Summary of LTX results

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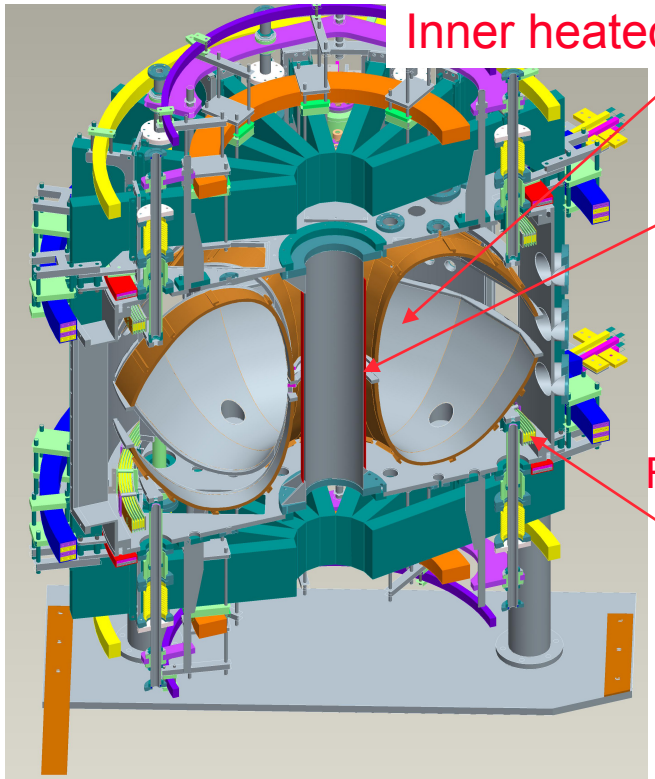
Outline

- LTX overview
- Lithium evaporator system
- Overview of results with room-temperature (solid) lithium wall coatings
- Results with hot “liquid” lithium walls
  - Implications for past and future NSTX experiments
- Shell motion during a discharge
- Summary

LTX configuration - full, 5 m^2 heated, conformal wall



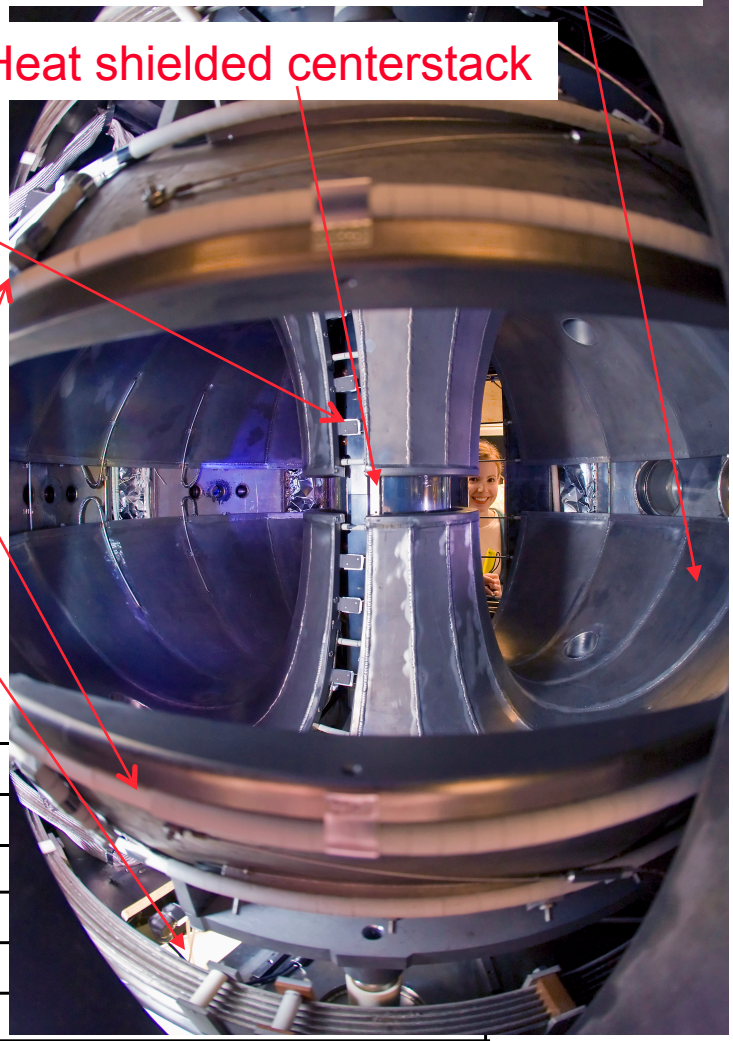
Inner heated shell (explosively bonded SS on copper)

Heat shielded centerstack

2-axis Mirnov coils

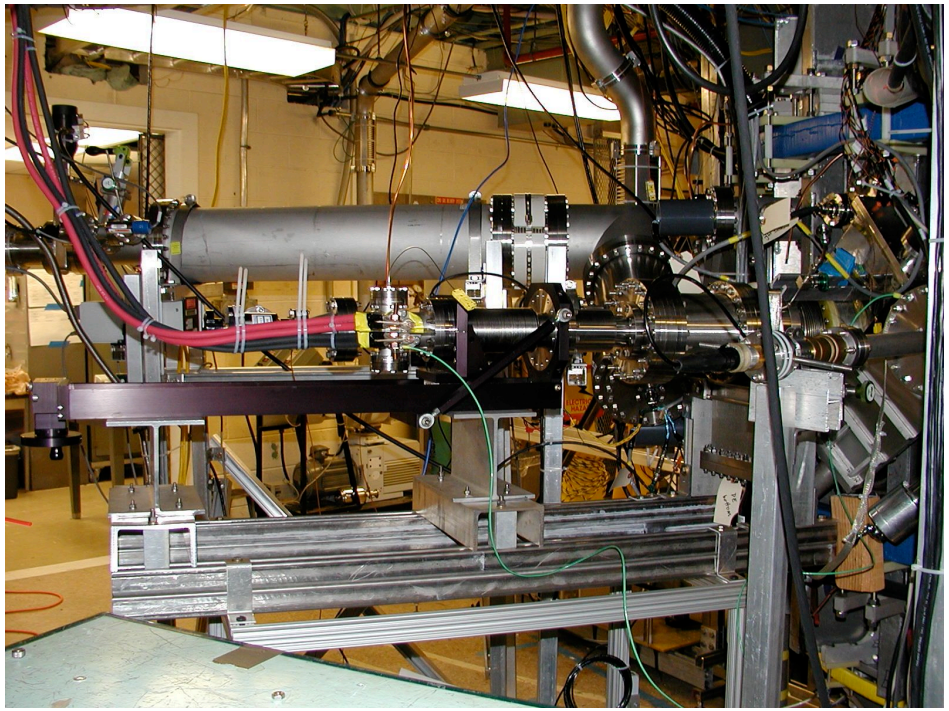
Flux loops

Fast, uncased internal coil

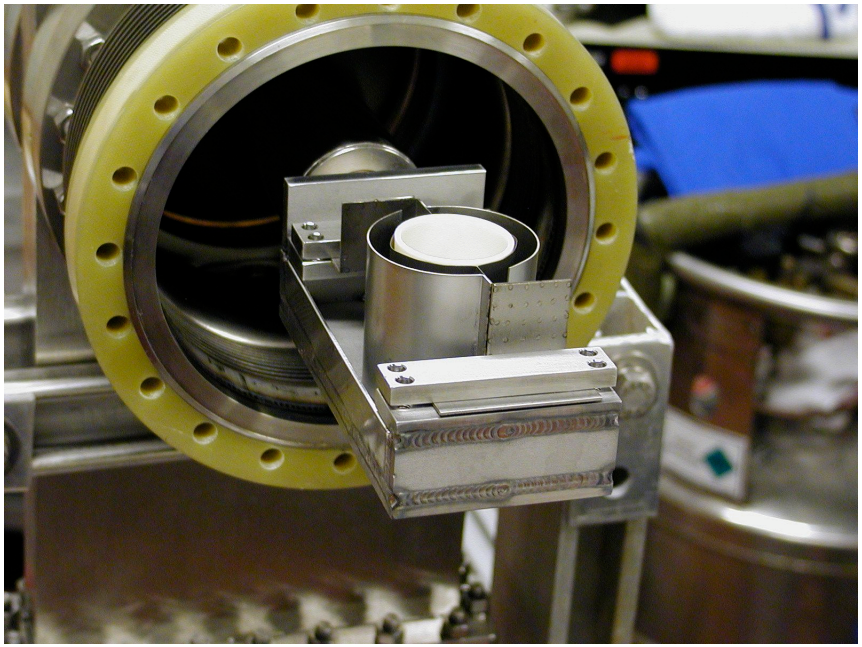


Parameter	CDX-U	LTX
Major radius	0.34 m	0.4 m
Minor radius	0.22 m	0.26 m
Toroidal field	0.21 T	0.34 T
Plasma current	100 kA	400 kA
Current flattop	5 ms	>100 ms
Ohmic flux	30 mV-s	160 mV-s (centerstack maximum: 225 mV-s)
Wall temp.	20 °C	400 °C now, ~ 600 °C future

New lithium coating systems developed for LTX



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

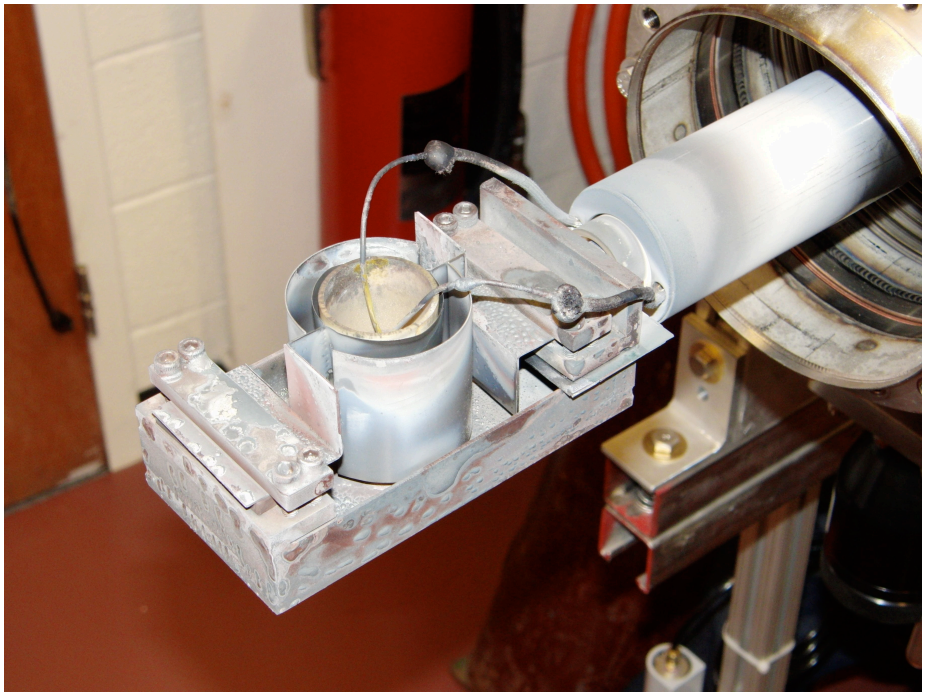


Y_2O_3 crucible, Ta heater
- Tested to 700 °C

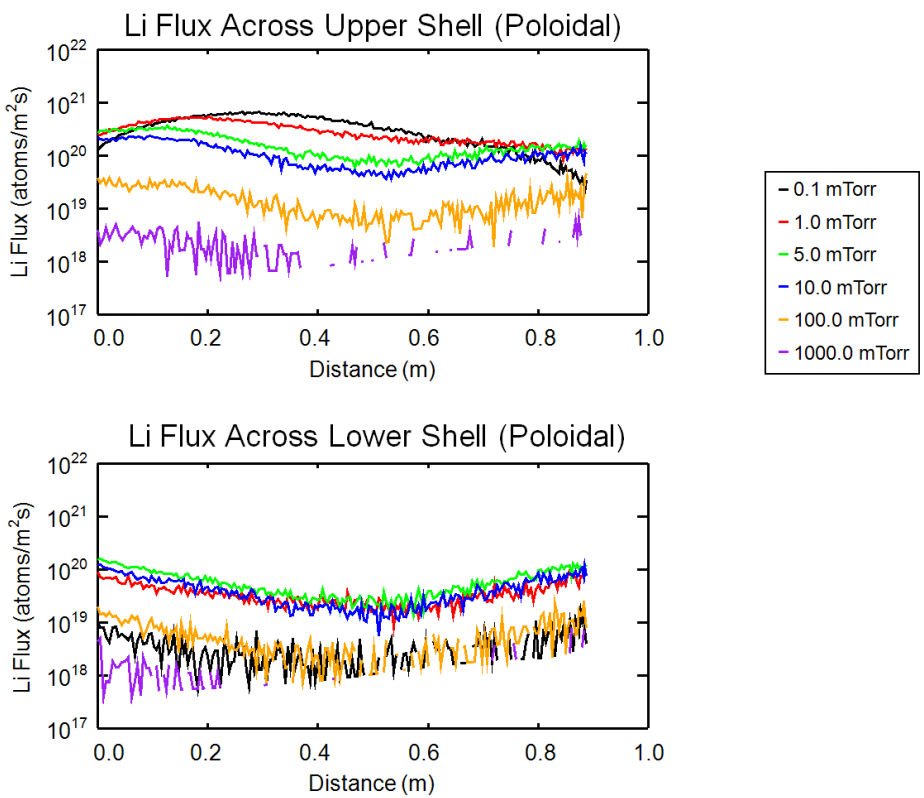
- Two evaporators installed
- Total of 10 g evaporated onto walls in first experiments
  - 44g total lithium evaporated in 2010
  - Sufficient for a 4 micron coating of the entire shell

Crucibles and heaters effective, simple, reliable

Crucible after 8g lithium evaporation

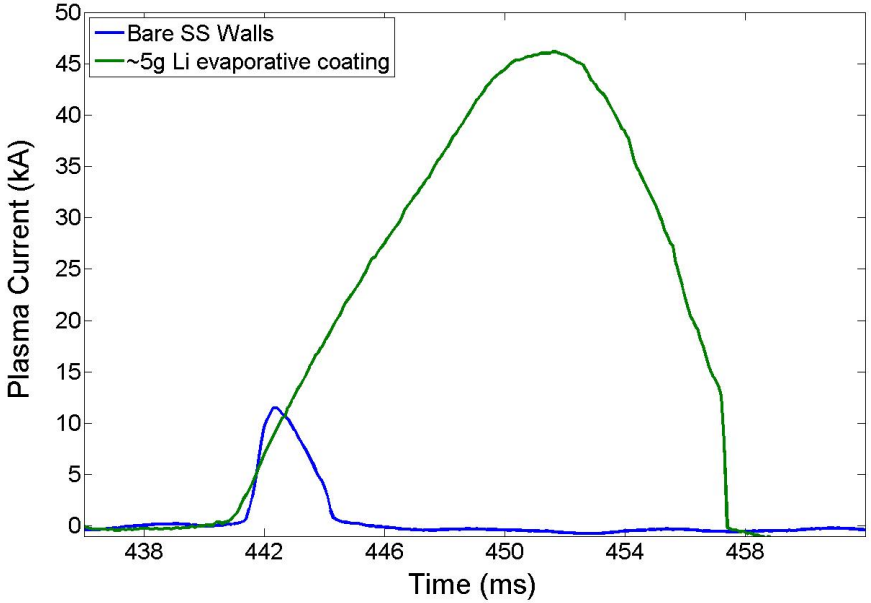


DEGAS2 modeling of lithium coverage by T. Abrams with D. Stotler

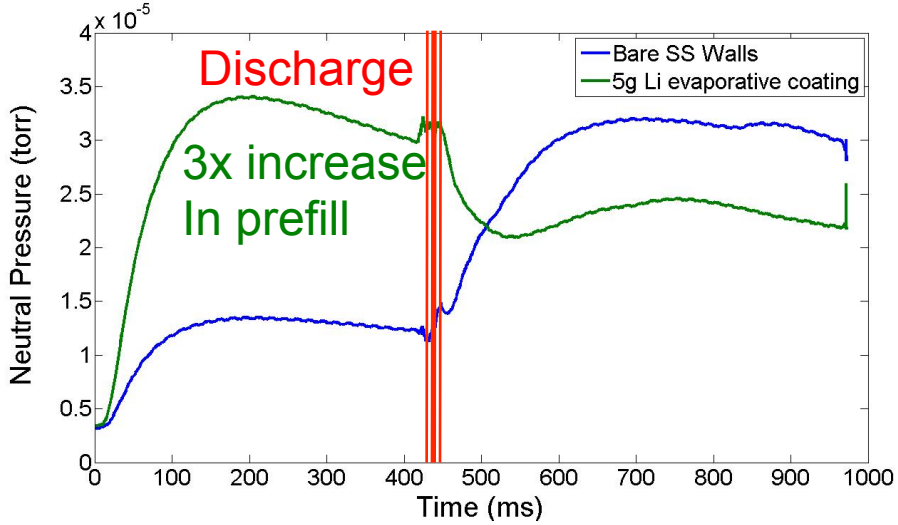


- Helium glow or simple backfill used to disperse lithium
- Cleanup relatively straightforward
- Coverage moderately uniform for helium fill pressure ~ 10 mTorr

Lithium wall conditioning produced immediate effect on the discharge



Plasma current comparison

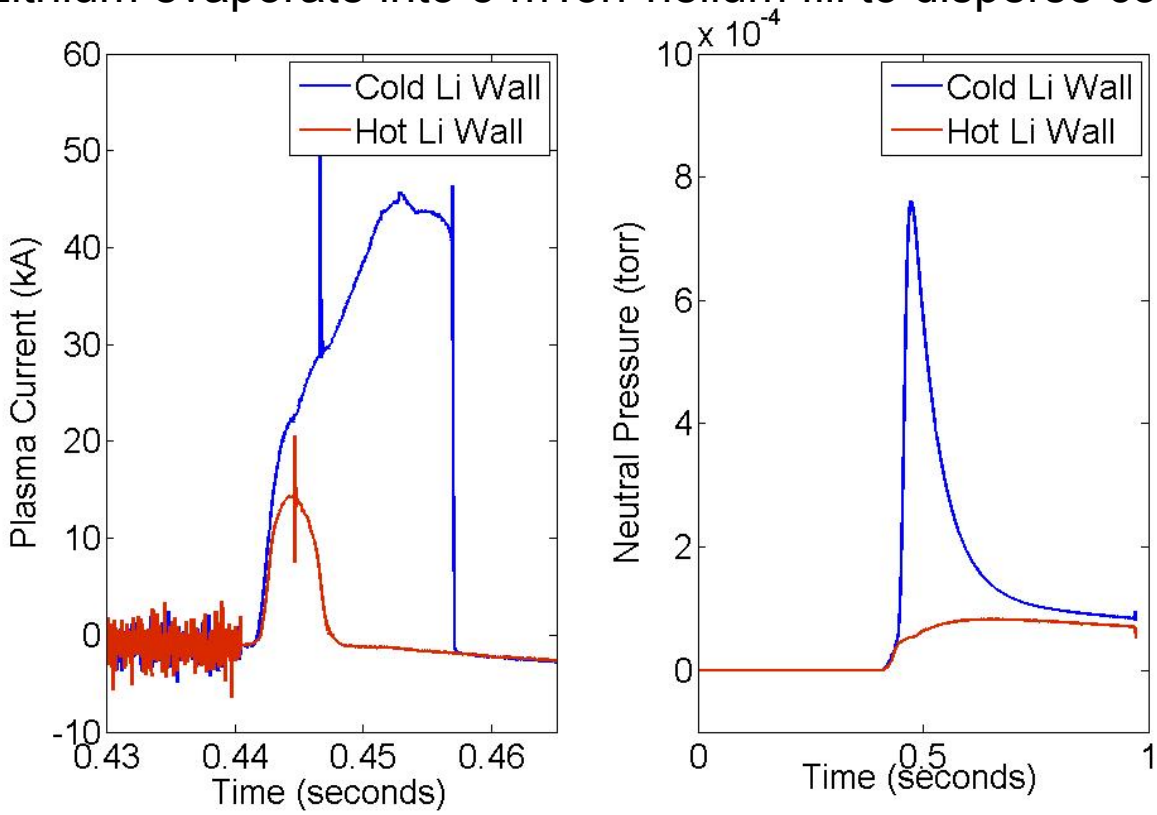


Pressure evolution

- 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

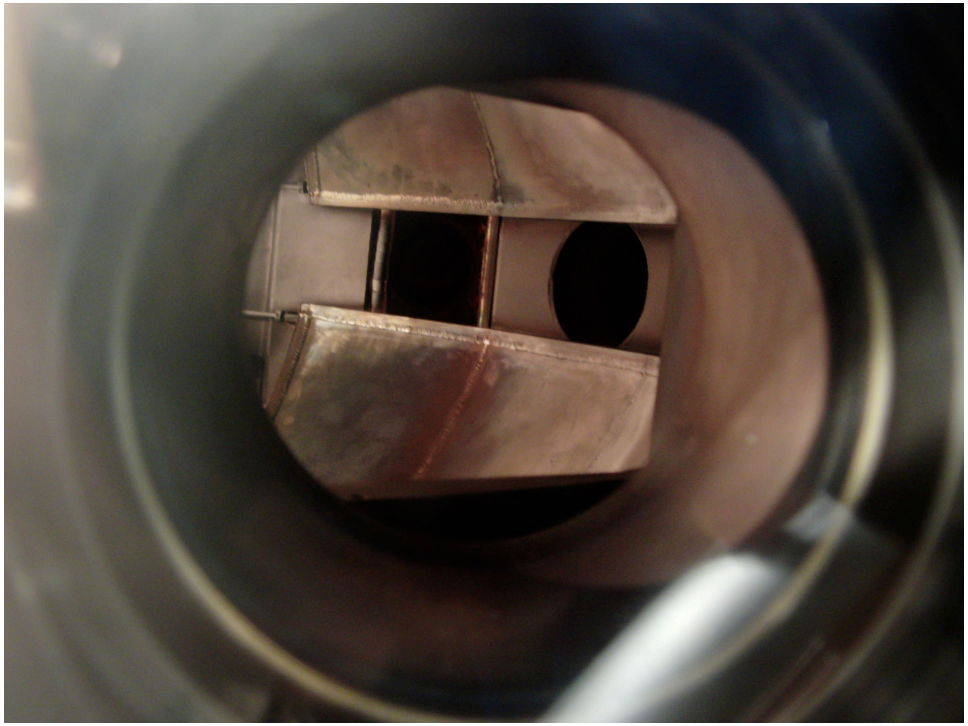
LTX was operated with a lithium-coated 300 °C shell

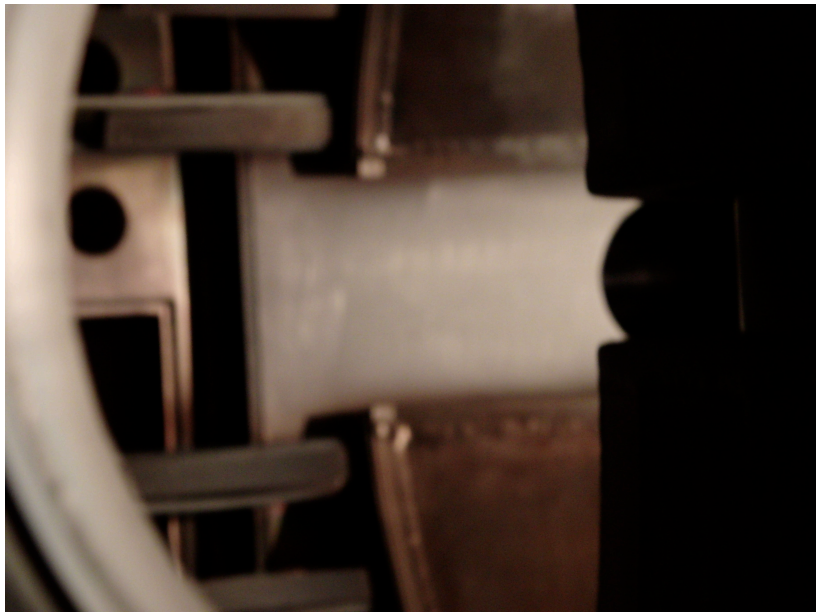
- First full high temperature, high Z wall operation of a tokamak
  - Lithium evaporate into 5 mTorr helium fill to disperse coating



- 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

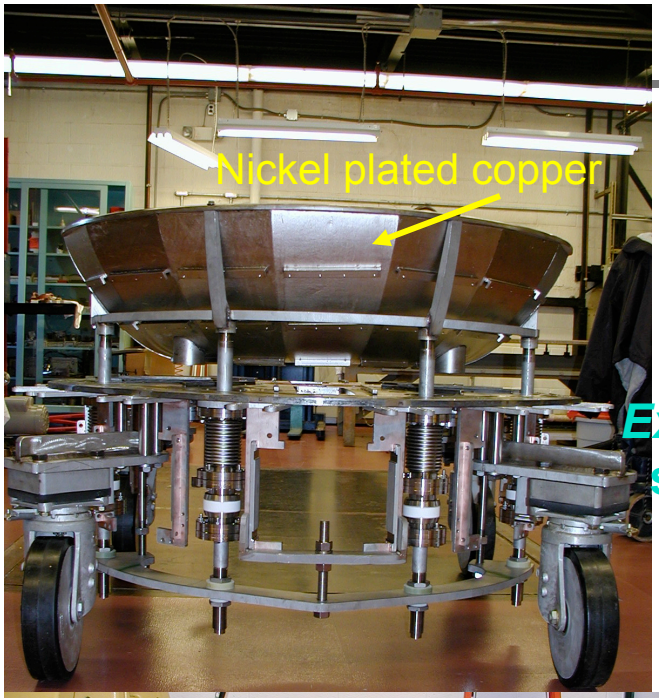
Discussion of hot wall results

- 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

Electromagnetic forces on the shells

- Shells are extensive, 1 cm thick copper structures
- Shell eddy currents during a discharge ~10 – 15 kA
  - Measured; agrees with modeling
- Forces on the shells during a disruption modeled at ~5 kN
  - Overturning moment
- Shells expected to undergo a "clamping" force during PF ramps
- All predicted forces are substantially vertical
- *Observed* shell motion is primarily toroidal
- Toroidal motion not predicted, not fully restrained, difficult to explain
  - Strong toroidal motion only observed with toroidal field.
    - » No toroidal J x $B_{toroidal}$ force is generated (obvious)
    - » Nonlinear effect, due to restraining force on toroidal eddy currents in the shells?
- Additional restraints for the shell added during a recent vent
  - LTX is now pumped down, being readied for bakeout

Shell support structure designed for overturning forces



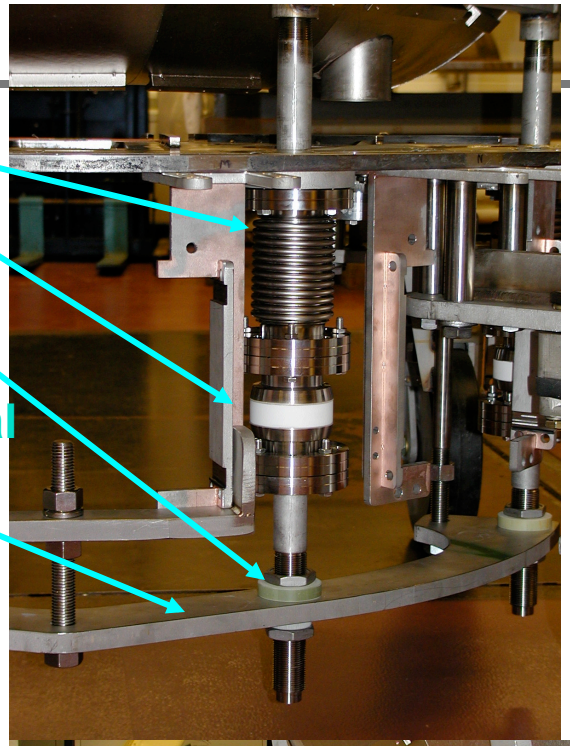
Bellows

Ceramic break

G10 bushing

External mechanical support structure

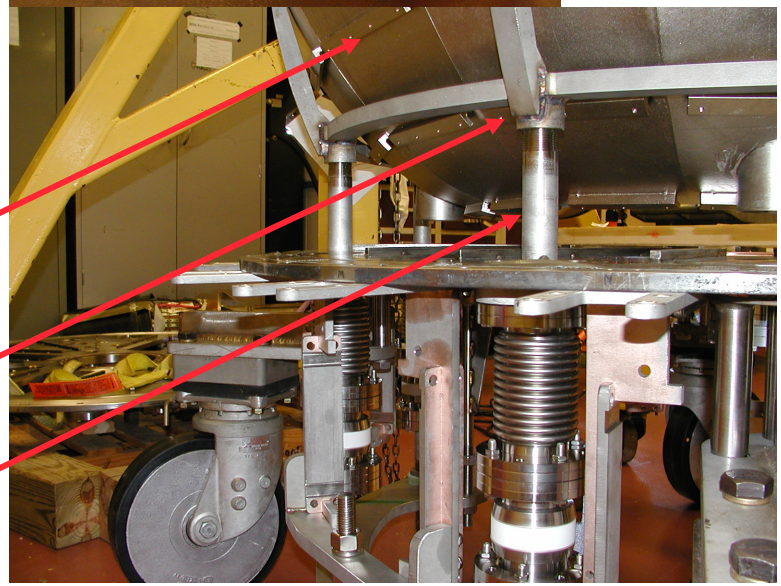
Shell grounding: single point through a ~ 1 Ω resistor



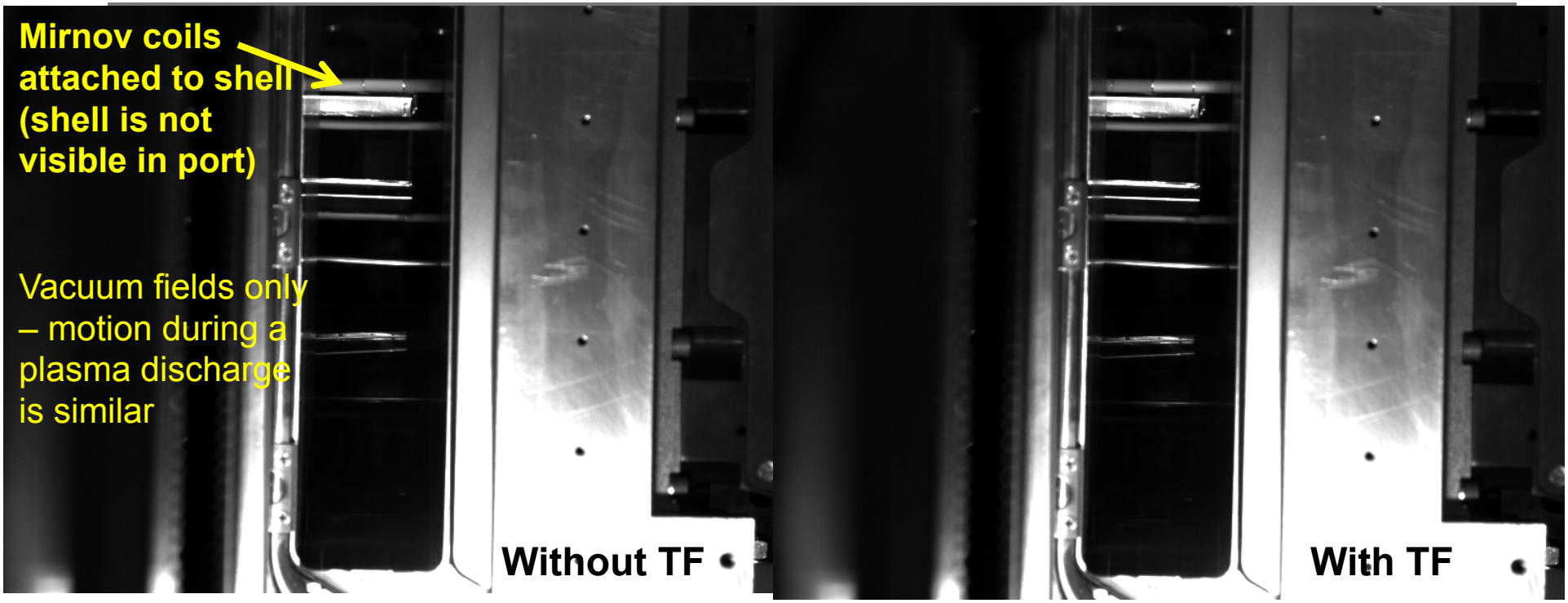
Heater clamps

Pipe thread fitting

Support tube



Shells are observed to move ~8 mm during a discharge



- High-speed video of shell motion
  - 500 Hz, 280 msec total clip duration
- Total shell weight: half a metric tonne
- Total motion (with TF) ~ 8mm, primarily toroidal
  - Now reduced to a few mm
- Was NSTX LLD damage due to similar, unexpected mechanism?
  - Any issues with ITER Cu-Cr-Zr structures?

Summary

- LTX began operations with lithium walls in October 2010
- Lithium had an 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
- Unexpected shell motion partly remediated
  - Further remediation expected with careful PF programming
  - Backup plan: pin shells at midpoint with welded restraints
  - But still no model of eddy currents + PF + disruptive forces which produces the observed effect
- Enhanced pumping being installed with new lithium getter pumps
- LTX under vacuum
- Operation with lithium wall coatings to restart soon
- Liquid lithium fill of lower shells scheduled for later this year