Plasma Impurity Modeling for Liquid Walls and Effects of Wall Recycling

Presented at the APEX Meeting

UCLA
Los Angeles, CA

November 3, 1998

by

T.D. Rognlien

for the UEDGE Modeling Group

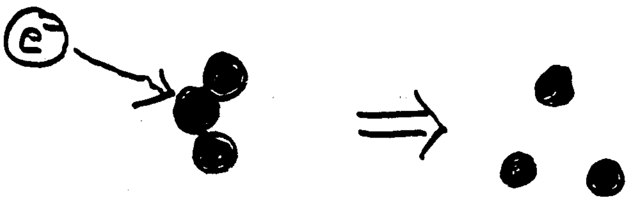
Lawrence Livermore National Laboratory

Important Near-Surface Effects

- Ionization source width, Δ_r, given by

$$\Delta_r \approx v_n / \langle \sigma v_e \rangle_i n_e$$

- Neutral velocity, v_n, given by dissociation kinetics



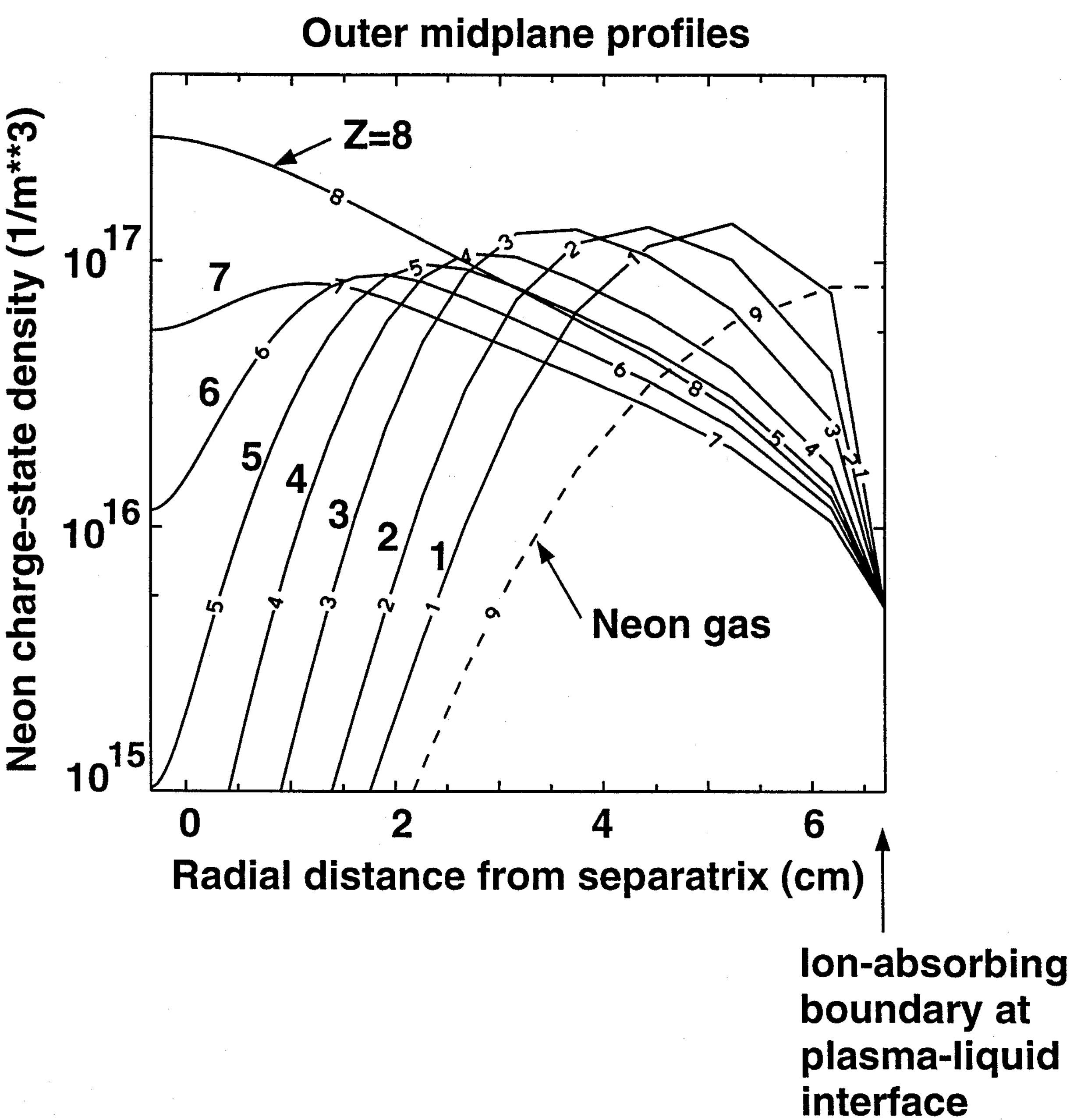
resulting atoms at few eV energies?

BeF_2

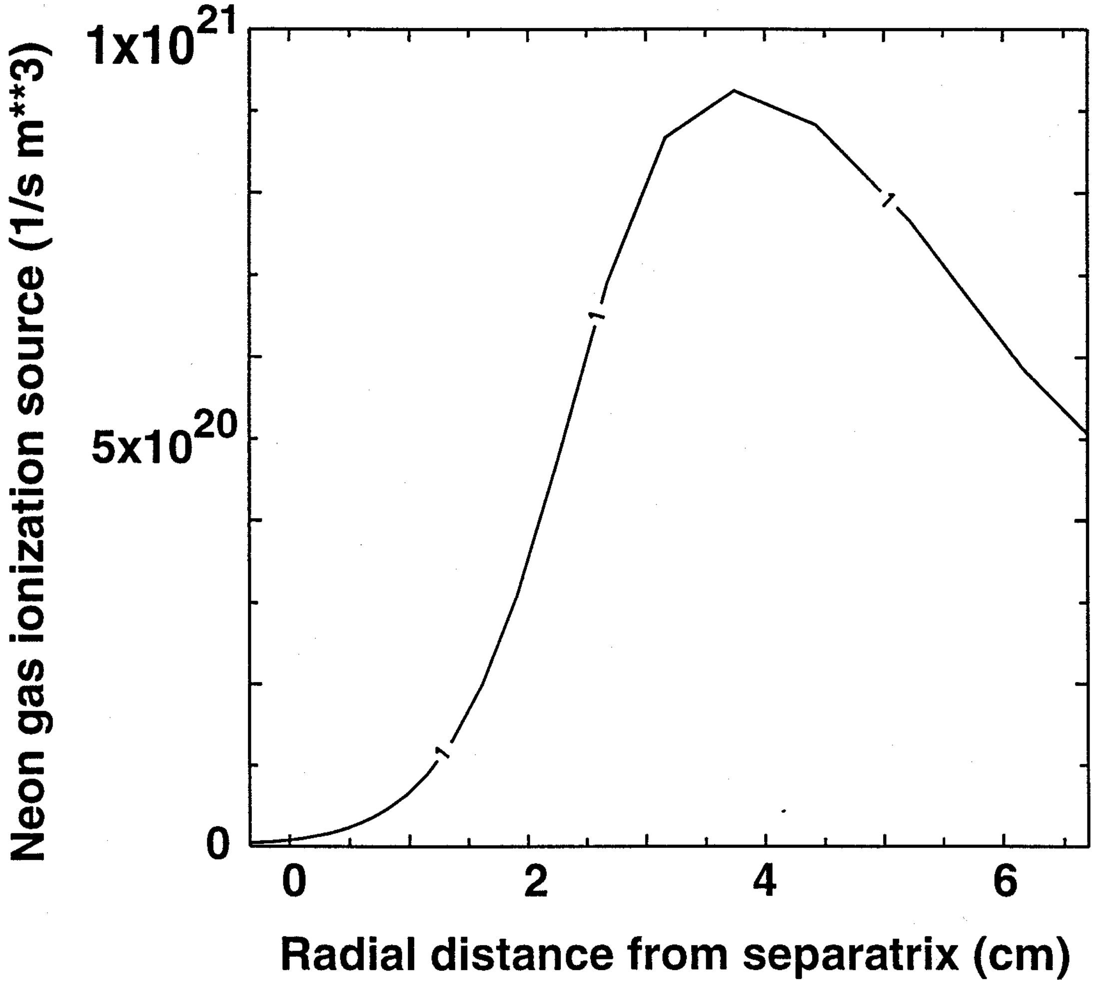
- What is the recycling process and net R_w for fluorine, beryllium on Flibe?

Flibe

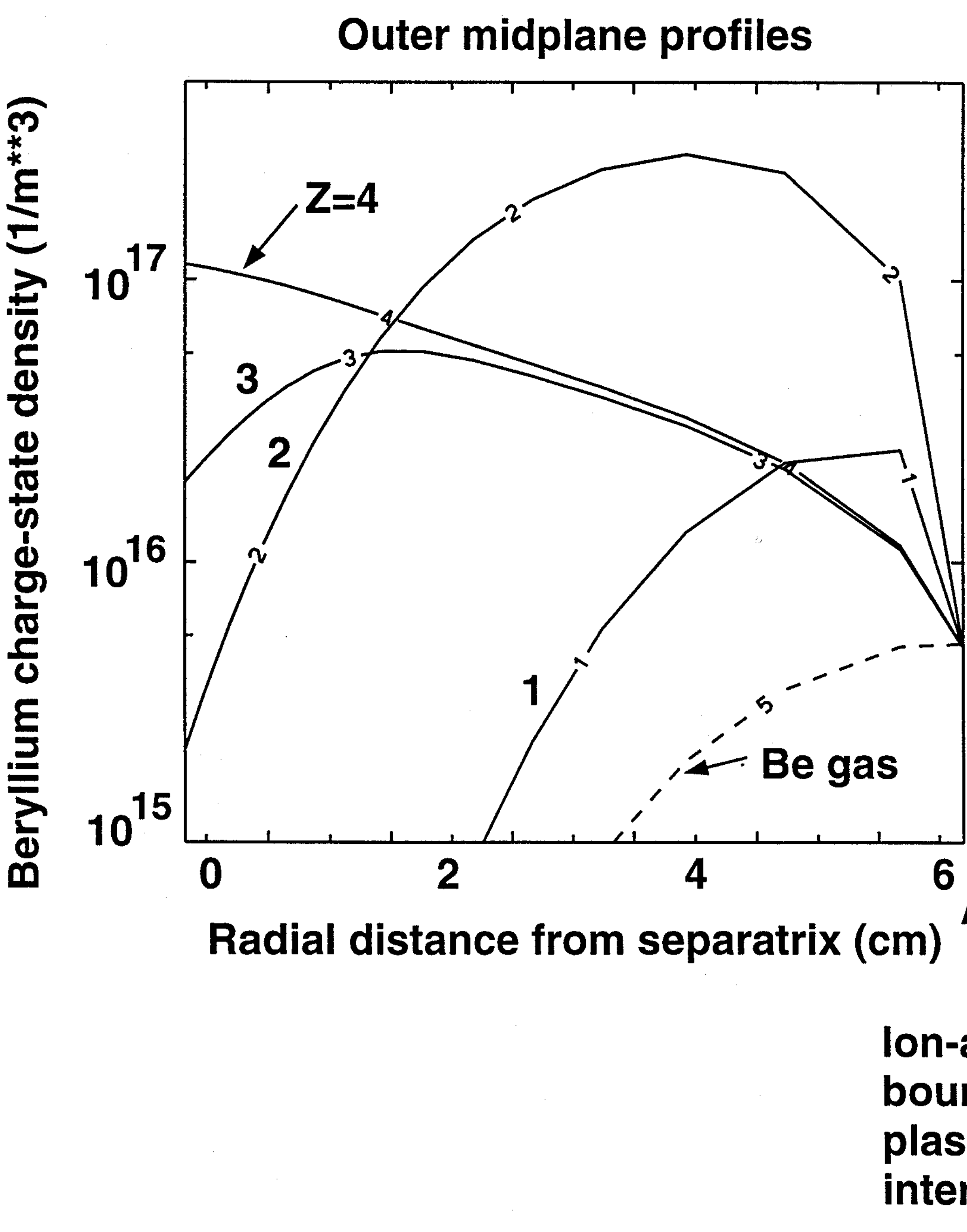
Ion-absorbing boundary has little effect



Neon particle source is not localized



Beryllium profiles similar to neon

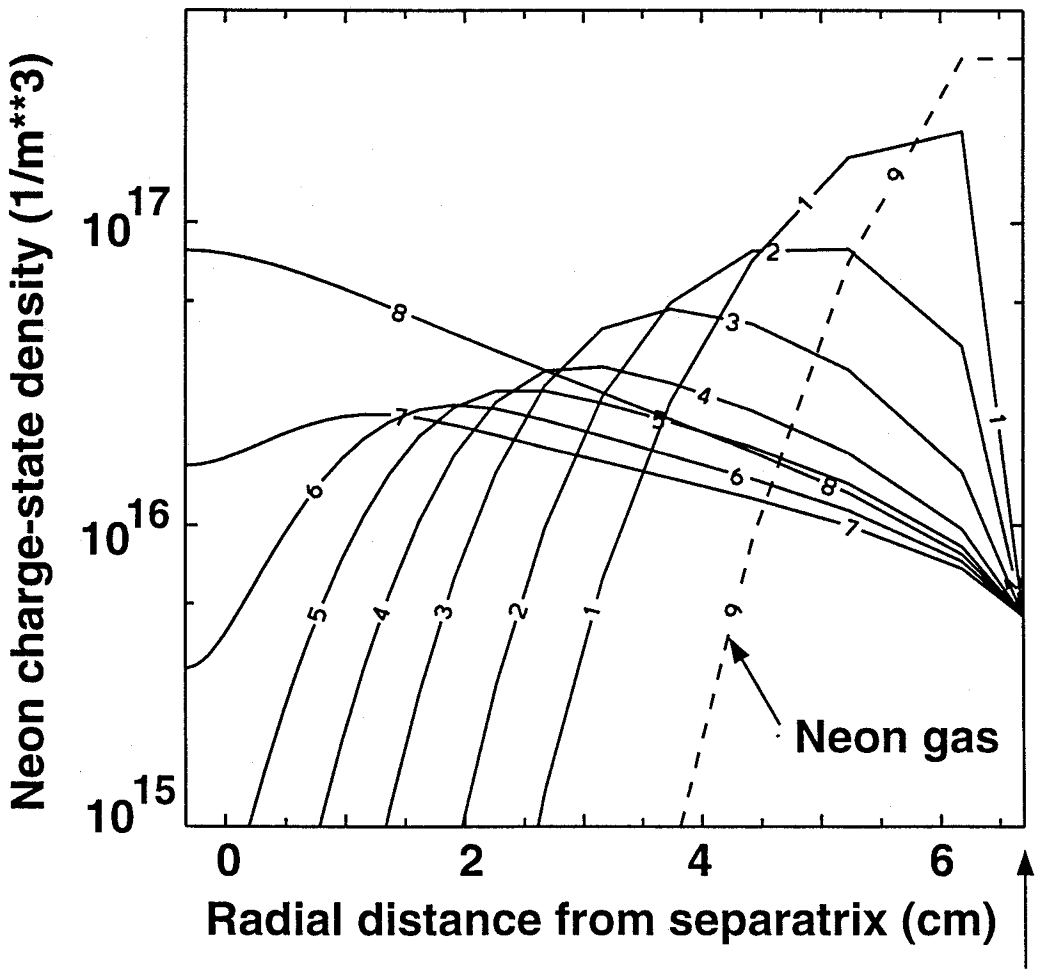


Ion-absorbing boundary at plasma-liquid interface

Reducing impurity gas temperature decreases impurity ion penetration

T_{gas} is reduced from 10 eV to 1 eV

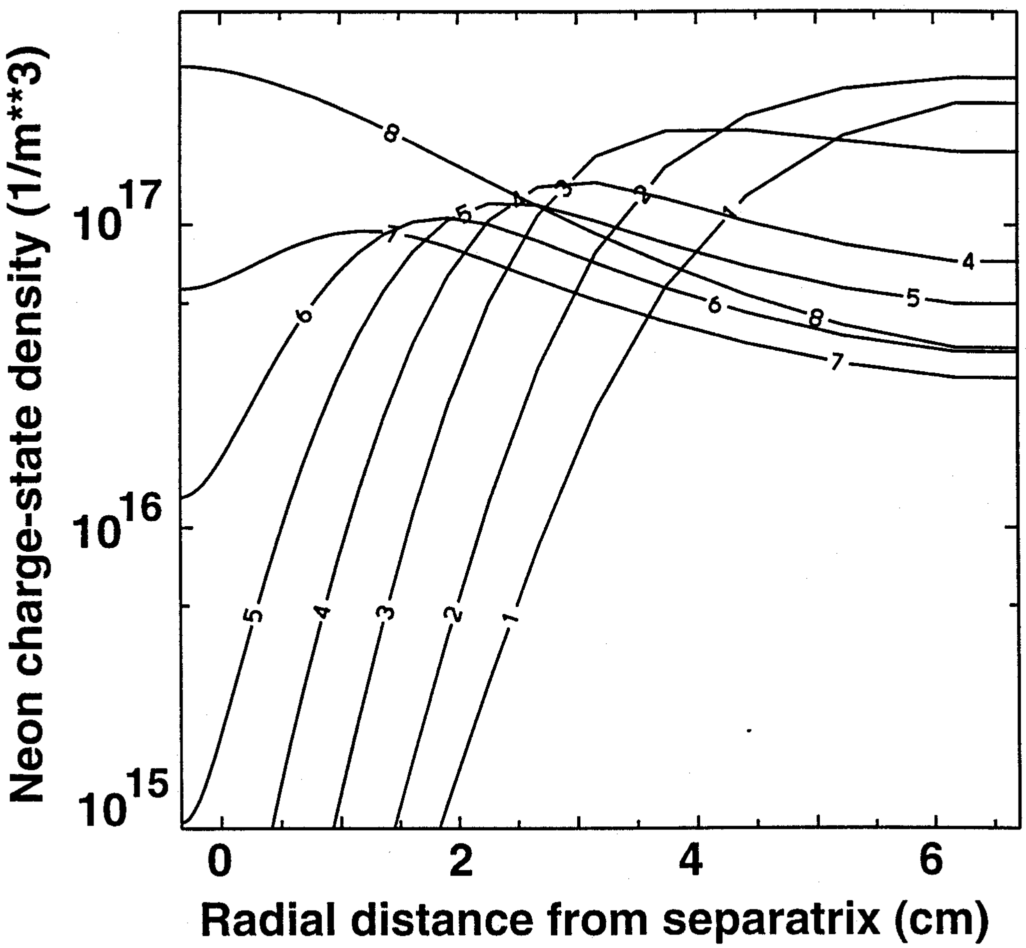
Outer midplane profiles



Ion-absorbing boundary at plasma-liquid interface

Reducing impurity plate recycling from R=0.5 to R=0.1 has little effect

Plate R=0.1 for impurities
Outer midplane profiles



Summary

- Reflux of impurity ions back to the liquid wall could reduce core influx
- Very important parameter is atomic gas velocity (energy) giving the ionization source length
  - dissociation processes need to be evaluated
  - ion/neutral scattering/heating probably small
- Recycling of ions on the liquid wall important if near unity
- Too much reflux/recycling may produce wide, low Te region in front of the wall, allowing deeper penetration

Outline

1. UEDGE multispecies calculations with no reflux to the wall

2. Analytic model for reflux and recycling at the wall

3. UEDGE results with reflux

   - Comparison of neon (fluorine) and beryllium

   - Variation with gas temperature

   - Effect of divertor plate recycling

4. Summary

Basic Parameters for Neon Simulations

Input quantities:

P_outer = 100 MW

n_h_core = 4e19 1/m**3

Neon wall flux = 3.8e19 particles/m**2 s

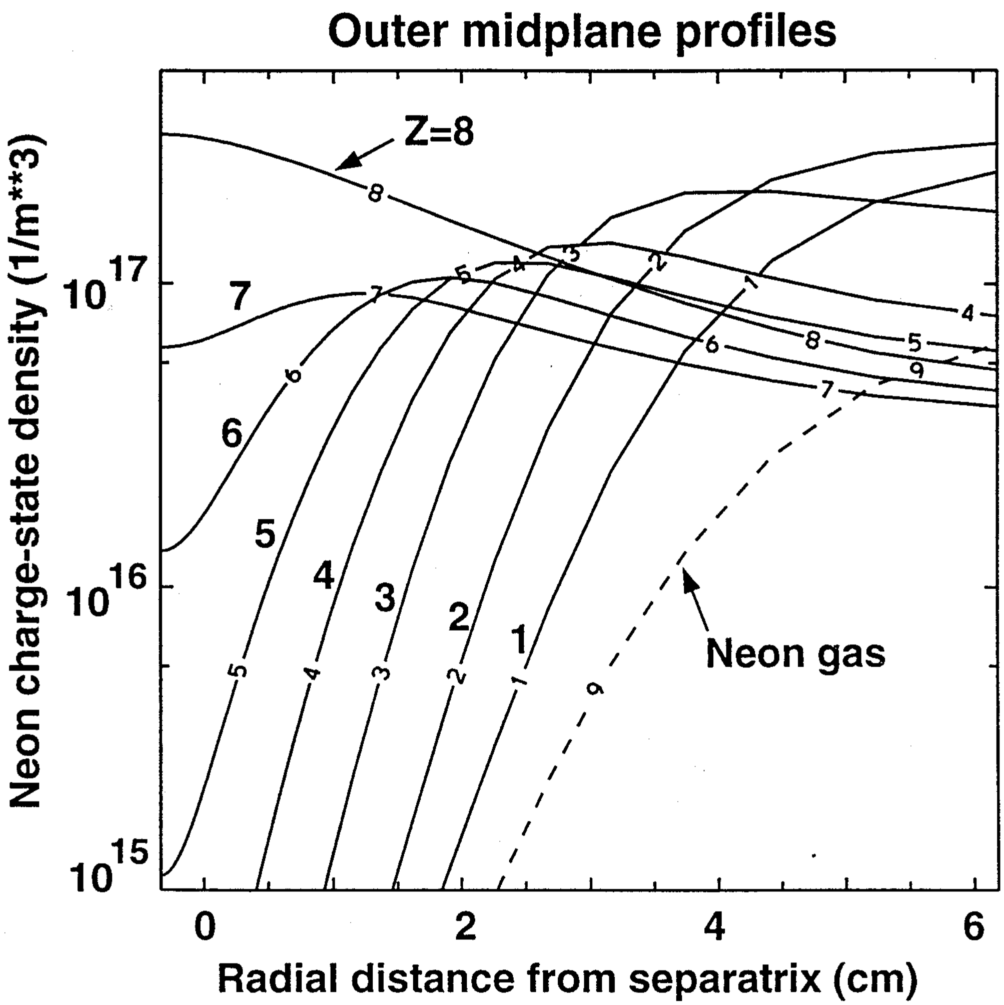
Calculated quantities:

P_plate = 53 MW

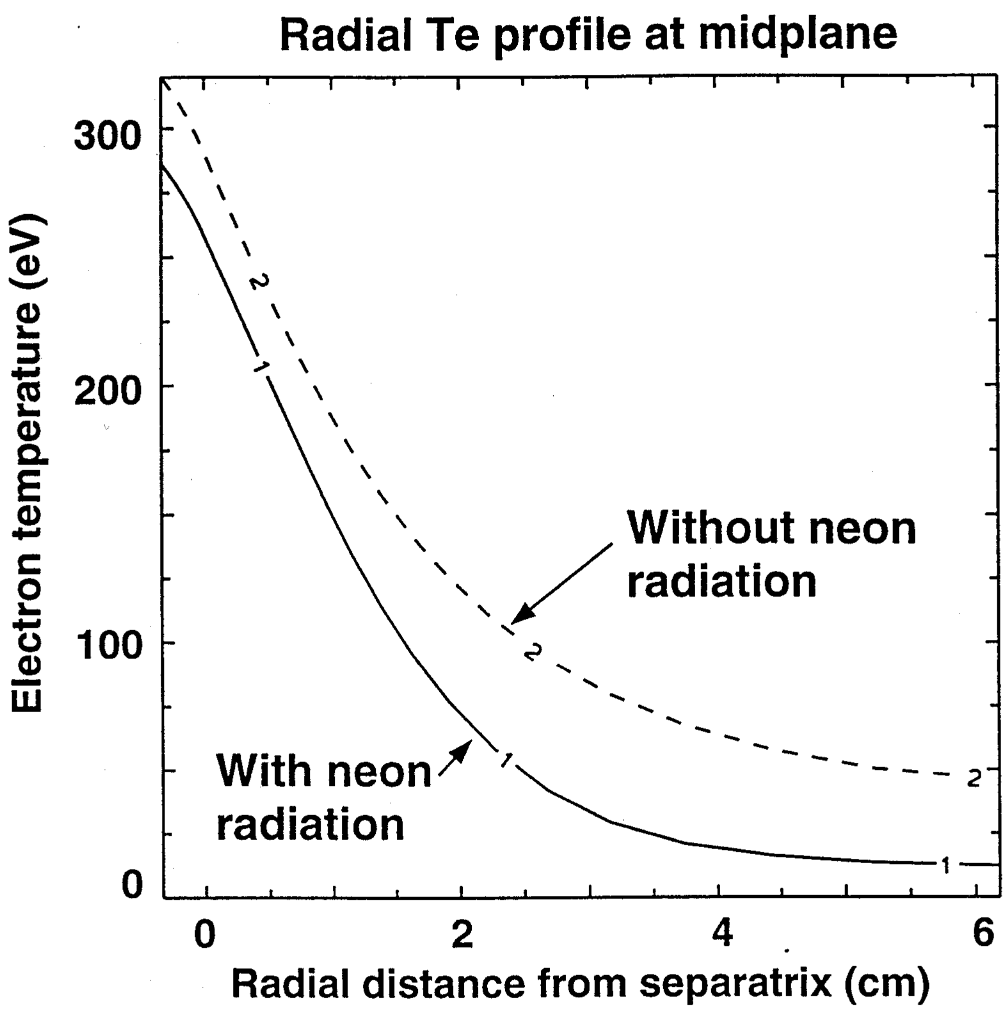
P_rad_neon = 45 MW

n_neon_core = 4e17 1/m**3 (Zeff = 1.47)

Radial Profiles of Neon Charge States



Te Profile Contracts with Neon Radiation



Base-Case Impurity Flux Close to Flibe Melt pt.

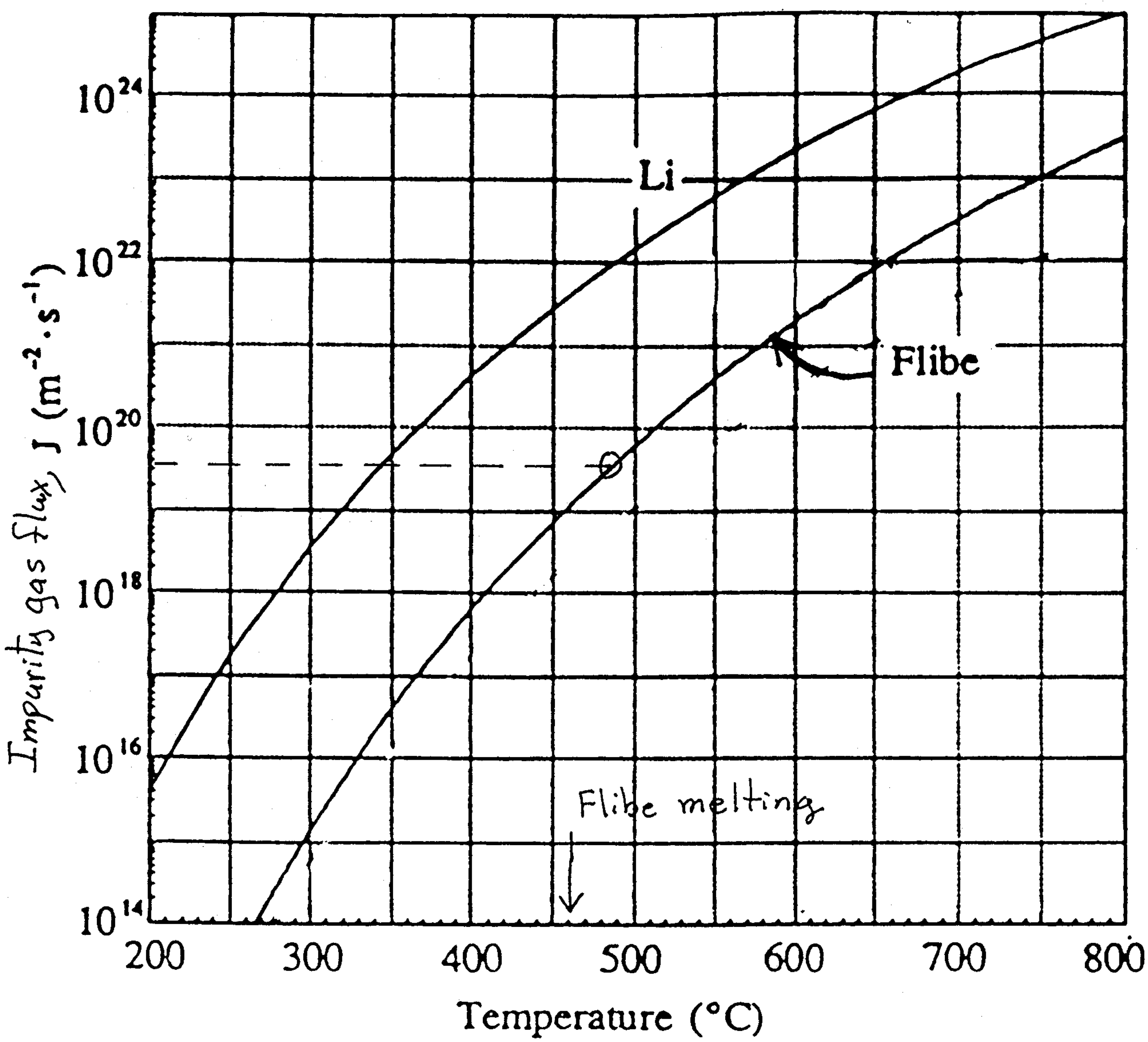
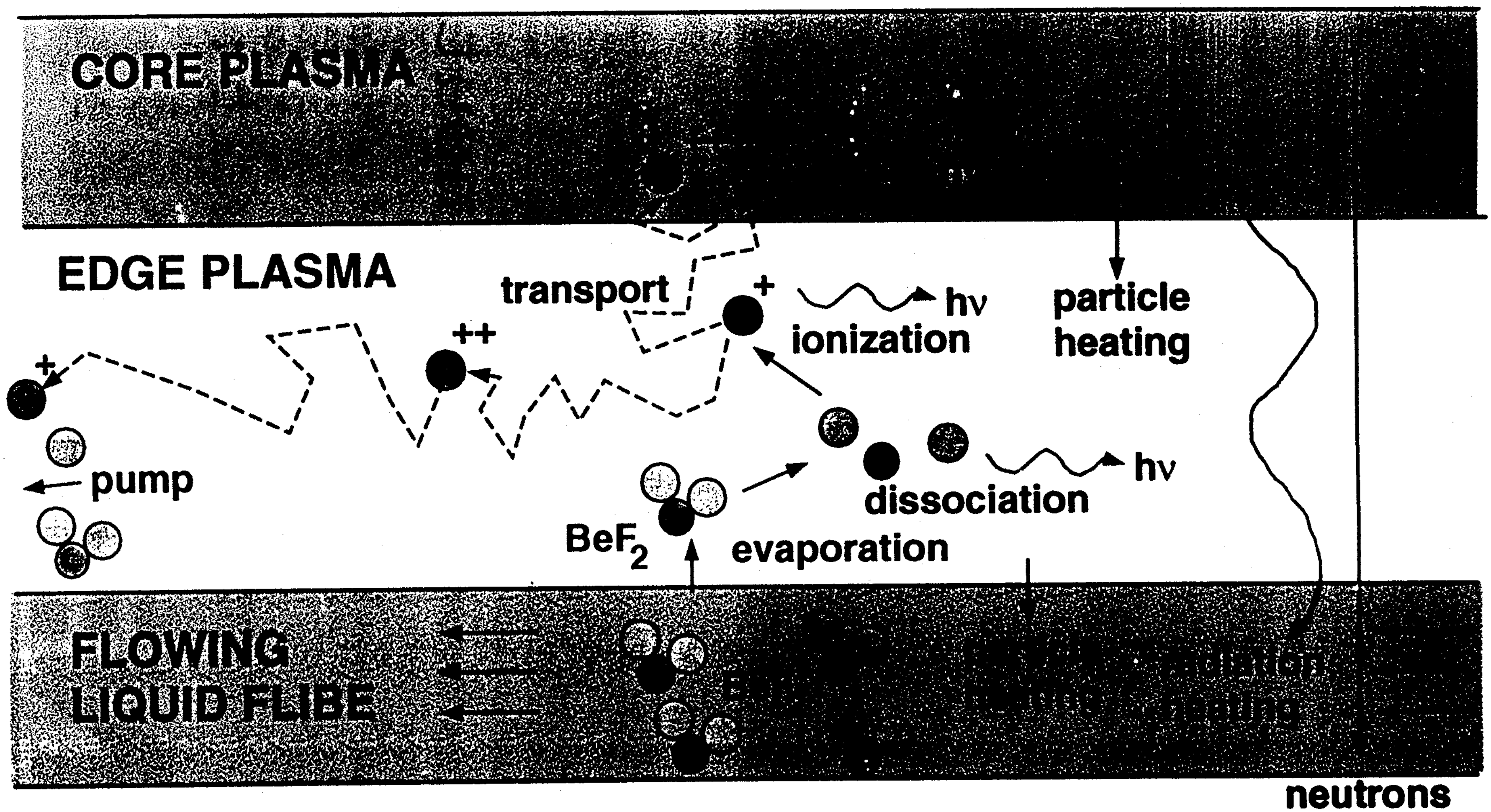
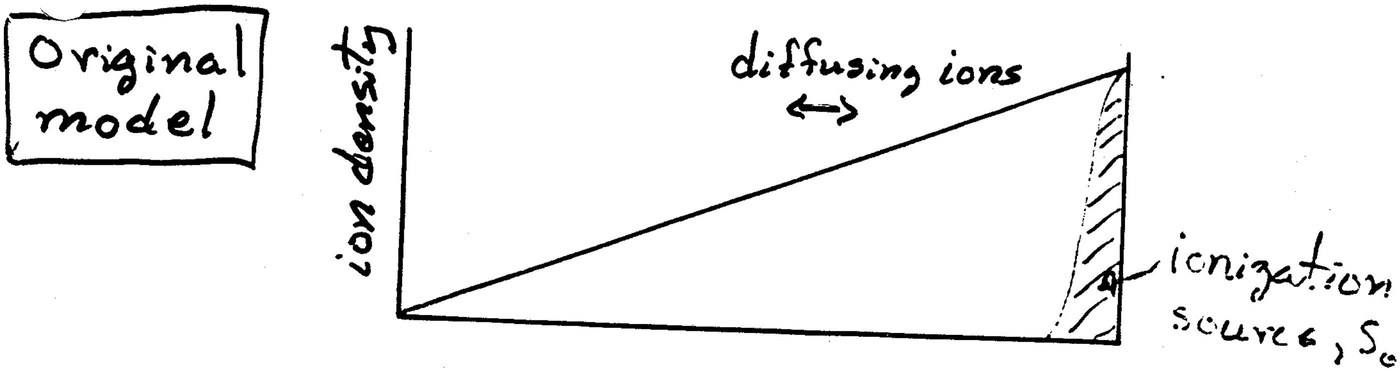


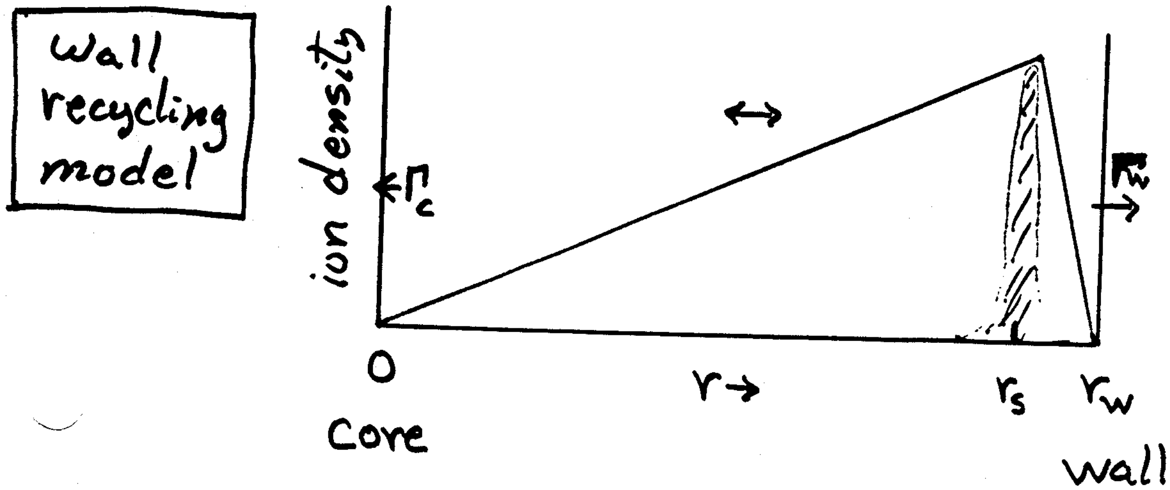
FIG. 6. Rate of evaporation versus temperature. For Flibe the evaporating species is over 90% BeF_2 and less than 10% LiF. For $Li_{17}Pb_{83}$ the volatile evaporating species is over 95% lead and less than 5% lithium.

Processes to be Modeled for Liquid First-Walls



Ion diffusion back to wall can reduce flux to core plasma





Model diffusion Eq.

$$-D \frac{d^2 n_i}{dr^2} = S_o \, \delta(r - r_s) - \nu_{II} n_i$$

(ignore: $-\nu_{II} n_i$)

Flux to core, $|\Gamma_c| = \dfrac{nD}{r_s}$

Flux to wall, $|\Gamma_w| = \dfrac{nD}{r_w - r_s} = \dfrac{nD}{\Delta_r}$, $\Delta_r \equiv r_w - r_s$

Particle conservation gives

$$S_0 = nD \frac{r_w}{r_s \Delta r} \qquad (2)$$

The source has two components

$$S_0 = \underbrace{\Gamma_e}_{\text{evaporation}} + \underbrace{R_w \Gamma_w}_{\text{recycled ion flux}} \qquad (3)$$

From (2) and (3),

$$\Gamma_e = \frac{r_w - R_w r_s}{r_s \Delta r} nD$$

or

$$\frac{nD}{r_s} = \frac{\Delta_r \Gamma_e}{r_w - R_w r_s}$$

Flux to core

$$\boxed{|\Gamma_c| = \frac{nD}{r_s} = \frac{1}{1 + \frac{(1-R) r_s}{\Delta r}} \Gamma_e}$$

Strong reduction in $|\Gamma_c|$ if

$$(1-R) r_s \gg \Delta r.$$