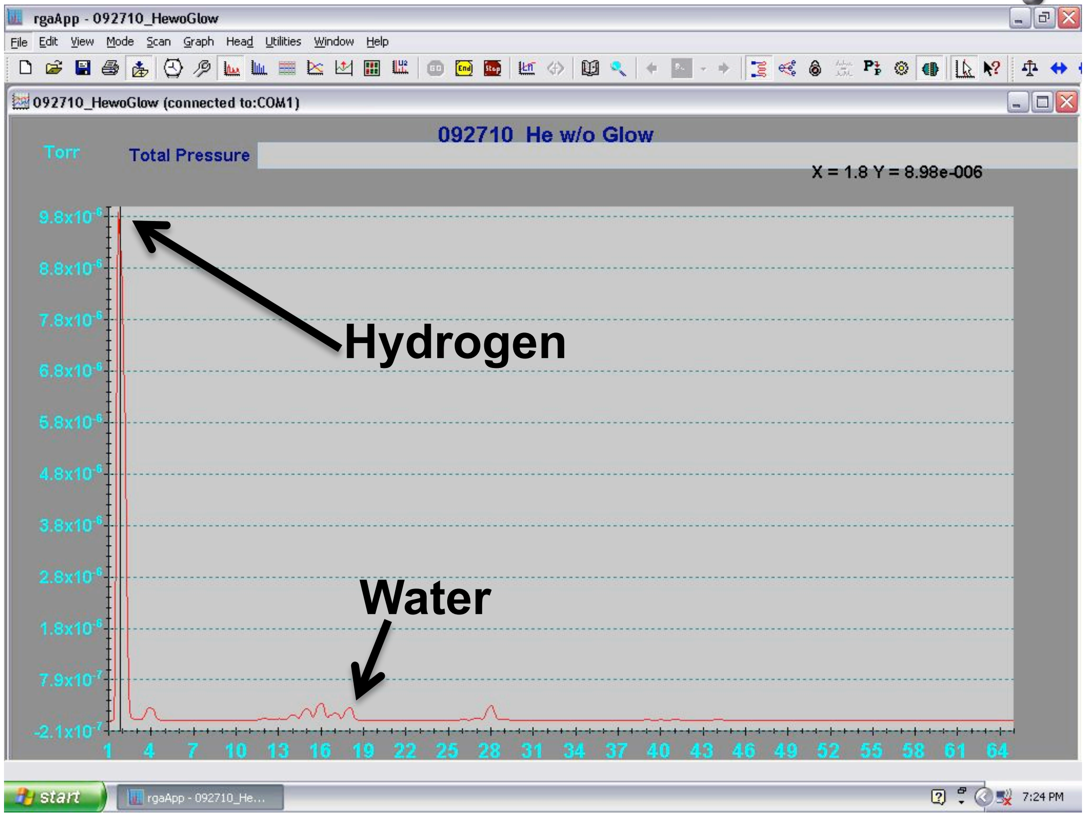


- Plasma current ~70 kA, shot duration ~20 msec
  - Thomson: T_e ~ 50 – 150 eV
- Shells routinely heated to 300 C for bakeout
- Operated with lithium coatings October – December 2010
- Presently vented for maintenance, upgrades: preparing for pumpdown
    - » *More engineering details: T. Kozub (tkozub@pppl.gov) for poster copy*

Lithium initially evaporated into helium glow



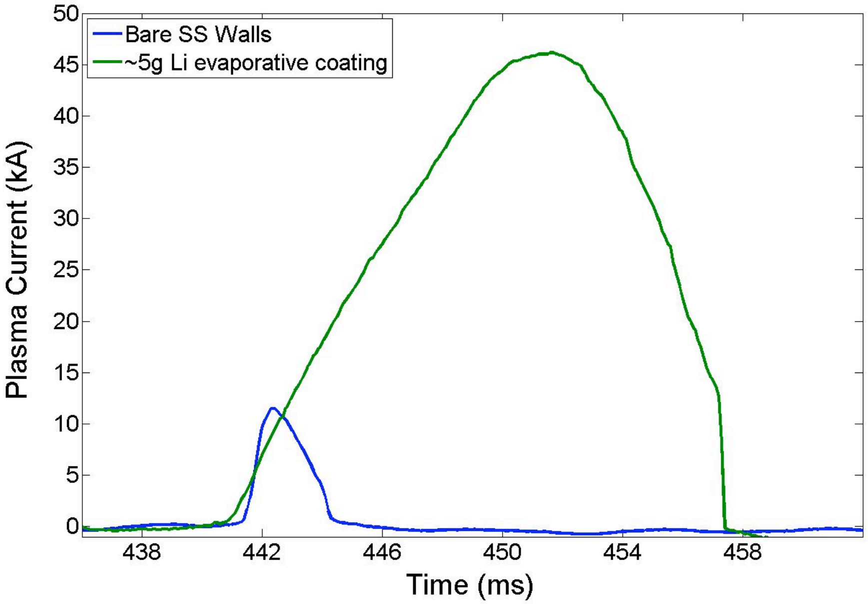
Glow probe head
>Lithium-dominated discharge
>Working gas was helium



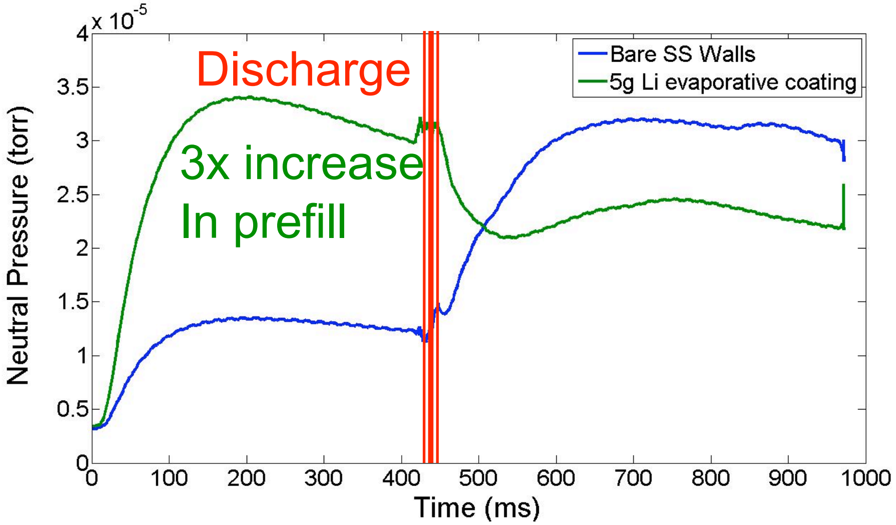
RGA trace indicating lithium gettering of water
>Trace is dominated by liberated hydrogen

- Lithium introduced by evaporation from yttria crucibles at 550 C
- 5 gram load per crucible, 2 crucibles, 1.2 g evaporated in first run

Lithium wall conditioning produced immediate effect on the discharge



Plasma current comparison

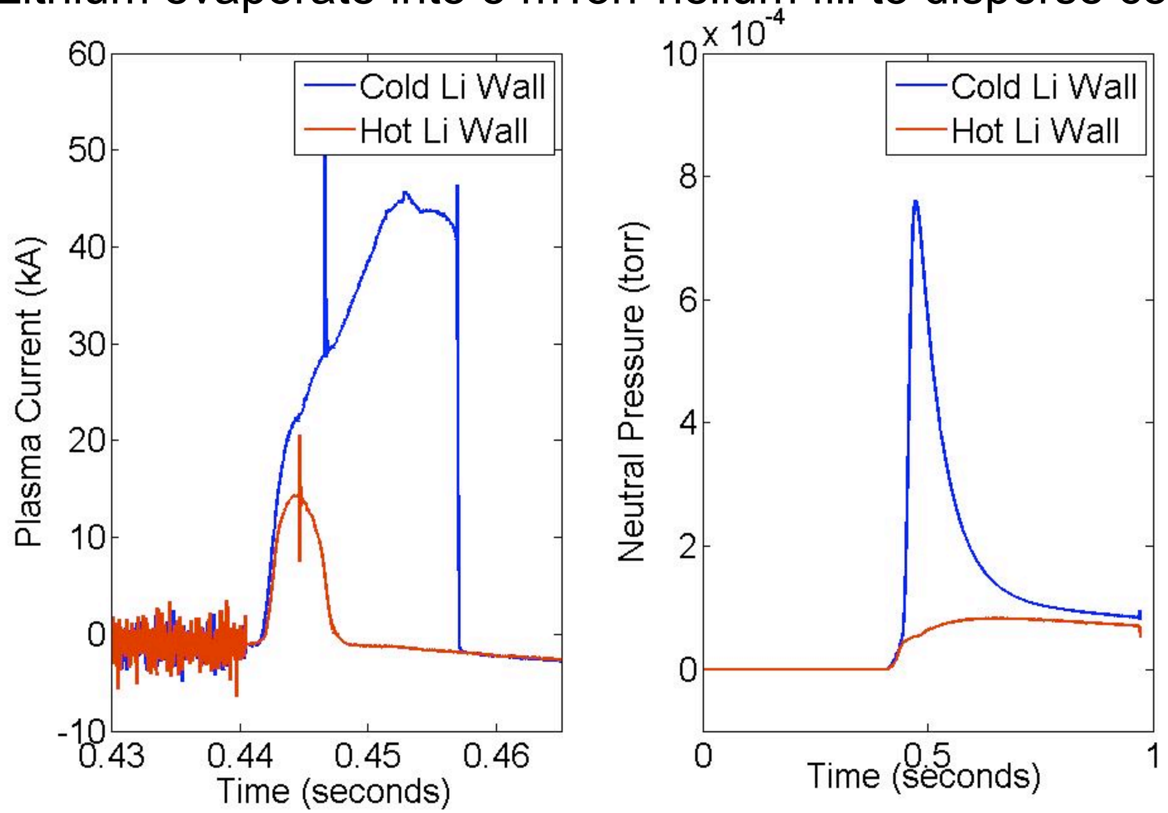


Pressure evolution

- First lithium operation shown – cold shell
- Lithium glow preceded by helium glow with hot (250C) shell for preconditioning
- Discharge current, duration significantly increased after only a few hours of operation following Li glow
- Pressure history shows evidence of reduction in recycling

LTX was operated with a lithium-coated 300 °C shell

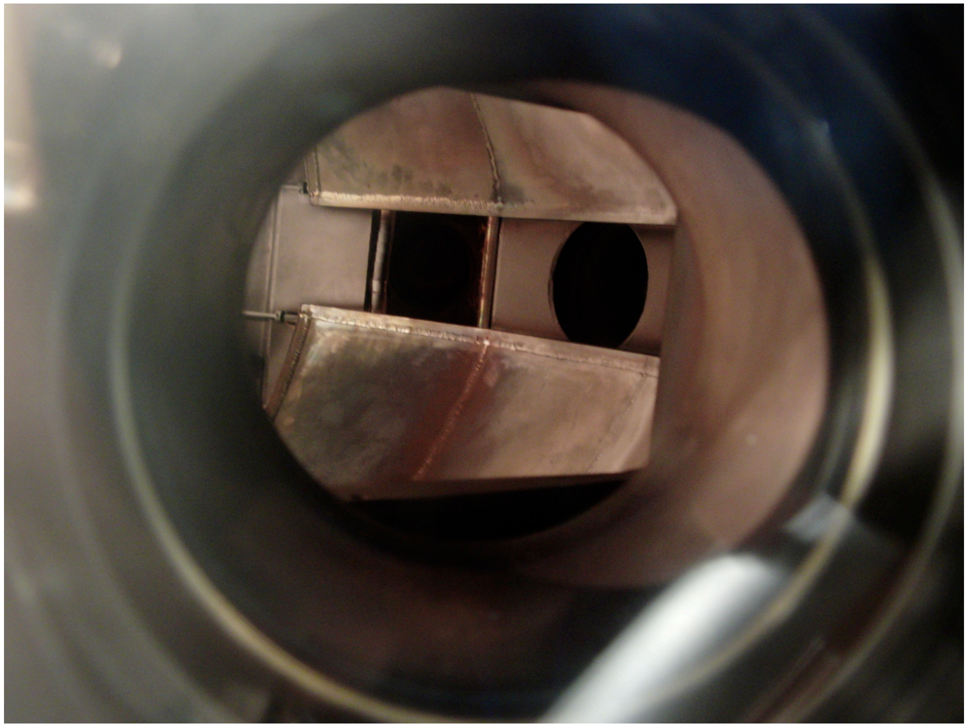
- First full high temperature, high Z wall operation of a tokamak
  - Lithium evaporate into 5 mTorr helium fill to disperse coating

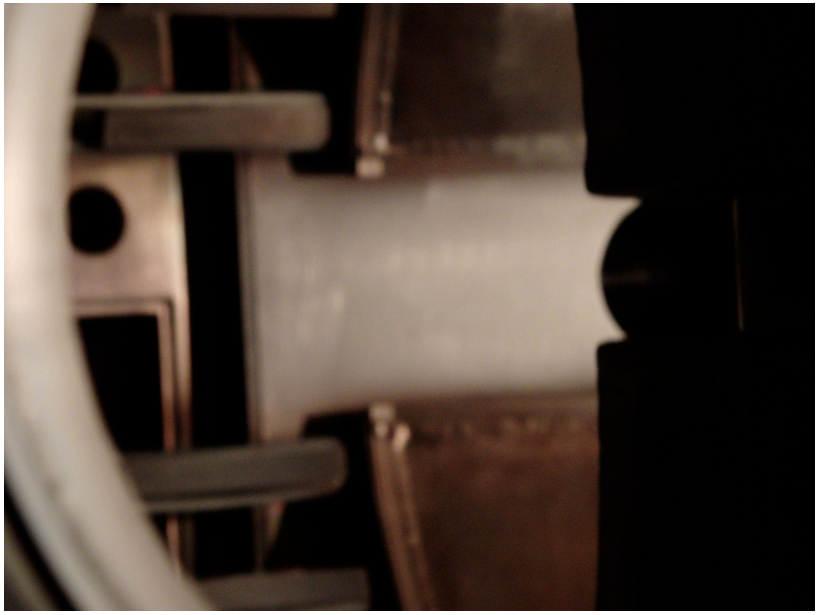


(Warm) cluster injector system, wall puffer employed for fueling with cold lithium walls

- Hot (300 °C) shell with thin lithium coatings does *not* exhibit a significant reduction in recycling
  - "Liquid" lithium is impurity-dominated
  - Relevant to any experiment with lithium on a hot substrate

Shell interior at 300 °C after 4 g lithium deposition





- Deposition rate ~0.75 g/hour/evaporator; 3 hour evaporation
  - Evaporate into 5 mTorr helium to distribute lithium
  - Est. 1.6 micron average deposition layer
- Lithium coating darkens rapidly
- No visual evidence of metallic surface

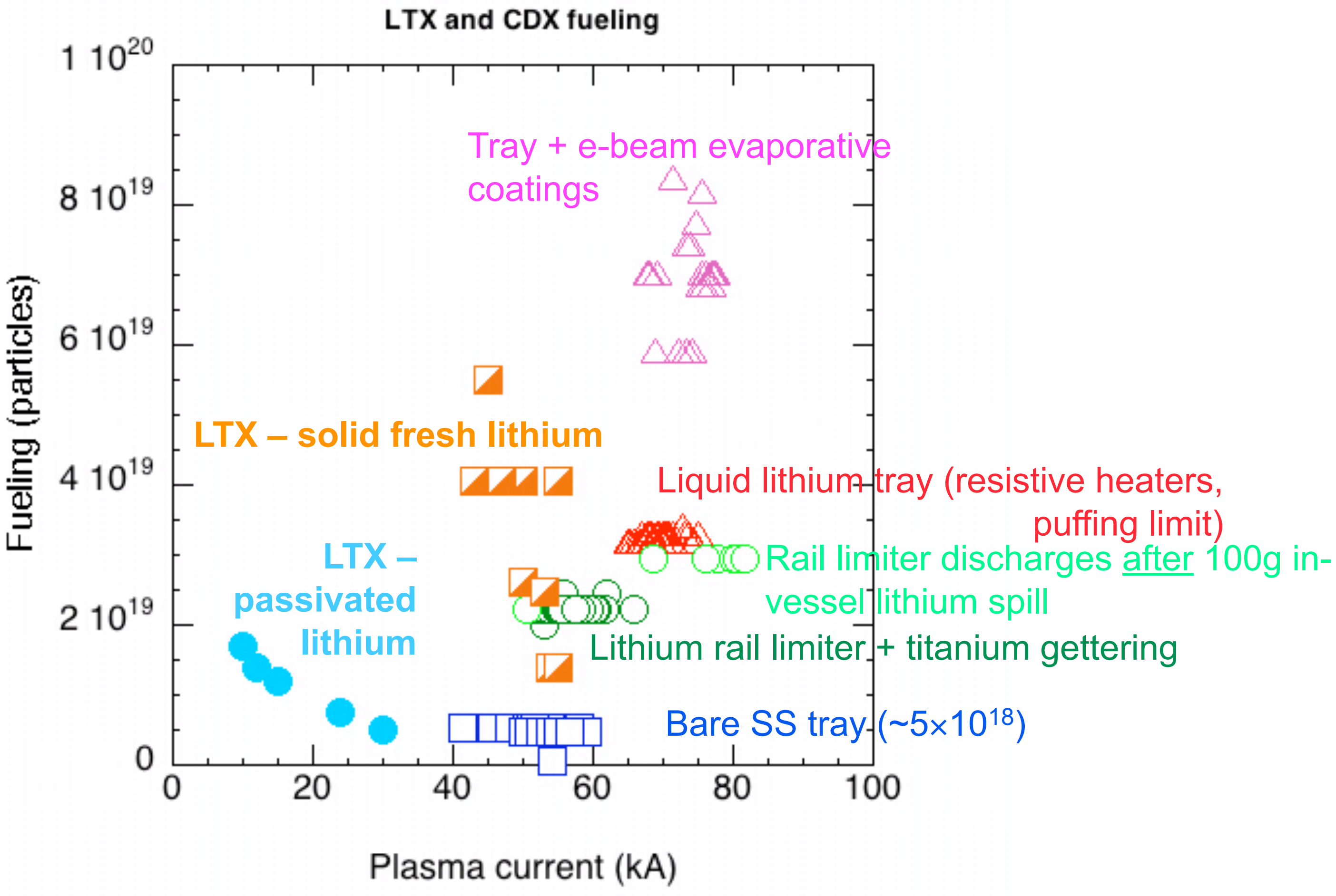
Discussion of hot wall results

- Partial pressure of water during cold wall lithium evaporation was ~ 5 x 10^{-9} Torr
- Partial pressure of water during the hot wall experiment was ~2 x 10^{-8} Torr
- With cold walls, improved discharges were obtained for ~48 hours
- With hot walls, no improved discharges were observed
  - Delay between termination of coating and tokamak operations was 1 hour, 15 minutes
  - If the only factor affecting the condition of the lithium coating was background water pressure, coating should have been active for **~12 hours**
- Therefore, hot coating passivated more quickly than can be accounted for by background water pressure
- Suspect segregation of oxygen, other impurities to the surface was responsible for rapid passivation

LTX and CDX-U fueling

- Fueling requirements for LTX are approaching CDX-U requirements for low recycling operation
  - LTX: similar shot duration
  - Lower plasma current, density

Total fueling
⇒including
prefill



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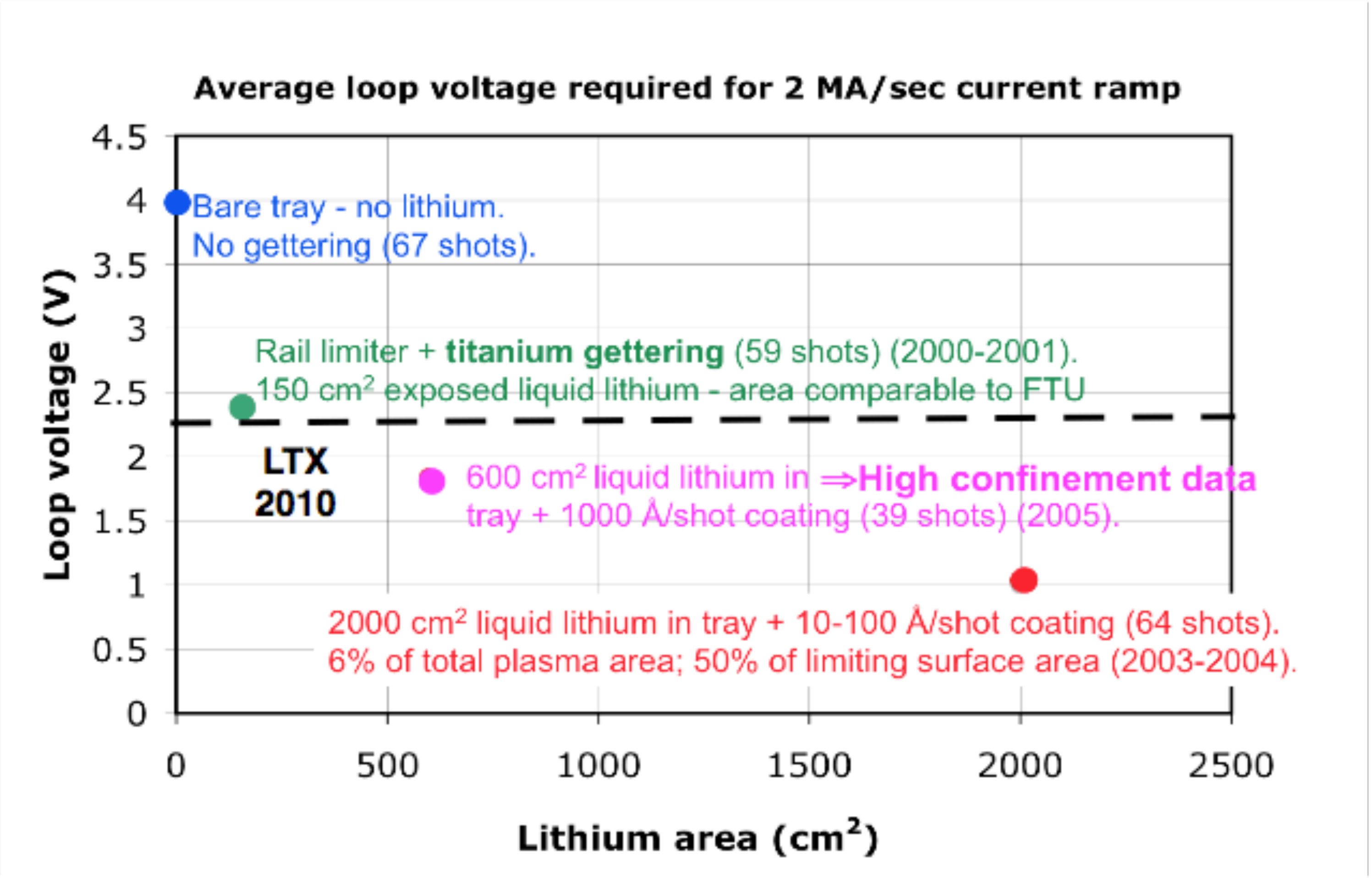
Loop voltage comparison indicates modestly improved discharge performance with cold wall coatings

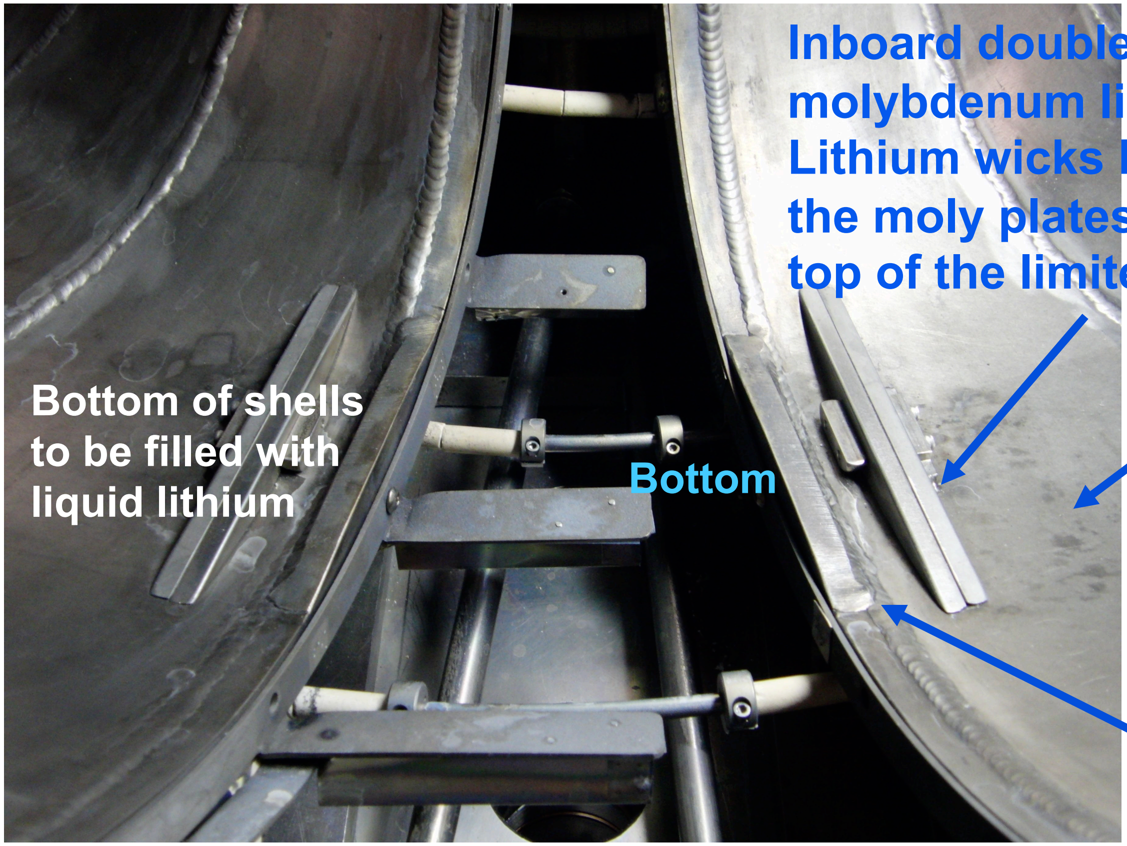


- *Preliminary* result (just a few discharges from LTX)
- Require more discharges, full confinement assessment

Near-term (2011) plans

- Improve vacuum conditions in LTX
  - Adding vacuum vessel bakeout to 120 C
  - Vessel will be cooled during tokamak operations with hot shell
- Increase shell bakeout temperature to 400 C
- Add water pumping
  - Installing two lithium getter pumps
  - Pumping speed for each unit estimated at 2500 L/sec
  - Each pump will employ a heated lithium crucible and a large wall area for lithium deposition
- Summer 2011: begin operations with liquid lithium fills in both lower shells
  - Fill system in preparation; modification of evaporation system
- Preliminary assessment of confinement with partial liquid lithium walls later this year

Lower shells designed for liquid lithium pools



- Lower shells have welded stainless steel lips to retain lithium
- Double molybdenum limiters are designed to wick lithium
  - Tested – wicking system works
  - Limiters extend 2 mm above the stainless steel retention lips to reduce plasma contact with the retention lips

Summary

- LTX began operations with lithium walls in October 2010
  - No wall conditioning preceded introduction of lithium
- Immediate effect on discharge
  - Plasma current: 15 ➔ 70 kA (~CDX-U)
  - Plasma duration: 5 – 20 msec (~CDX-U)
- Observe rapid passivation of hot (300C) lithium films
  - Tentative indications of impurity surface segregation
- Better thermal control of the vacuum vessel in implementation
  - Controlled bakeout + active cooling
- Enhanced pumping being installed with new lithium getter pumps
- Liquid lithium fill of lower shells scheduled for late this summer, or early fall