Lithium Vapor Box Divertor: Modeling & Plans

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PPPL

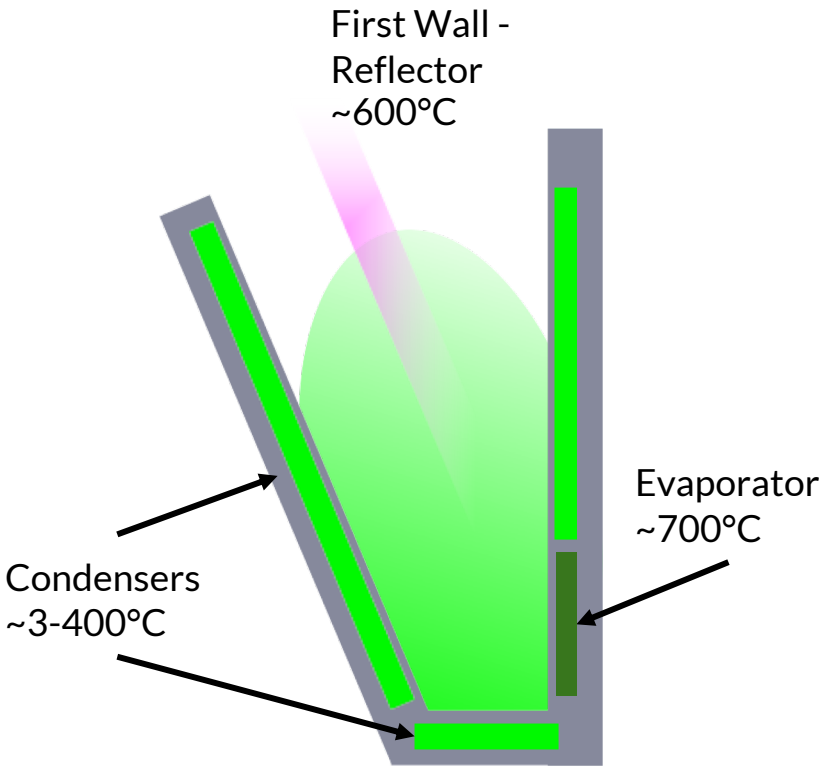
PRINCETON UNIVERSITY

Outline

- Why a Lithium Vapor Box?
- Modeling
  - UEDGE - SPARTA
  - SOLPS - ITER
- Plans
  - Magnum PSI
  - NSTX-U
  - Off-Line R&D

The Lithium Vapor Box Divertor

- Localizes lithium vapor in divertor
- Evaporation close to target, condensation elsewhere in slot.
- Exploring cases without baffles.
- Cannot be achieved with gaseous impurities: pumping is too weak
- Target resilient to reattachment.

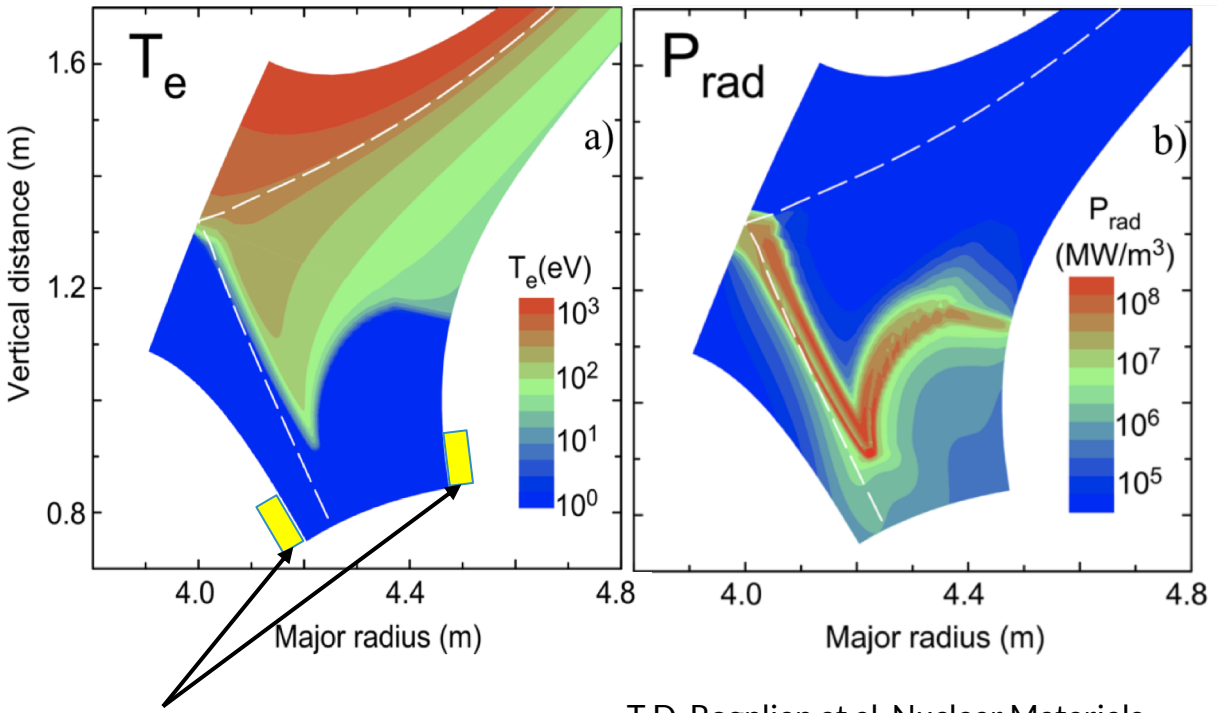


Why a Lithium Vapor Box?

- Gaseous impurities easily lead to X-point MARFEs, degrading pedestal performance (OK in a reactor?).
  - Lithium can be pumped by condensation, like in heat pipe
- Want $P_{sep} \geq P_{LH}$ and $P_{target} << P_{LH}$
  - Need separate control of mantle & SOL radiation
- Lithium has low ionization potential (5.6 eV), well contained by hydrogen isotope recycling (13.6 eV).
  - Nitrogen: 14.5 eV, Neon 21.6 eV

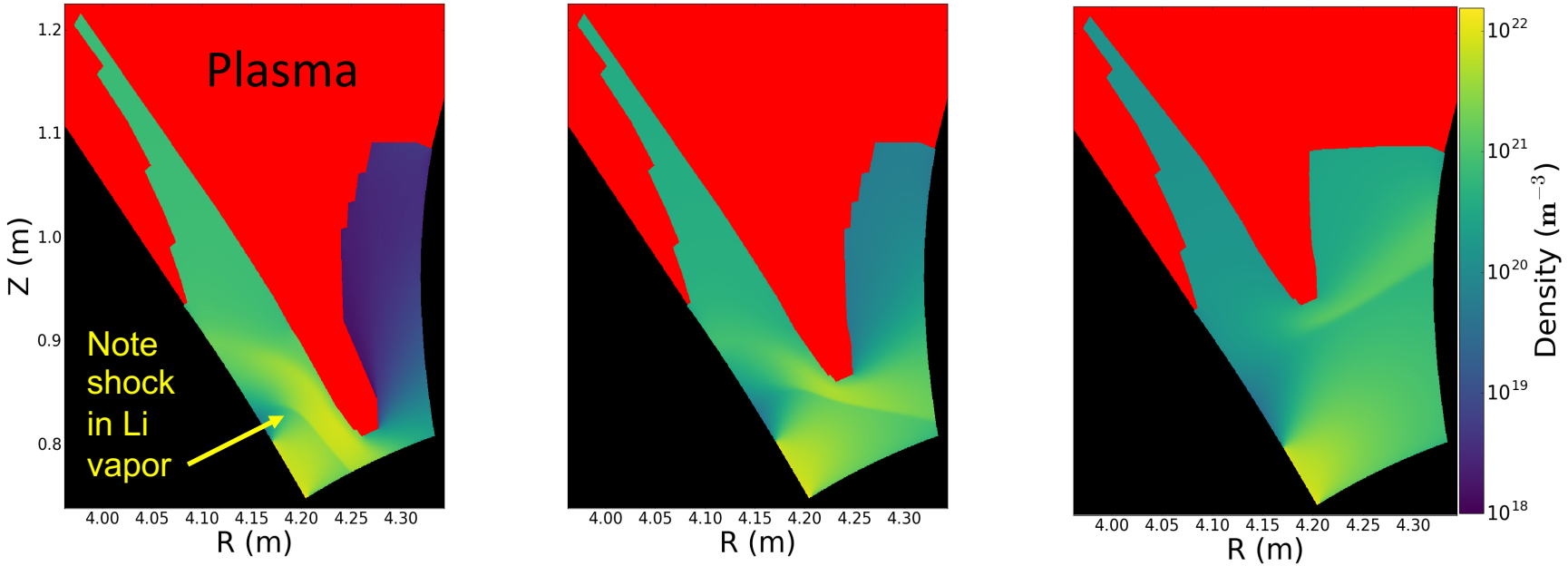
UEDGE Achieves Stable Detachment

- High levels of recombination before hitting the target, temperatures < 0.2 eV
- No baffles required



T.D. Rognlien et al. Nuclear Materials and Energy 18 (2019) 233–238

SPARTA Shows Detachment Stability



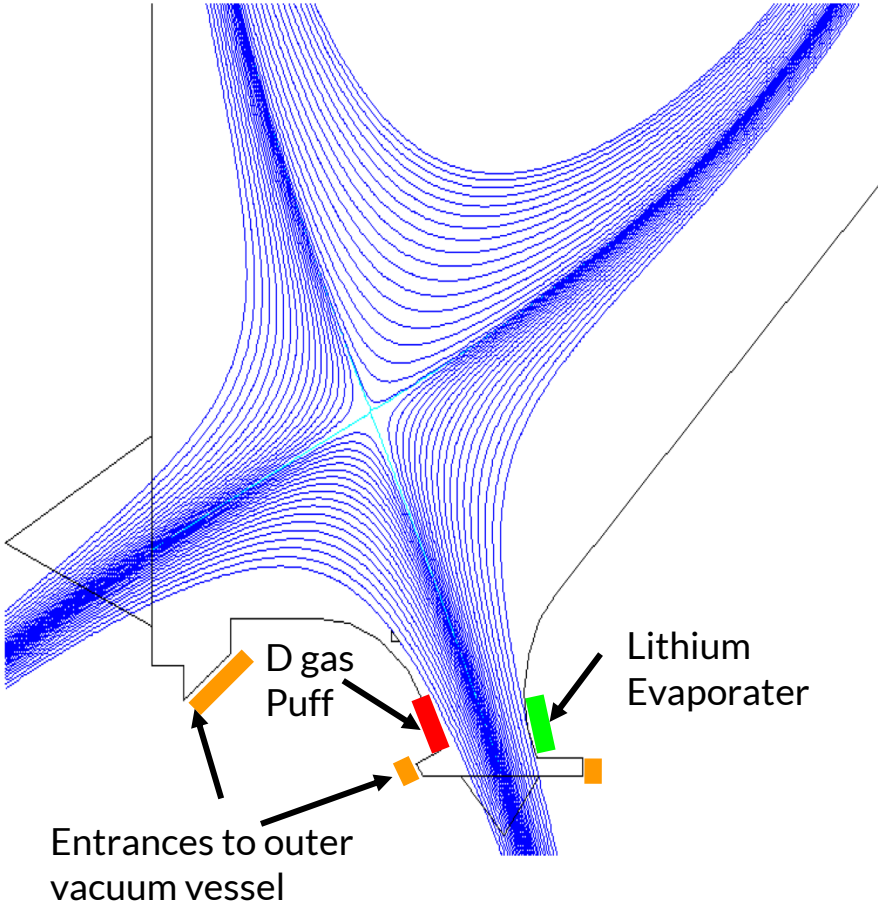
Factor of 6 reduction in lithium ionization as plasma retreats from vapor region ⇒ stable detachment front

SOLPS-ITER

- Monte-Carlo modeling of neutrals
  - More sophisticated than UEDGE, less so than SPARTA
- More modern thermal force model than UEDGE
  - Sytova et al. (2018) Contrib. Plasma Phys.
- Allows more self-consistent simulations

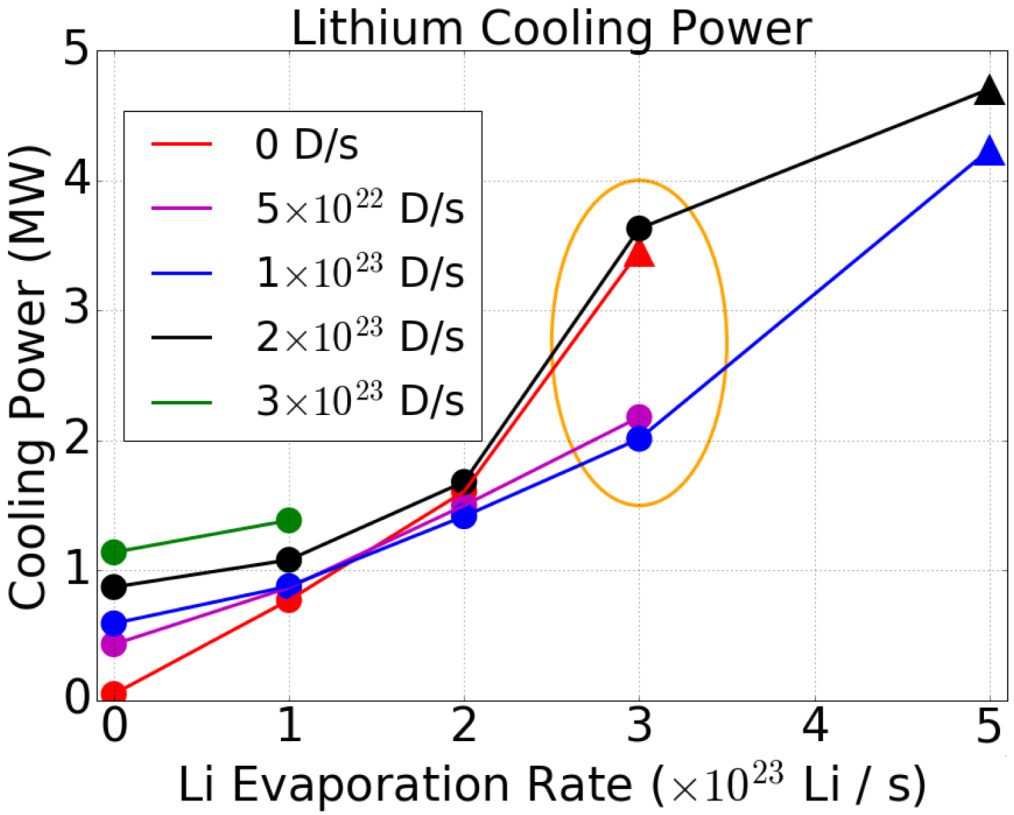
Using SOLPS-ITER

- Applied to a realistic EAST PFC geometry and equilibrium
- Added in lithium evaporation from the far scrape off layer region and a deuterium gas puff injection from the private flux region
- Deuterium entirely recycling while lithium was being entirely absorbed.
- 4MW of input power



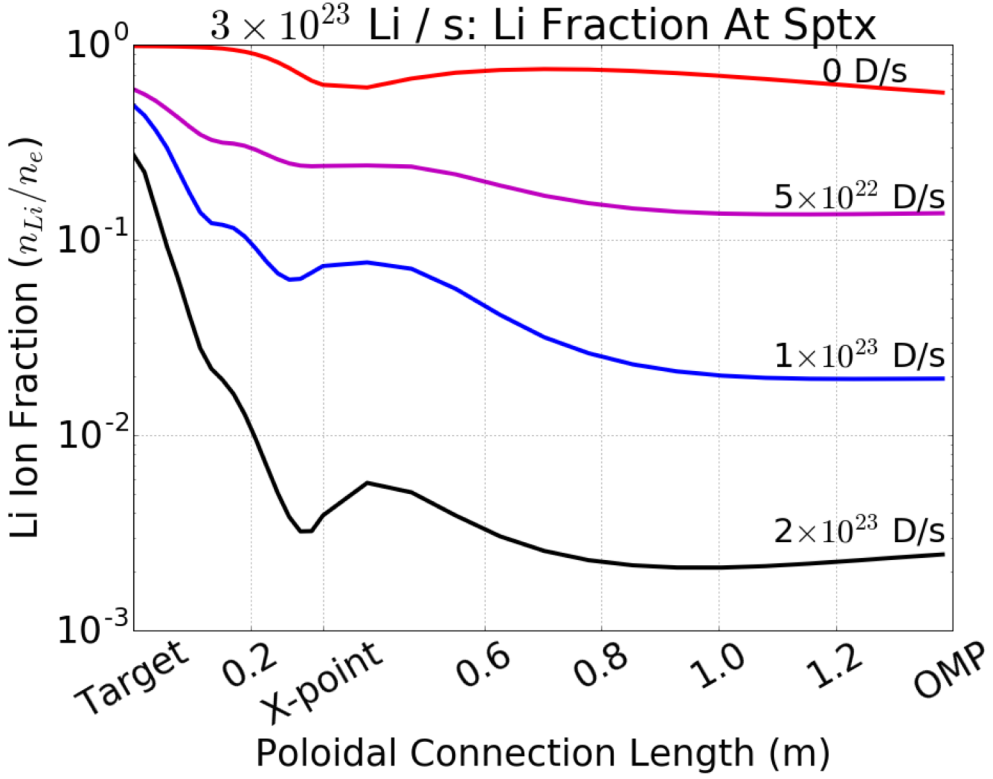
Lithium Causes Large Radiation Fraction

- Without lithium, radiation only gets to ~1 MW
- 90% of input power can be radiated while maintaining high upstream pressure

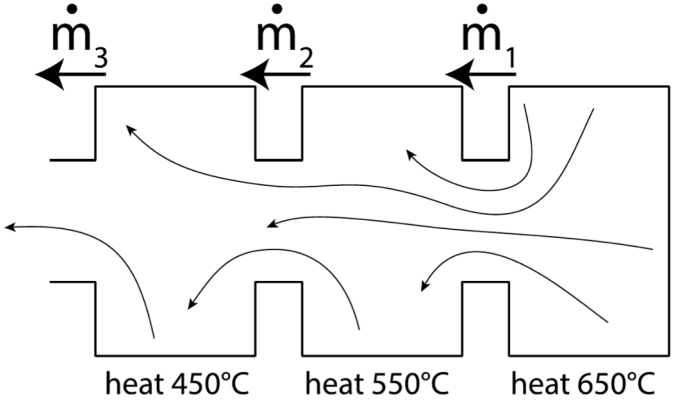


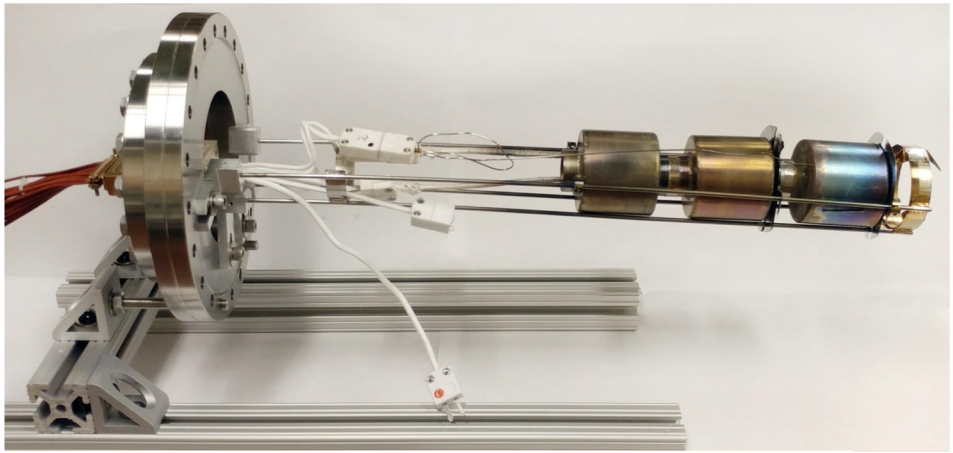
Lithium Can be Contained to Divertor

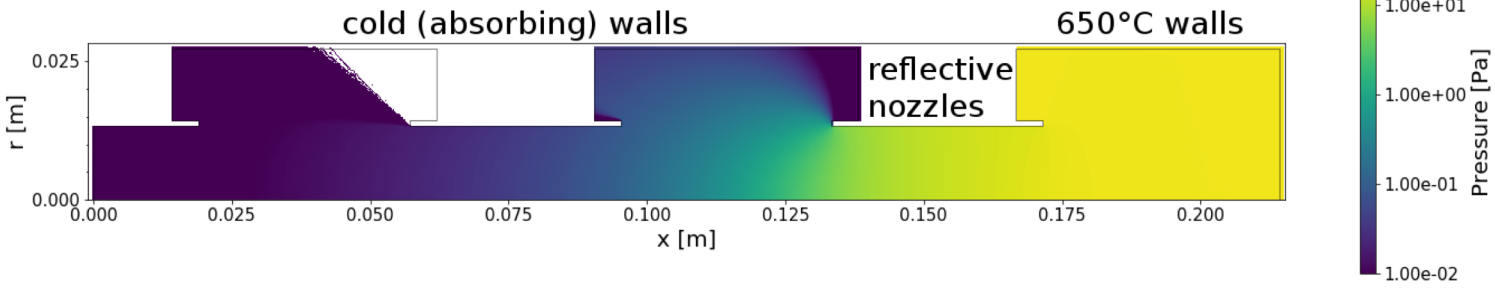
- Higher deuterium puffs pushes the lithium into the divertor
- OMP Lithium fraction reduces from 14% to 0.25% across a factor of 4 increase in the deuterium gas puff.



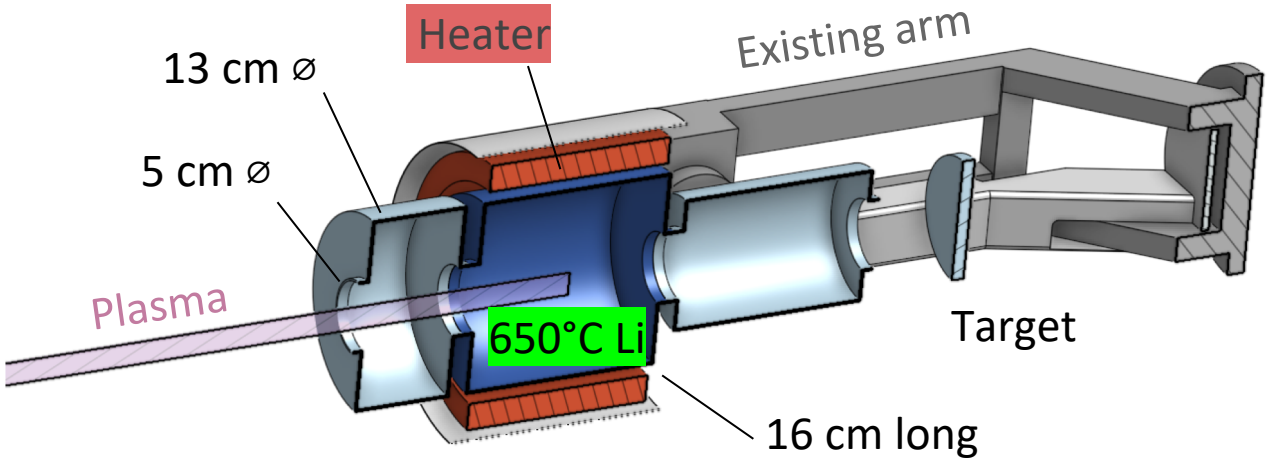
Validate Li vapor model at PPPL

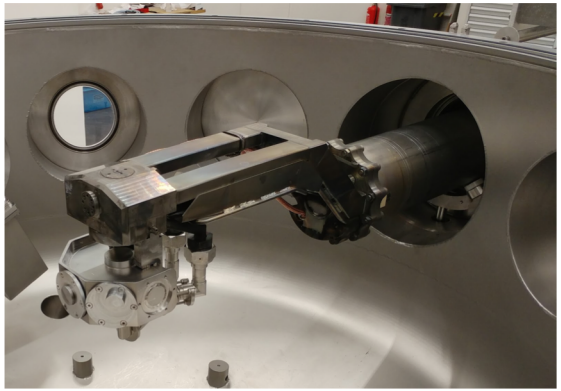






Device to demonstrate detachment, volumetric recombination at Magnum





- Li vapor in central box
- Demonstrate volumetric energy loss by Li

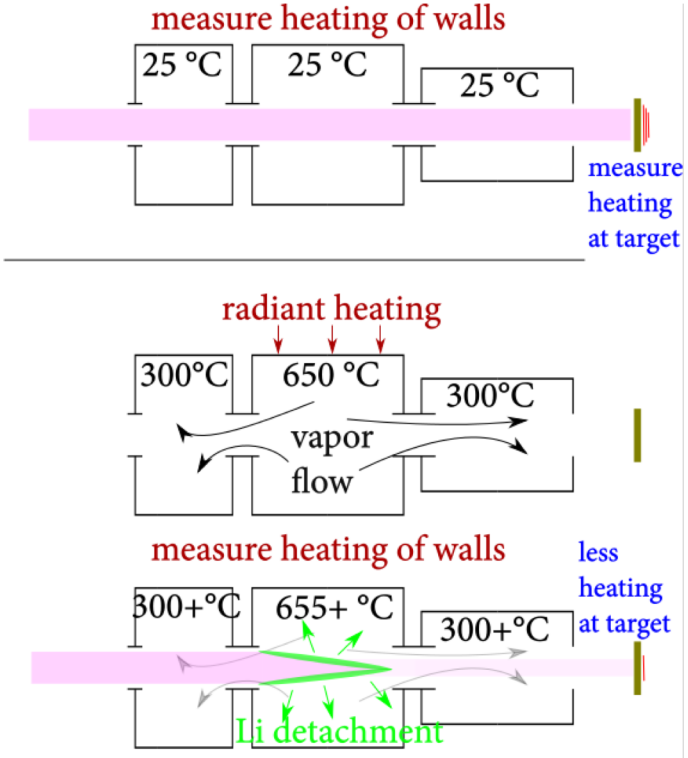
Demonstrate detachment via Li vapor

Without Li:

- Turn on plasma
- Measure dT/dt at walls and target

With Li:

- Heat box to make vapor cloud
- 10 second plasma pulse
- Measure dT/dt at walls and target

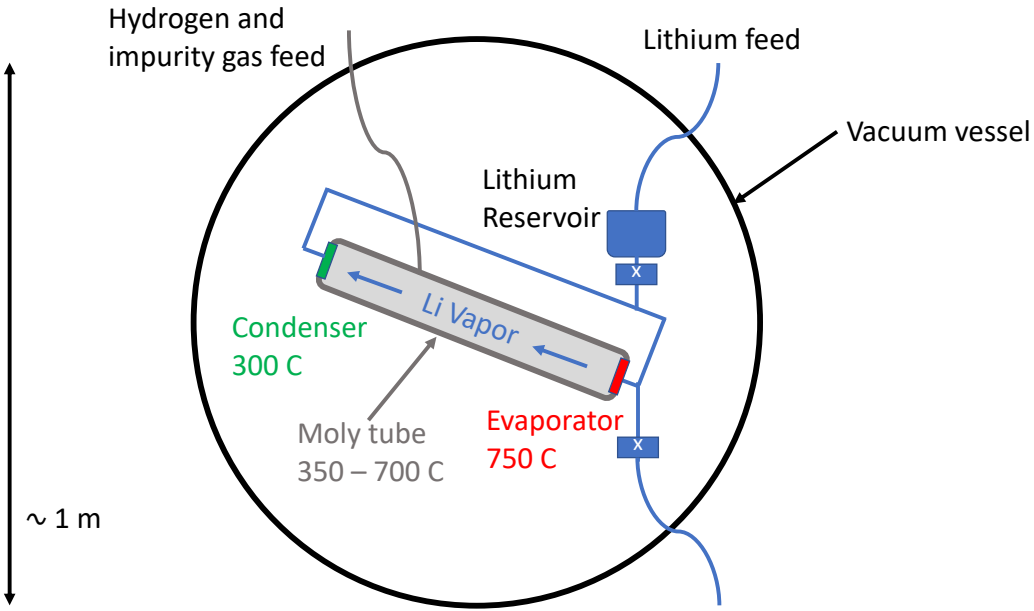


Options for NSTX-U

- 50 cm toroidal segment of 3-D printed tungsten
  - No divertor slot configuration
- = Technology test in tokamak environment.
  - Can we maintain clean plasma-facing surface with carbon walls, or do we require high-Z walls?
  - Can we maintain desired Li temperature?
  - Can we refill reservoir between shots?
- Move to full toroidal ring with slot
  - Slot configuration optimized with modeling

Needed Off-Line R&D

- Inject D & Impurities.
- Add glow probe to produce ionization.
- Measure D retention on tube surface.
- Recirculate Li using capillary force.
- Add B field across flow.
- Clean lithium flow.



Conclusions

- Lithium Vapor Box is promising
  - To maintain stable detachment front
  - To provide SOL-only power loss (other impurities in core?)
  - To retain impurities in divertor
- Next steps
  - Test lithium vapor containment at PPPL
  - Test volumetric energy loss at Magnum-PSI
- Potential Future steps
  - Divertor segment at NSTX-U
  - Full vapor box at NSTX-U
  - D retention & lithium recirculation studies in test stand