DIII-D Wall Change Community Forum

DIII-D Wall

Virtual Forum, 12th June, 2024

Helium Ash Pumping with Lithium using an Instrumented Tile Experimental Manifold (ITEM)

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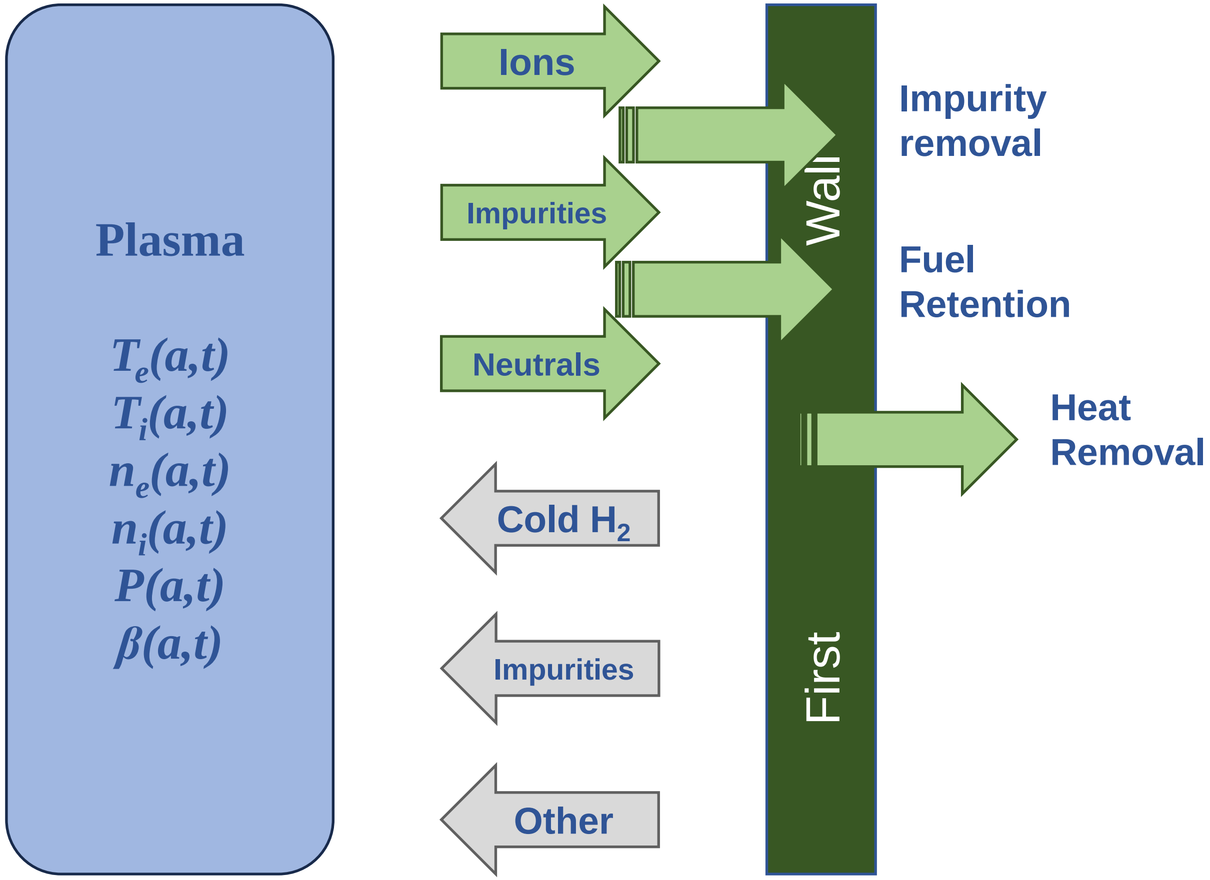
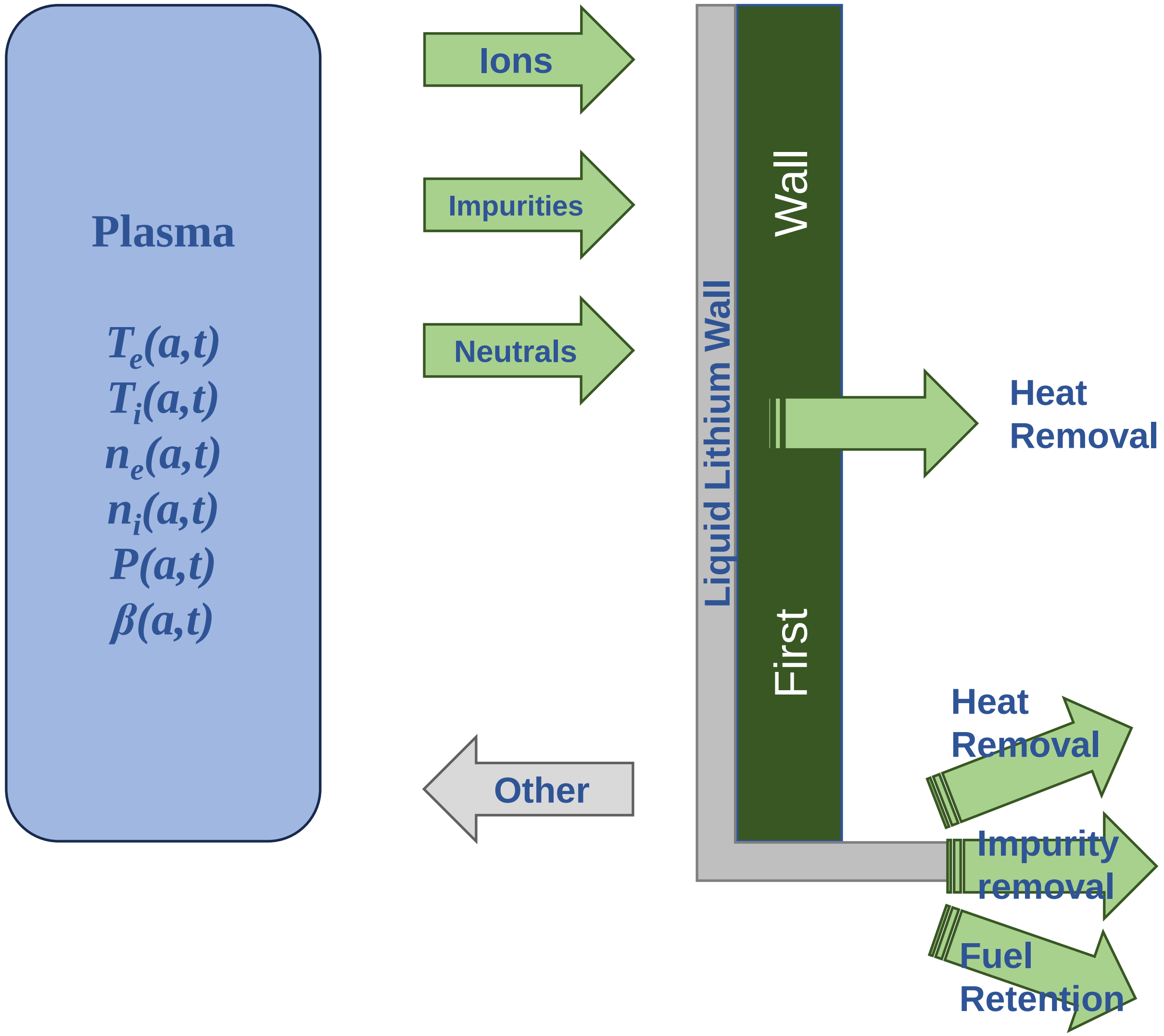
Complex Behavior of Materials and Plasma - Solids

- Incident high energy ions and neutral will have a significant impact on the reactor surface
- Damage
  - Displacement of atoms within the lattice structure of the materials
  - Leads to embrittlement
- Surface structure formation
  - Fuzz
  - Blisters and bubbles
  - Fuel retention within the structure
- Recycling
  - Cold hydrogenic species
  - Impurity atoms
  - Secondary electron emission
  - other



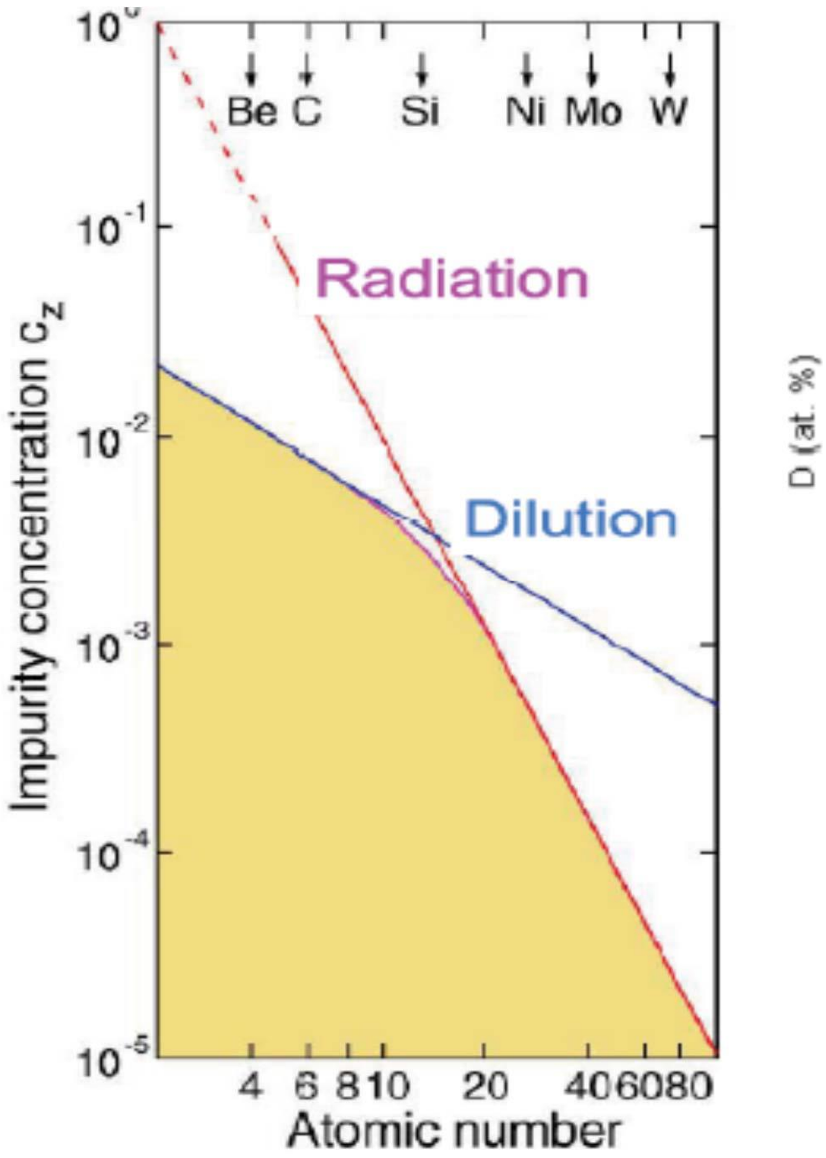
Complex Behavior of Materials and Plasma - Liquids

- As low-Z as possible:
  - Minimize power losses by reducing high-Z impurities entering the core.
- High affinity for ionized fuel species:
  - Mitigates instabilities and eliminates ELMs, Increases cross-sectional T_i while reducing particle wall flux.
- Constantly refreshing:
  - Removes impurities and products (if flows outside chamber) + minimizes erosion
- Stable flow
  - Need to avoid any dry out or lack of wetting
  - Damage to the substructure
- Neutron tolerant

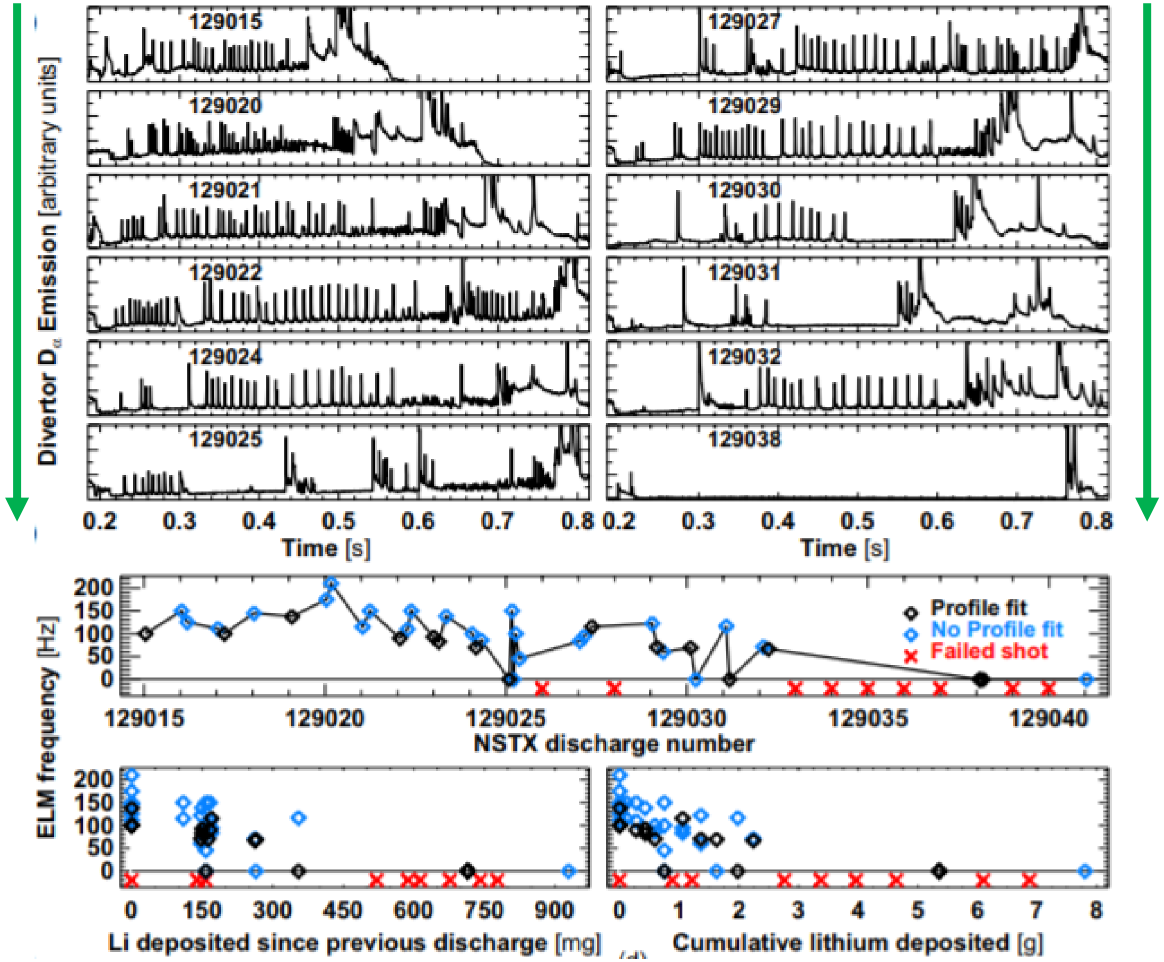


Minimization and Control of Impurities in the Plasma

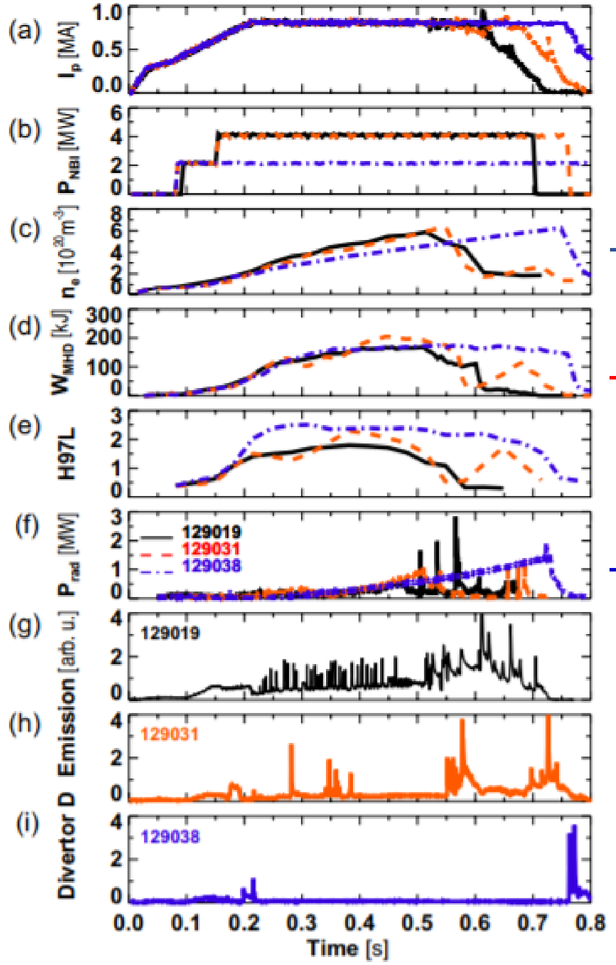
- There is a maximum level of impurity allowed inside a fusion reactor
- Tolerances for High-z are much stricter than for low Z
- Anything the plasma touches will almost most definitely end up the fusion reactor and plasma
- So as low-Z as possible is desired



Lithium coatings reduce the D recycling, reduces H-mode power threshold, broadens T_e profile, reduces electron thermal diffusivity, improves confinement and ELM Suppression



Increasing
Lithium
Up to 600 mg



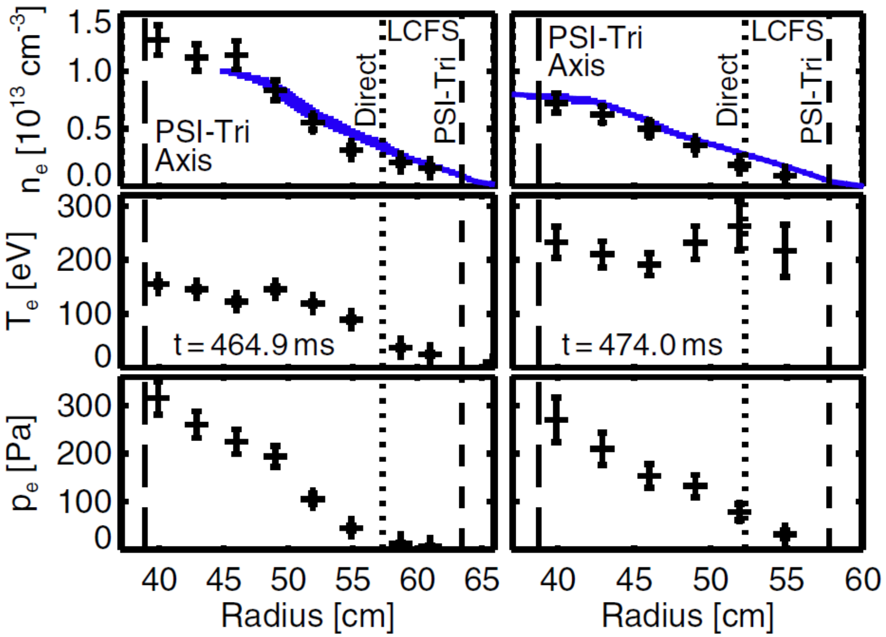
– No Li

– Medium Li coating

– Thick Li coating

D. P. Boyle et al., Plasma Phys. Control. Fusion 53 (2011) 105011

Flat Temperature Profiles Observed on LTX

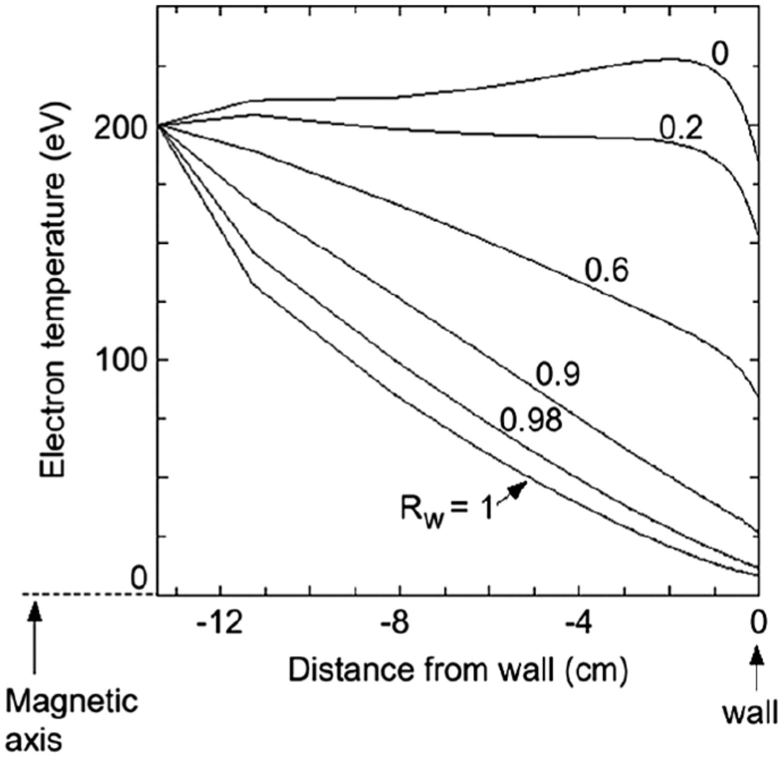


Thomson scattering n_e, T_e, and P_e profiles during the peak of the gas puff (left) and after fueling ceased (right). The magnetic axes and last closed flux surfaces (LCFS) from PSI-Tri magnetic reconstructions are shown as vertical dashed lines, while the LCFS from direct magnetic measurements are shown as vertical dotted lines. **Reflectometer ne profiles** are overlaid on the TS profiles.

- For a couple decades, now, the prevailing understanding of low recycling regime is that the temperature profiles should flatten out
  - Should be flat all the way out to the wall
- Never comprehensively observed until recently in LTX
- 60% of the hydrogen retained in the liquid metal walls
  - About a R = 0.4
- Density profiles slightly lower but also smooth out as expected.

D. P. Boyle et al., Phys. Rev. Letter. 119 (2017) 015001

T_e profiles from UEDGE simulations as function of wall recycling coefficient R_w (ratio of incoming wall neutrals to outgoing plasma ions). Core T_e and n_e were held fixed at 200 eV and 5×10^{19} m^{-3}.

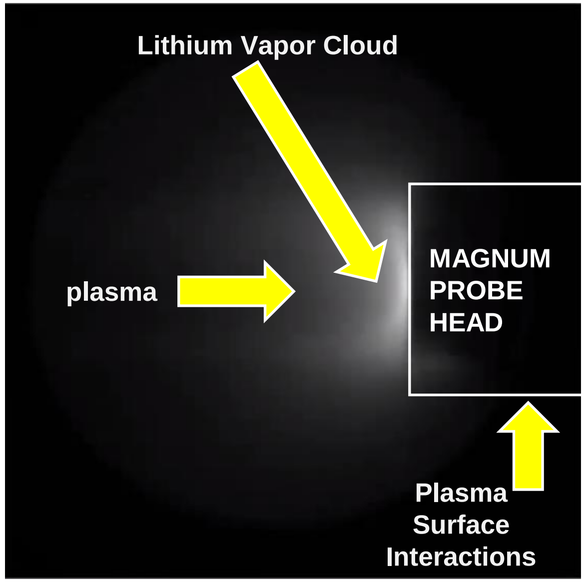


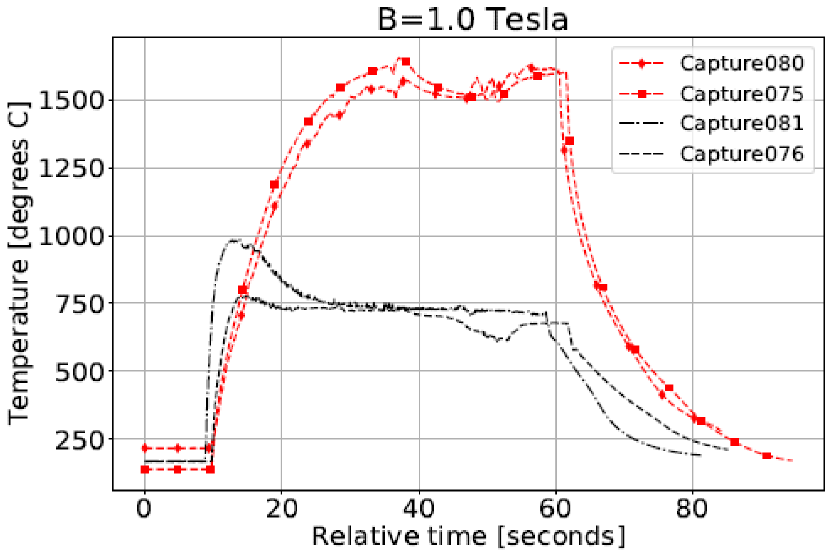
Power Dissipation in Li Vapor Shielding Experiments

- Li vapor shielding experiments performed on MAGNUM PSI have shown that when in vapor shielding regime:
  - A locking temperature is attained
  - Around 750 °C – 800 °C attained at about 6.0 MWm^{-2}
  - Holds at least up to 20.0 MWm^{-2}

- The picture on the right shows 15 – 20 MWm^{-2} shots on solid (red) and Li (black) targets

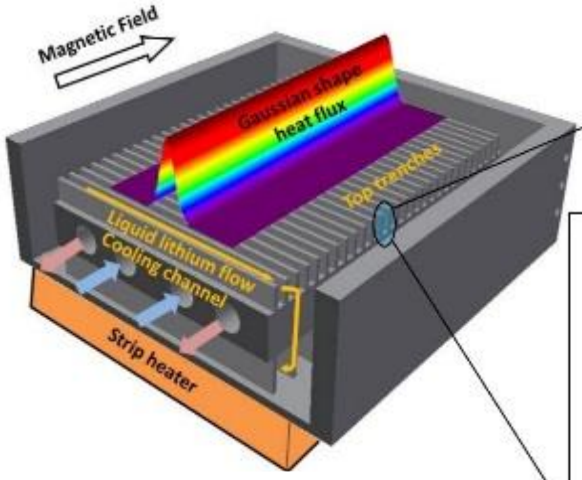
- The incident heat flux is therefore reduced by a certain amount which equilibrates to yield that locking temperature

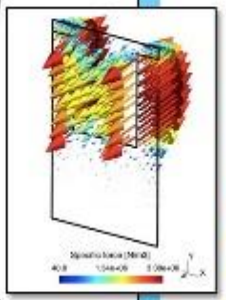


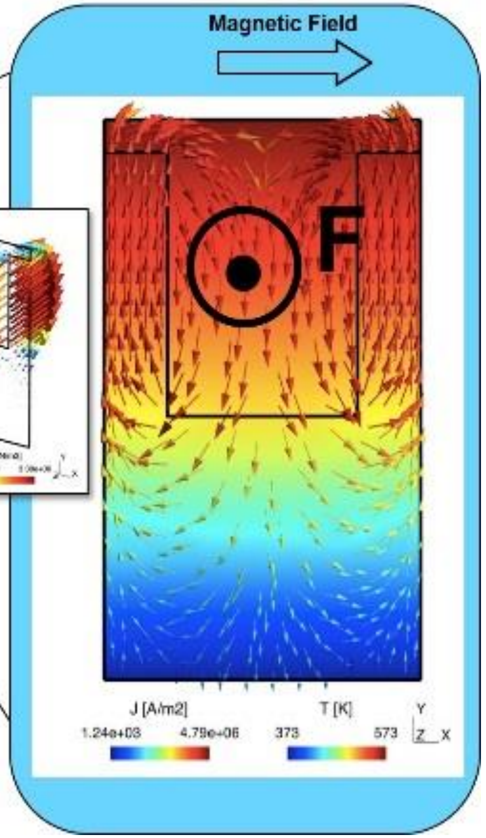


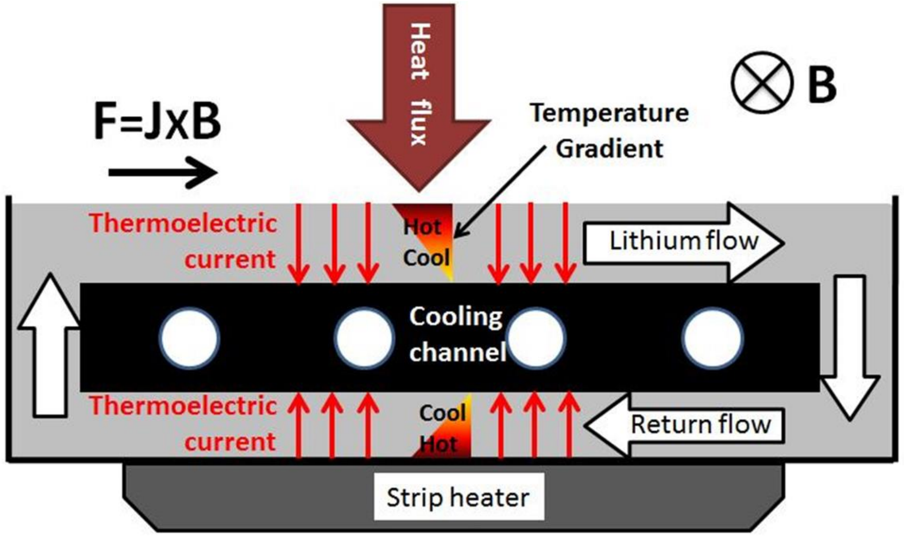
Liquid Metal Infused Trenches (LiMIT)

- Seebeck Effect creates thermoelectric current at junction between liquid lithium and solid trenches when a thermal gradient is present
- A transverse magnetic field is applied, which generates a ***J*×*B*** force, propelling the liquid through the trenches









$$\nabla \cdot \bar{u} = 0 \quad \nabla \cdot \bar{J} = 0$$

Electric current

$$\bar{J} = \sigma(-\nabla\phi + \bar{u} \times \bar{B} - S\nabla T)$$

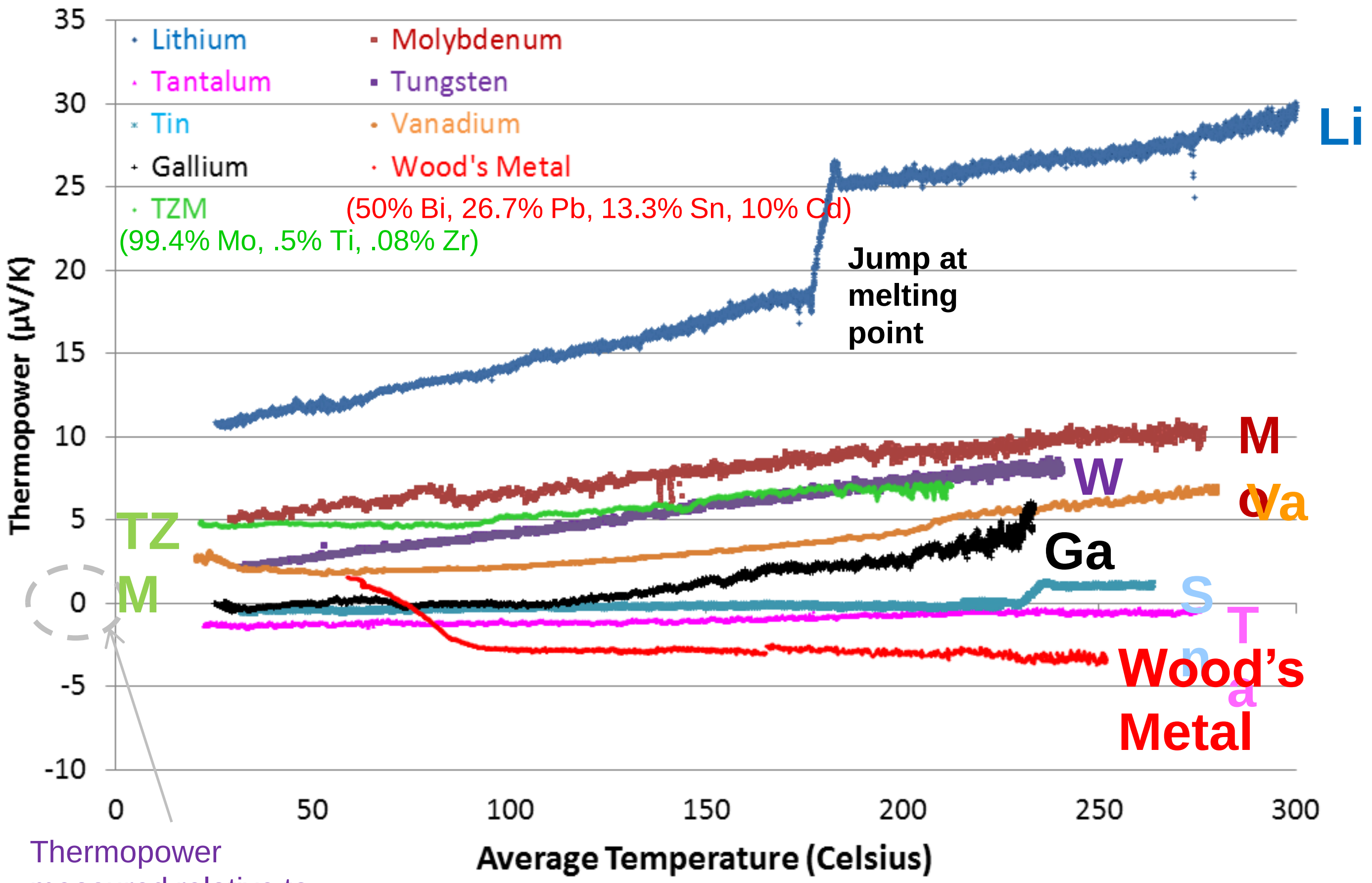
Laminar flow

$$\rho\left[\frac{\partial \bar{u}}{\partial t} + (\bar{u}\cdot\nabla)\bar{u}\right] = \nabla p - \mu\nabla^2\bar{u} + \bar{J} \times \bar{B}$$

Heat transfer

$$\rho C_P\left(\frac{\partial T}{\partial t} + \bar{u}\cdot\nabla T\right) = \nabla\cdot(k\nabla T)$$

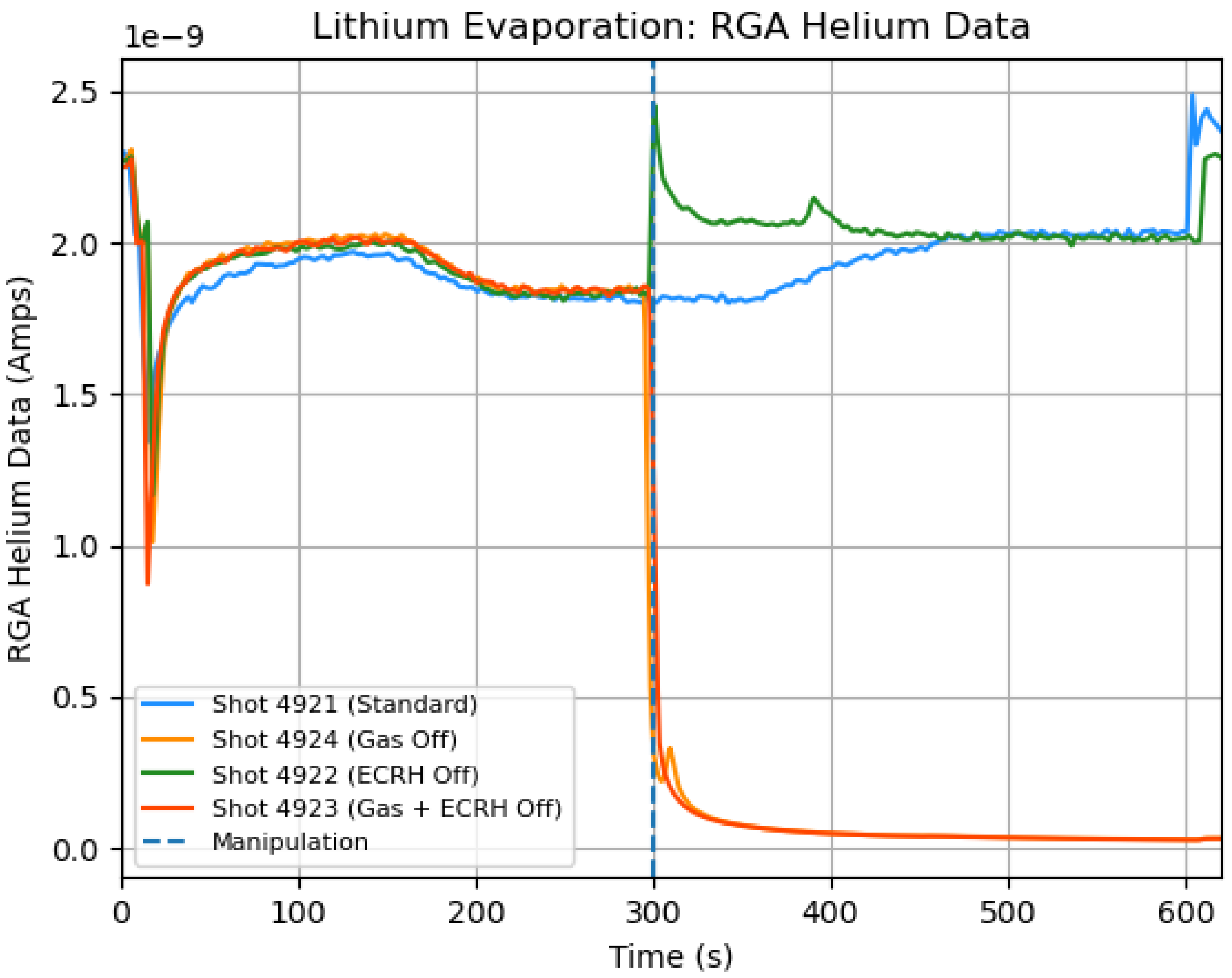
Flowing Lithium in the LiMIT Trenches

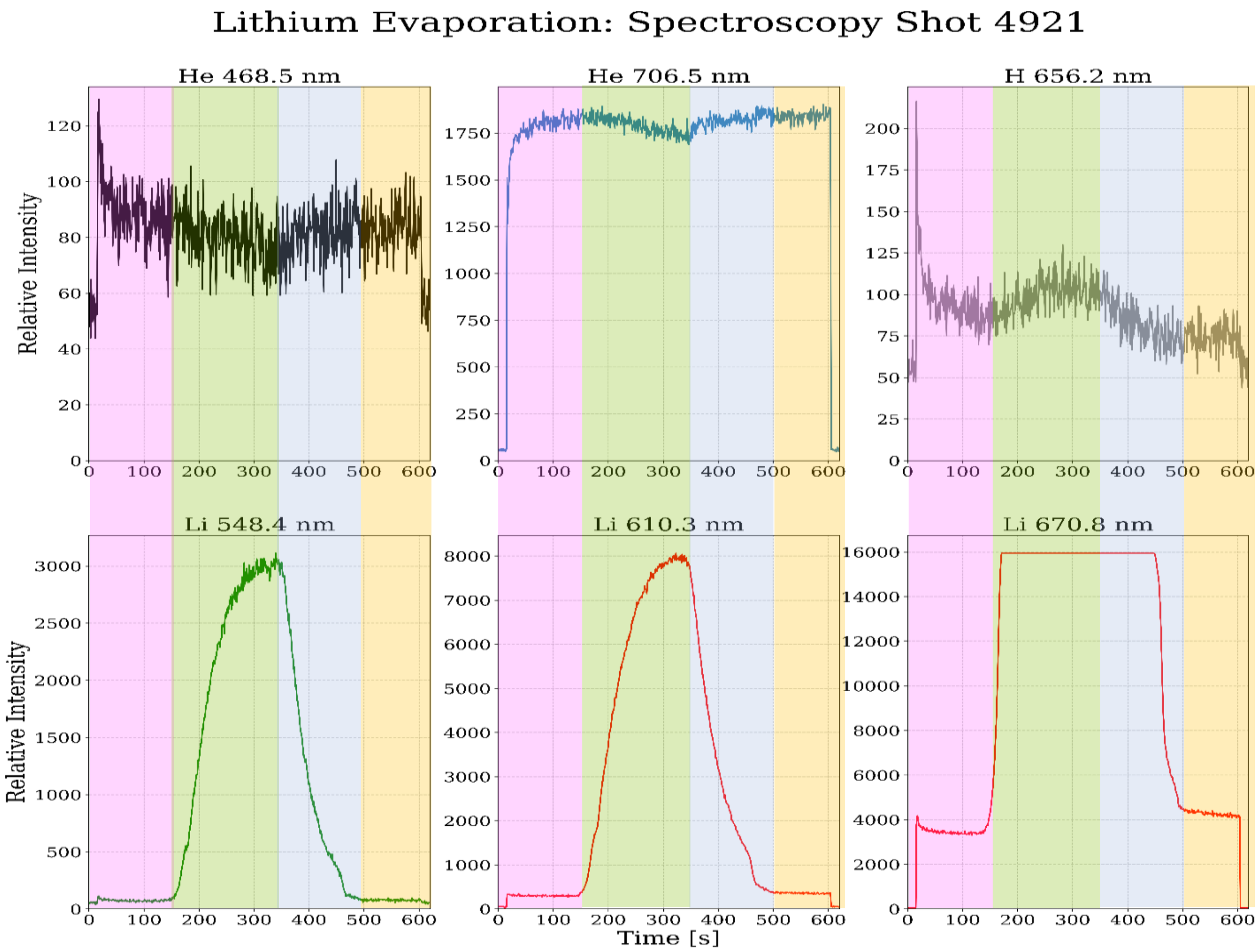


Thermopower measured relative to **stainless steel**

P. Fiflis et al., J. Nucl. Mater 438 (2013) 224

Made Sure that What we Are Seeing is Due to Lithium and not Other Plasma Effects





- Again, the Spectroscopy Shows that the Helium is affected by the Li^{+} ion

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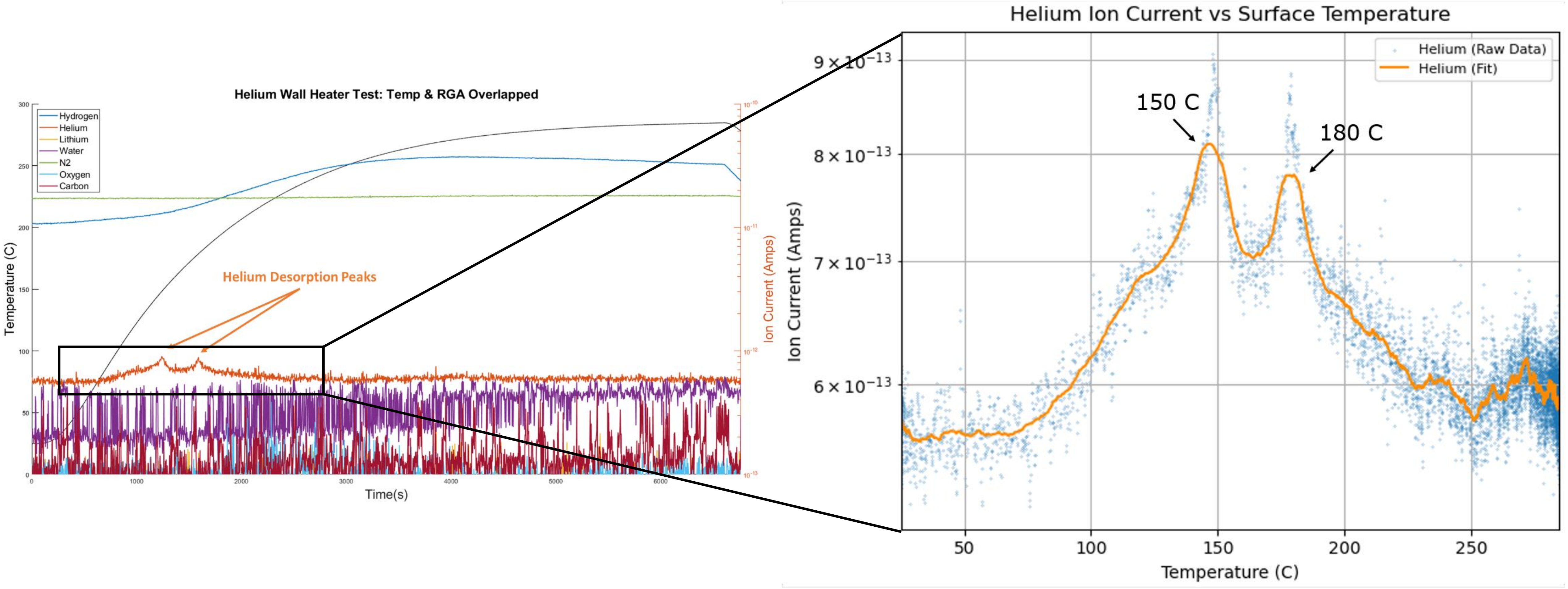
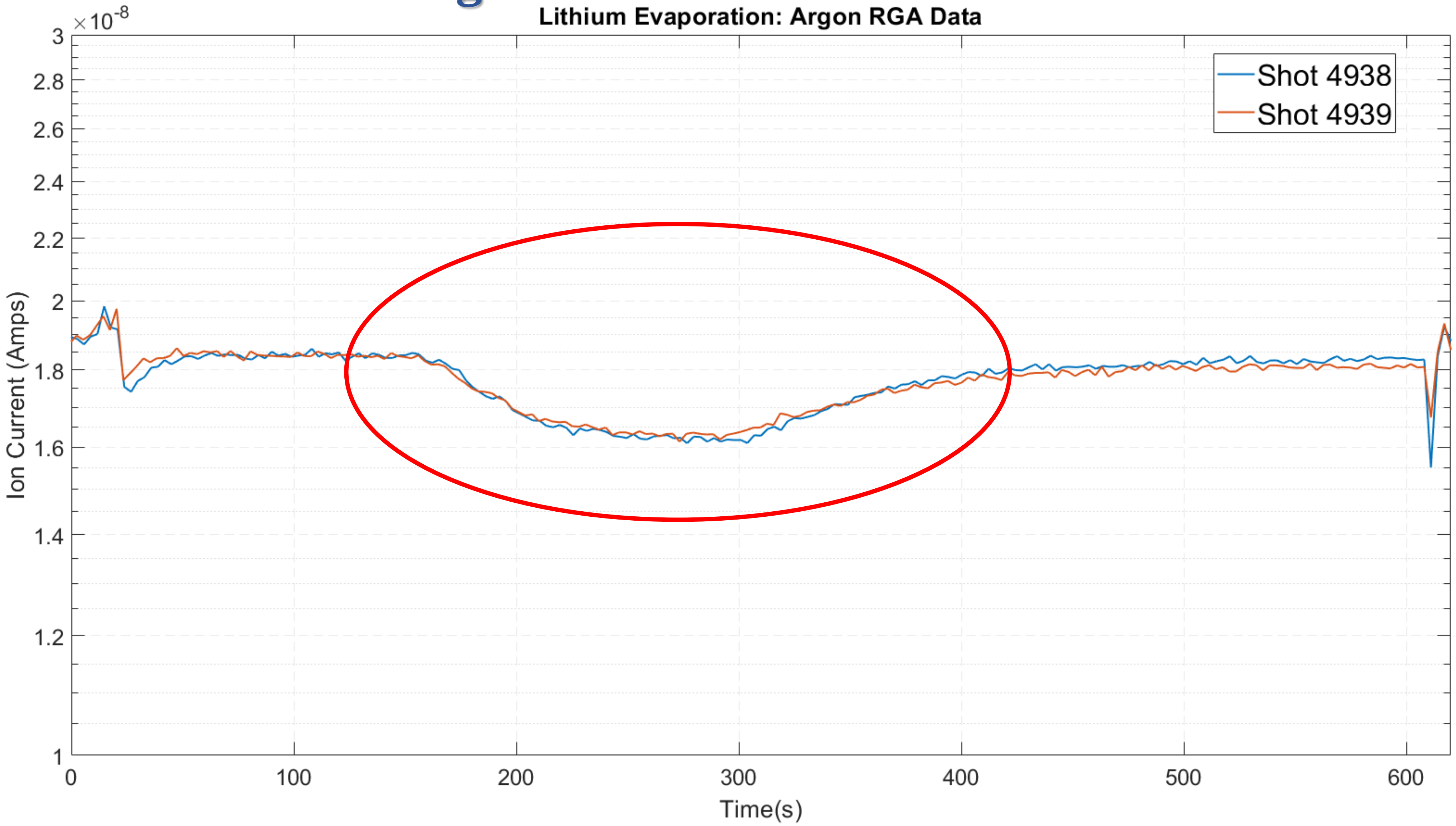
Heating Up the Wall Heater – Helium Desorption

Heating up the wall heater, where Li and He were deposited we see that after 18-24 hours after the last plasma, we see helium desorption from the wall heater. This means that helium is not only being taken out by the lithium, but it is being co-deposited and trapped at the wall as well.

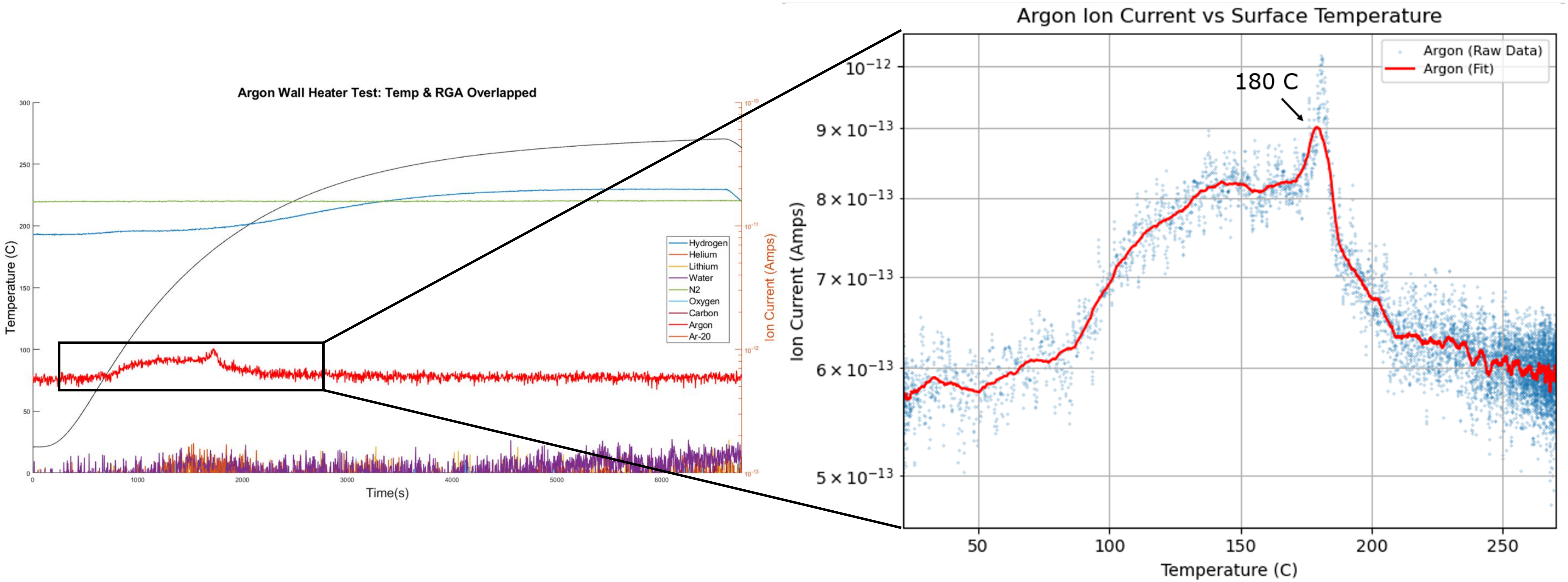


RGA, Spectroscopy (not shown) and Pressure (not shown) also show that Argon suffers the same effect



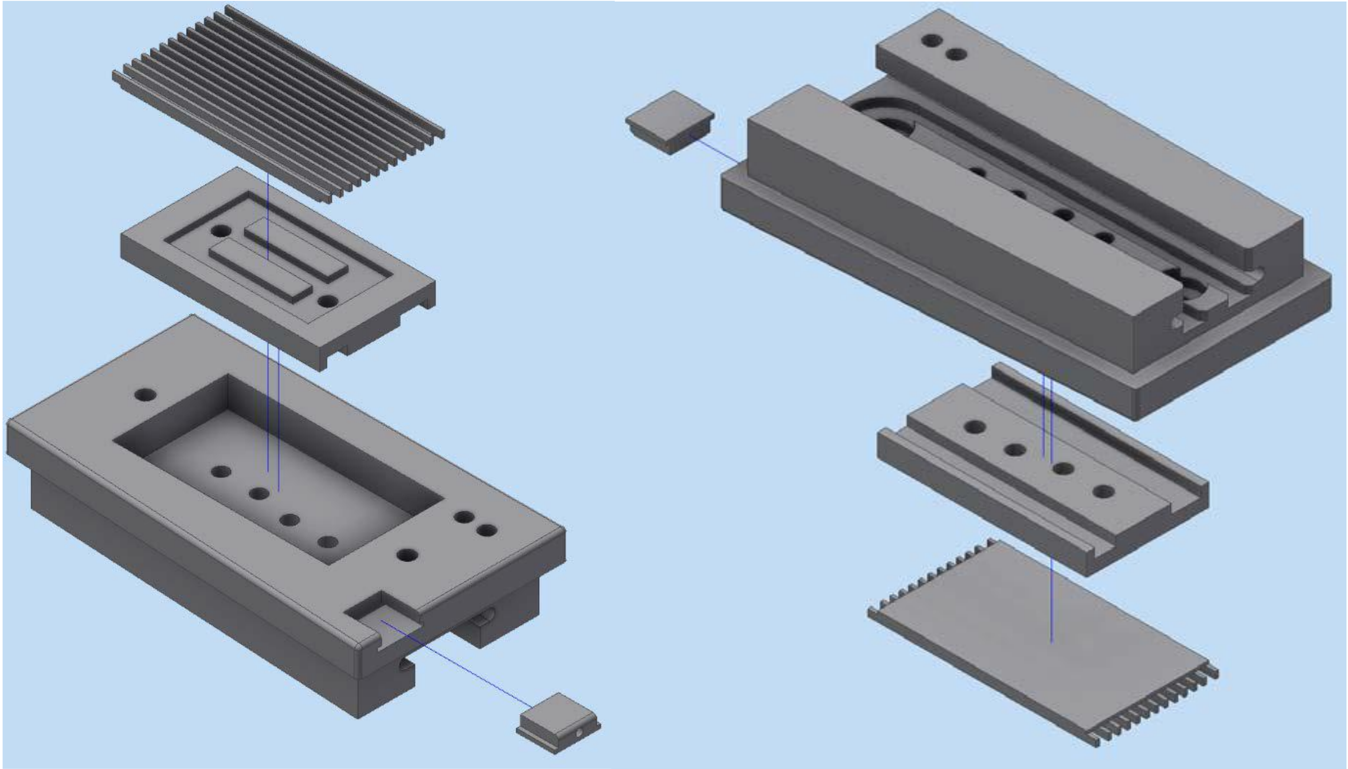
Argon, Similar Behavior to Helium!

Once again we see that at least when lithium melts, 180 ºC, there is a large release if gas, there may be a smaller one at 150 ºC. Just like it was seen in lithium.



Instrumented Tile Experimental Manifold (ITEM)

- The idea behind the ITEM diagnostic is to substitute one of the outer divertor tiles in DIII-D with a variety of advanced concepts.
- Have diagnostic attachments, heater attachments, and cooling attachments, but would otherwise be identical to the tile in terms of total shape, size and support structure.
- Liquid lithium concepts could be mounted and tested, once the local parameters have been determined. For example a LiMIT tile could be mounted (see figure)
- In an ideal world this substitute tile would be on a retractable arm similar to the DiMES probe and fit into the rest of the divertor structure.
- However, if cost of such a mechanism would be prohibitive, instead this diagnostic tile would be installed and removed during a vacuum opening by a technician.
- If a new experimental tile was not desired, a standard tile could be attached in its place. This simplifies the introduction mechanism and greatly reduces the cost.



Exploded top and bottom views of a LiMIT tile configured as an experiment to be placed in ITEM. The small tab which slides into the plasma-facing side of the tile will be have embedded markers in it and is easily removable for post-exposure analysis.

Summary

- Lithium as plasma facing material is being explored and considered more and more around the world.

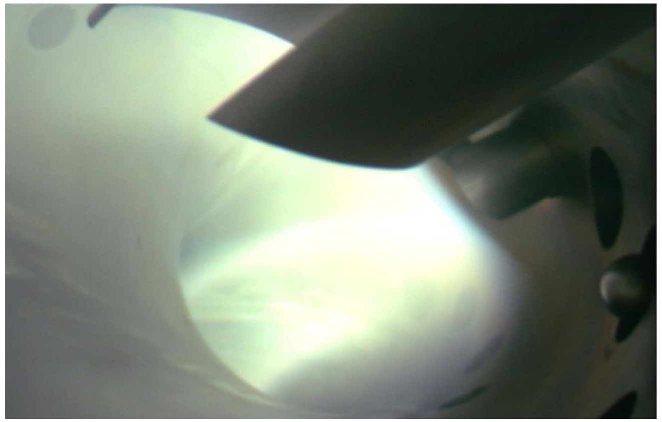
- Its plasma material interactions have many effects and benefits
  - Lower recycling
  - Reduction in instabilities
  - Flattening of the temperature gradient
  - Impurity reduction and removal
  - Helium retention and removal
  - Heat flux handling
    - 3-D structuired mesh (LiMIT)
    - Vapor Shielding

- The Instrumented Tile Experimental Manifold (ITEM) may be a way to have DIII-D start to conduct more relevant liquid lithium experiments to help support the program and verify many of the effects seen elsewhere.

Back Up Slides

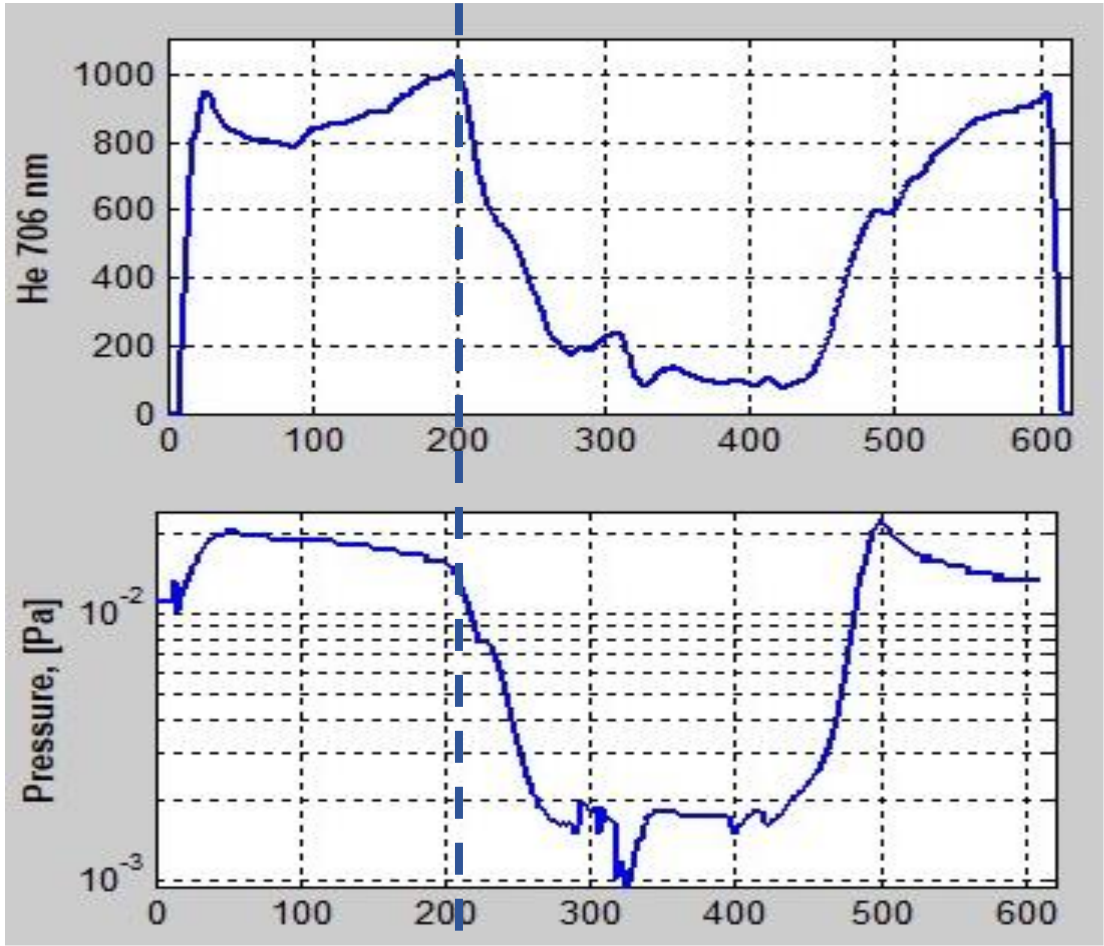
First Helium Retention Results at UIUC: Zeus Shots

Typical helium plasma

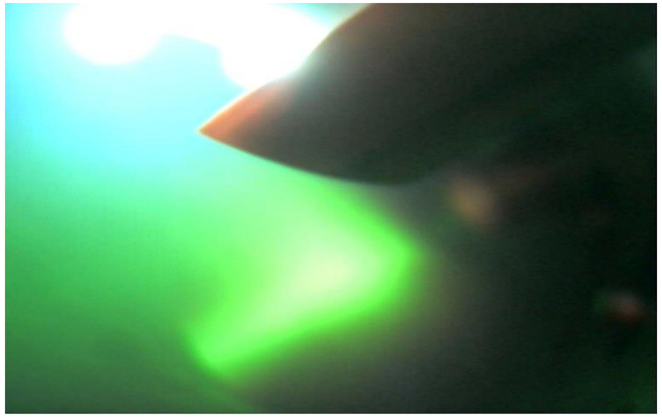


Steady-State

D. Andruczyk, A. Shone, Plasma Phys. Control. Fusion 64, 1 (2022).



Lithium evaporation



Large decreases in pressure and He line intensity

Helium gas flow remains constant throughout the entire 600s pulse

The helium retention has also been observed in MAGNUM-PSI Separate from the vapor shielding experiments

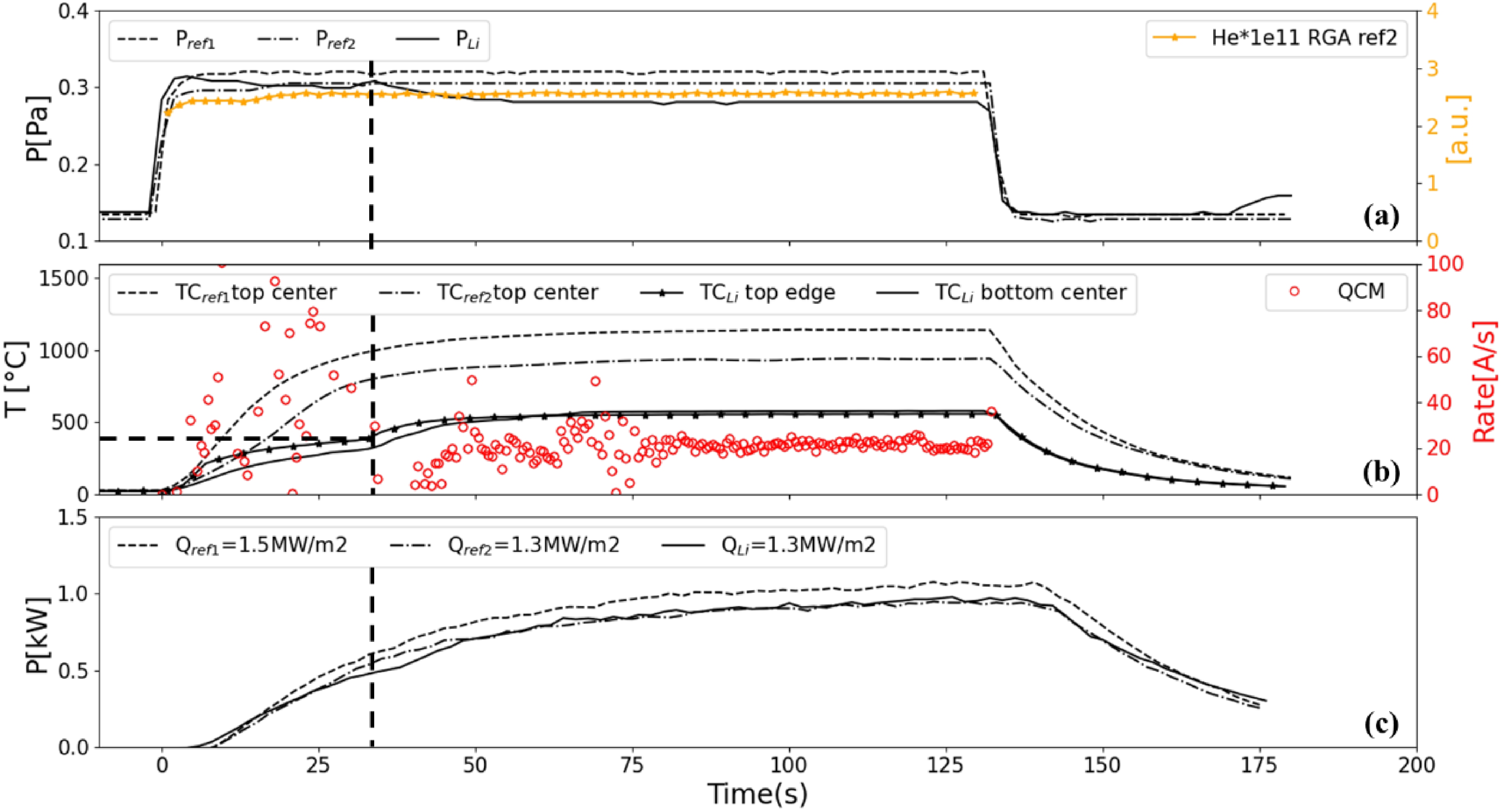
140s helium plasma exposures were done on a CPS and a Li-CPS. Two reference shots on the CPS provide

(a) pressure and *M/Q* = 4 RGA,

(b) temperature and QCM, and

(c) power data to be used in comparison to the Li-CPS exposure.

Results show neutral pressure drops with the Li-CPS when lithium evaporation begins at *t* = 33 s and overall CPS temperature stays lower.



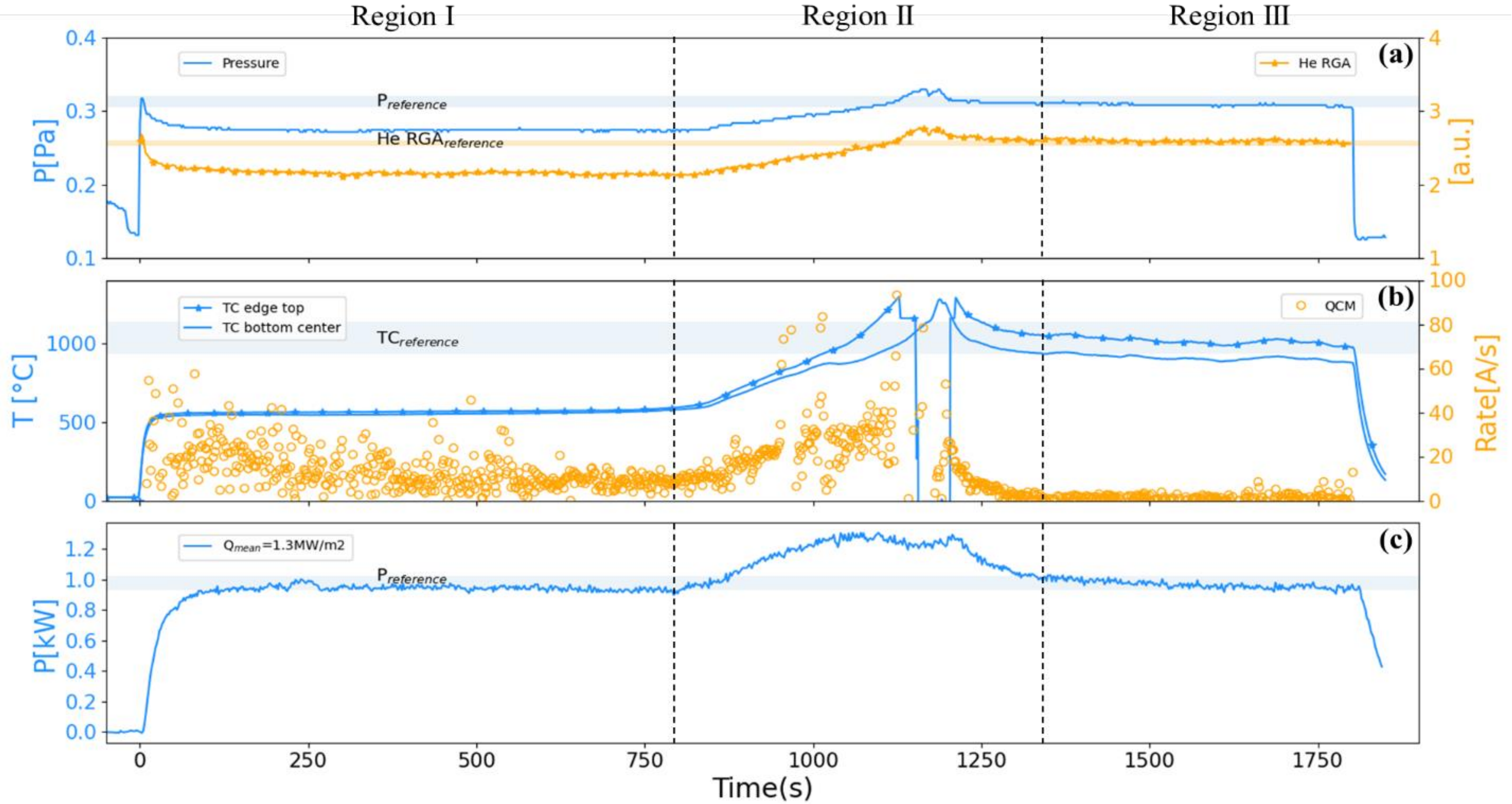
The helium retention has also been observed in MAGNUM-PSI Separate from the vapor shielding experiments

The 1800 s exposure of the Li-CPS has been divided into three sections. Region I, II, and III are classified by abundant lithium in the CPS, active depletion of lithium, and full lithium depletion, respectively.

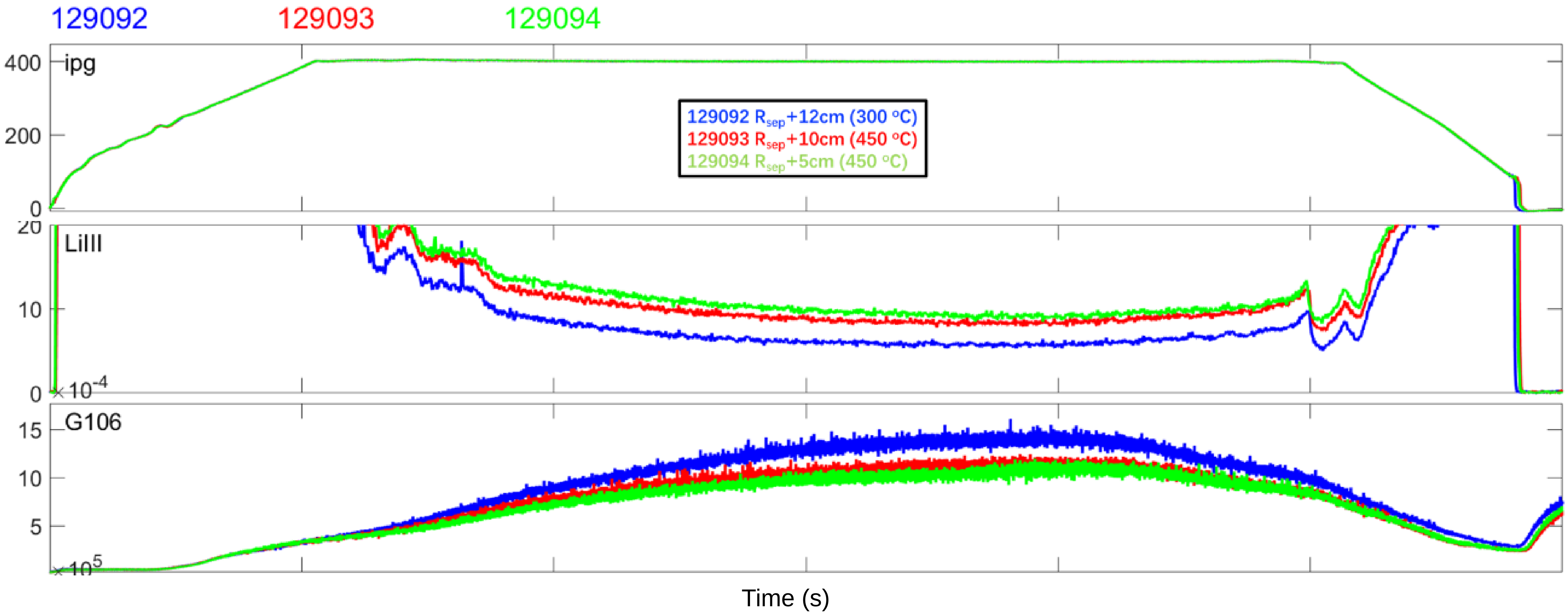
Helium retention behavior is seen in Region I of the (a) pressure and RGA data with measurement levels being significantly lower than reference during lithium evaporation.

The (b) temperature and QCM data show a correlation between lithium in the CPS and CPS while the

(c) calorimetry data indicates how the thermal conductivity of the CPS behaves throughout the exposure.



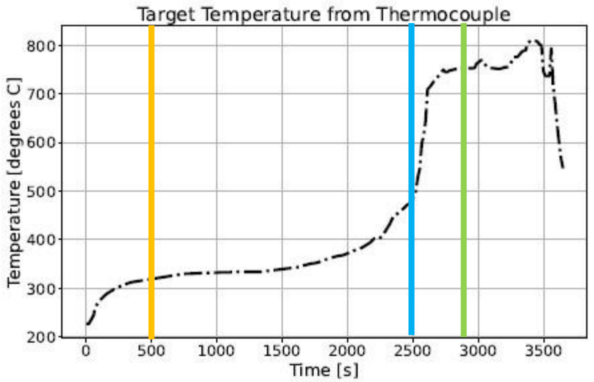
Furthermore, experiments in EAST are also showing this evidence also… though more work still needs to be done… again this is in a full helium plasma!

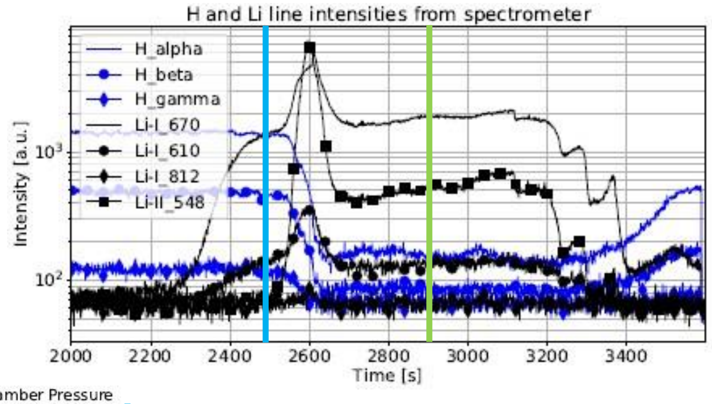


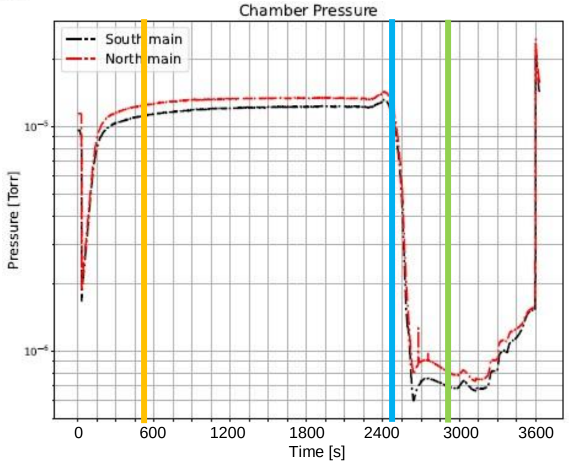
Data from diagnostics measuring plasma current, lithium spectroscopy, and pressure for shots 129092-129094. The plasma current is ramped up to 400kA and has a flat-top for ~8 seconds. All three shots have identical ramp profiles. The lithium spectroscopy data is collected via a filterscope with a LOS from the lower divertor, through the plasma edge and to the outer wall. The final diagnostic is the lower divertor pressure gauge located >3 m below the divertor on the same side as the LiMIT plate.

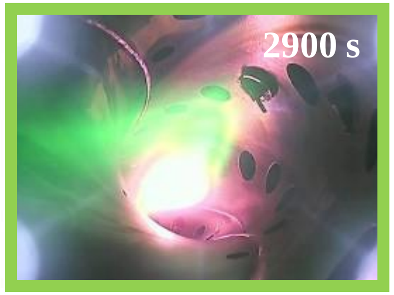
Effects in HIDRA Plasma Operation – Evidence of Vapor Shielding

- An H plasma with 20% forward power was run with the Li target slowly pushed in as the shot went on.
  - When the temperature started to rise, the target position was locked;
    - 18 mm from LCFS.
  - Temperature locking was observed.
  - Li started dominating H emission.
- A big drop in pressure was observed when massive Li evaporation occurred.
- Transition to a Li plasma happened rapidly coupled with an increase in reflected power.
- Similar observations are seen during He shots.
  - A Li target was exposed to a He plasma at 90% forward power;
  - 18 mm from the LCFS.
- But we also saw helium from somewhere!
- Our first









TEMHD Concepts

- Seebeck Effect creates thermoelectric current at junction between liquid lithium and solid trenches when a thermal gradient is present
- A transverse magnetic field is applied, which generates a ***J***×***B*** force, propelling the liquid through the trenches