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# The effect of liquid lithium PFCs on plasma performance in CDX-U

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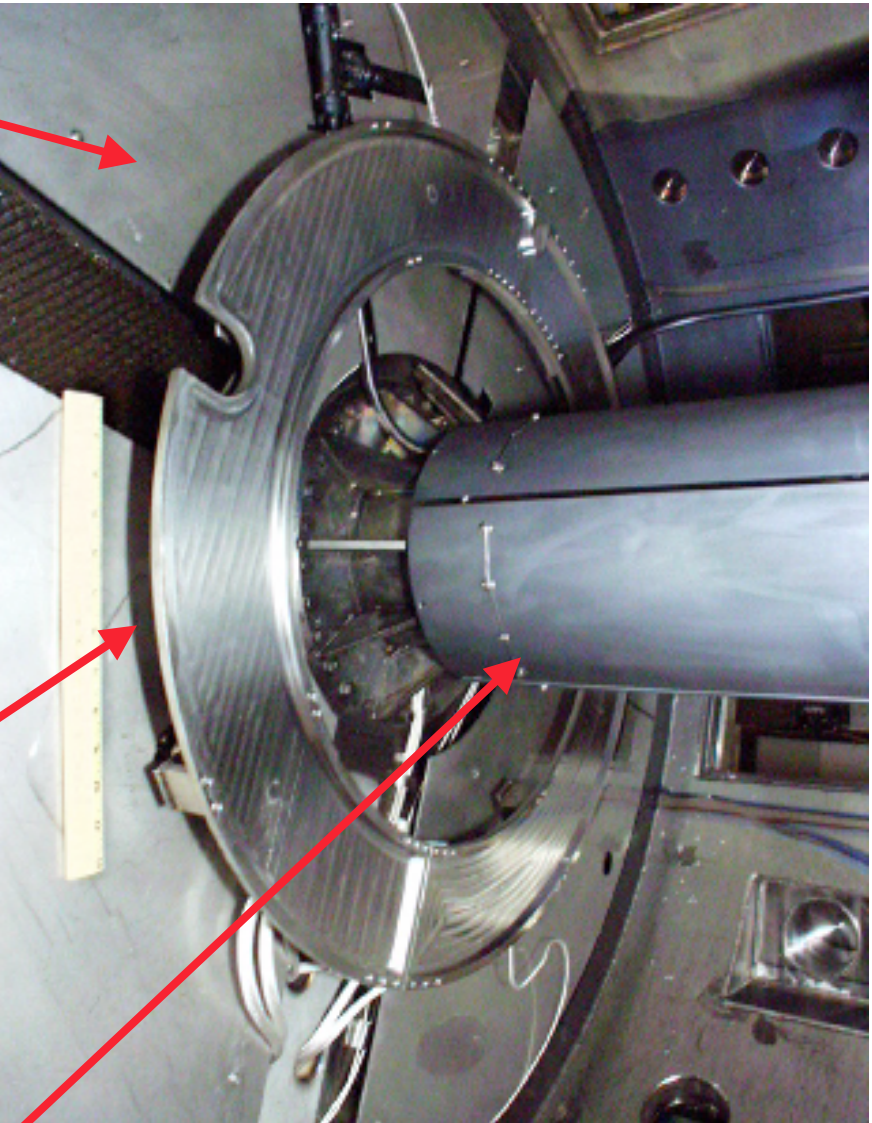
# Goals of the CDX-U lithium experiments

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- ◆ Effects of liquid lithium PFCs on plasma operations in a tokamak
  - Recycling and fueling
  - Impurity reduction
  - Performance enhancement
  - Radiation losses and core lithium accumulation
- ◆ Practical implementation of liquid lithium systems
  - Safety issues
  - Impact on diagnostics and heating systems
  - Motion of the liquid during PF ramps, disruptions, halo current strikes
  - Cleanup:
    - 
- ◆ Present system is a full toroidal liquid lithium belt limiter
  - Experiments will continue through 2003.

# CDX-U lithium tray limiter installed Spring 2001

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- Discharges run on bare SS tray to establish baseline prior to lithium filling
- 34 cm major radius, 10 cm wide, 0.64 cm deep
- Fabricated in two halves with a toroidal electrical break
  - Isolated from vessel
  - Halves connected to electrical feedthroughs
- Heaters beneath for temperature control up to 400°C. Typ. ops 200 - 250°C
- TiC coated heat shield on center stack
- Tray temperature monitored with thermocouples around edge

- Heat/lithium shield between tray and lower vacuum flange

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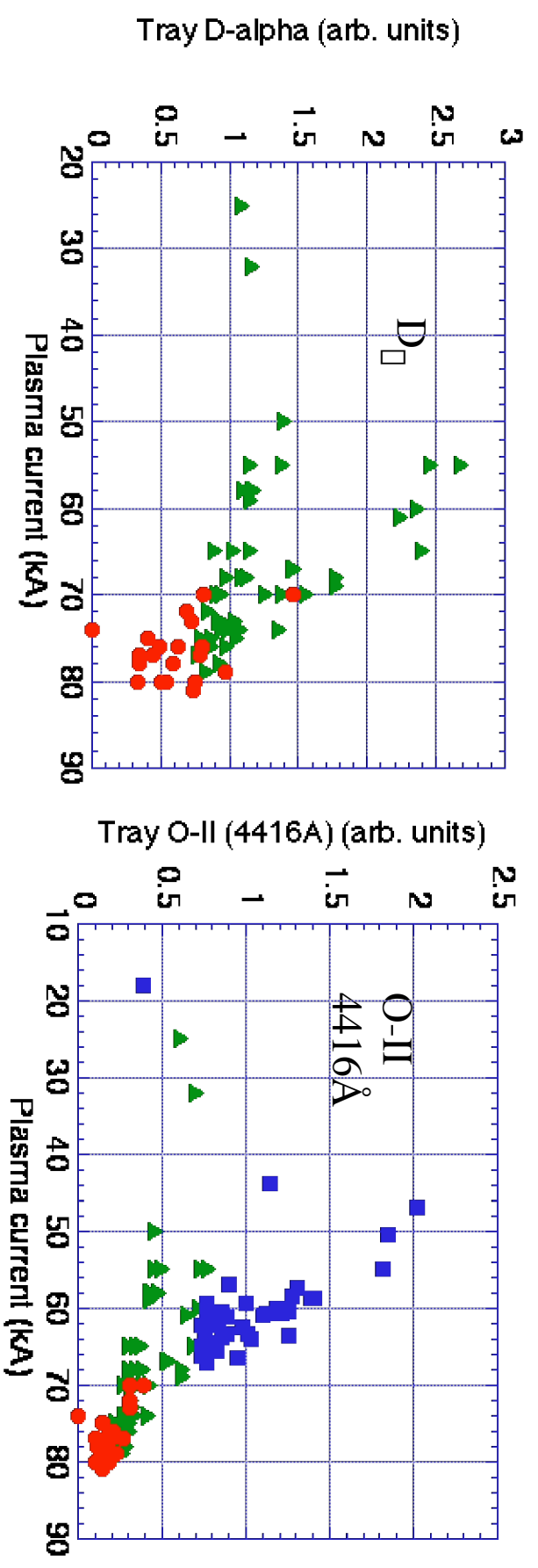
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# Liquid lithium PFCs reduce $D_{\square}$ , oxygen emission

- Liquid lithium in tray (250° C)
- ▲ Cold lithium in tray
- Bare stainless steel tray

•  $D_{\square}$  data not available for the bare stainless steel tray



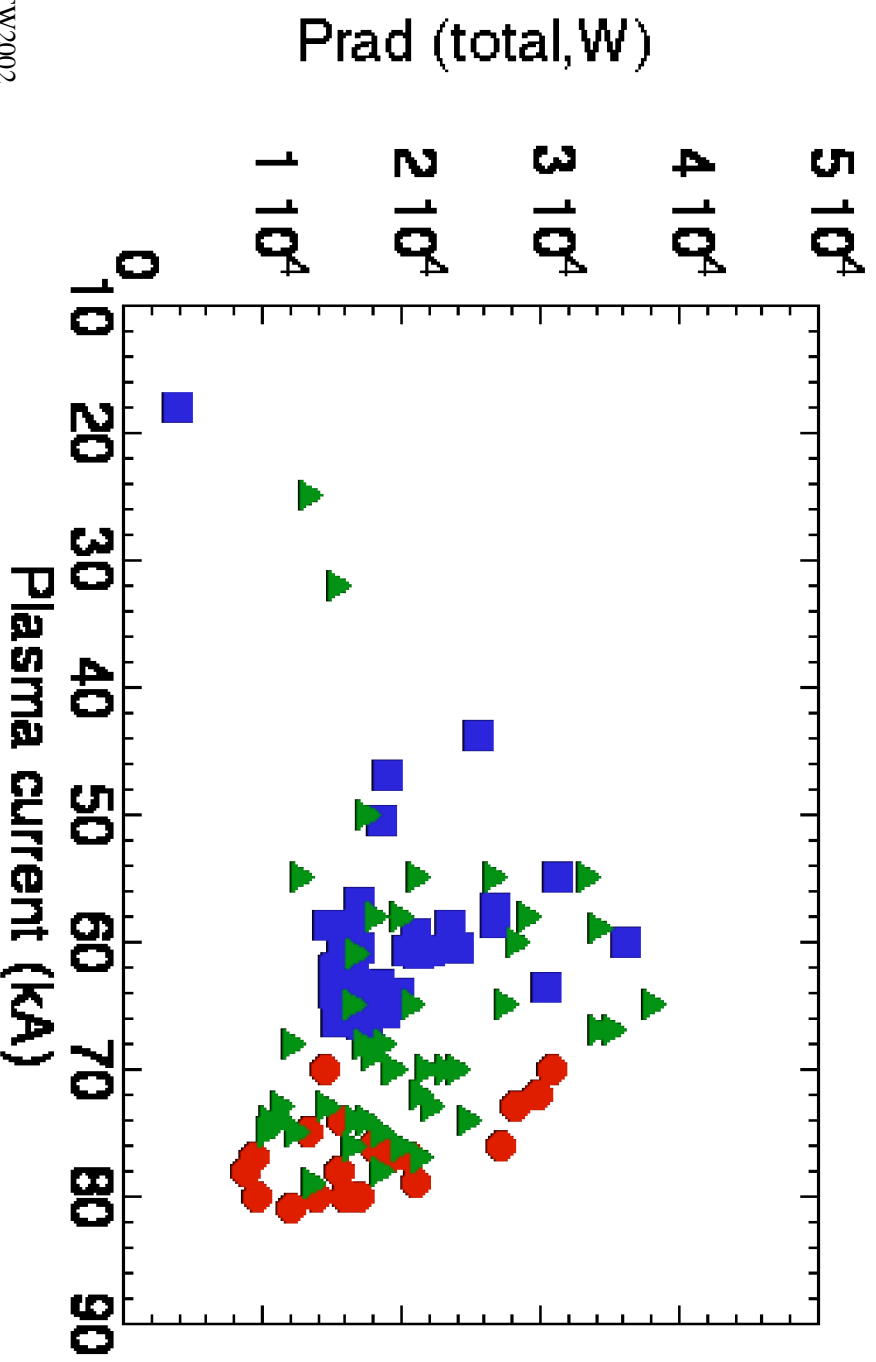
Data from the ORNL **tray** filterscope



# Total radiated power is slightly reduced for discharges limited on liquid lithium

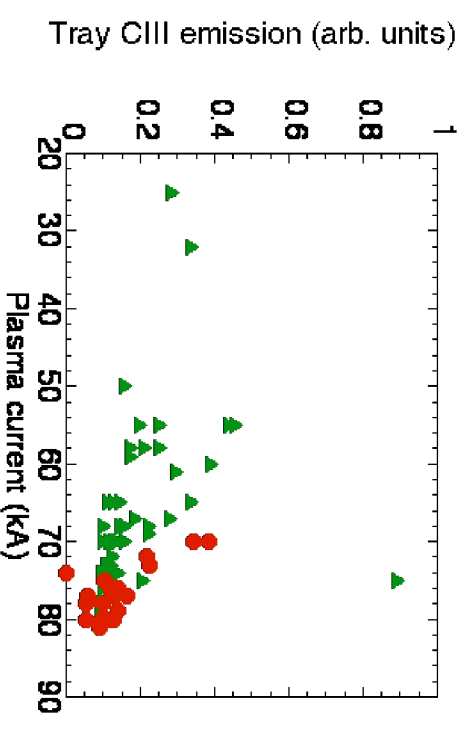
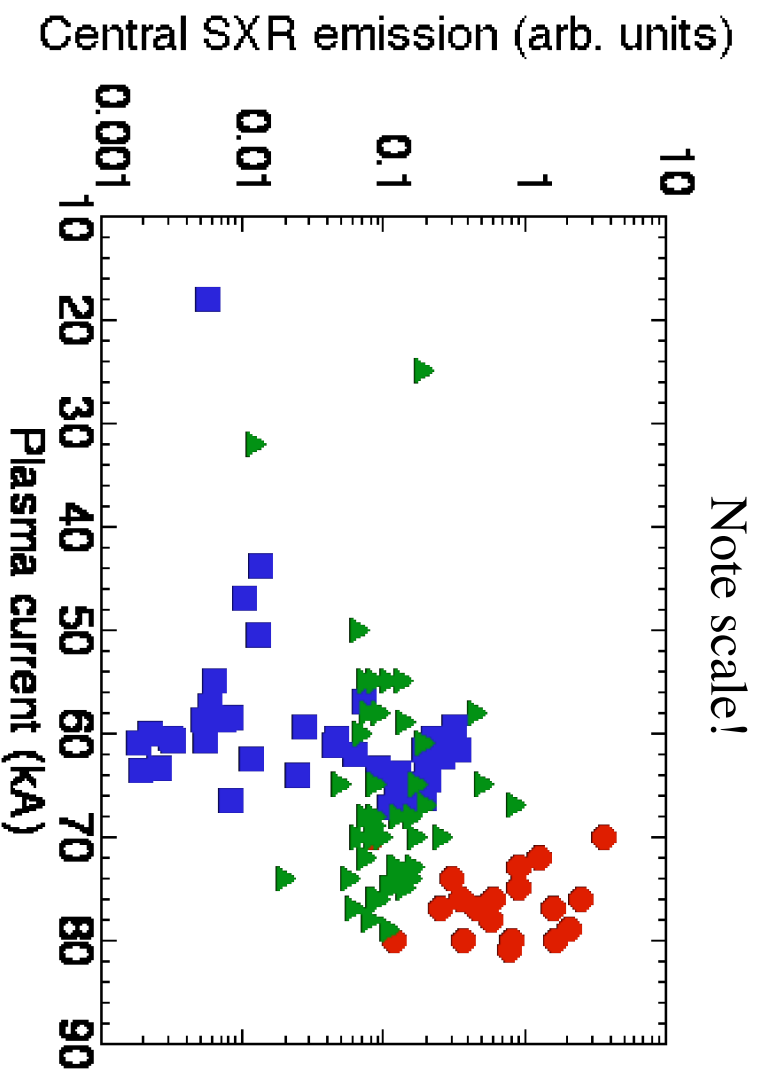
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- ◆ Data from Johns Hopkins tangential bolometer
- Liquid lithium in tray (250° C)
- ▲ Cold lithium in tray
- Bare stainless steel tray



# Central soft x-ray emission indicates that plasmas limited on liquid lithium have higher core $T_e$

- ◆ Edge carbon emission indicates that rise in emission is not due to a carbon influx



● Liquid lithium in tray (250° C)

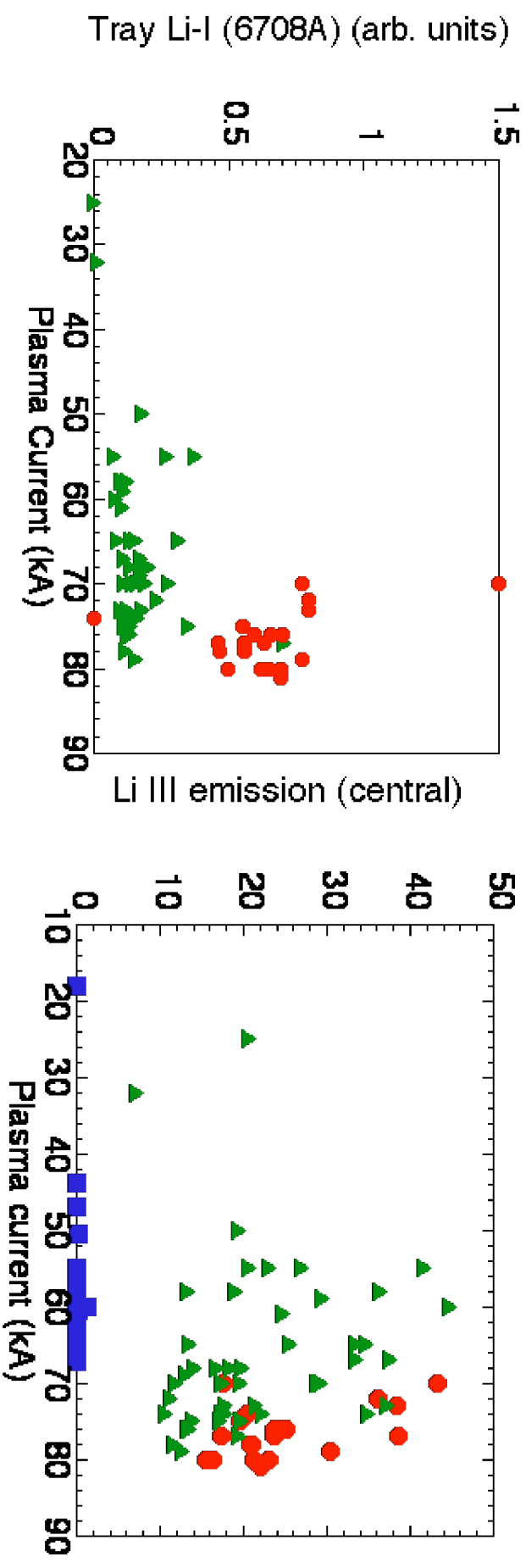
▲ Cold lithium in tray

■ Bare stainless steel tray



# Edge, core lithium spectroscopy indicate some lithium influx

- Core lithium emission does not increase with liquid lithium operation, compared to the solid.
  - $T_e$  increase complicates interpretation



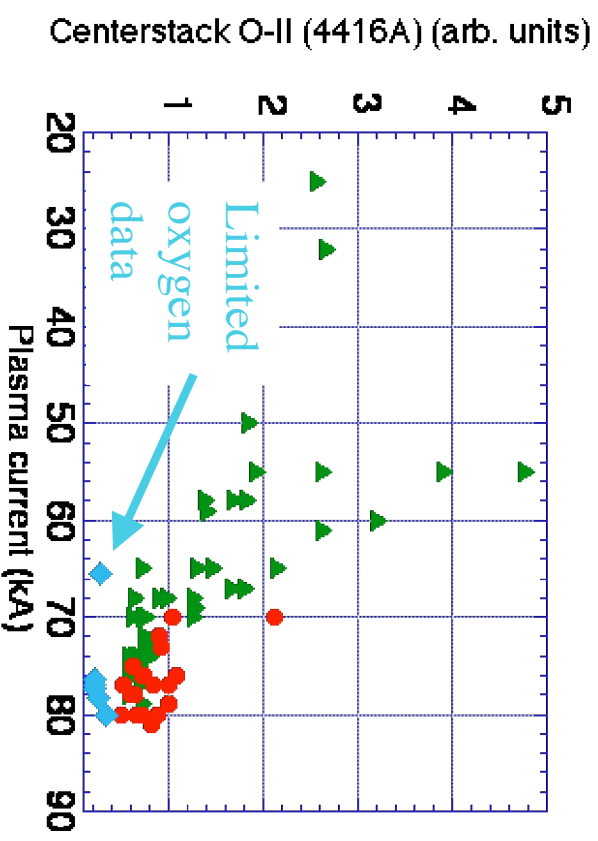
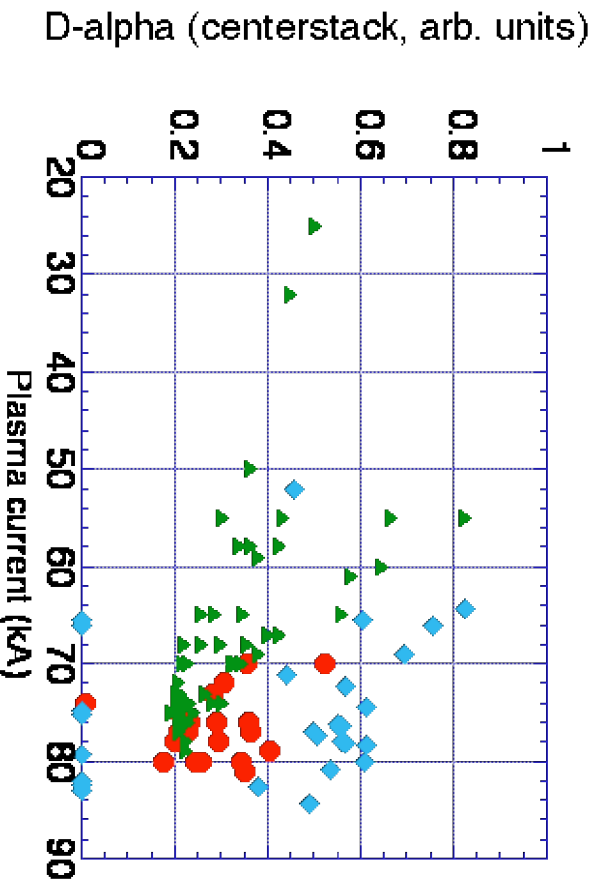
- Liquid lithium in tray (250° C)
- ▲ Cold lithium in tray
- Bare stainless steel tray



# Vessel interior was coated with lithium during Dec 01

## Recycling, impurity results compared with tray data

- ◆ Spectroscopy of edge plasma visible light emission at the centerstack indicates that cold, solid lithium coatings saturate in CDX
  - Possible lithium deuteride formation
  - Do not reduce recycling during a discharge
- ◆ Cold coating DOES strongly reduce oxygen in discharge



● Centerstack emission with hot tray

▲ Centerstack emission with cold tray

Centerstack emission with coated centerstack (cold tray)

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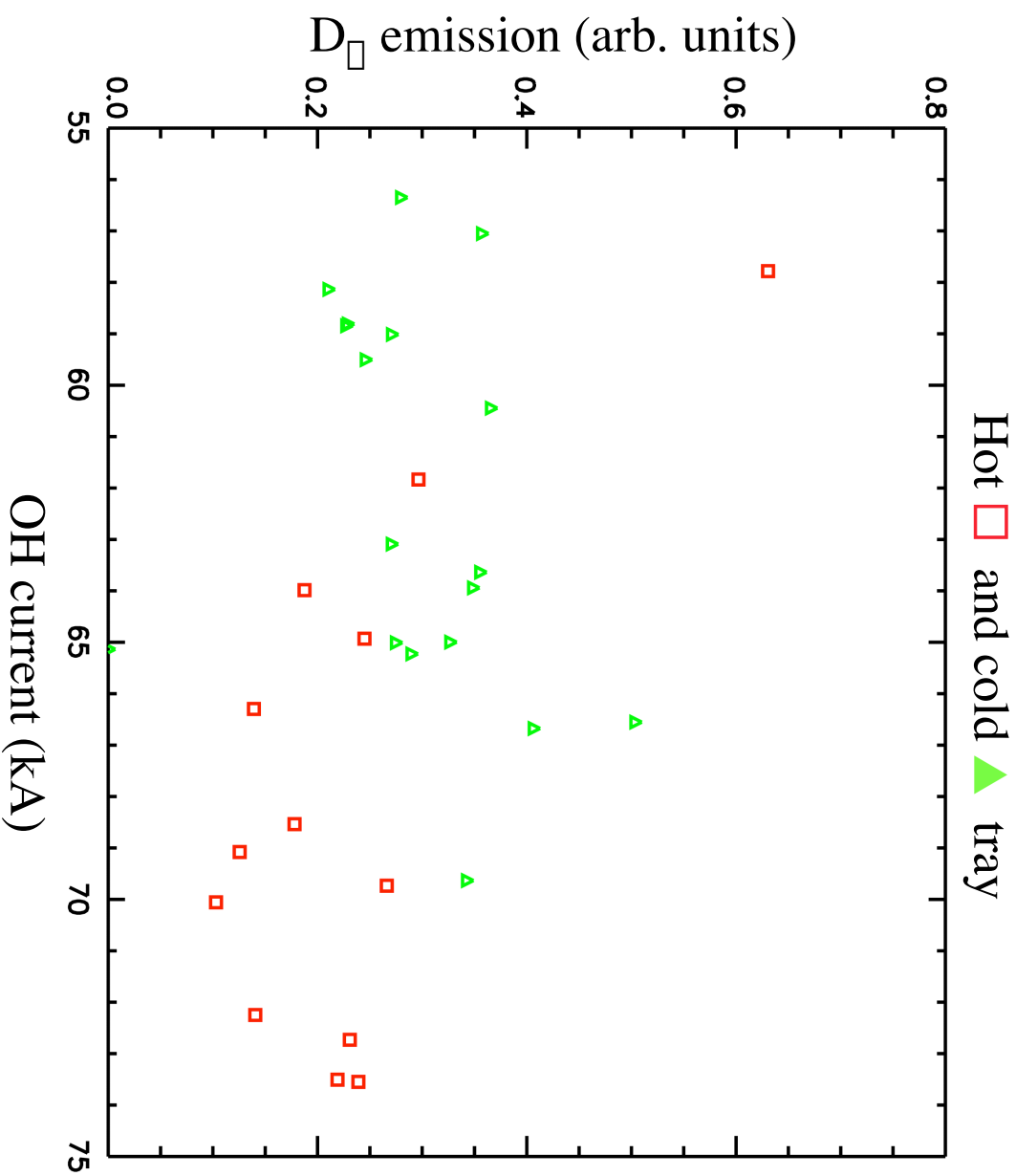
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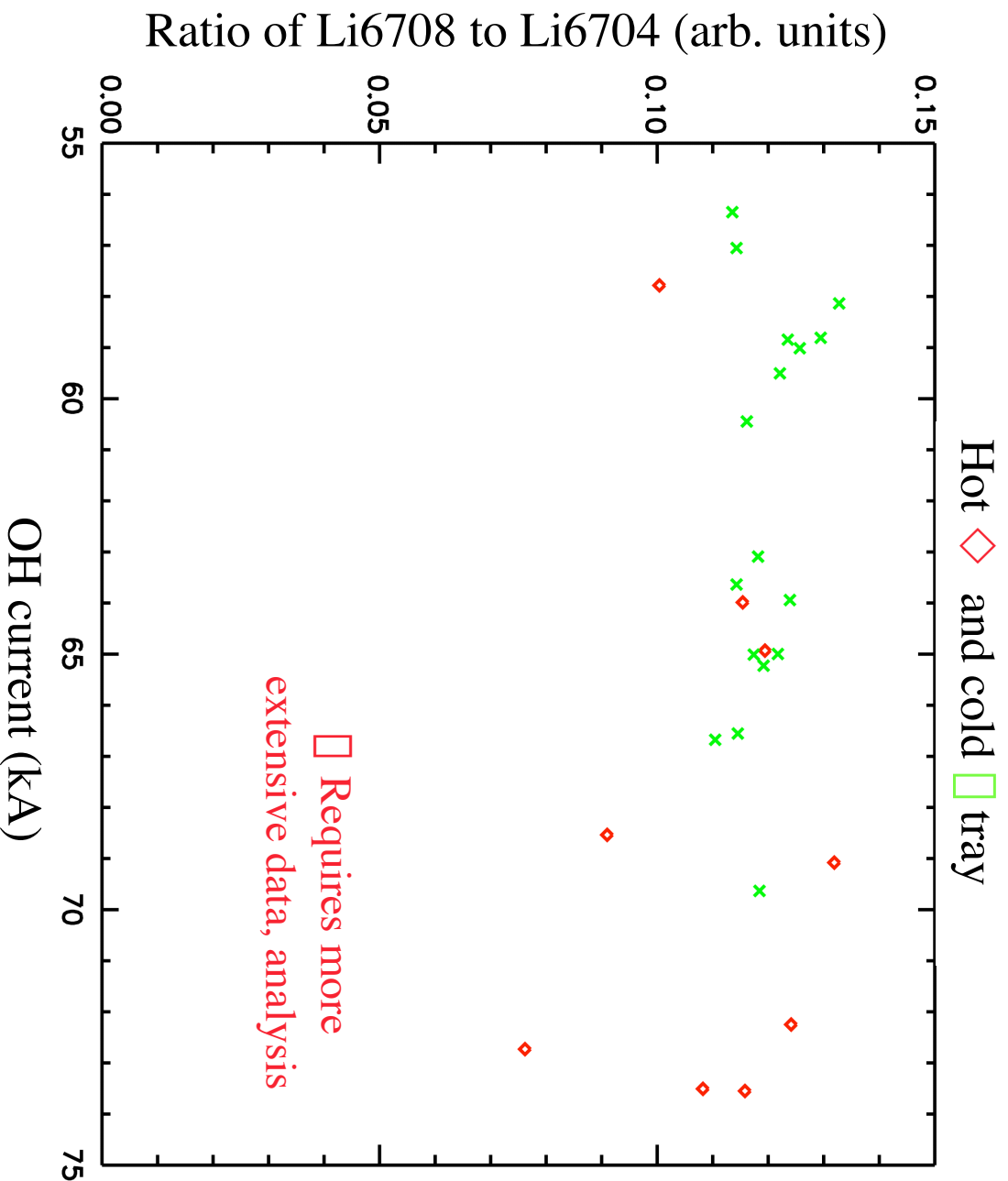
# Reduction in tray $D_{\square}$ was less apparent after ~6 months operation

- ◆ Data taken after overnight argon glow (original data followed 24 hour glow)



# New spectroscopy yields no evidence for an increase in edge $T_e$ local to the tray

- ◆ Lithium 6708/6704 line ratio is sensitive to the electron temperature.



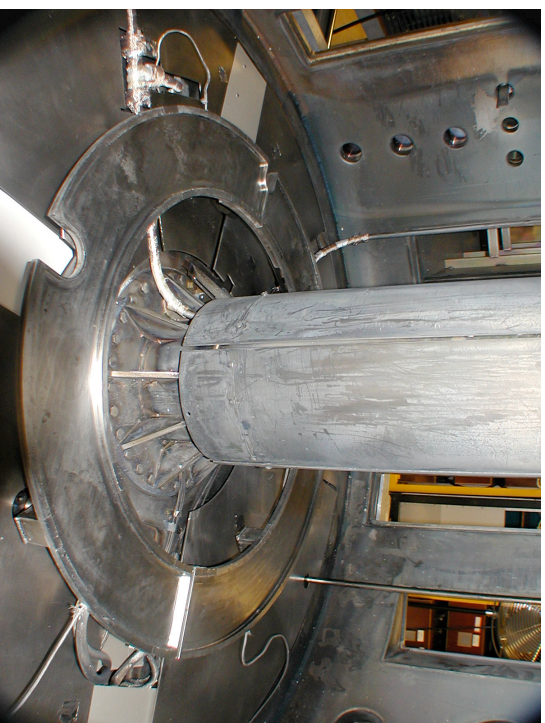
# CDX-U vented for tray cleaning

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After vent but before cleaning



After cleaning



- ◆ Prior to vent, sodium hydroxide added to tray in attempt to promote wetting
  - No significant effect on wetting
  - Reaction products obvious on tray
- ◆ Air circulated through vacuum vessel for several days
- ◆ Lithium hydroxide distribution indicates lithium covered most of tray
- ◆ Coating well adhered - reaction between lithium and stainless steel?
  - Complicated by sodium hydroxide experiment

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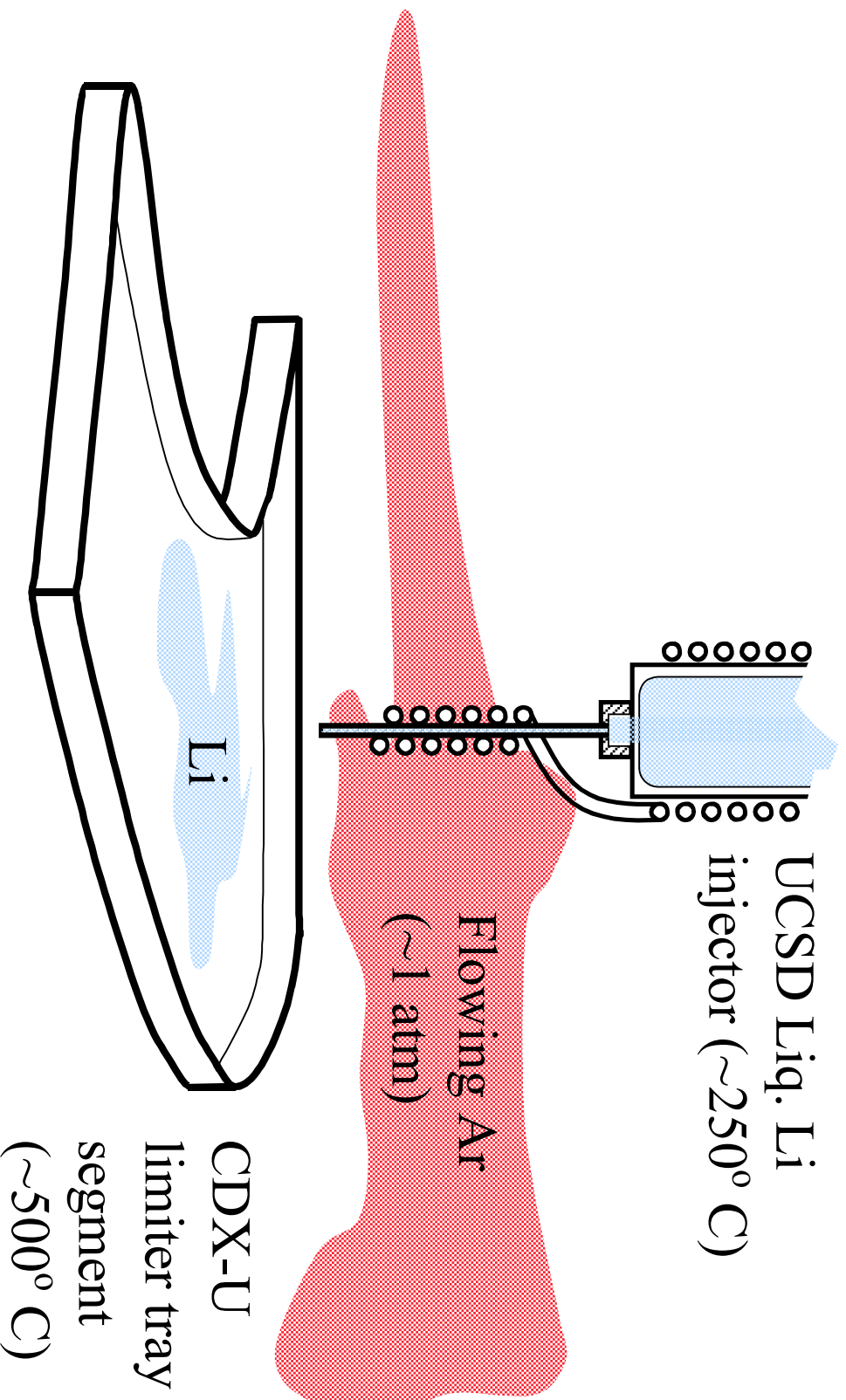
## Next step is to achieve more uniform lithium layer in tray by filling with liquid instead of solid lithium

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- ◆ Difficult to remove impurity layer on solid lithium pieces
- ◆ Flow over tray surface will improve with liquid lithium
- ◆ Liquid lithium still requires special conditions
  - Fill must be performed under flowing argon atmosphere
    - » Minimize lithium hydroxide formation
    - » Inhibit window, vessel coatings
- ◆ Other plans:
  - Explore high Mach number gas jets for “core” fueling
  - OH system improvements
  - Implement ESC modeling of equilibria

# Schematic of UCSD liquid lithium injector concept

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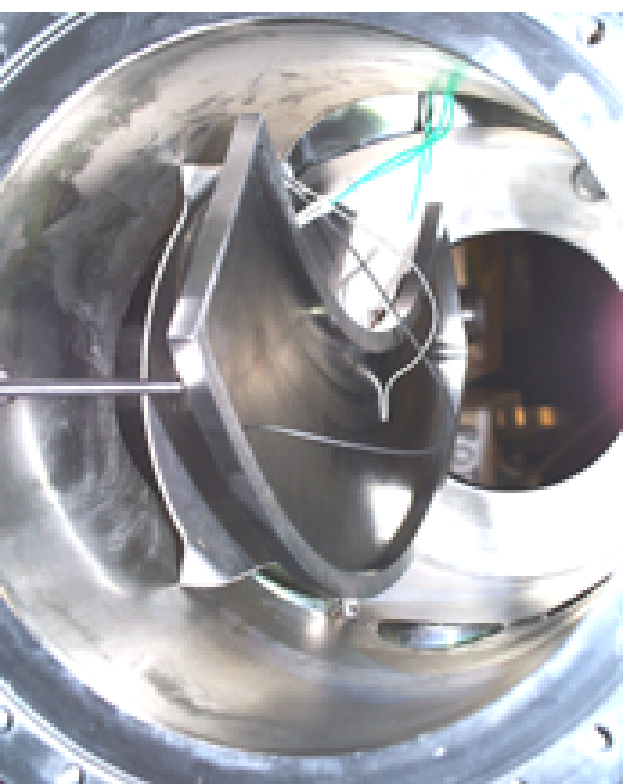
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# Liquid lithium filling technique demonstrated with mockup of CDX-U limiter tray

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- ◆ Mockup has one-fourth of total area of CDX-U limiter tray
  - View from below shows heaters identical to those used in CDX-U tray
- ◆ Position of mockup in test chamber at UCSD
  - CDX-U tray and mockup both made of stainless steel

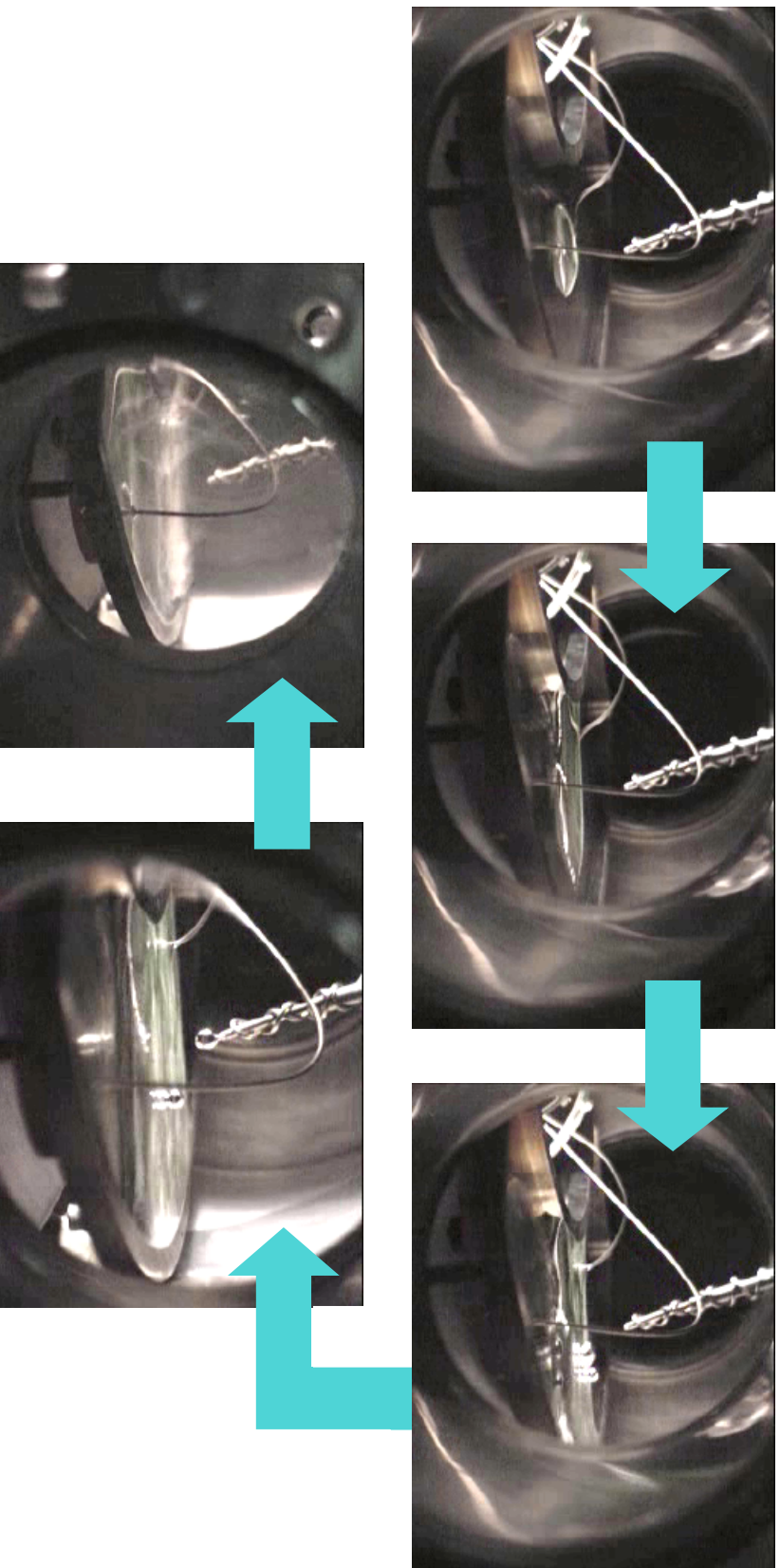
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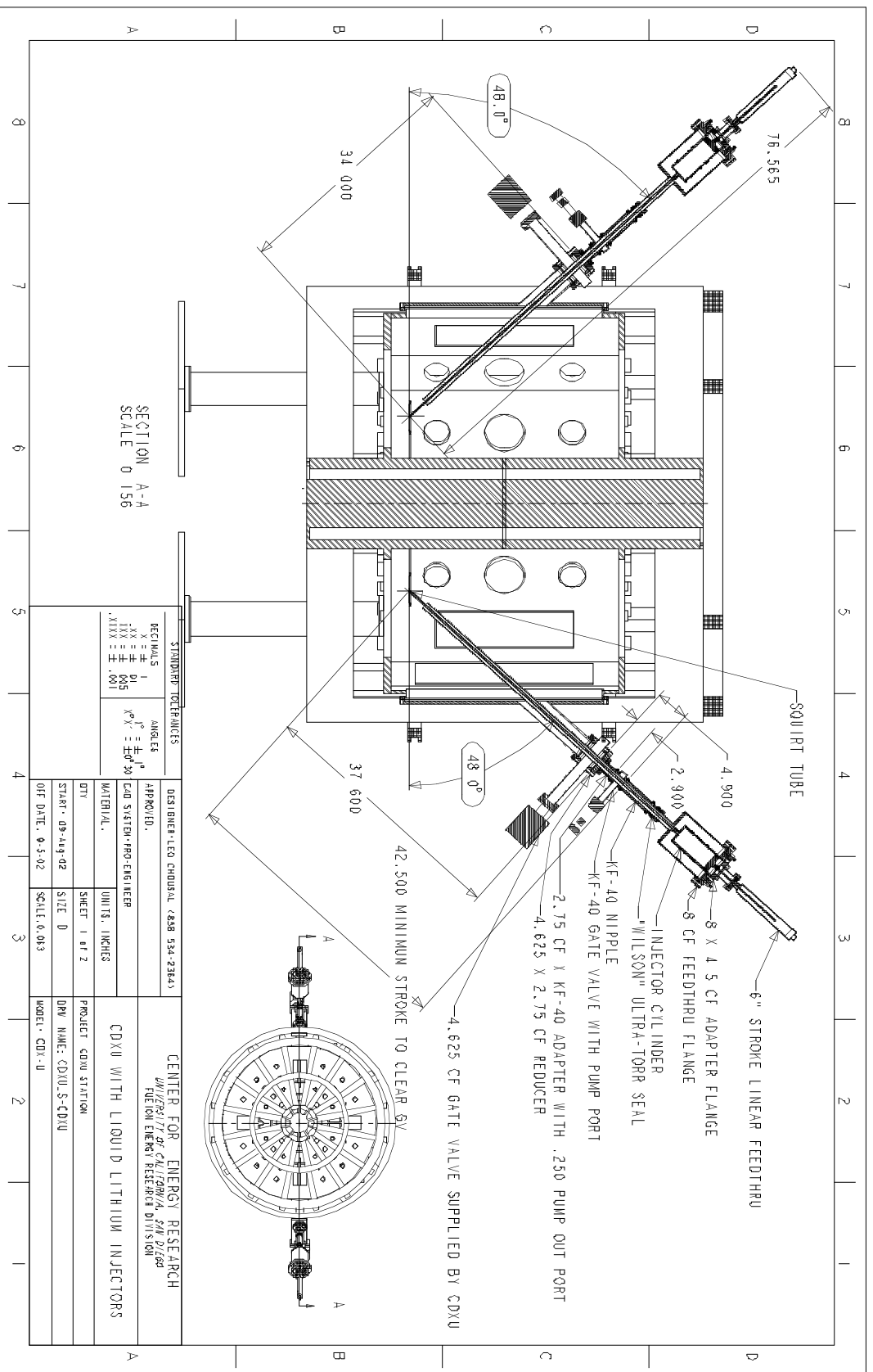
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# Liquid lithium spreads across surface of CDX-U limiter tray mockup

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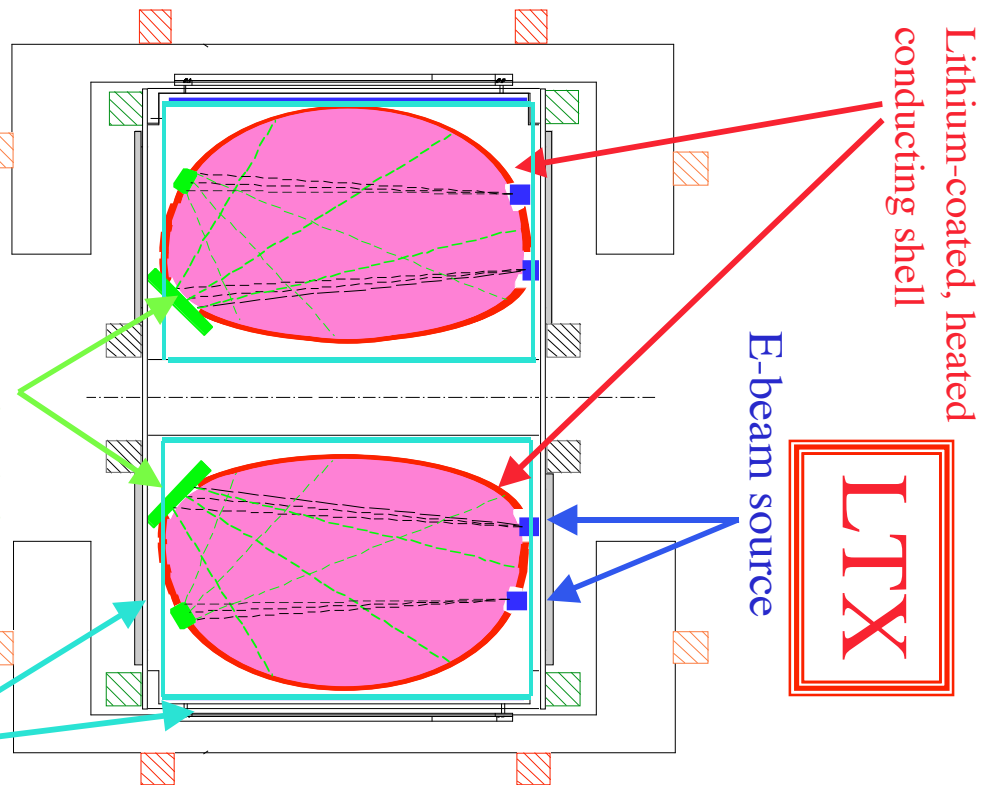


# Liquid lithium will be injected into both halves of toroidal limiter tray from two locations on CDX-U





## Summary



- ◆ Implementation of liquid lithium PFCs has been shown to be feasible
- ◆ Liquid lithium PFCs are found to reduce recycling and impurities
  - Enhanced tokamak performance
  - Effect still observed in CDX-U nearly a year after original lithium loading
- ◆ Cleanup, recovery was straightforward
- ◆ A new tray was installed earlier this year.
  - New filling technique to be implemented (PISCES-B group, UCSD)
  - New discharge cleaning techniques
- ◆ We have further proposed the extension of these experiments to a device with full lithium walls - the Lithium Tokamak experiment (LTX)