Edge Plasmas, Edge Radiation, and Liquid-Wall Temperature Limits*

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Topics

1. Geometry and profile effects for Sn ARIES CLiFF design
2. Liquid module for C-MOD
3. Impact of divertor plate location/orientation
4. Scaling studies for impurity intrusion
5. Results for spheromaks
Sn tokamak impurity-based wall-temperature limits show substantial model sensitivity

Core Sn concentration for 4 case with increasing detail for CLIFF

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_w [K]</td>
<td>1010</td>
<td>1030</td>
<td>1070</td>
<td>1100</td>
</tr>
</tbody>
</table>
Particle Pumping Rate in C-Mod is Controlled by Strike Point Position

![Diagram showing weak and strong pumping configurations with divertor tiles and liquid Li]
Pumping C-Mod plasma through plate $R$ increases core-boundary temperature.

Decreasing plate density with decreasing $R$ lowers pumping efficiency - depends on details.
Options for (liquid) divertor-plate orientation show reduction of CLIFF peak heat-load

3 divertor plates for ARIES-AT

Corresponding plate heat fluxes

For analysis of divertor/wall integration

3 divertor plates for ARIES-AT
Simple 1D model displays important processes and trends

Consider radial diffusion $D$, ionization source $S$, & axial loss

\[-D \frac{d^2 n}{dr^2} = S \delta(r-r_s) - \nu_n n \quad \Rightarrow \quad -\hat{\nu}_r \frac{d^2 N}{dx^2} = \delta(x-x_s) - \hat{\nu}_\parallel N\]

where $x = r / r_{wall}$.

Analytic solution gives profiles and scalings; the core density as source distance from wall,

\[n(0) \sim S(1 - x_s)\]
Low hydrogen-recycling regime yields much lower impurity influx to core

Larger axial flow for smaller $R_h$ gives much better impurity removal

Hydrogen particle fueling required for low recycling is an important issue; implies low edge density
Core-boundary impurity concentration scales significantly with parameters.

These variations can be understood qualitatively from the 1D model.

Fluorine case with $R_h = 0.99$
Core impurity limit with increasing gas flux is coincident with major $T_e$ profile contraction & ionization shift.

Fluorine for hydrogen recycling $R_h = 0.99$

Impurity conc. & rad. fraction

Concentration

Radiated fraction

F core limit

Bifurcation

Ionization source

Profiles shift at bifurcation

Electron temperature

Ionization source

Impurity gas flux (m$^{-2}$ s$^{-1}$)

Impurity conc. & rad. fraction

Core impurity limit with increasing gas flux is coincident with major $T_e$ profile contraction & ionization shift.
Two different impurity core boundary conditions give nearly the same F density.

Fluorine charge-state profiles

Zero core flux B.C. for all charge states. Calc. F core edge density is $4.9 \times 10^{15}$.

Zero density for all states except highest $Z$ from the core; net flux to core is still zero. Calc. F core edge density is $5.2 \times 10^{15}$.
Spheromak temperature limits are between those for tokamaks and FRCs

**SUMMARY OF LOW-RECYCLING CASES**
allowable wall temperatures in degrees C

<table>
<thead>
<tr>
<th></th>
<th>Li</th>
<th>Flibe</th>
<th>SnLi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tokamak</strong></td>
<td>380</td>
<td>480</td>
<td>590</td>
</tr>
<tr>
<td><strong>Spheromak</strong></td>
<td>410</td>
<td>520</td>
<td>630</td>
</tr>
<tr>
<td><strong>FRC</strong></td>
<td>480</td>
<td>620</td>
<td>720</td>
</tr>
</tbody>
</table>

FRC is compact, high density
Summary

Analysis of wall evaporation for Sn in ARIES (CLiFF) shows temperature limit increases with more detailed geometry and evaporation profiles -- 1100 K max.

Modeling of possible liquid modules for NSTX and C-MOD shows that substantial particle pumping could result without excessive heat loads.

Simulation of lithium large-scale lithium influx for the disruptive DiMES shot on DIII-D shows lithium radiation can be much larger than the coronal equilibrium values.

Studies of divertor plate orientation for liquid wall / divertor integration shows ~50% heat flux reduction by moderate tilting (~50 deg), and that flux compression via divertor-leg length can be balanced by tilting.

Scaling studies help clarify roles of high/low recycling, anomalous transport, core power density, and magnetic geometry.

Impurity influx modeling for spheromak - temperature limits are between those for tokamaks and FRCs.