The Lithium Vapor Box Divertor

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Demo Needs Very High Dissipated Power
(Transport, Radiation, CX)

\[ n_{OMP} = 5 \times 10^{19} m^{-3} \]
\[ \lambda_q = 1 mm, R_0 = 6 m \]
\[ q_{\parallel,OMP} = 18.5 GW / m^2 \]
\[ p_{OMP} = 6300 Pa \]

\[ T_{Target, eV} \]
\[ T_{OMP, eV} \]

\[ q_{\perp, Target} = 300 MW/m^2 \]
\[ f_{power} = P_{dissipated} / P_{upstream} \]
\[ q_{\perp, Target} = 10 MW/m^2 \]
Continuous Lithium Vapor Shielding

- Provide a localized cloud of Li vapor away from main plasma
  - Evaporation at ~ 700° C
  - Condensation at ~ 400° C
- Return liquid lithium via capillary porous material.
- An inside-out heat pipe – with the heat source inside the pipe!
- Vapor gradient → resiliency to variable heat flux.
- Cannot be done with gaseous impurities.
- Use low-Z impurity to maximize radiation in SOL.
Lithium Modeling

• Using SPARTA Monte-Carlo Direct Simulation code
• Li collision model based on known viscosity vs. T.
• Model evaporation and condensation based on known equilibrium Li pressure vs. T, and Langmuir fluxes from/to surfaces.
• “Not bad” agreement with simple model based on choked flow and conservation of enthalpy.
• Plasma absorption, however, is a very big effect, reducing vapor efflux from baffled region.
  • Assuming 100% absorption of lithium at plasma boundary. Recombination at plasma detachment point.
Lithium Modeling

Figure 2: Effect of plasma on lithium density.
UEDGE Modeling

- UEDGE has very different, diffusive model for lithium transport, and very different geometry.
  - Based on collisions of lithium atoms with residual plasma in SOL, far SOL.
  - Short divertor leg, no baffling or vapor box yet.
  - Transports lithium and calculates radiation self-consistently.
    - Issues with thermal force model at high impurity fraction.
  - Achieves detached plasma in FNSF with nearly 100% lithium radiated power.
    - About 60 eV radiated per lithium ionization, but 1/2 of ionization is in far SOL.
Figure 1. Detached FNSF plasma.
Lithium Modeling in UEDGE Geometry

- Using UEDGE plasma contours, have shown dramatic decrease in lithium to far SOL with baffles.
Using UEDGE plasma contours, have found dramatic decrease in lithium to far SOL with baffles.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Without Baffle (MA)</th>
<th>With 2 Baffles (MA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Evaporated from the Walls</td>
<td>2.59</td>
<td>11.8</td>
</tr>
<tr>
<td>Lithium Condensed on the Walls</td>
<td>2.59</td>
<td>11.8</td>
</tr>
<tr>
<td>Ionization in Far SOL</td>
<td>0.56</td>
<td>0.003</td>
</tr>
<tr>
<td>Ionization in baffled region</td>
<td>0.25</td>
<td>1.07</td>
</tr>
<tr>
<td>Total Ionization</td>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Lithium Modeling in UEDGE Geometry
Resilience

- Moved UEDGE contours into and out of baffled region.
- For fixed lithium evaporation rate, ionization in plasma increases dramatically as plasma penetrates highest density region.
- Should provide very substantial robustness against variable power flux.
Simpler and More Complex Questions

- **Simpler question:** How much energy is lost from upstream plasma due to Li influx?

- **ADAS answer for Li atoms**

- **More Complex Question:** What are the mechanisms of detachment with high Li content?
Need data down to energies $\sim 0.1$ eV (?).
What do We Need to Know?

- Current model is that lithium is rapidly ionized at plasma edge, even in UEDGE. Many processes are not included, e.g., CX incl. Li, molecular interactions: H₂, LH
- A more detailed model is needed to understand how much upstream loss is needed (and how to get it) vs. dissipation in the detachment region.
- As plasma recombines there should be much H, H₂ and perhaps LH co-located with much Li vapor. CX effects?
- How does Li in its various charge and excitation states interact with H atoms and with H₂ and LH molecules in their various charge and excitation states, at energies down to ~ 0.1 eV?
- Is photon opacity an issue?
References

Energy Exhaust through Neutrals in a Tokamak Divertor

Liquid Lithium Divertor System for Fusion Reactor
Y. Nagayama et al., Fusion Eng. Des. 84 (2009) 1380

Recent Progress in the NSTX/NSTX-U Lithium Program and Prospects for Reactor-Relevant Liquid-Lithium Based Divertor Development
M. Ono, M.A. Jaworski, R. Kaita et al., Nuc. Fusion 53 (2013) 113030

Liquid-Metal Plasma-Facing Component Research on NSTX

Recent advances towards a lithium vapor box divertor