NSTX LIQUID LITHIUM IN VACUO DELIVERY SYSTEM

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ABSTRACT

Lithium evaporator ovens have been used to deposit lithium coatings on the NSTX lower divertor and other plasma facing surfaces. The use of this approach in extensive experimental campaigns is limited by slow evaporation rates, mild focusing, and small capacity requiring frequent reloading. In some experiments, relatively fast deposition of several grams of lithium at a specified location would be desirable. To accomplish this, a system has been devised which can deliver ~0.5 g/s of molten lithium at ~320°C into a vacuum to a selected location. This MAnaged INjection FIller for Liquid Lithium (MAIN FILL) system has been constructed from a valve bellows with a precision threaded rod and nut attached for controlled delivery. The liquid lithium passes through several different fittings, a high temperature valve, a 90° bend, and travels for 110.5 cm. The system is described and photographs show the results of liquid lithium delivery on a cold stainless steel surface, on cold lithium, on hot molten lithium, and on a hot porous molybdenum surface. A configuration with additional applications on NSTX is presented.

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Introduction

- LLD - Liquid Lithium Divertor: Four Divertor segments on NSTX utilizing lithium fill.
- Two LIThium EvaporatoRs (LITERs) used to fill LLD segments.
- About 4.5% of evaporated Lithium from LITERs would reach the LLD. Further Lithium distribution gained from "wetting".

For evaporative (LITER) fill of LLD:

- LLD segments needed 37g for fill which is ~823 grams (1.8 lbs) of Lithium in LITERs - with the desired "wetting" response.
- One LITER load is ~ 80 grams (0.18 lbs) of Lithium.
- This equates to 5+ fills at full load using 2 LITERs.
- Once filled, LLD could require Lithium refresher.

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(LIquid) LIthium Filler for LITER:

- LIFTER has improved ease of filling LITER as well as efficiency (~100% or 2x) over previous dry filling method.
- LITER spill-over of lithium in NSTX has been reduced/eliminated with heating of lithium at the filling stations prior to LITER machine installation.
- With increase in availability of lithium has come increase in experimental demand.

NSTX Shutter Limitations

- Lithium evaporation on NSTX is shuttered during plasma discharges.
- Extensive use of LITER for Li wall coating (incl. LLD) has caused heavy shutter coating and mal-function.
- NSTX operation has been interrupted to remove, clean and re-install shutters.
- Inconveniences could be averted and appropriate quantities of lithium deposited on the LLD if direct application were made.
- Why not use LIFTER technology to directly coat a substrate?

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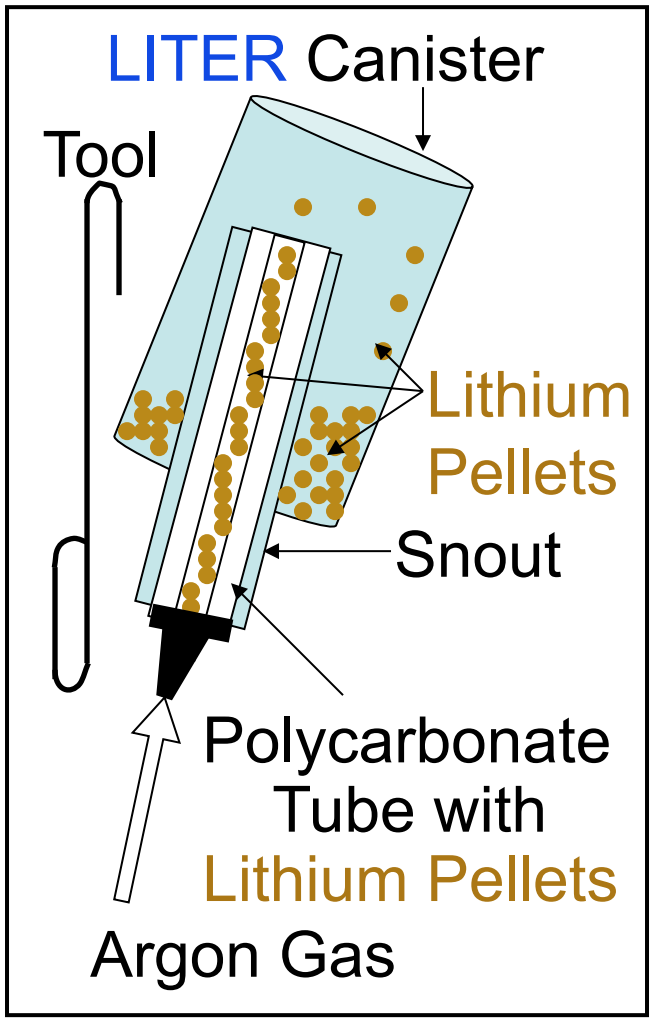
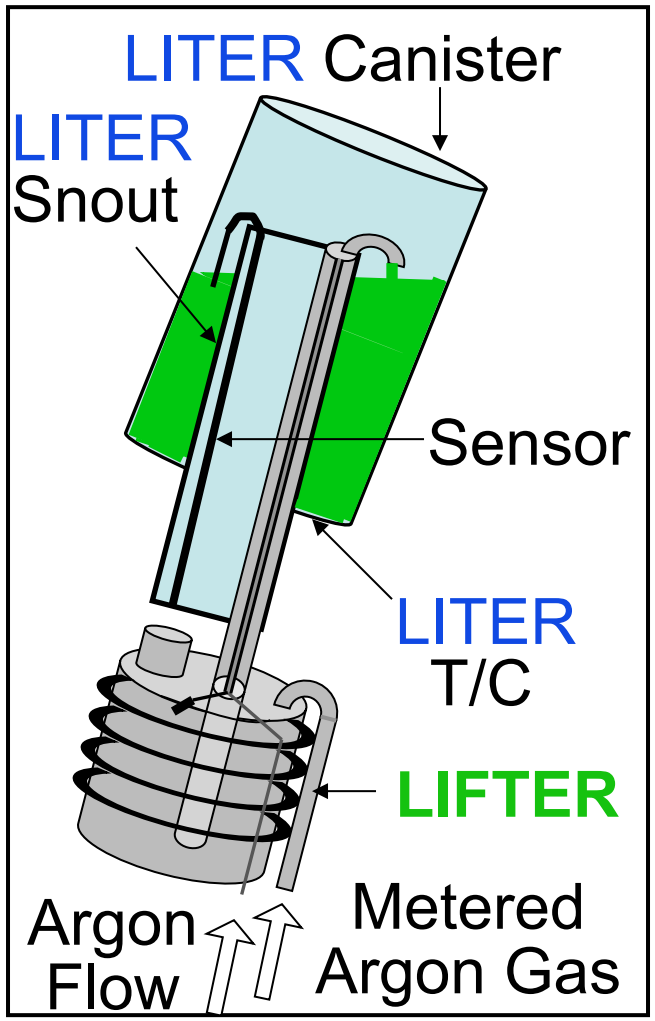
Filling LITER with Lithium

Dry Method vs Liquid Method





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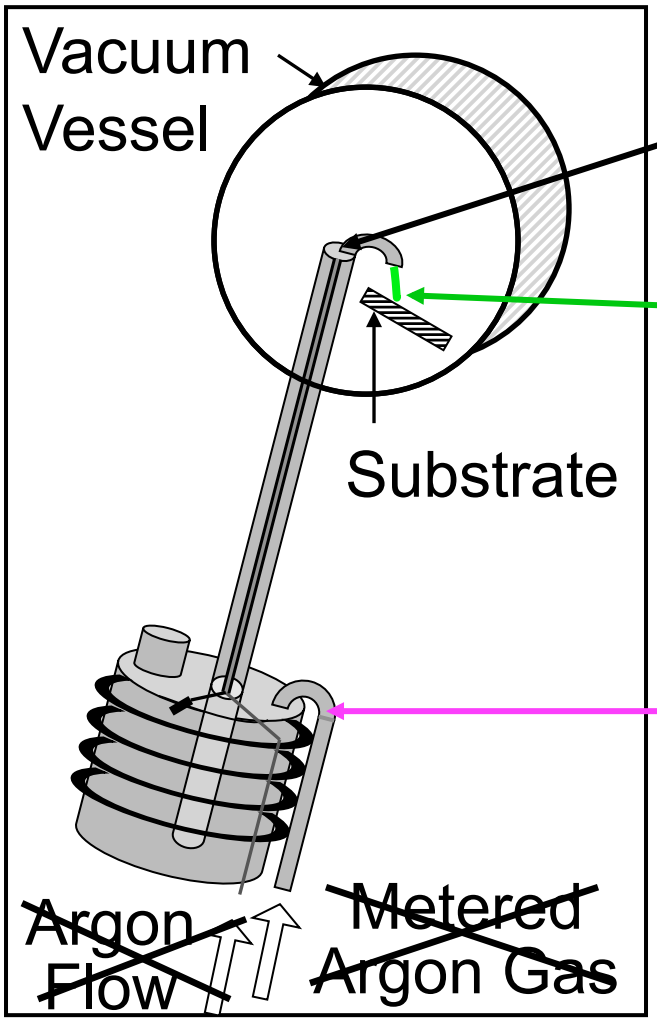
LIFTER Direct to Substrate?



- ✓ **Need to eliminate purge (easy).**
- ? **How does one measure Li quantity???????**
- ? **Replace metered argon with????? (needs to be at vacuum vessel pressure).**

NEED A NEW CONCEPT

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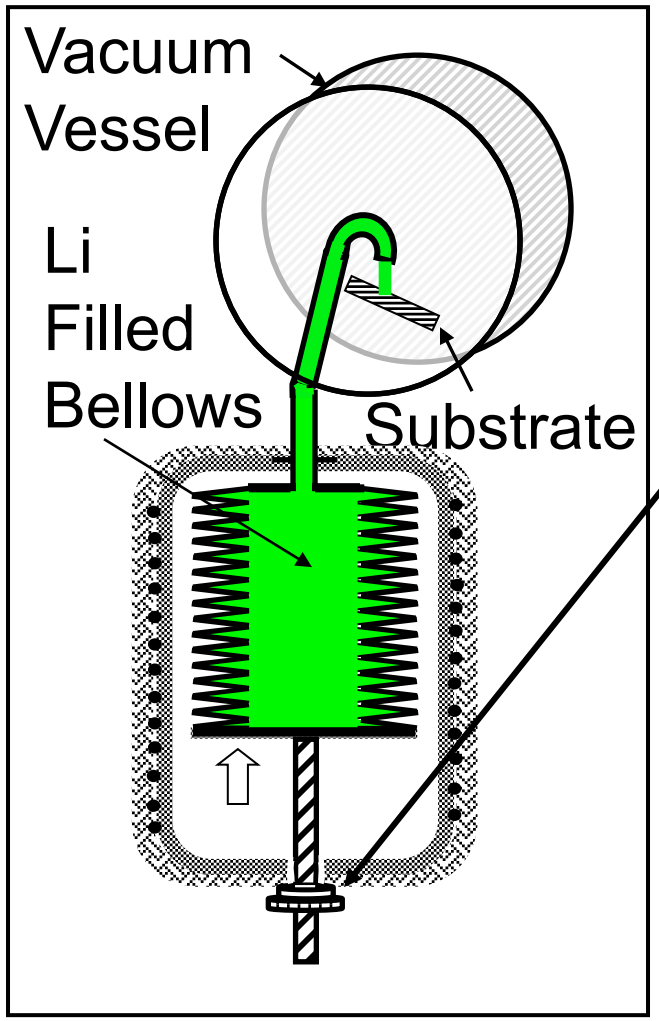
MAnaged INjection FIller for Liquid Li



In this simplified cartoon, the MAIN FILL method consists of a bellows filled with molten lithium and a controlled means using a precision threaded rod and nut for managed amounts of liquid lithium to be applied to a substrate in vacuo.

This method has been successfully tested in the laboratory.

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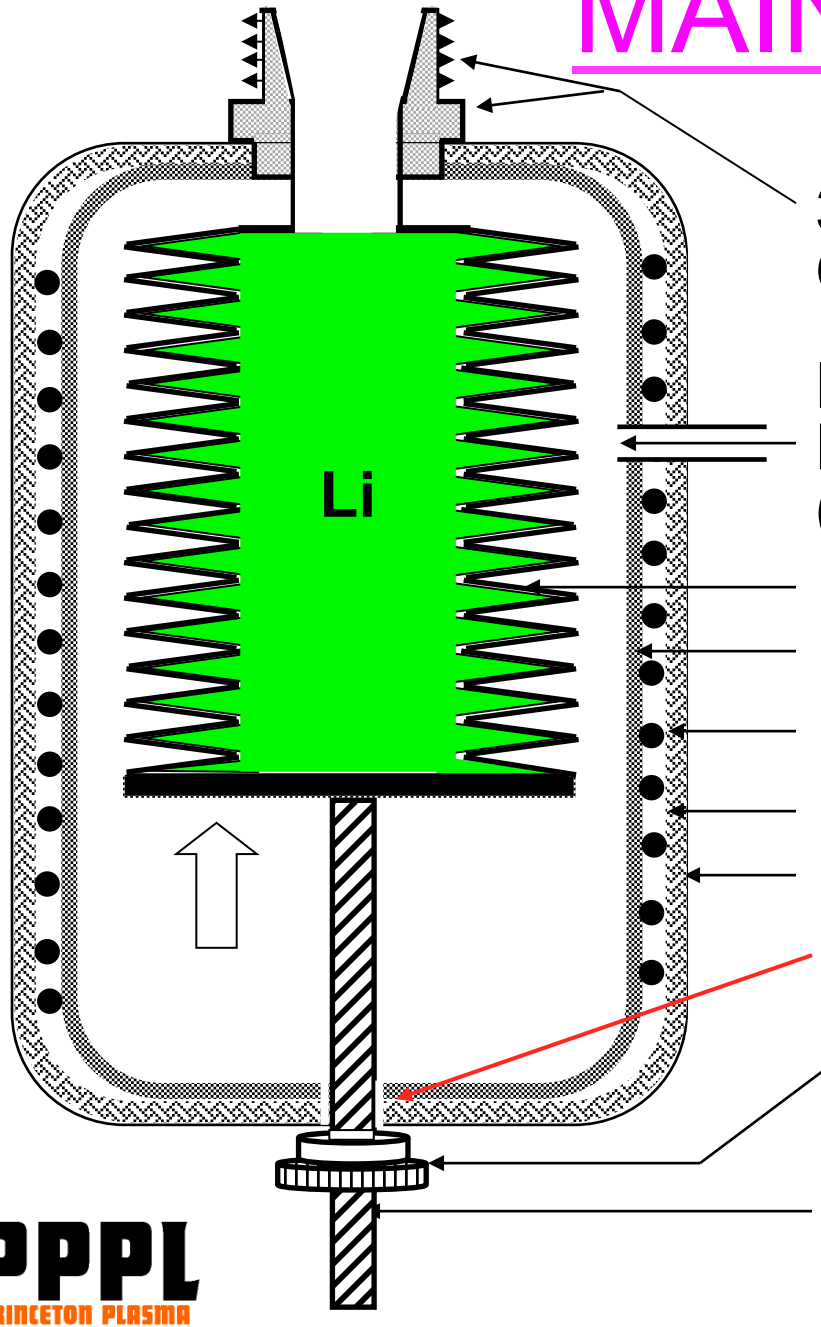
CONCEPTS

MAIN FILL Bellows -1



3/4 in. Swagelok Connector

Helium Gas Filled Chamber (Option)

Bellows

Chamber Wall

Chamber Heater

Insulation

Heat Shield

Opening

Precision Threaded Nut w/Gear

Precision Threaded Rod

SINGLE CONTAINMENT CONCEPT

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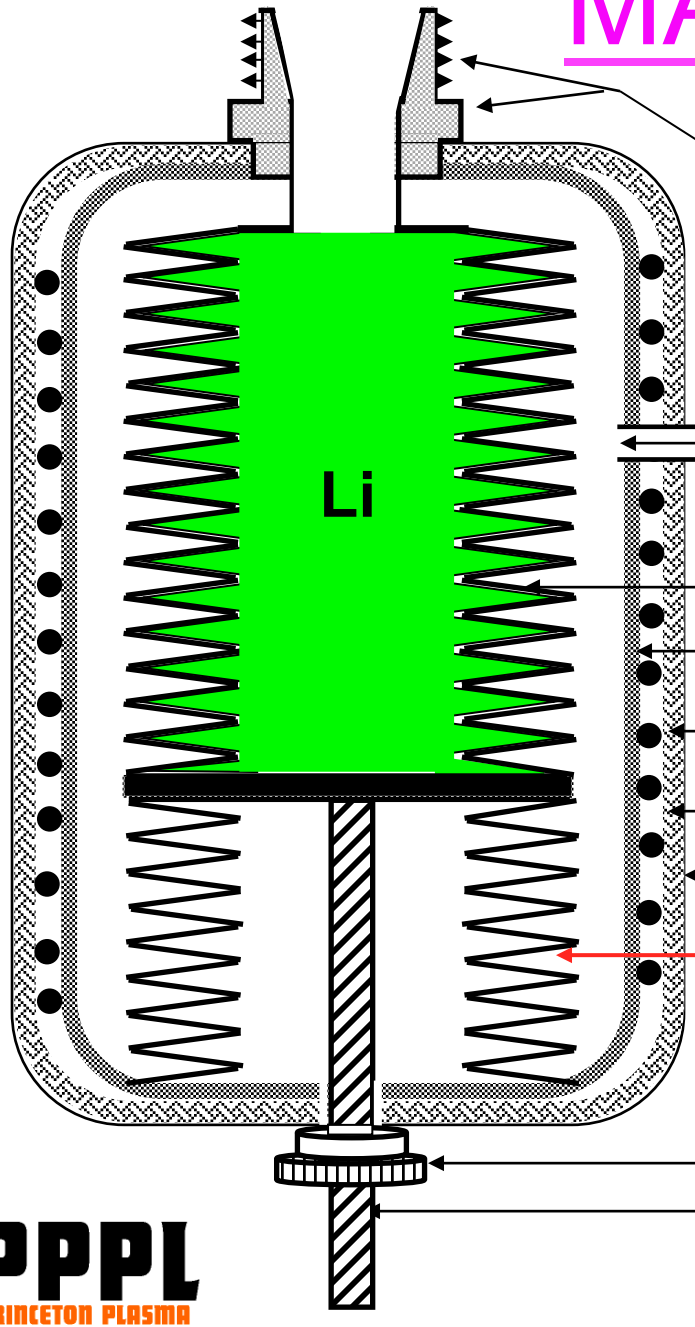
MAIN FILL Bellows - 2



3/4 in. Swagelok Connector

Gas/Vacuum Chamber (Option)

Bellows

Chamber Wall

Chamber Heater

Insulation

Heat Shield

Second Bellows

Precision Threaded Nut w/Gear

Precision Threaded Rod

DOUBLE CONTAINMENT CONCEPT

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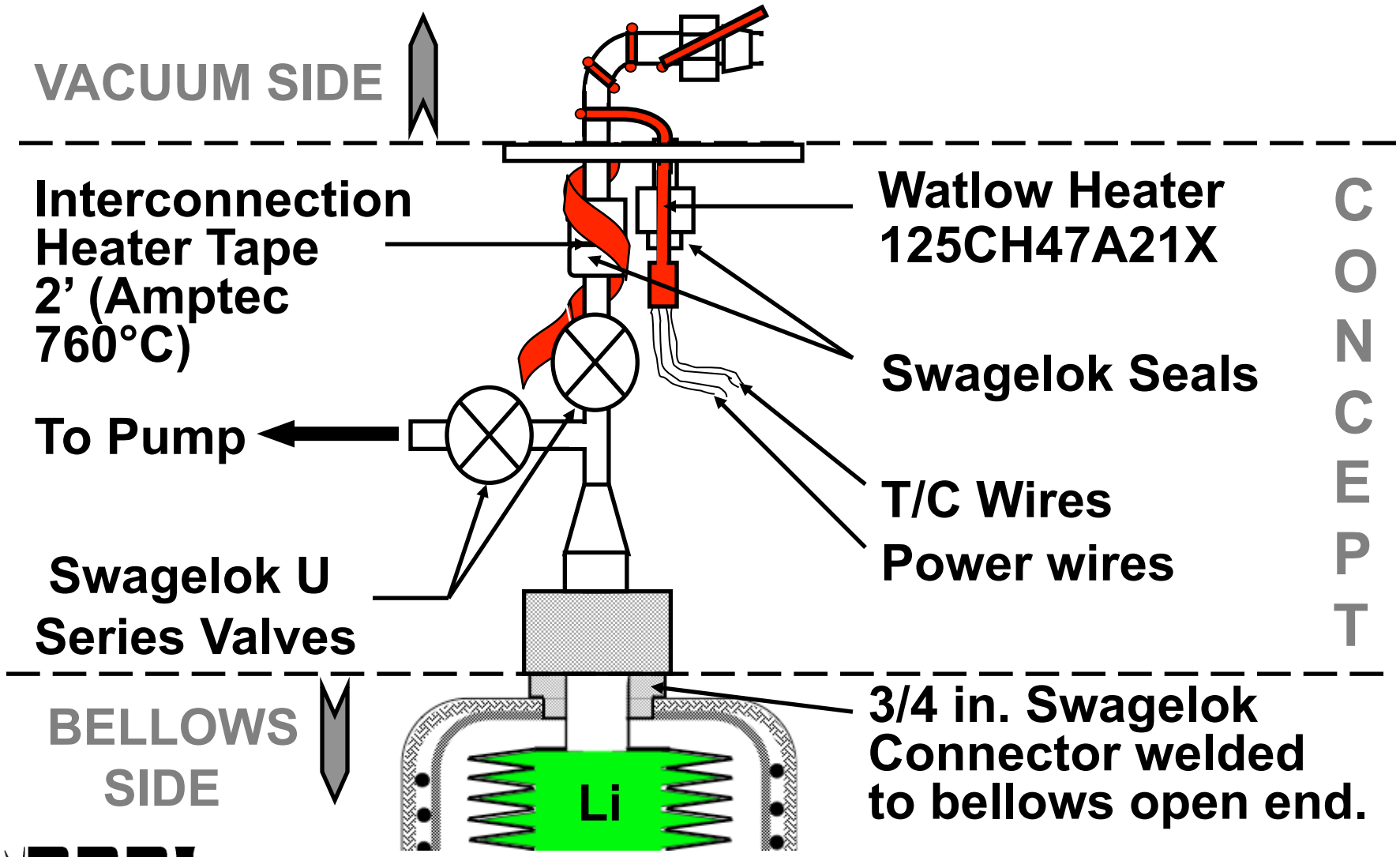
MAIN FILL (Ideal) Inter-connection



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MAIN FILL Demo Construction

A laboratory demonstration device was constructed from available parts with simplifications:

- A 3.37 in. pneumatic right angle valve - dissected and cleaned for its bellows assembly.
- 3/8”-8 304 SS precision acme threaded rod welded to bellows base, 3/4 in. Swagelok Connector welded to bellows open end. (Allows insertion of 1/2 in dia. lithium rods.)
- Device put into a 3.37 in. spool piece with gas port.
- Gear added to 3/8”–8 bronze precision acme round nut and installed on threaded rod.
- Wrapped with 6’ heating tape (HTS/Amptek 760°C max).
- Insulated with thermal blanket (COTRONICS 370-1).
- Heat shield added (from 5 mil SS shim stock).

AS CONSTRUCTED

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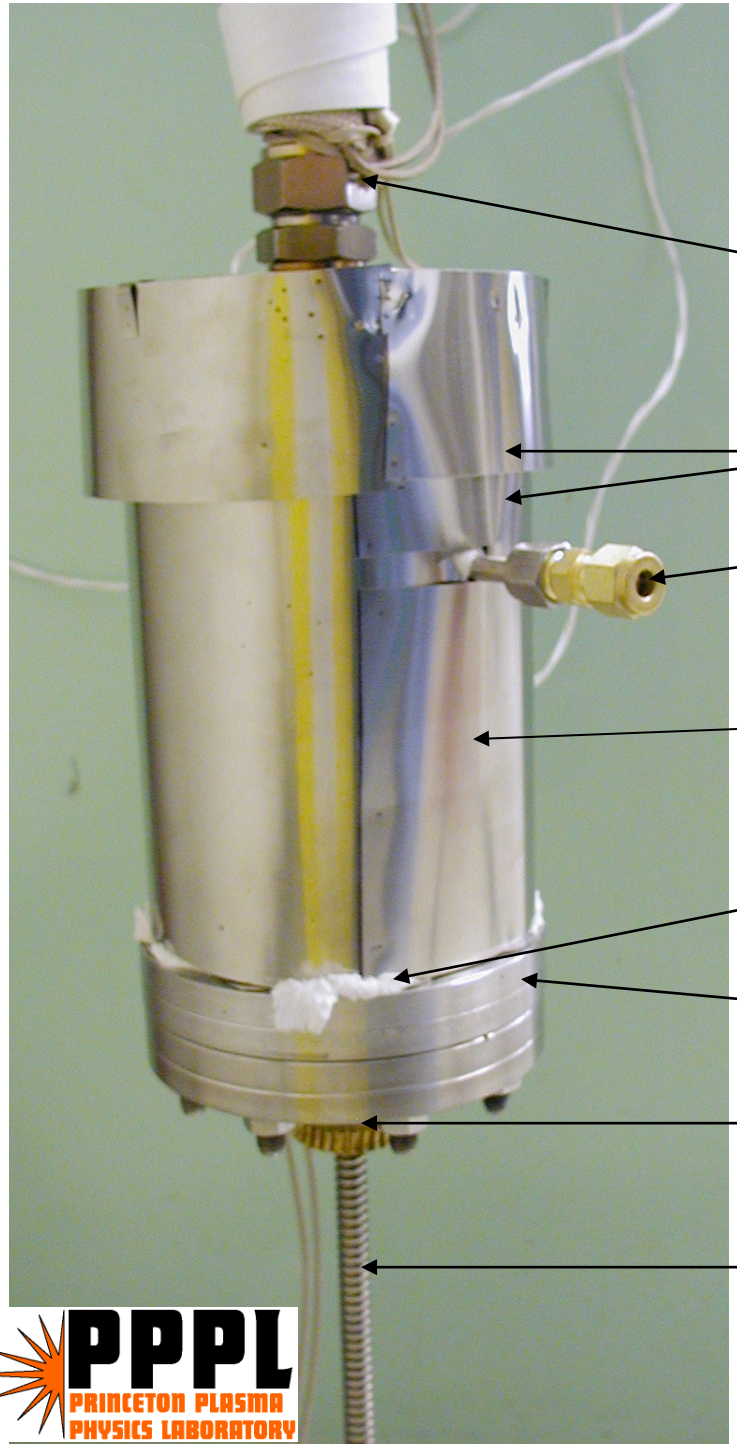
ACTUAL Bellows - 1



3/4 in. Swagelok connector welded to bellows open end.

Heat Shield

Gas Port

Chamber Heater (Not seen) Amptec 760°C Tape

Insulation

Chamber Wall (Spool Piece)

Precision Threaded Nut w/Gear

Precision Threaded Rod

SINGLE CONTAINMENT ACTUAL

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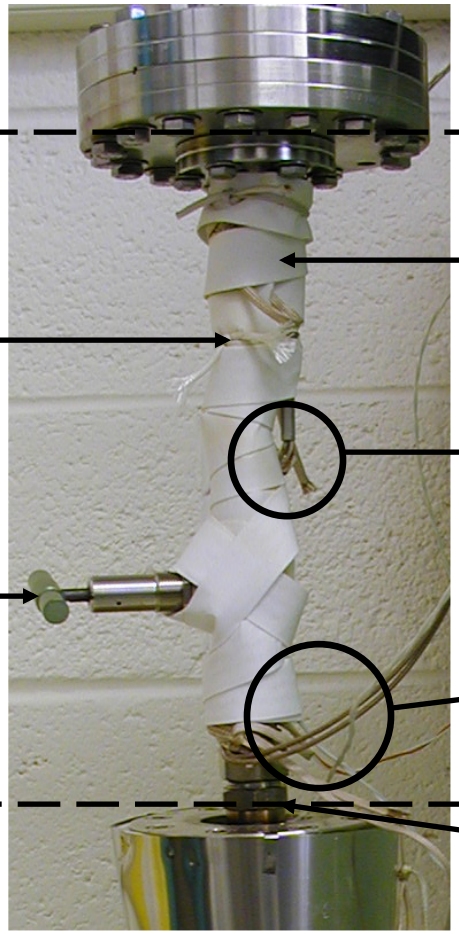
ACTUAL Inter-connection

VACUUM SIDE



(Amptec 760°C)
Interconnection
Heater Tape 2'
(Under Insulation)

Swagelok
SS-8UW-TW

Swagelok Seals
(Not Seen)

Watlow Heater
125CH47A21X
T/C & Power
Wires

2' Tape Power
& T/C Wires

3/4 in. Swagelok
Connector welded
to bellows open end.

ACTUAL

BELLOWS
SIDE

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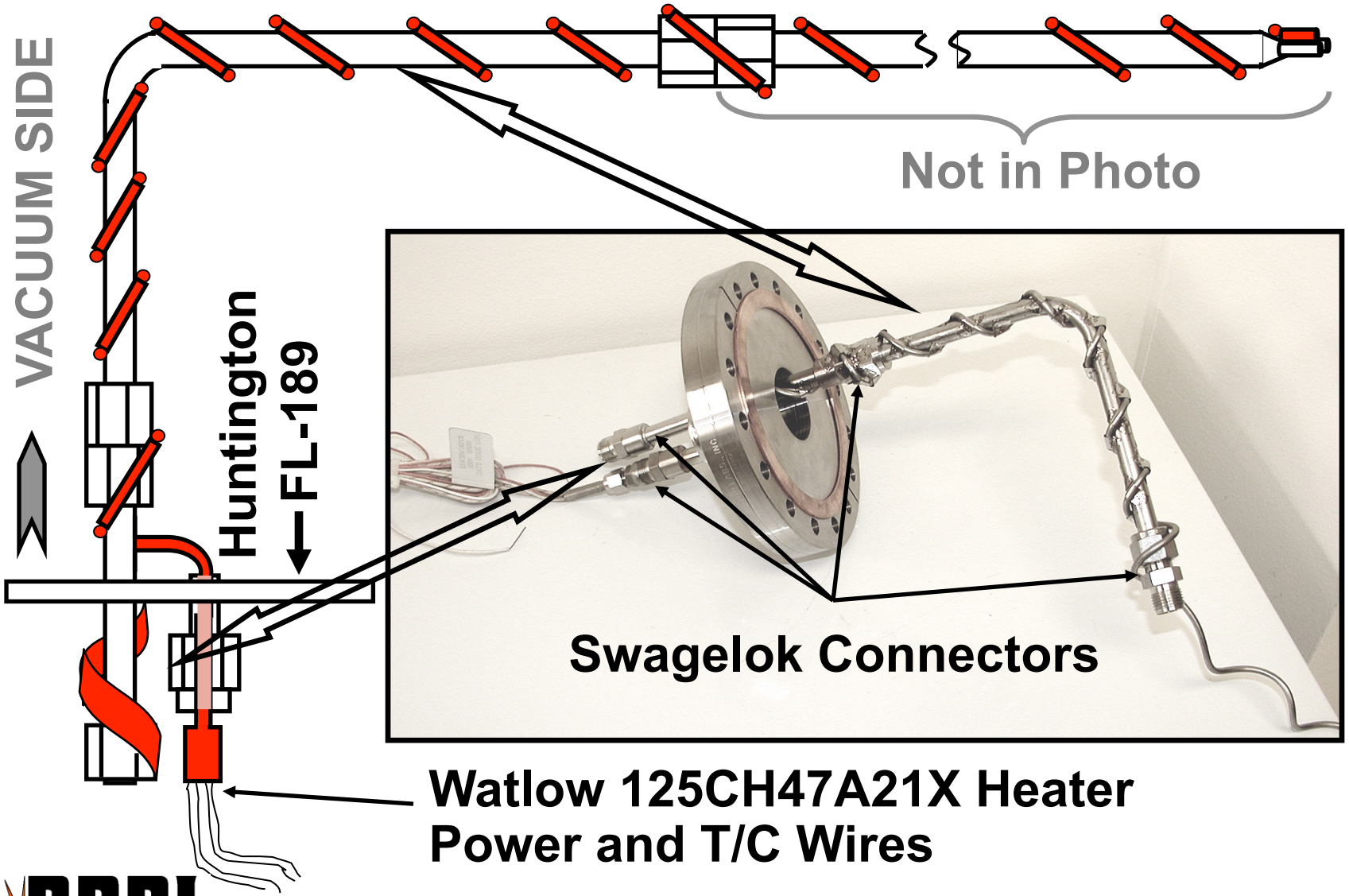
MAIN FILL Vacuum Feed



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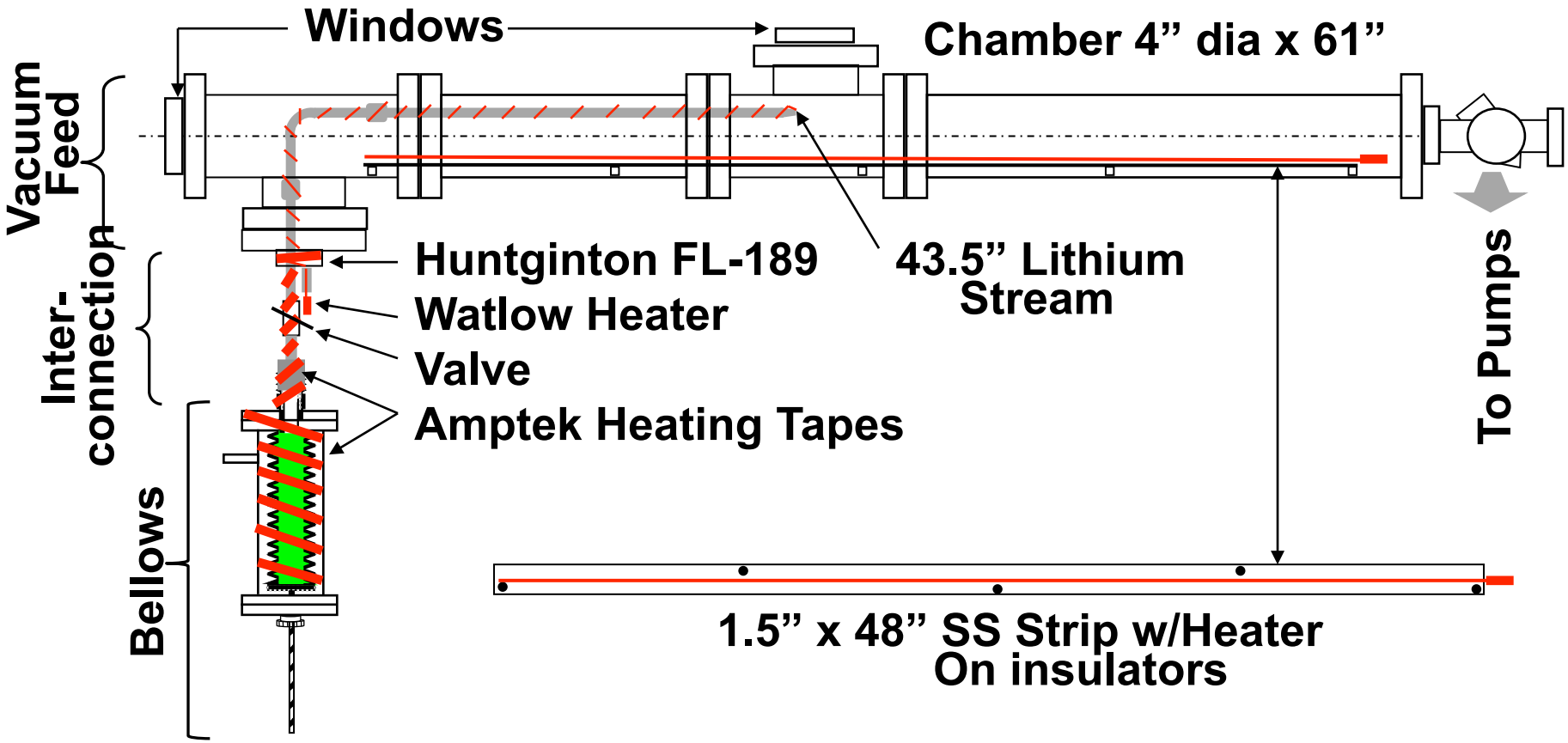
Laboratory Test Set-Up



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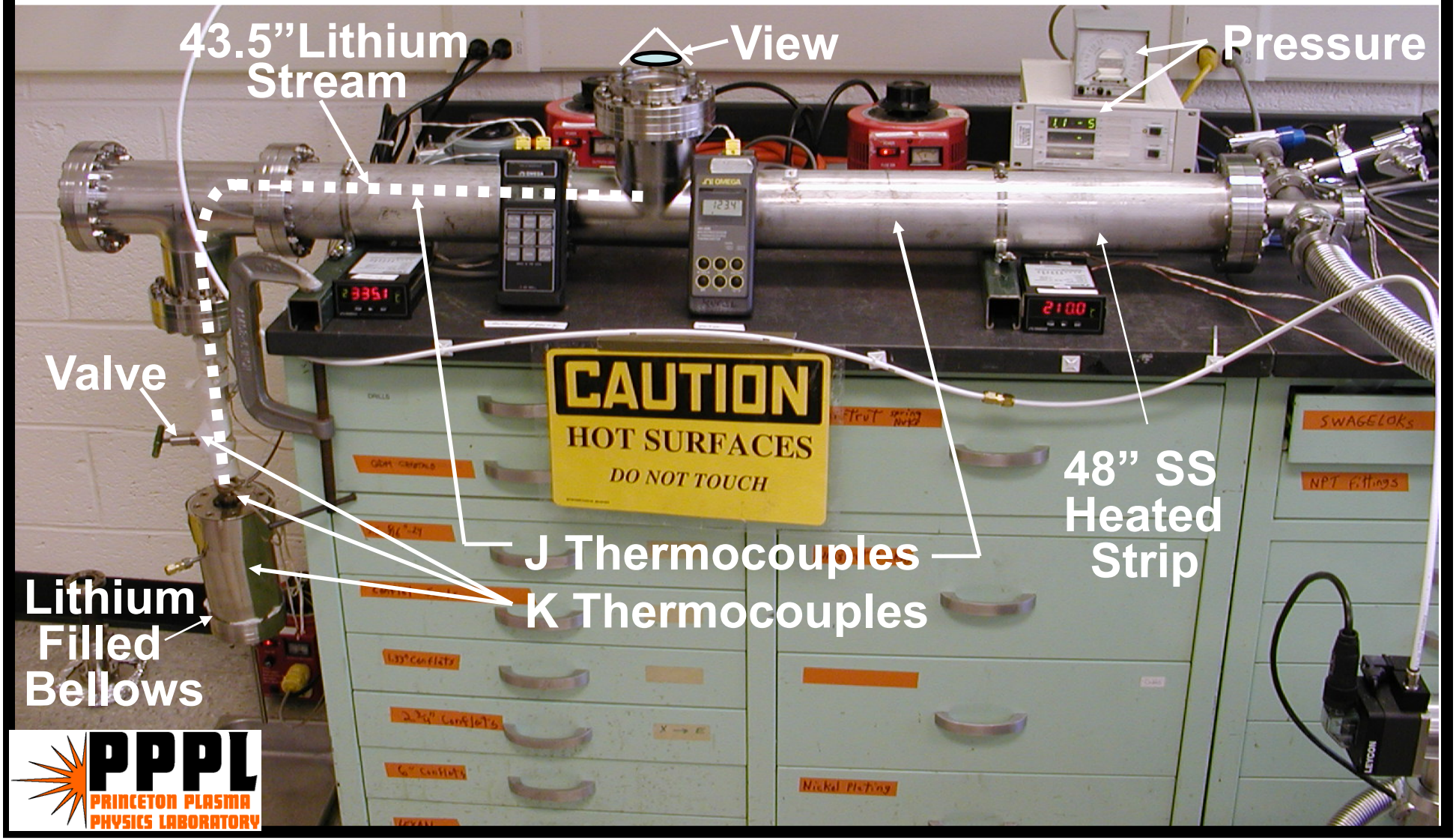
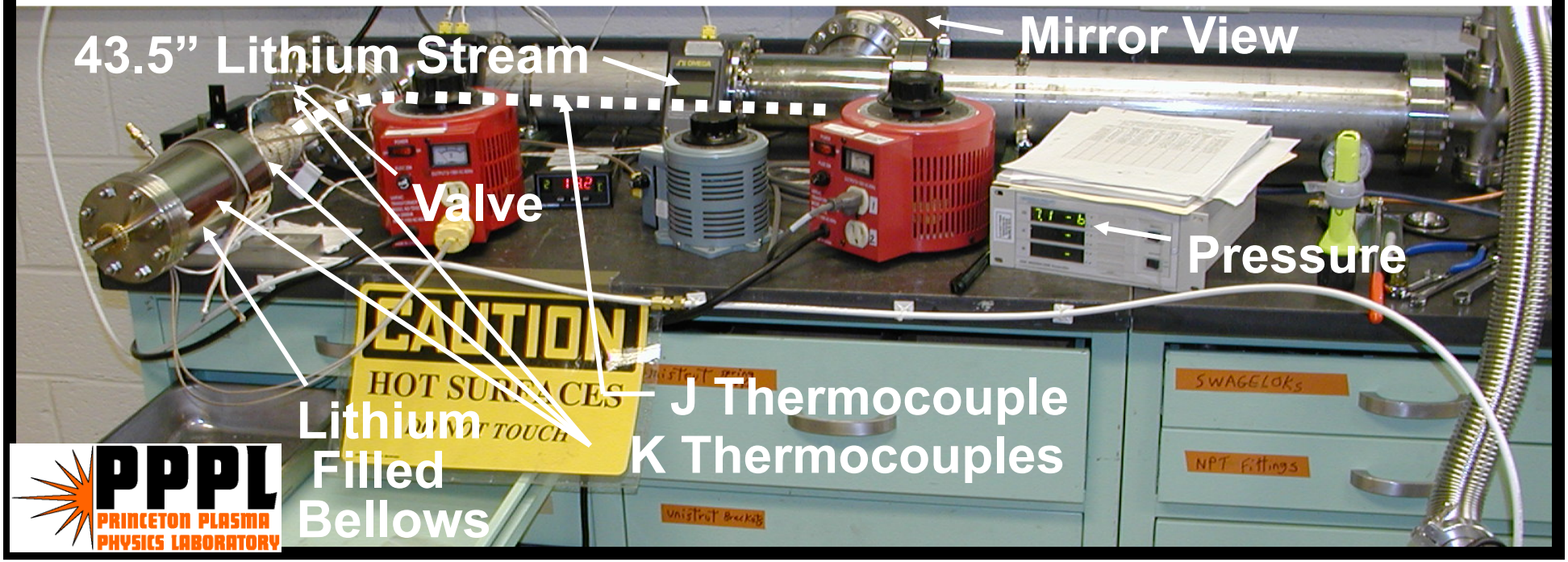
Vertical Testing



Horizontal Testing



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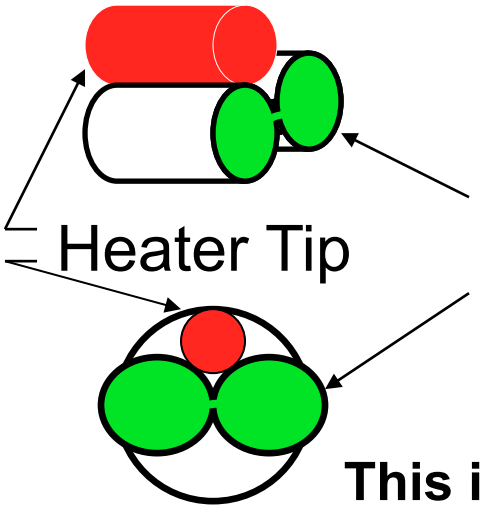
Lithium Stream Termination

LIFTER made from 3/8 to 1/4 in tubing or 0.277” I.D. to 0.152” I.D.



MAIN FILL:

3/8 inch 304 SS tubing squeezed down to two ~ 1/8 inch apertures for injection or 0.277” I.D. to 2x 0.125” I.D.

This is to reduce flow from 0.277” dia. opening and from LIFTER experience allow for potential blockage of smaller opening. **NOTE: Though operational, this does not mean the nozzle is fully developed.**

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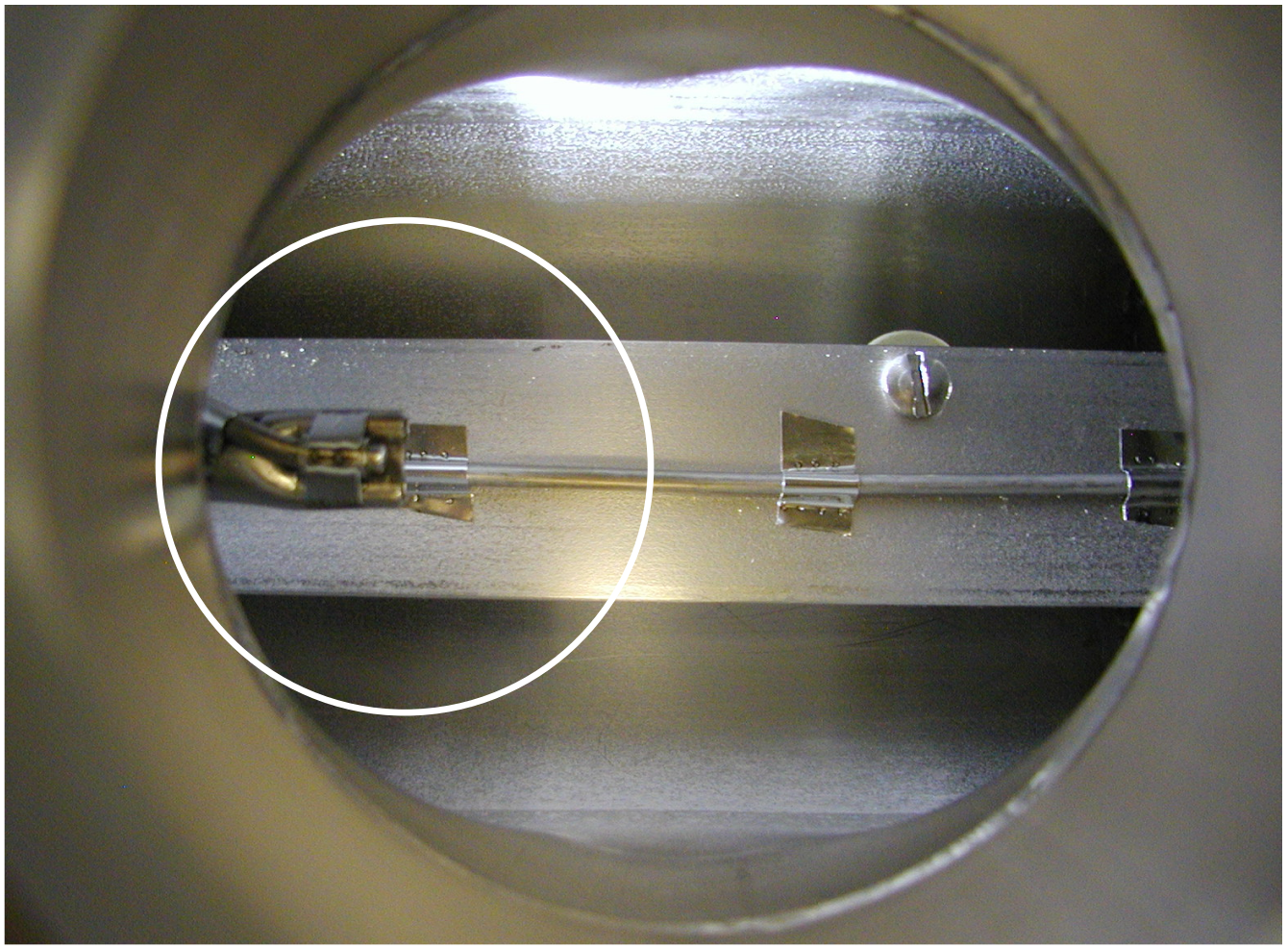
Lithium on SS Seen from View Port



No Lithium!

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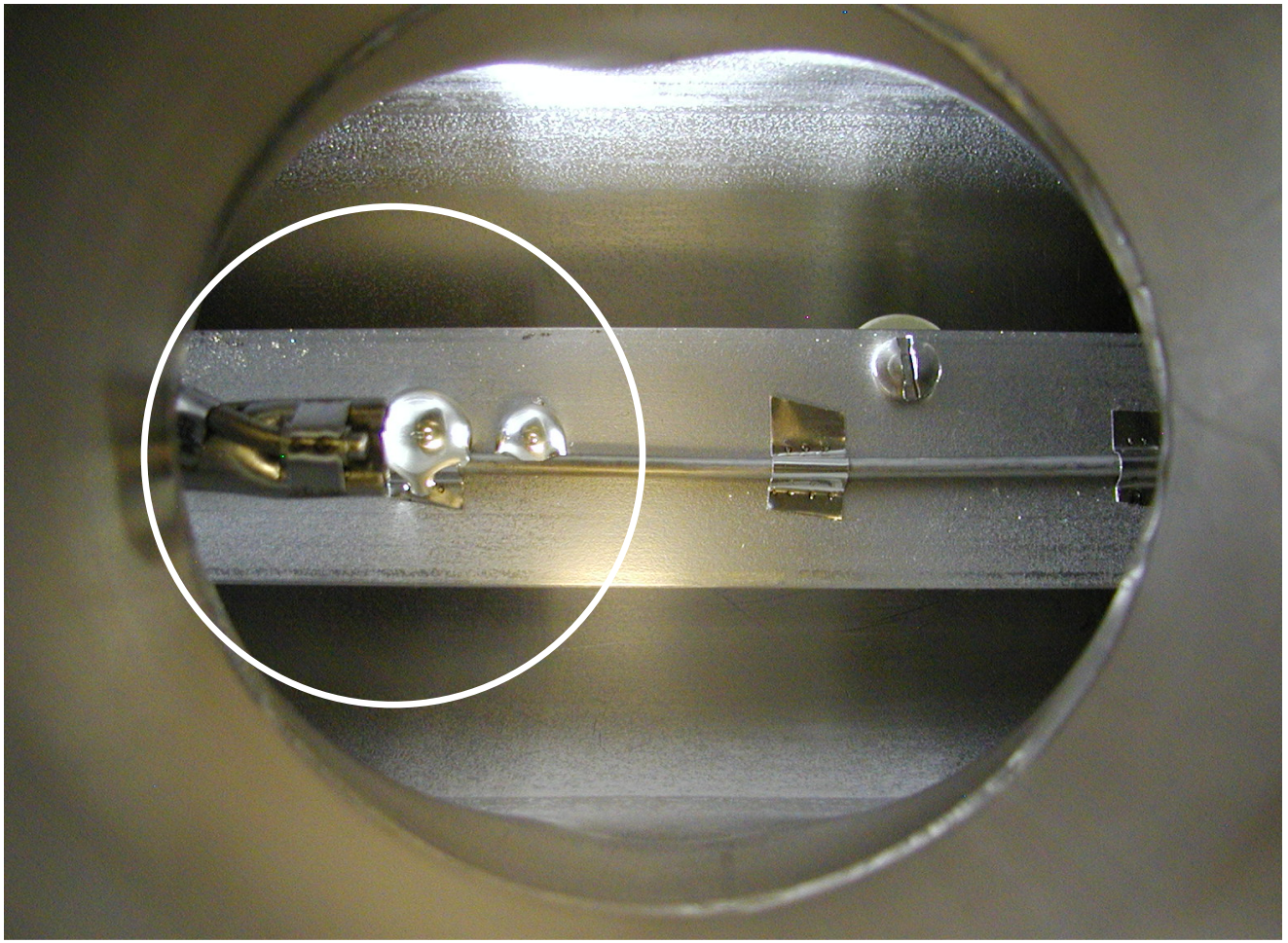
Lithium on SS Seen from View Port



Lithium Just Started

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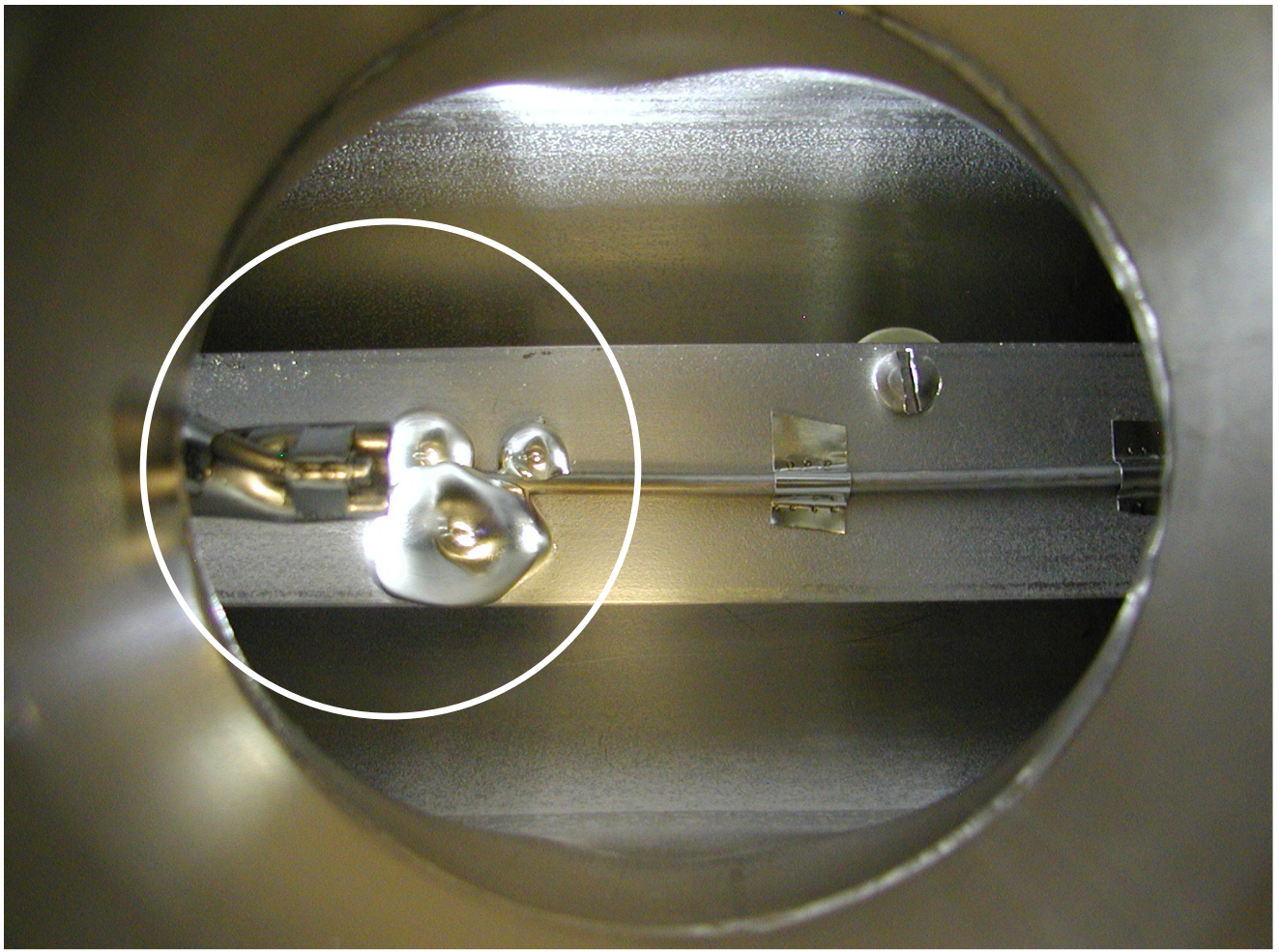
Lithium on SS Seen from View Port



Lithium From One Full Turn of Precision Nut

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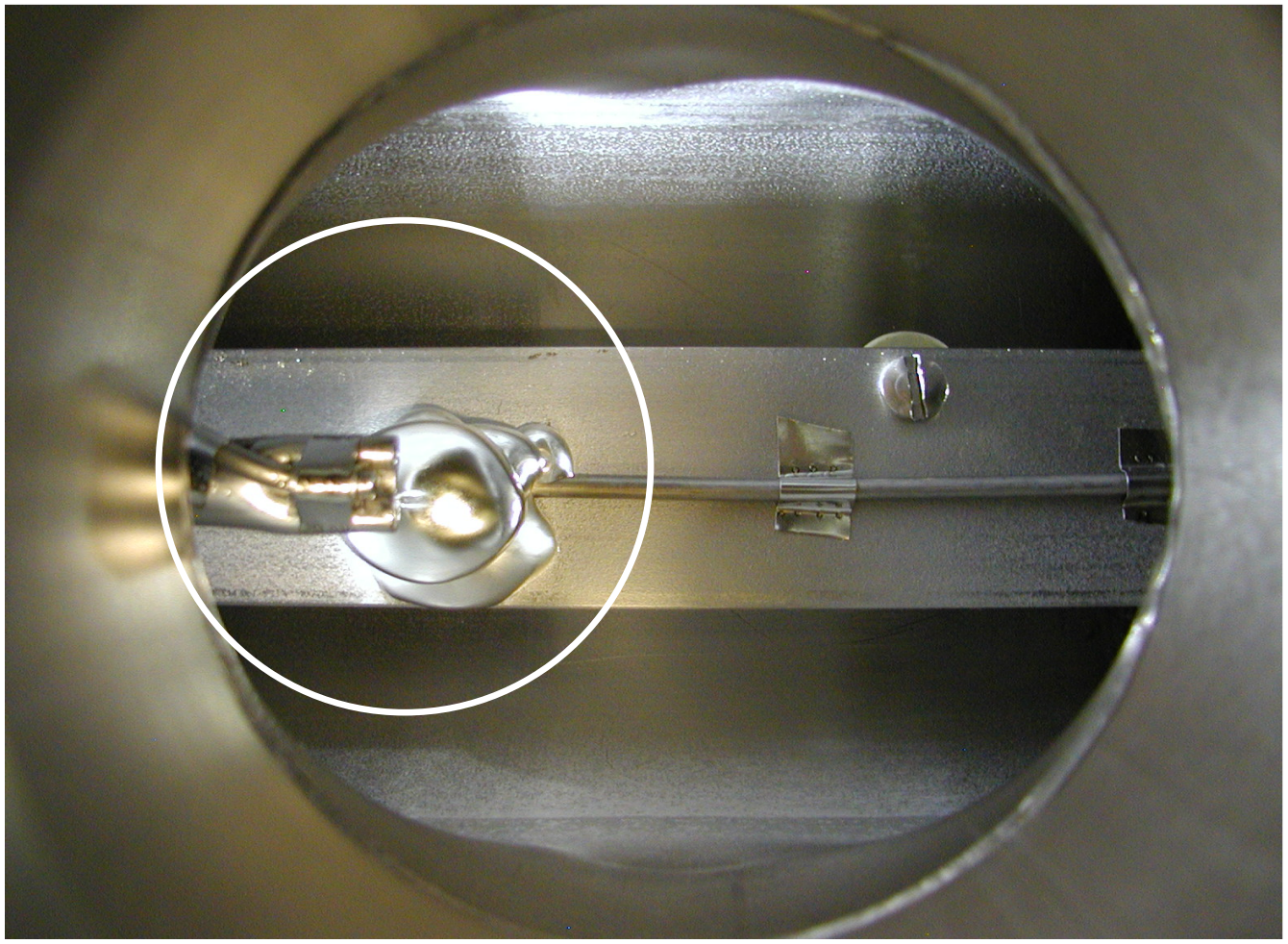
Lithium on SS Seen from View Port



Lithium From Two Full Turns of Precision Nut

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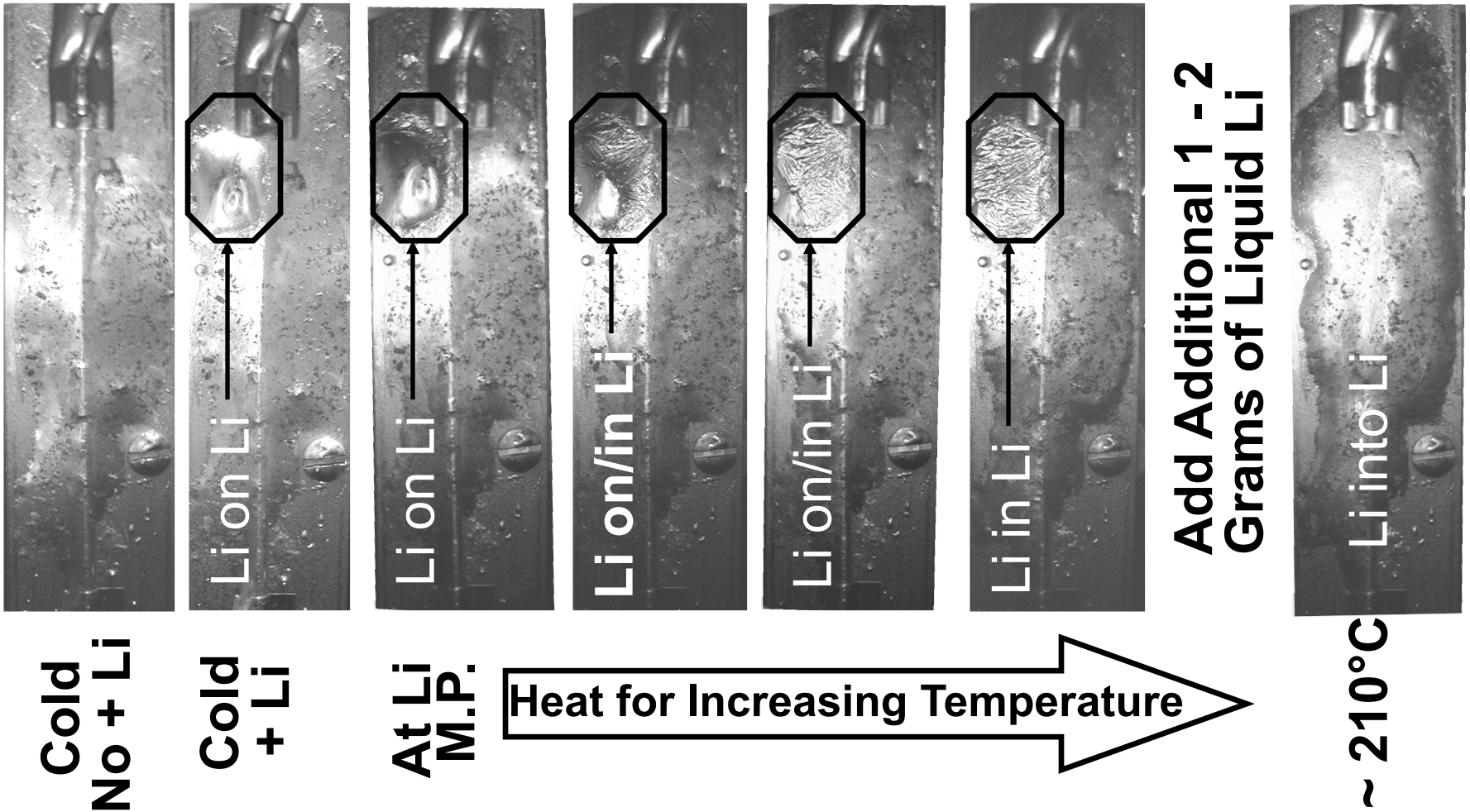
Li on Li on SS Seen from View Port



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Will Liquid Lithium Disperse in Porous Mo?

- During an experiment in C128, molten lithium dripped onto a 12” curved porous Mo substrate.
- The sample temperature was 200 - 250°C.
- Lithium was being evaporated from LITER 1c which was above the substrate.
- The exact reason for the lithium dripping is not clear, but LITER 1c has an orientation which was inverted.
- The quality of the lithium that dripped was not as pristine as seen from MAIN FILL.
- The dispersion of this lithium into the porous Mo substrate is evident.

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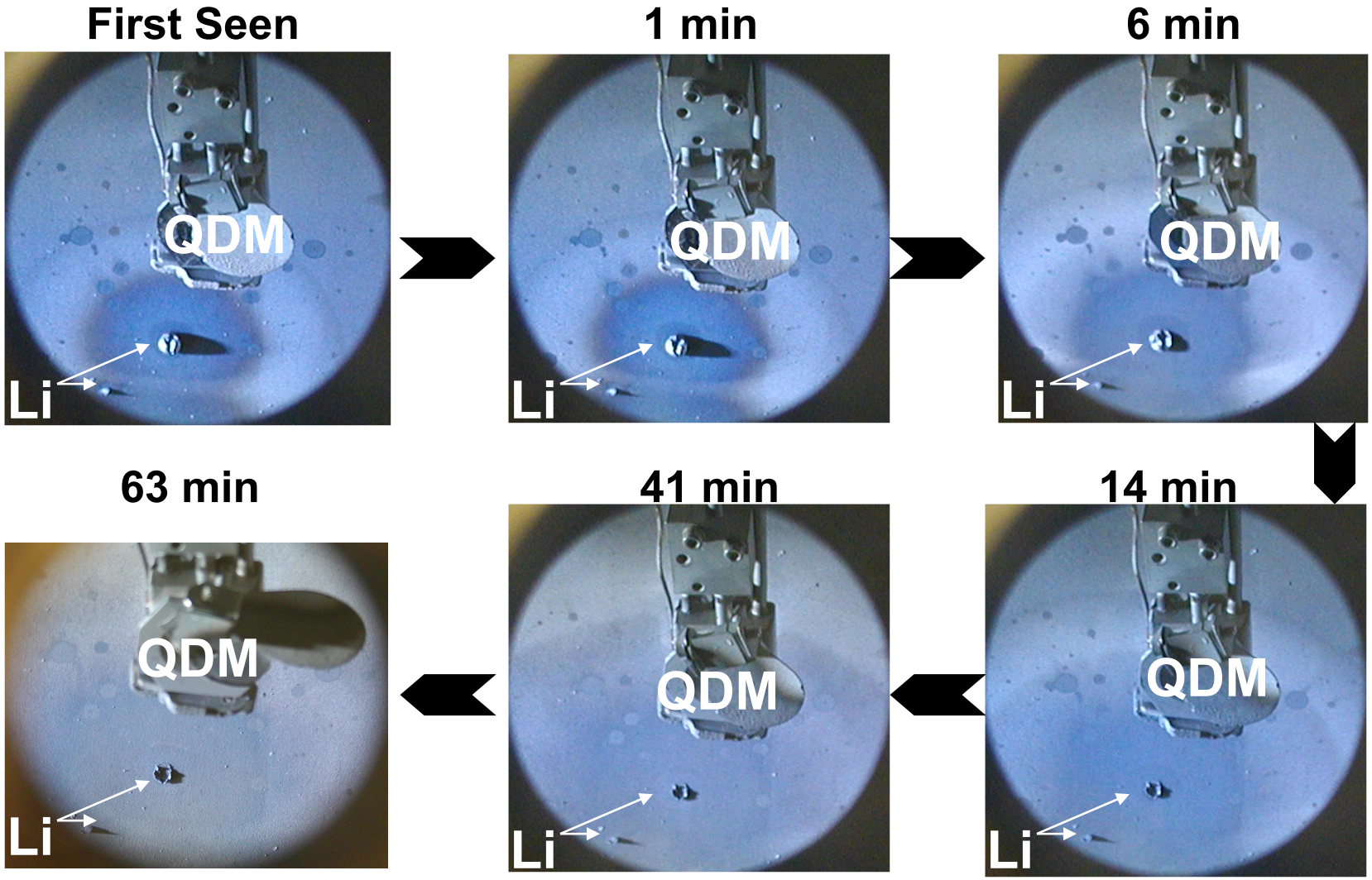
First Seen
1 min
6 min
14 min
41 min
63 min
QDM
Li

Summary

✓ We have demonstrated that we can deliver liquid lithium into a vacuum chamber and onto a substrate via a non-evaporative technique. This method used a bellows filled with 61.5 grams of lithium flowing through a valve and 110.5 cm of tubing holding >22.8 grams of lithium with a 90° bend and at least six fittings (Swagelok).

✓ We have provided a means for delivering measured quantities of liquid lithium, but we have not calibrated this delivery.

✓ We have kept heater and thermocouple wires out of the vacuum chamber.

✓ We have utilized a workable lithium stream termination, but we have not developed a specific nozzle.

✓ We have successfully utilized a high temperature flow valve for stream control, but have not set limits.

✓ We have evaluated successful recovery from down times of weeks, but have not evaluated recovery from down times of months.

✓ We have operated with the bellows in the vertical and horizontal position.

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Under Consideration

- **Configurations for utilization of this method of liquid lithium delivery into NSTX.**
- **Conversion of Lithium Stream to a mist or vapor for a more broad coverage area. Experimental work for Lithium Stream conversion is currently on hold while an ion heating technique is in progress.**
- **Ion heating of the LLD. This technique has thus far been successful at heating ~19 cm^2 of lithium on stainless steel to 293.7°C with ~182 watts in 32 minutes using argon gas.**
- **Removal of lithium from the LITER shutters in addition to heating the LLD using ion heating.**

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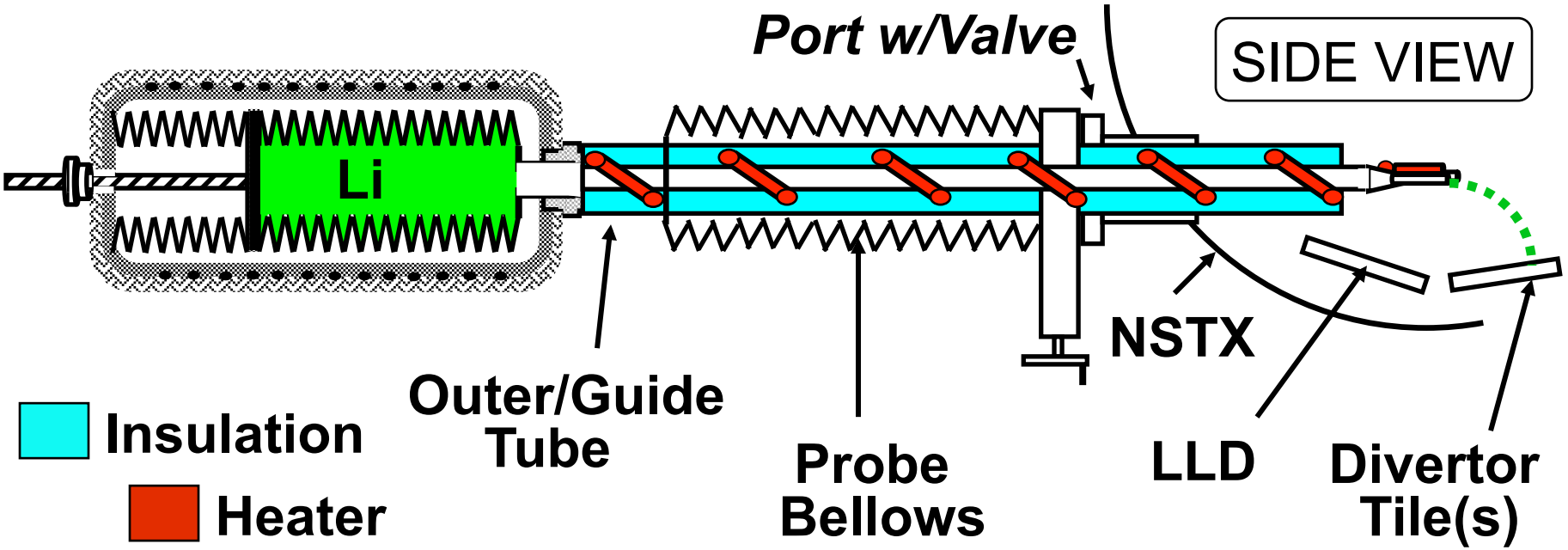
NSTX Configurations

Construct linear MAIN FILL probe that can reach as far as inner divertor tile(s) through a lower or upper port:



NOT TO SCALE

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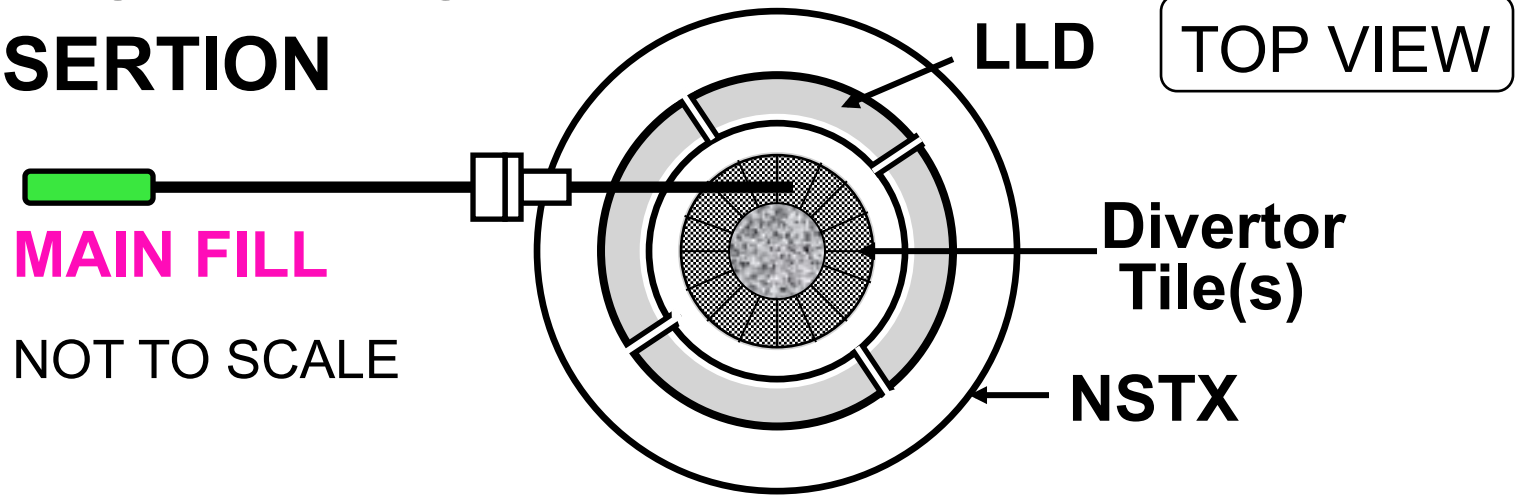
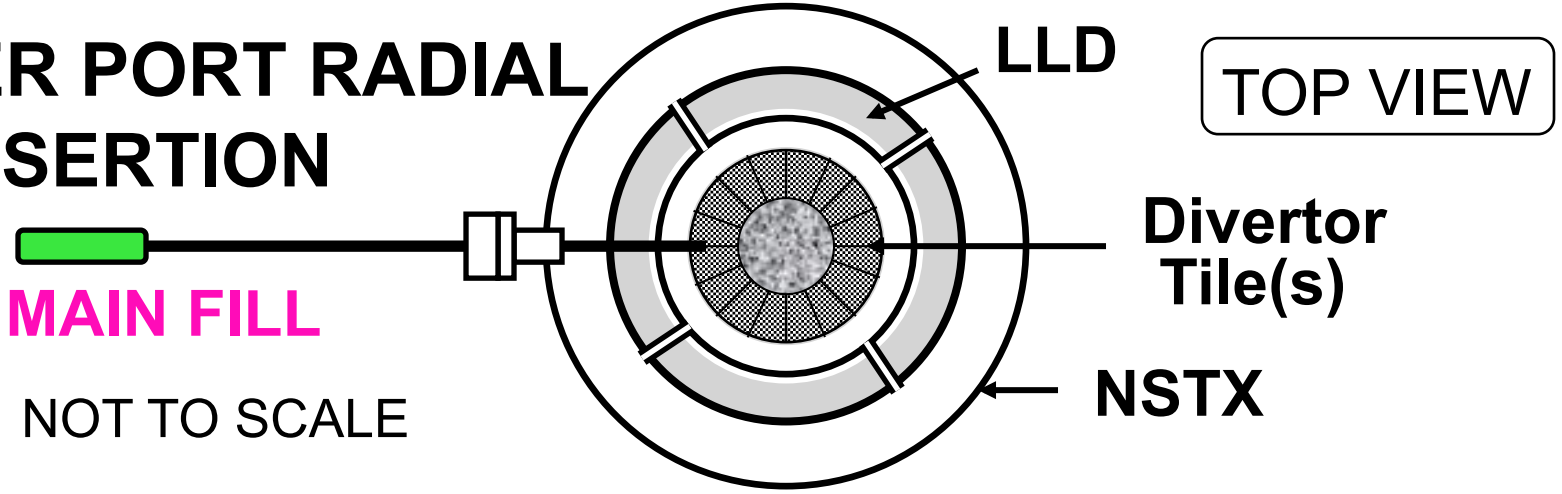
LOWER PORT TANGENTIAL INSERTION



LOWER PORT RADIAL INSERTION



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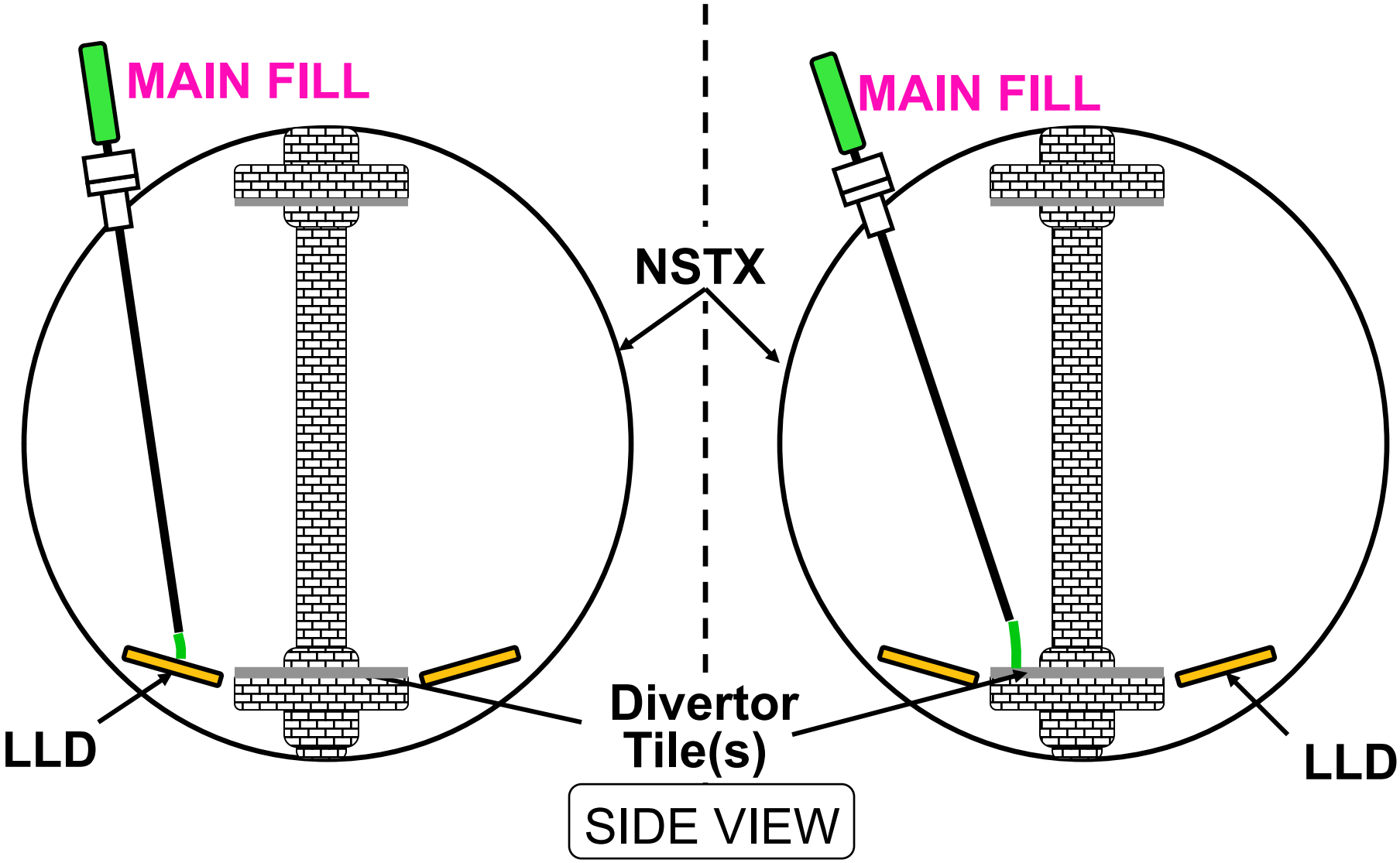
UPPER PORT INSERTION



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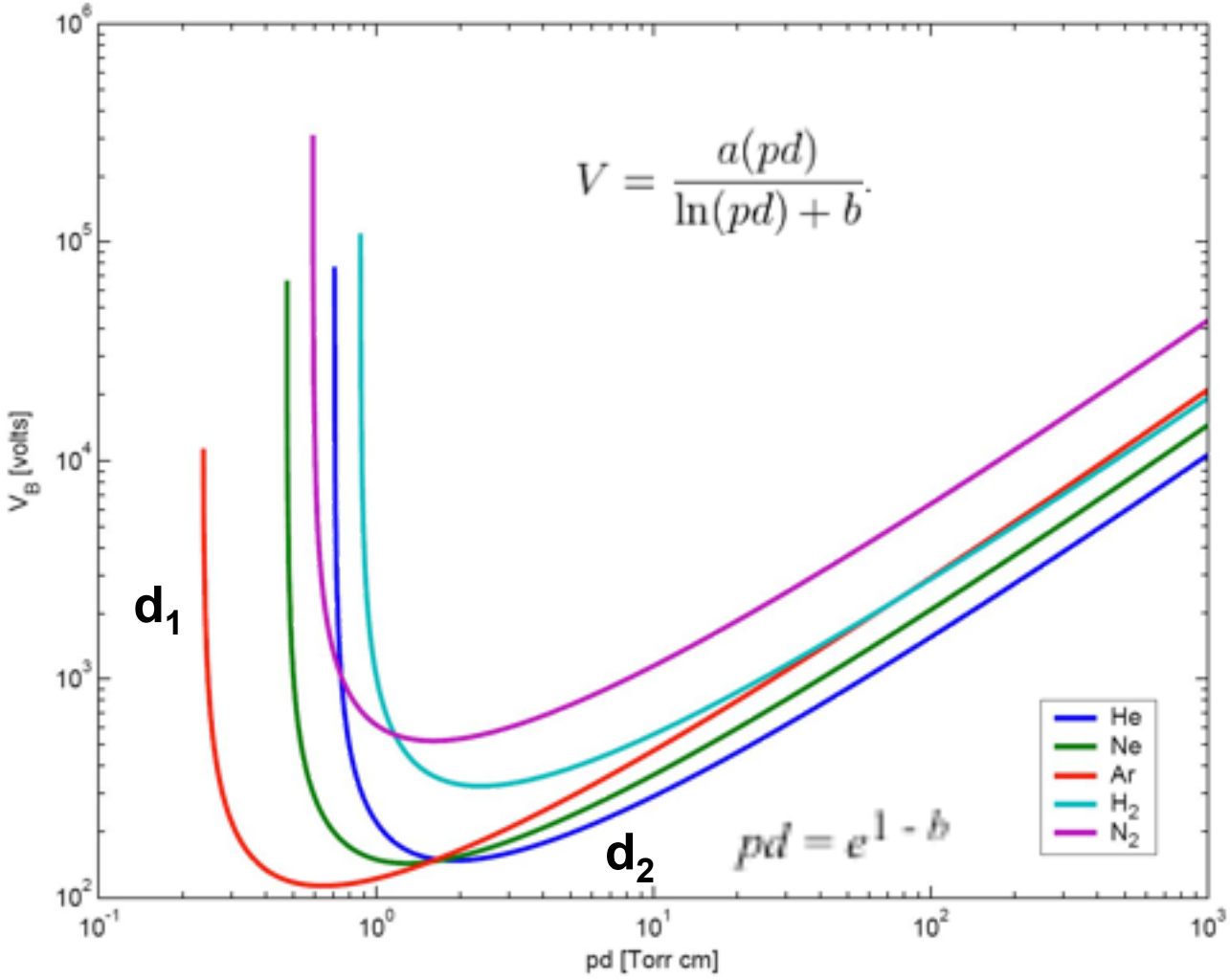
Paschen Curves



A three electrode configuration is used to produce gas ion heating on a substrate of lithium on stainless steel. Pressure and distance can be used to "focus" the heating. Essentially this is a full wave gas rectifier.

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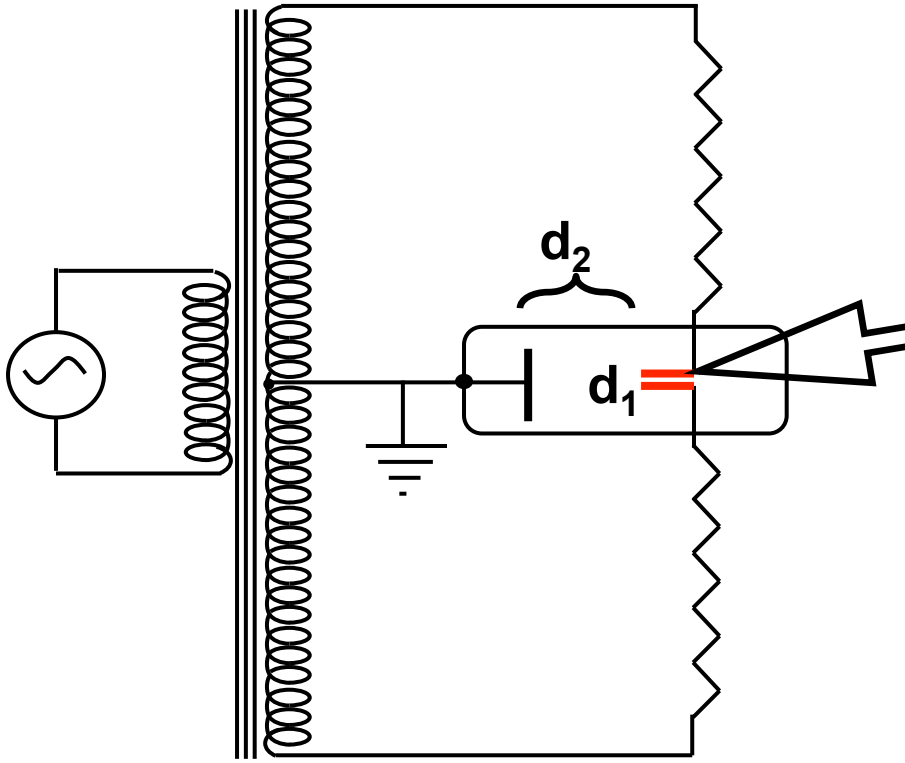

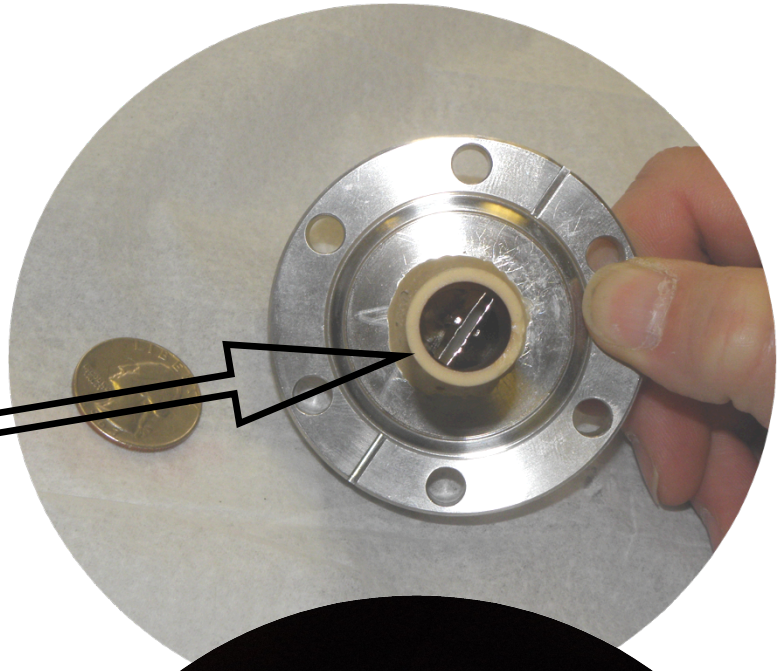

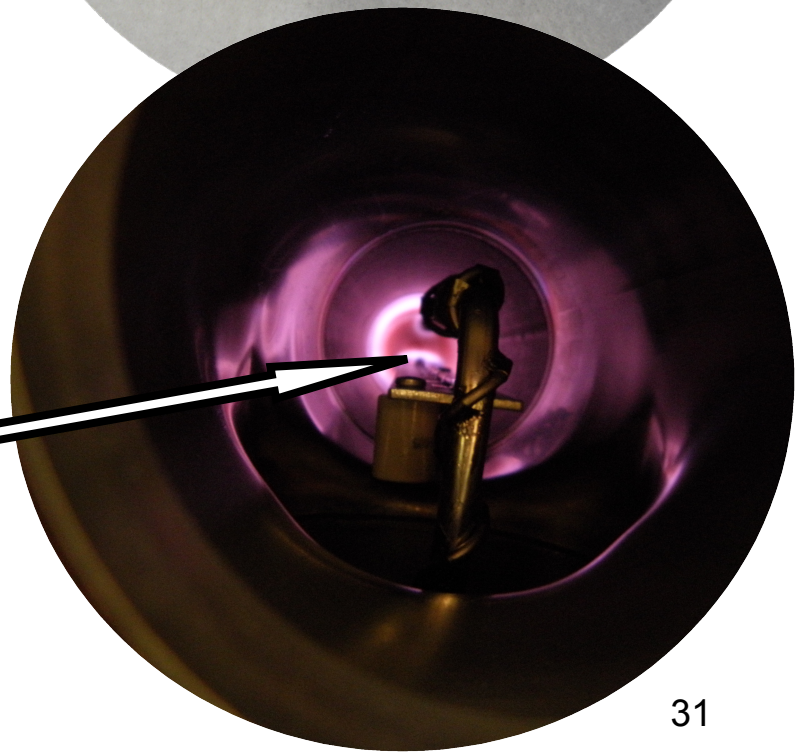

This Glow is under the pictured electrode which is 80 cm in the distance!

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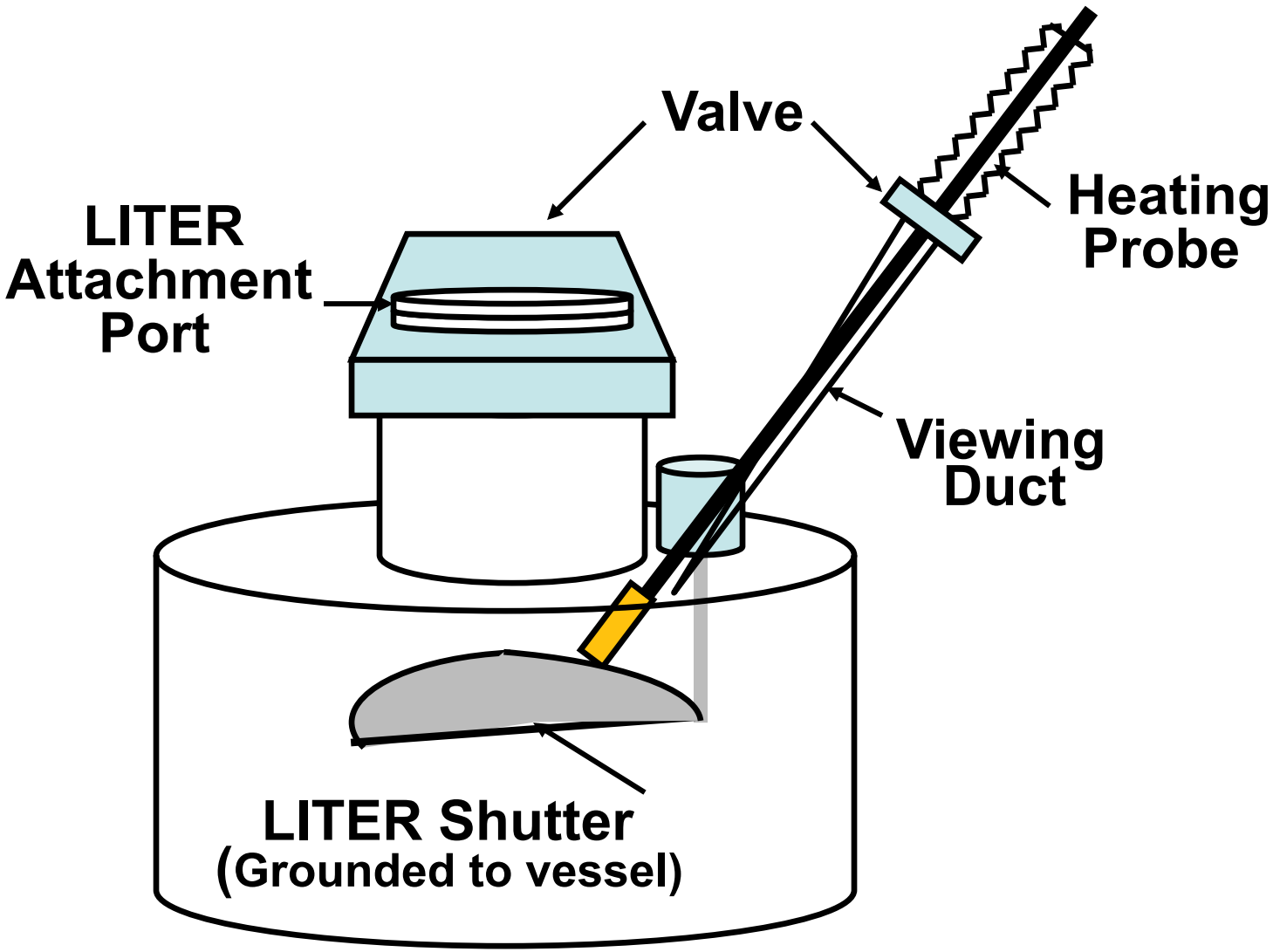
Arrangement for Melting Lithium on Shutter



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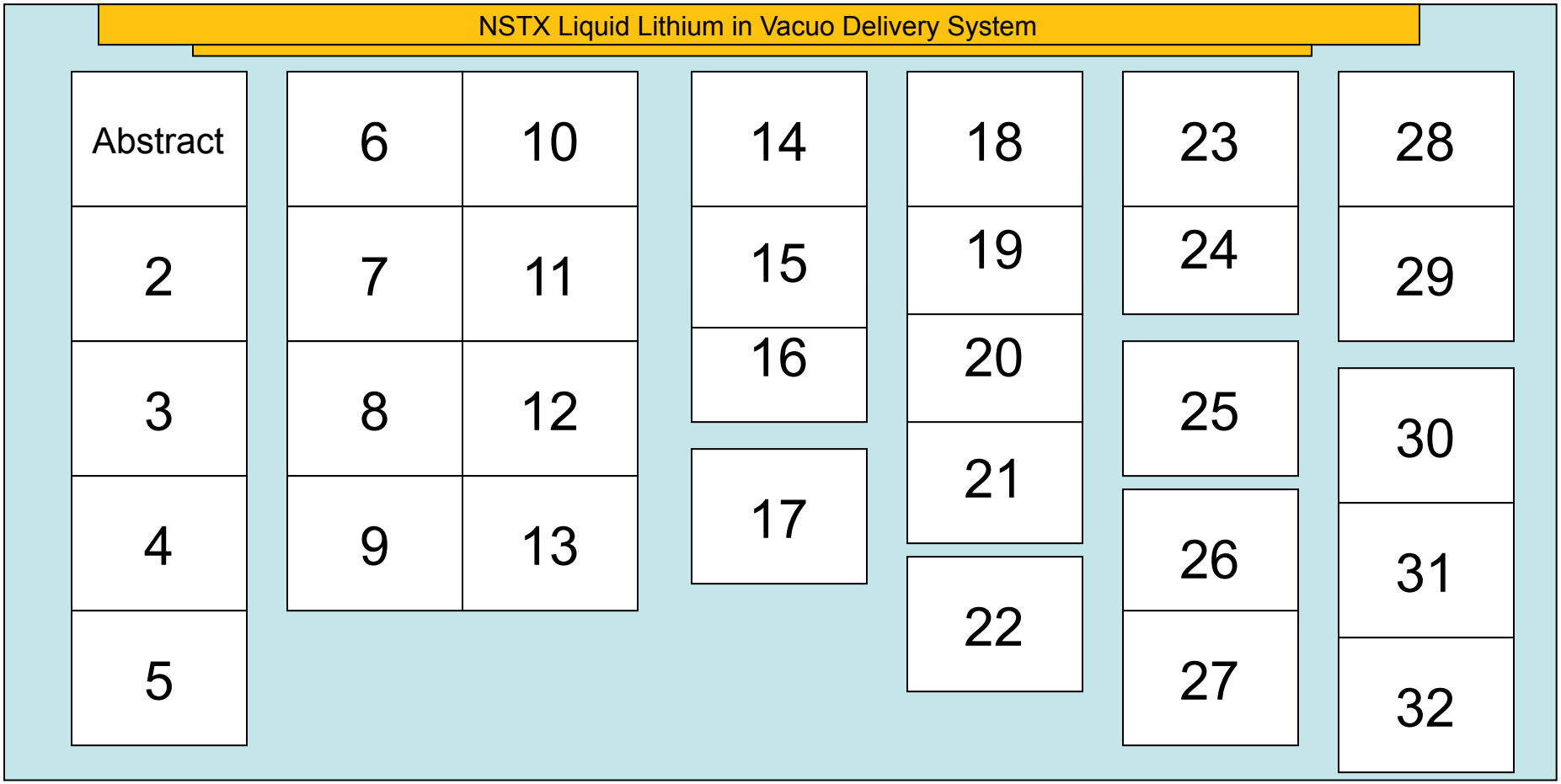

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