UCRL-PRES-147236-REV-1

Edge-plasma modeling for APEX & ALPS*

1. Overview for APEX; detached plasma & role of convection
2. CLIFF edge-plasma with acceptable power & shielding
3. Status of fluid edge-plasma transport modeling for NSTX

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Presented at APEX/ALPS Meeting

Grand Canyon, AZ

April 7-11, 2003

*Work performed under auspices of US DOE by Univ.of Calif. LLNL under contract No. W-7405-Eng-48.

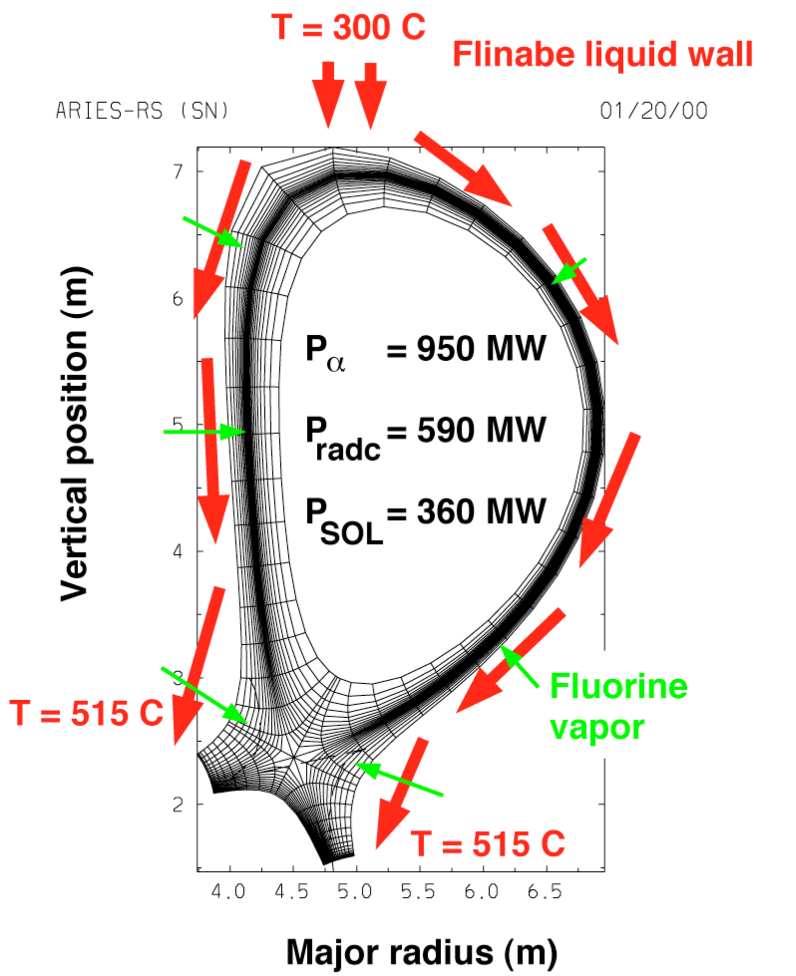
Outline

- Highly radiating detached SOL plasmas for CLIFF
- Beginnings of a study on strong convection
- NSTX module calculations

Properties of plasma surrounding liquid wall are modeled using the 2D UEDGE transport code

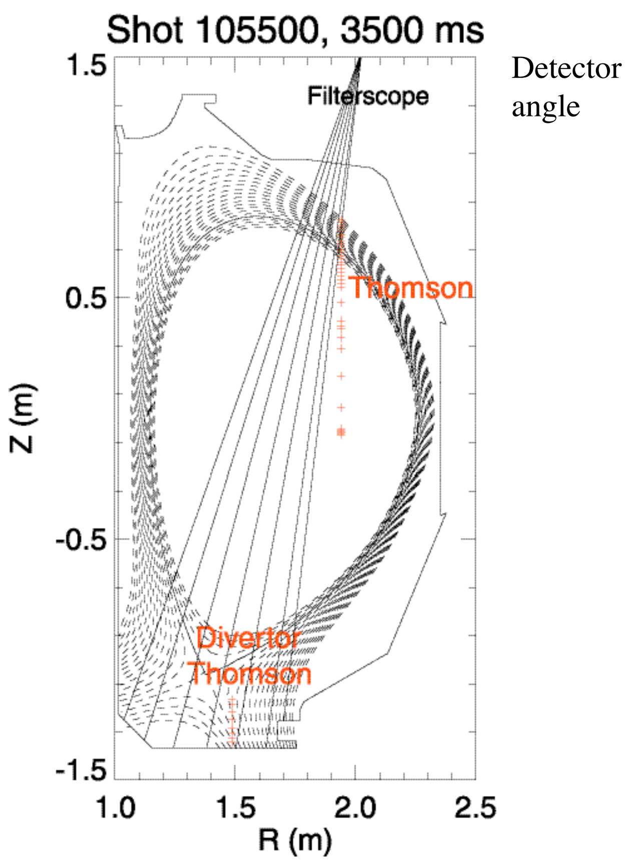
- Solves multispecies fluid equations (n_i, $v_{||}$, T_e, T_i, n_g) in annular poloidal domain
- Parallel transport along B classical; perpendicular is enhanced diffusion (convection)
- Used to model various experimental conditions in DIII-D, JT60-U, JET, and Alcator C-Mod

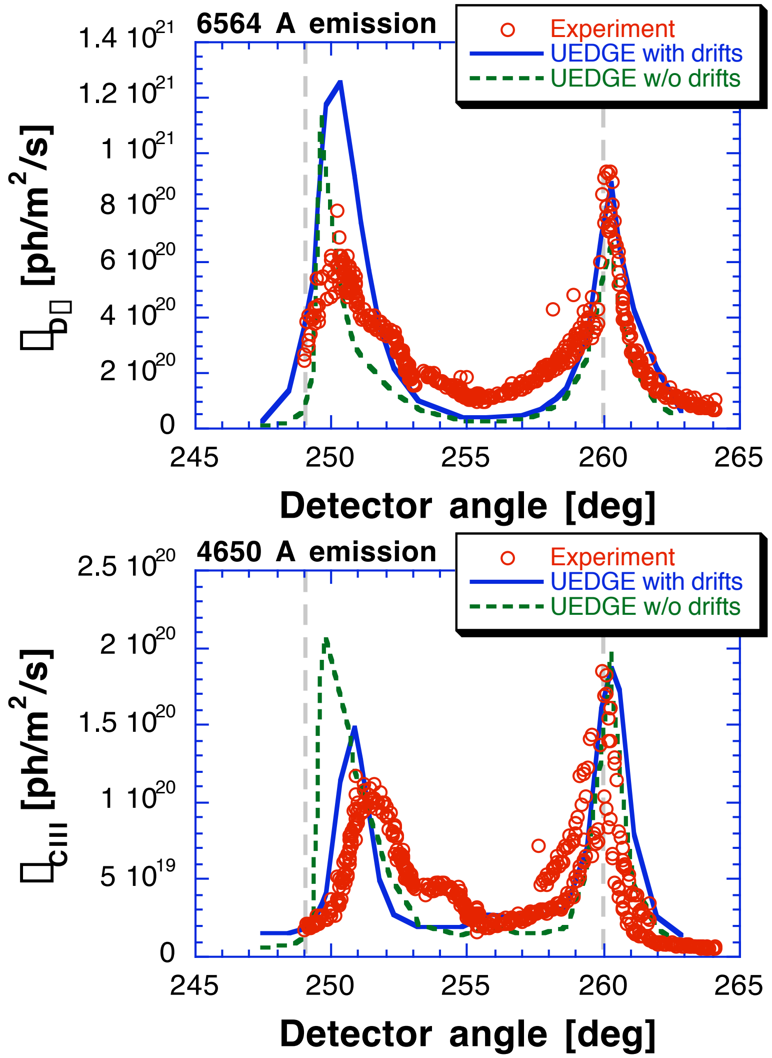
Initial temperature range; updated below



Carbon-III and D_ emissions are well matched by UEDGE (DIII-D simulations by Gary Porter, LLNL)

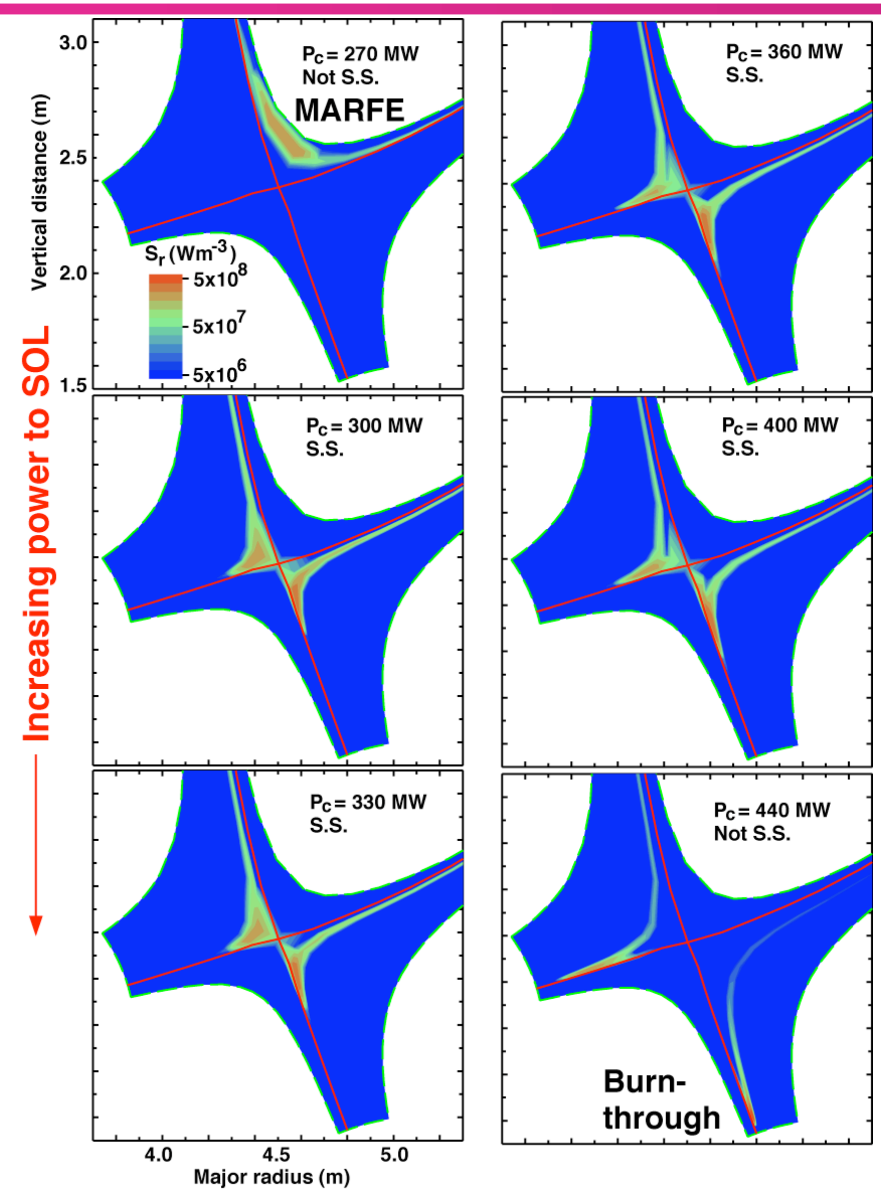
- **Swept data from filterscopes is combined for better radial resolution**





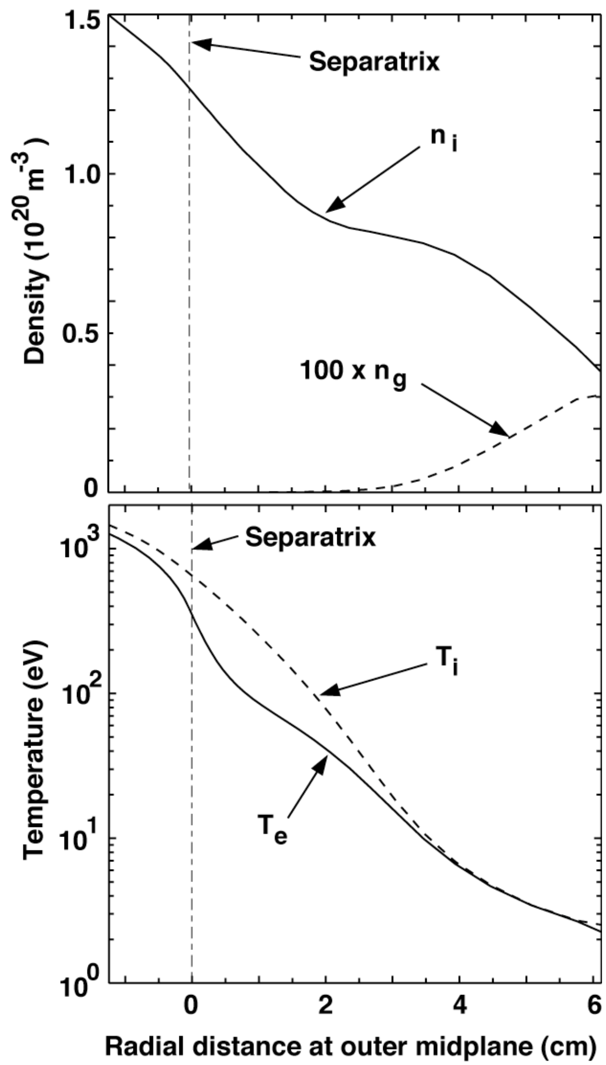
Weakly pumped, high density SOLs yield stable, highly-radiating edge plasmas

- Fluorine from the flinabe wall can provide an effective radiatorfor core alpha-particle power
- High core-edge density is helpful, but may not be essential
- An operating window in power and core-edge density is identified
- Stability of the radiating zone and sufficient core-edge temperature for good core confinement are key issues



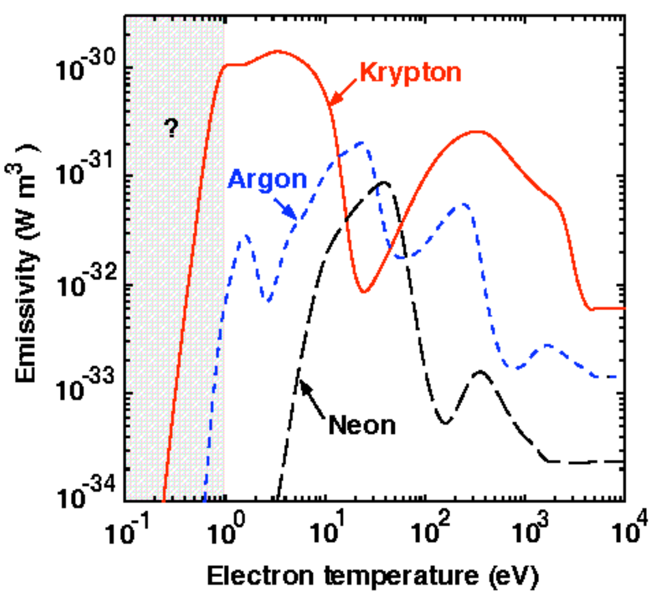
Plasma profiles at the outer midplane show large drop in temperature at the wall

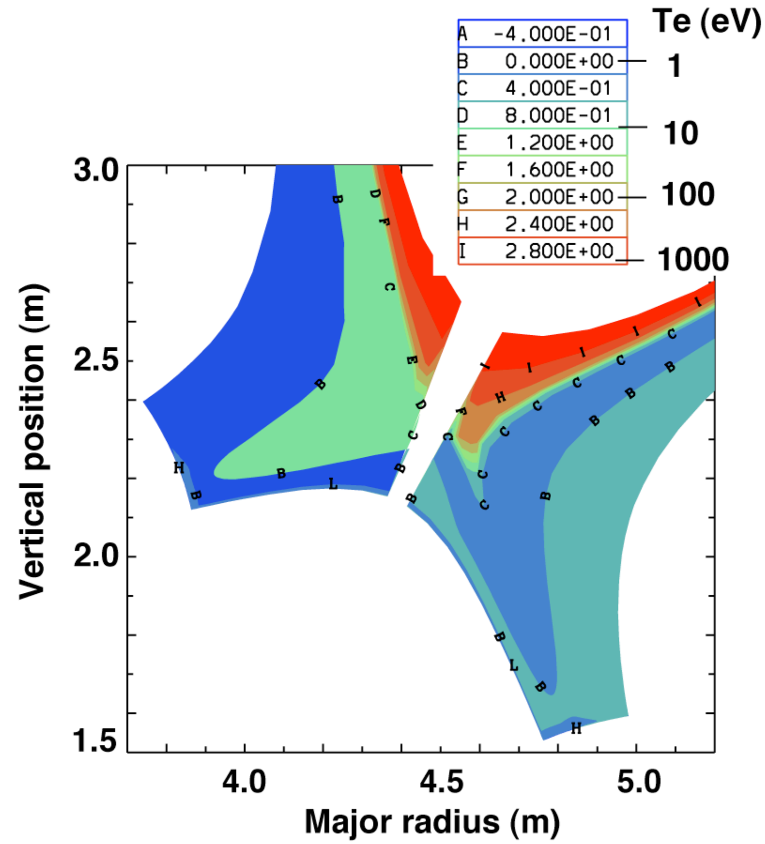
- Diffusive radial transport model used
- T_e and T_i are low (2-3 eV) at the flinabe wall from combination of hydrogenic and fluorine radiation
- Low temperatures imply low sputtering
- Convective loss will increase particle loss to wall, but local $T_{e,i}$ should remain low



Detached divertor plasmas characterized by $T_{e,I}$ of a few eV in the divertor legs

- **Fluorine and hydrogen radiation remove nearly all of the particle power crossing the core separatrix**
- **Hydrogen radiation is optically thick, and thus largely reabsorbed (80% assumed here)**



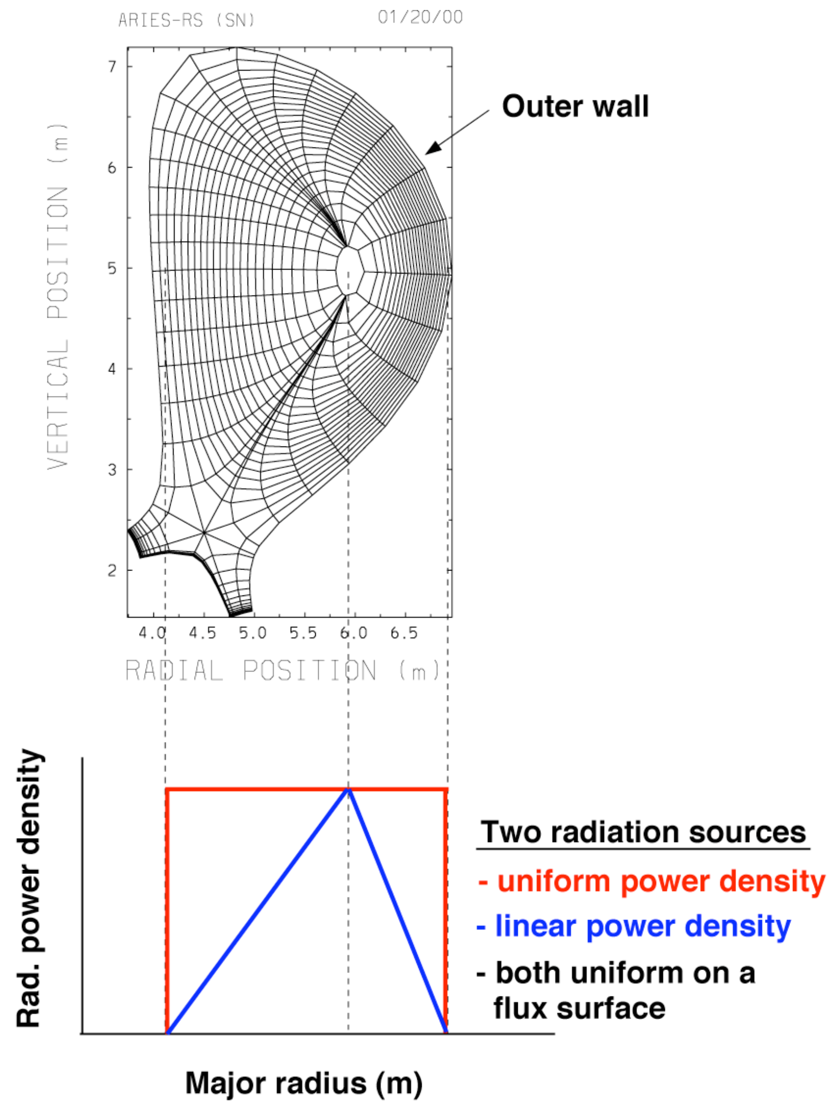


Profile of wall heat flux from core radiation evaluated by UEDGE extended into the core

- Two core radiation source profiles are compared - very little difference

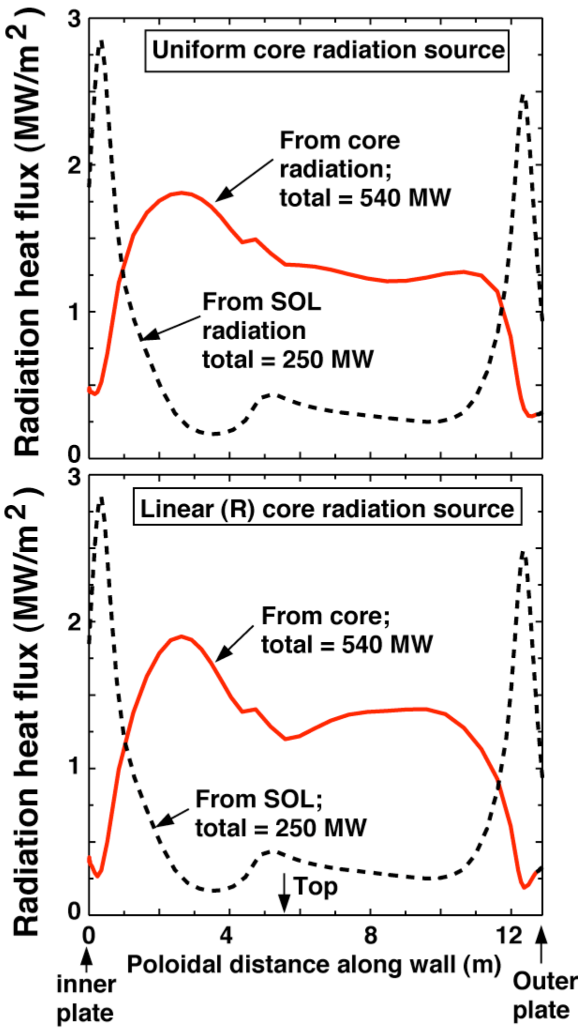
- Full CLIFF (ARIES-RS) geometry included

- Radiation is assumed optically thin, and having with no re-emission from the surface



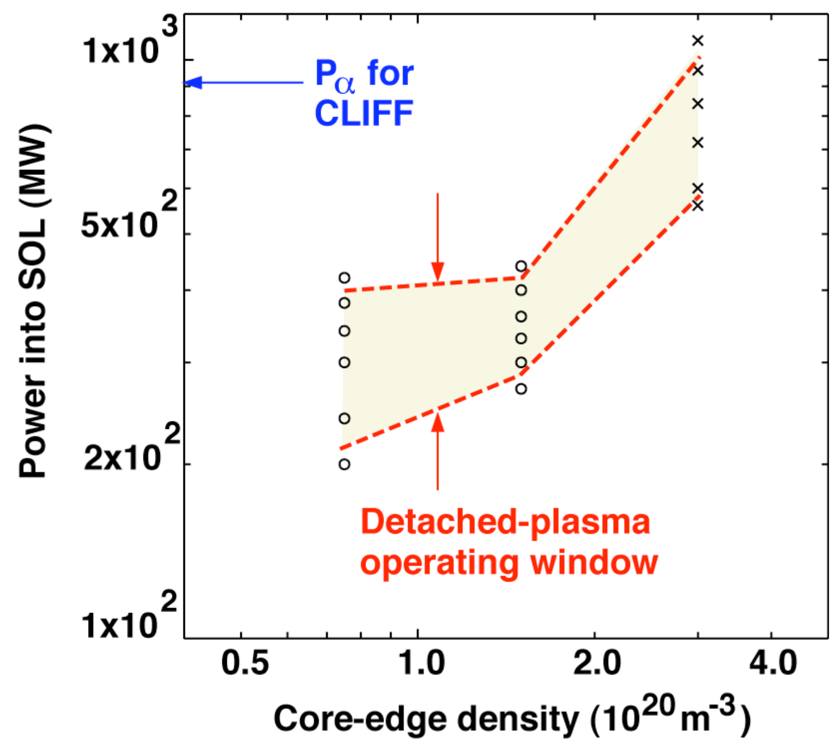
Profile of wall heat flux is then the sum of the SOL fluorine radiation & that from core

- **Core radiation is assumed to be a combination of bremsstrahlung and line radiation**



Substantial operating window exists for highly-radiating SOL plasmas in CLIFF

- Radiating plasma prefer high density owing to $P_{rad} \sim n_{imp} x\ n_e$
- Lower density portion of window is interesting plateau
- Upper limit is burn-through to divertor plate
- Lower limit is core MARFE



What about strong plasma convection?

- **A beginning study with Mike Kotschenreuther**

- **Plasma flux = -D d(n_i)/dr + n_i V_{conv}**
  - How do we distinquish between D and V_{conv}?
  - What are the consequences?
  - Is the D and V_{conv} characterization adequate

Plasma outward convection in the outer SOL may be a substantial source of wall sputtering

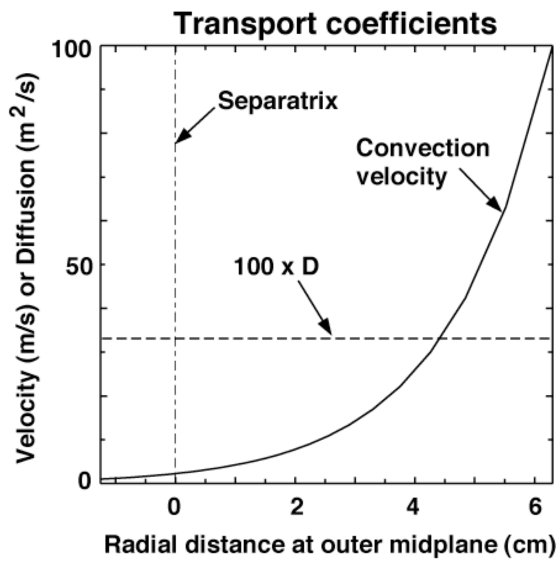
- Experimental data shows large transport in the far SOL, implying

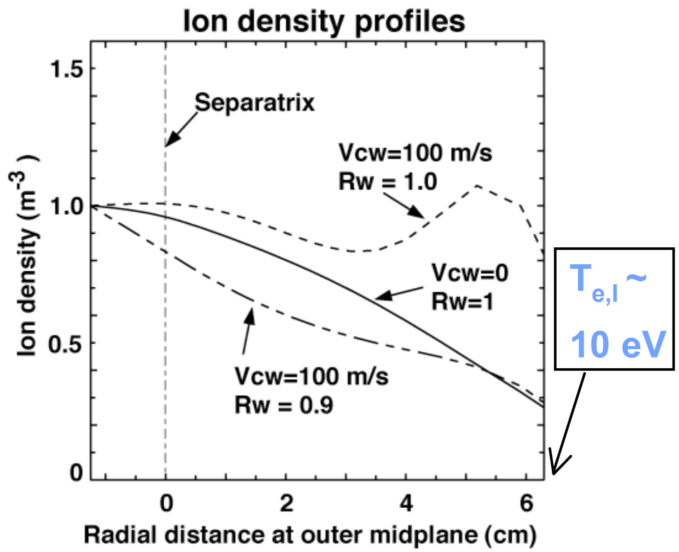
  ion flux = -D d(n_i)/dr + n_i V_{conv}

- Scaling from experiments, Kotschenreuther has found that such transport could give rise to significant first-wall sputtering & other effects

- Initial UEDGE modeling indicates that wall recycling is important in possibly reducing the plasma energy and thus sputtering

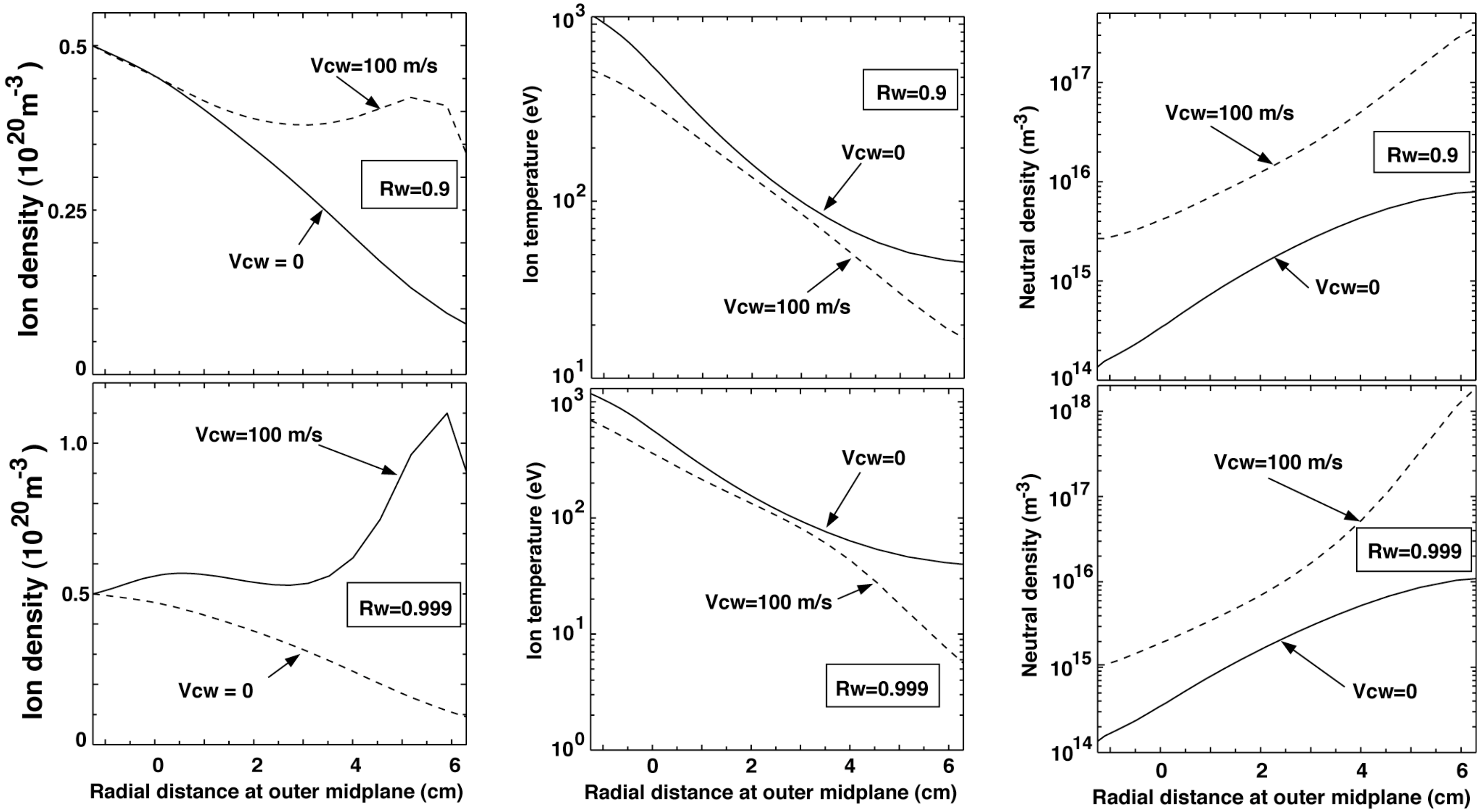
- High density and impurities help produce lower $T_{e,i}$ at the wall; much remains to be done





Convection at lower edge density also gives high wall density

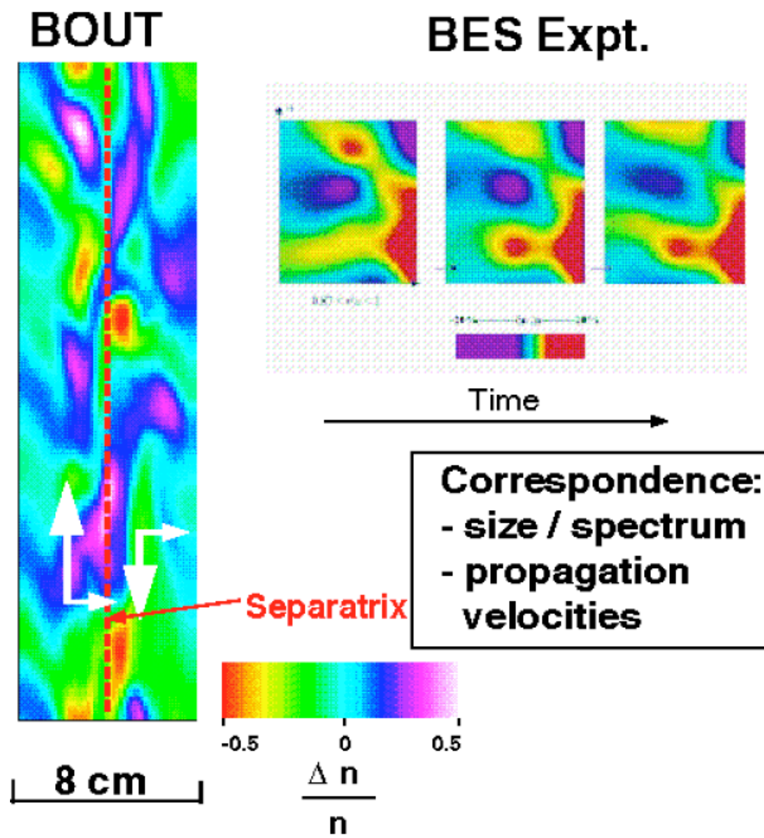
- **Again, wall recycling plays an important role**



Plus, better characterization of turbulence transport needs to be extended to impurities

- **Impurity transport may be increased - not simply outward convection for impurities from the wall, but may be inward**
- **Helium recycling on main chamber may reduce private-flux helium pumping**
- **Better theoretical model for convection, or rather, large SOL transport in general**

BOUT is a 3D fluid turbulence code by Xu, LLNL



Correspondence:
- size / spectrum
- propagation velocities

Summary for part 1; APEX overview

- **Highly radiating SOL plasmas offer a power-handling solution for CLIFF**
  - Reduce peak heat flux to low levels
  - Offer adequate impurity shielding
  - Require low pumping rate (throughput)
  - Stability and helium pumping need better assessment

- **Convection has been ignored in previous studies**
  - Initial self-consistent simulations have been done
  - Wall recycling tends to produce low-temperature, dense plasma near the wall - is this real?
  - Impurity transport will be affected - how much? We don't have adequate models presently. Associated turbulence needs better characterization

Convective transport raises a number of issues (summary from Kotschenreuther/Rognlien)

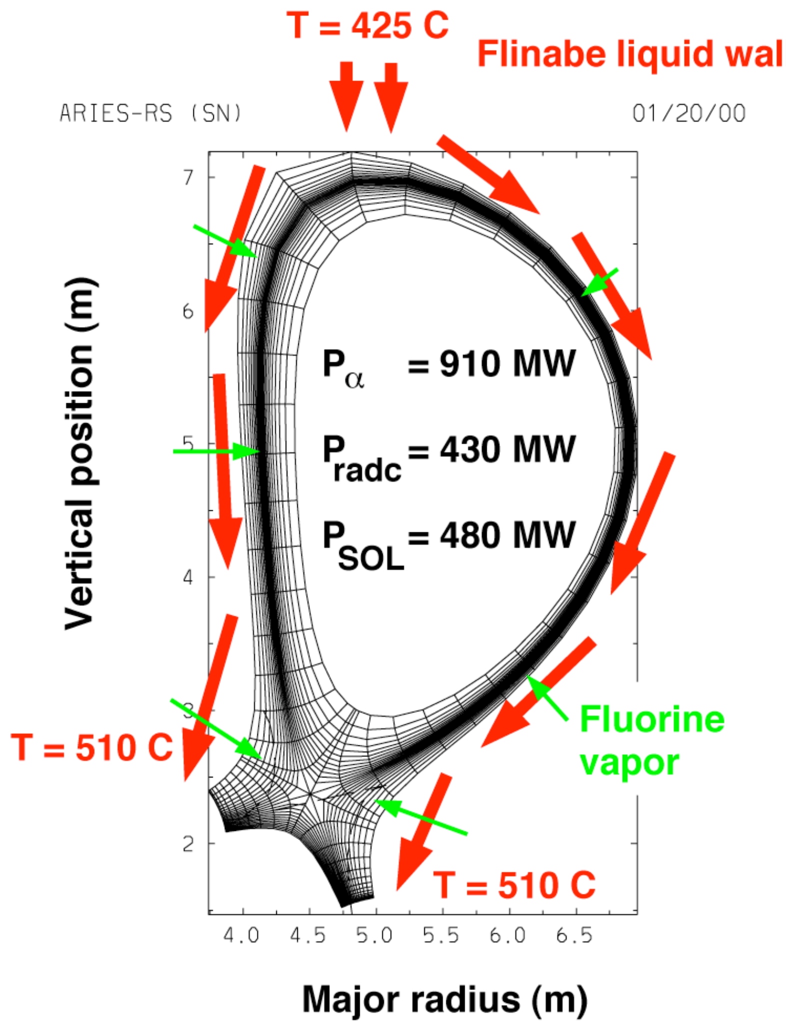
- Sputtering from local ion temperature at the wall is likely low
- But sputtering from hotter “tail” neutrals from non-local charge-exchange near the separatrix may be large
- Enhanced power detachment of near-wall plasma; may allow increased impurity intrusion, but could also shield via high density
- Impurity transport may be increased - not simply outward convection for impurities from the wall, but may be inward
- Helium recycling on main chamber may reduce private-flux helium pumping
- Better theoretical model for convection, or rather, large SOL transport in general

More details of CLIFF edge plasma simulations

- Temperature window in power and density
- Wall temperature now T_{inlet} = 425 C and T_{outlet} = 510 C
- New total wall and divertor heat fluxes acceptable
- Stability of tilted plate configurations

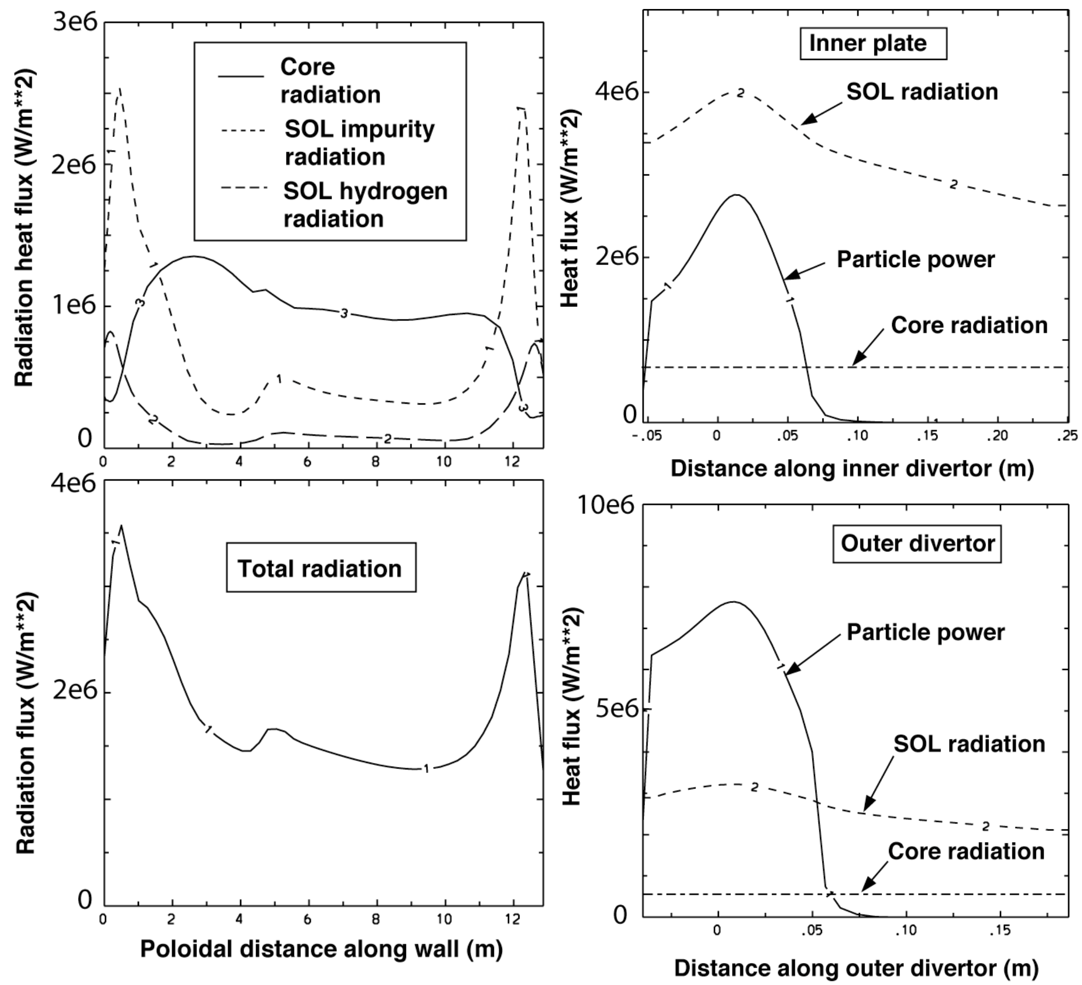
Surface temperature inlet/outlet values from S. Smolentsev now implemented

- **An iterative process**
  - Initially UEDGE used 300 C inlet and 515 C outlet
  - Resulting wall heat-flux profiles used by Sergey
  - New temperature inlet/outlet temperatures = 425 C / 510 C now used in UEDGE
- **Present base-case values shown on figure to right**
- **Need to check if iteration is sufficiently converged**



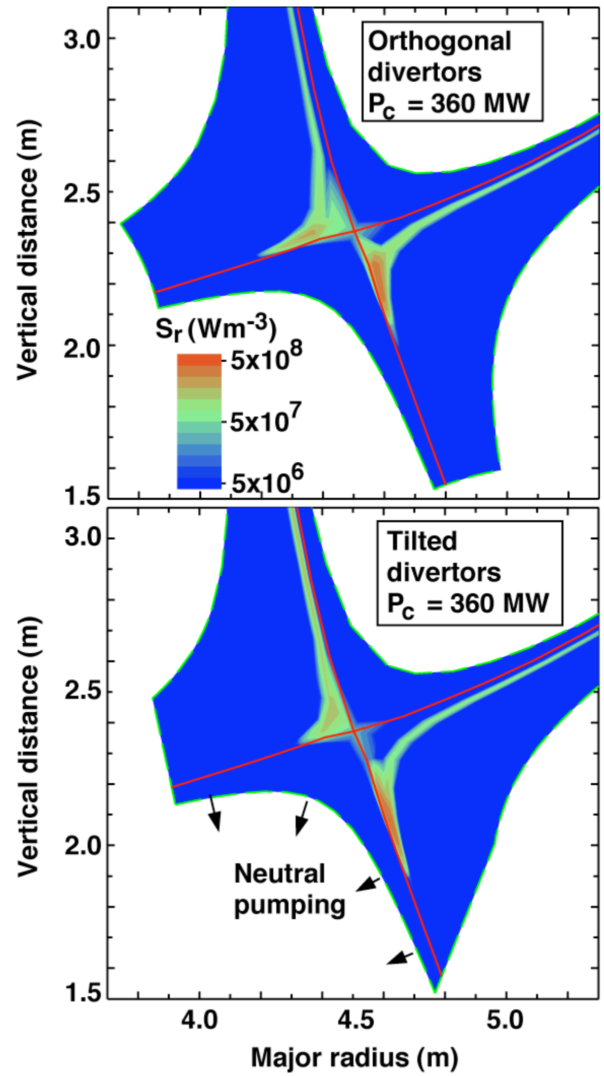
Base-case now radiates more power in SOL with acceptable wall/divertor heat flux

- **Inlet/outlet temperature are now 425/510 C, changed from 300/515 C**
- **Total SOL radiation is now 480 MW, leaving 430 MW from core**



Tilted divertor plates indicate sensitivity of solution to details of divertor flows/pumping

- **Tilting plates change neutral distribution near plates & private flux region**
- **Unbalanced pumping on inner and outer divertor (PF) regions may help balance inner and outer radiation zones for better stability**
- **Steady solutions for new base-case (April '03) have not been found yet, but unbalanced pumping may help**



Summary of CLIFF edge plasma simulations

- **Highly radiating SOL plasmas offer a power-handling for CLIFF**
  - Reduce peak heat flux to low levels
    - wall ~ 3 MW/m^2
    - Divertor ~ 10 MW/m^2
  - Offer adequate impurity shielding (< 1% fluorine at core boundary)
  - Operating window in n_{core} and P_{SOL}
  - Wall plasma temperature is low; small sputtering (need kinetic est.)

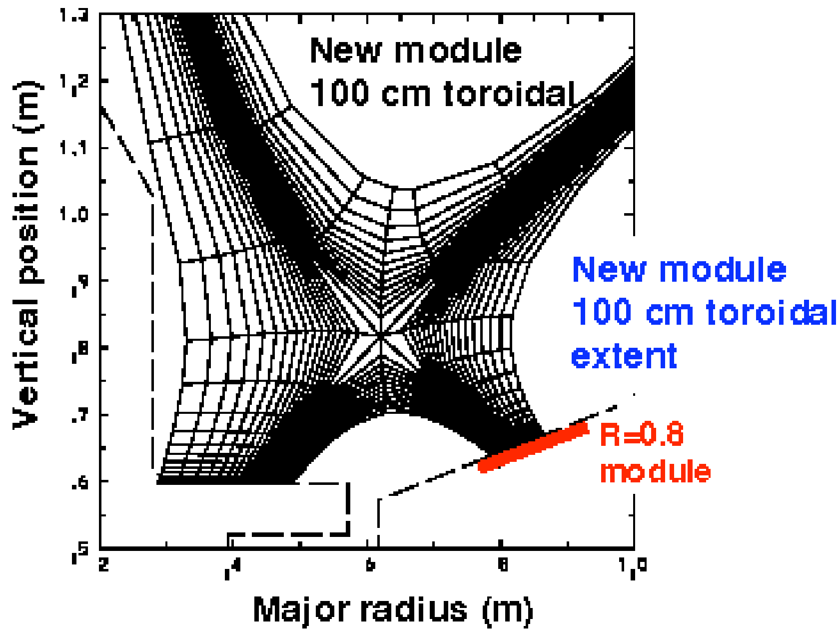
- **Issues to be resolved**
  - Stablity, especially for tilted plates
  - Helium pumping
  - Good core confinement (adequate T_{edge}) & required radiation
  - Role of convective transport, especially at high edge density

Simulations for new, larger NSTX module

- **The NSTX lithium module design has been modified**
  - Previously, partial insertion and 40 cm toroidal length
  - Now, complete radial coverage of outer divertor for a 1 m toroidal length

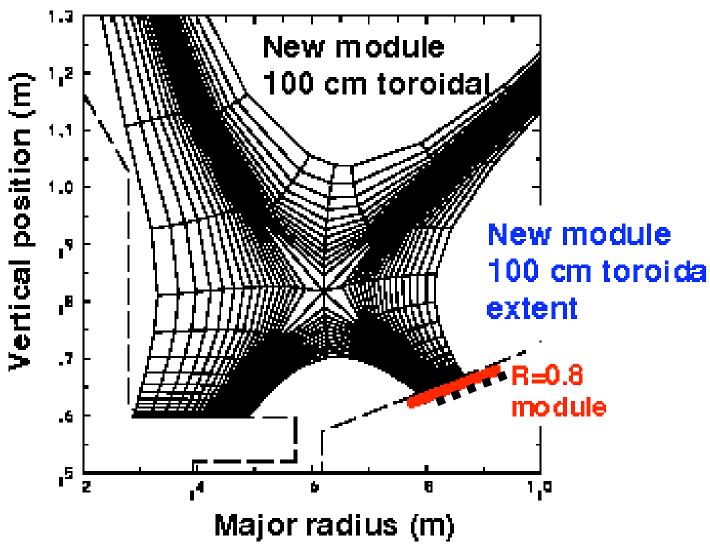
Lithium contamination of core from NSTX module modeled by coupling UEDGE & WBC

- Heat and particle flux to module computed by UEDGE
- Temperature rise of Li surface from Ulrickson's model
- Sputtering of Li from U. Ill. composite model
- WBC calculates lithium source near the divertor plate
- UEDGE uses this Li source to calculate lithium density at core boundary



NSTX modeling extended to larger Li module gives lower divertor density (more pumping)

- **Module extended radially and toroidally**

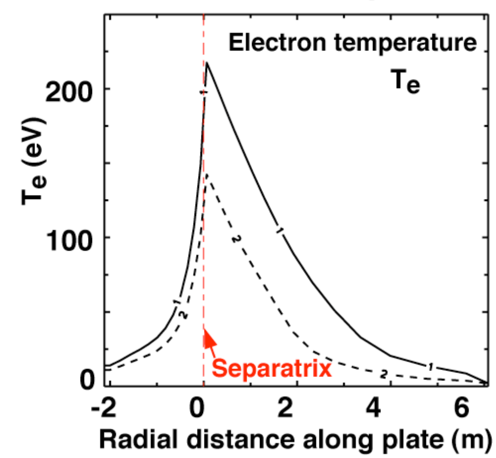


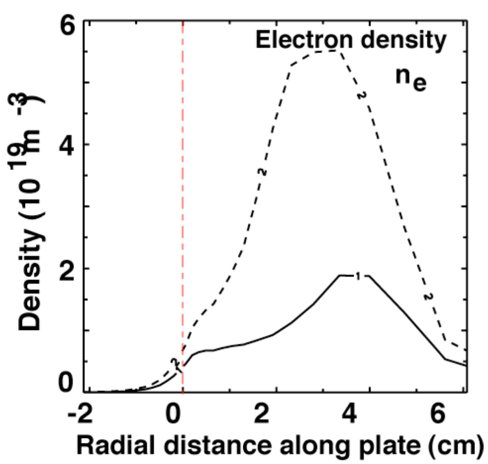
Legend

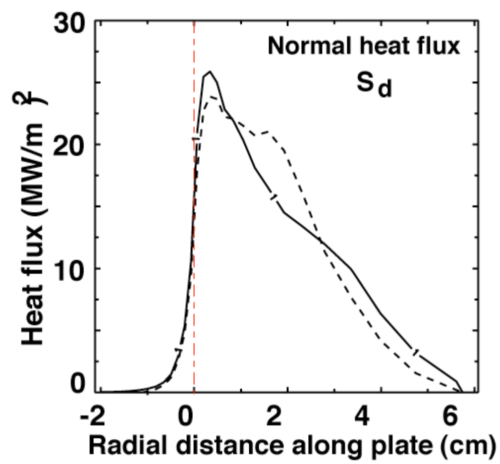
—— Present model of 1 m module pumping across entire outer plate; Reff = 0.8

- - - Previous model for 0.4 m module pumping for R-Rsep > 2 cm, Reff = 0.9; for R-Rsep < 2 cm, Reff = 1.0

Outer divertor plate





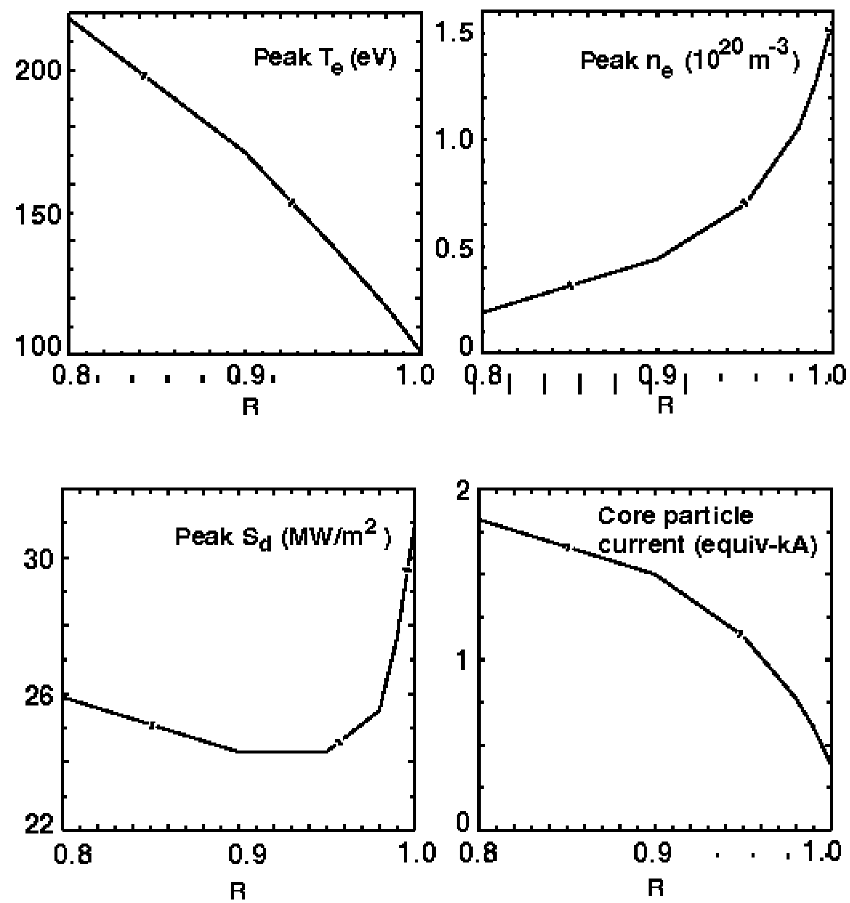


Changing pumping via R impacts edge density

NSTX with n_{core} = 4x10^{19} m^{-3}, P_{core} = 6 MW

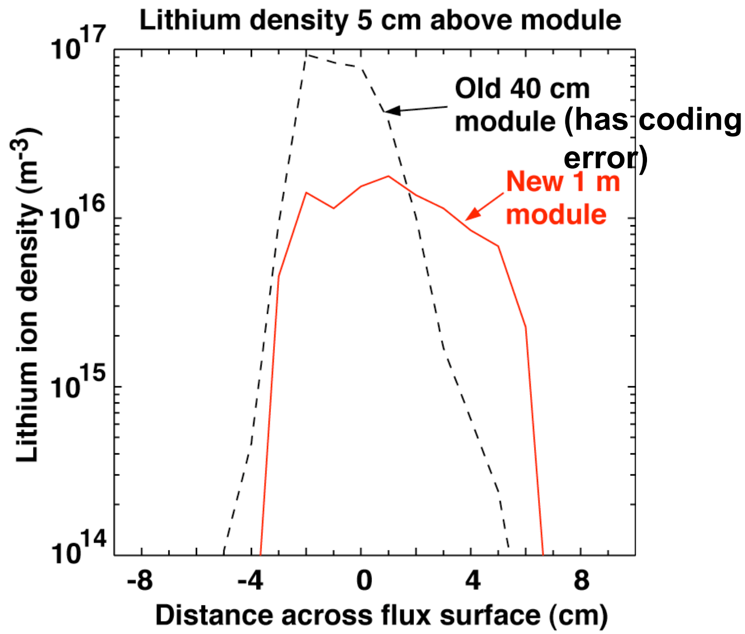
- Minimum toroidally-averaged recycling coeff. R = 0.8 for complete pumping on module
- Incomplete pumping characterized by R = 0.8 --> 1.0
- Edge-plasma density changes most strongly

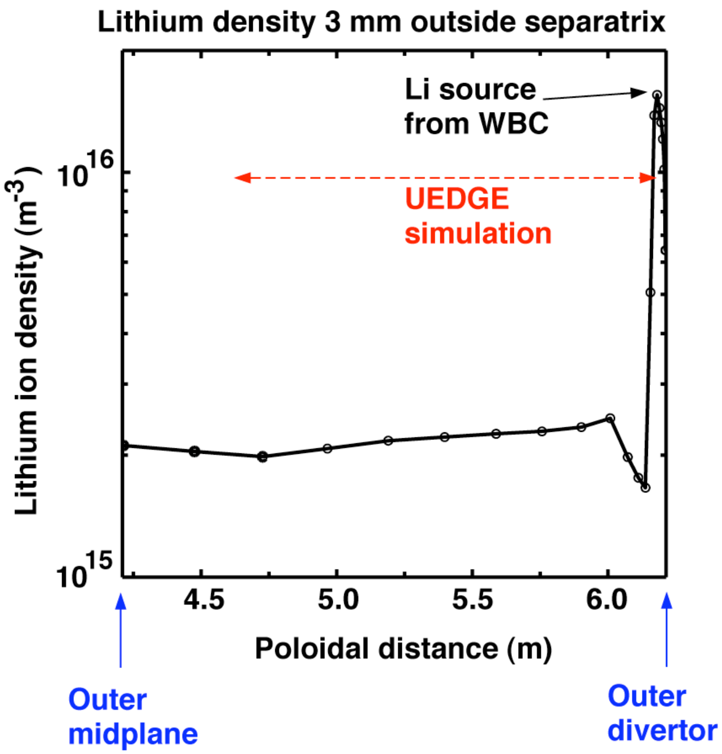
Outer divertor parameters vs. R



Larger module results in low influx of lithium to the core

- New 1 m module has lower Li density at 5 cm from WBC
- Subsequent penetration of Li to midplane further reduced (thermal force)





Overall summary - important progress in several areas

- **Substantial operating window for radiating SOL in CLIFF**
- **NSTX 1-meter lithium module produces small core Li content**
- **Begun evaluation of impact of convective SOL transport**