Edge Plasma and Divertor Modeling for ARIES

M. E. Rensink and T. D. Rognlien

Fusion Energy Sciences Program, LLNL

Presented at ARIES Meeting

Bethesda, MD

April 4-5, 2011

LLNL Involvement in ARIES

- Discussions with Mark Tillack and Chuck Kessel on input needs for ARIES

- Goals for edge/divertor modeling:
  - consistent edge divertor plasma solutions for ARIES design points
  - bracketing results over uncertain model parameters
  - connection to present-day experimental results via related modeling
  - development of reduced, parameterized models for system code use
  - optimize detailed divertor geometry; initially plate tilting and slot divertor; eventually perhaps snowflake or super-X
  - impact of off-normal events (longer term)

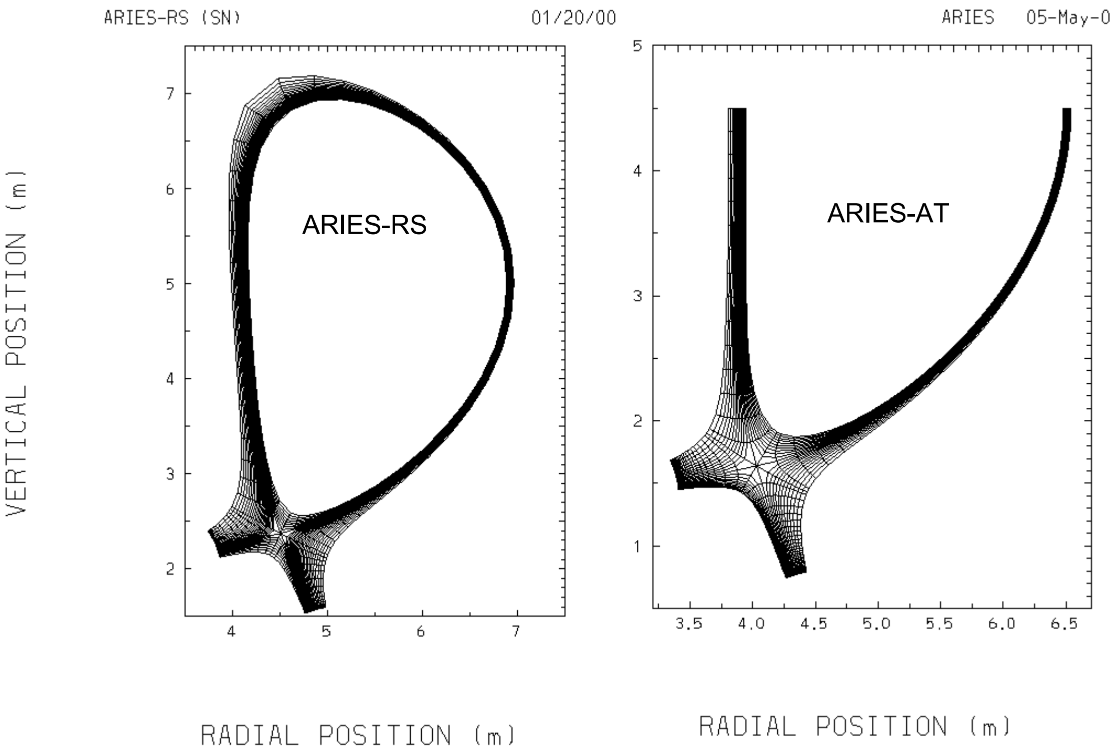
- Today we focus on the use of impurity radiation to disperse plasma power by spreading heat flux over large area of divertor and side walls

Outline

- Edge Plasma Model Description
- Constraints on SOL Power and Density
- Heat Flux on Divertor Surfaces
- Detached Plasmas
- Impurity Species
- Mantle Radiation

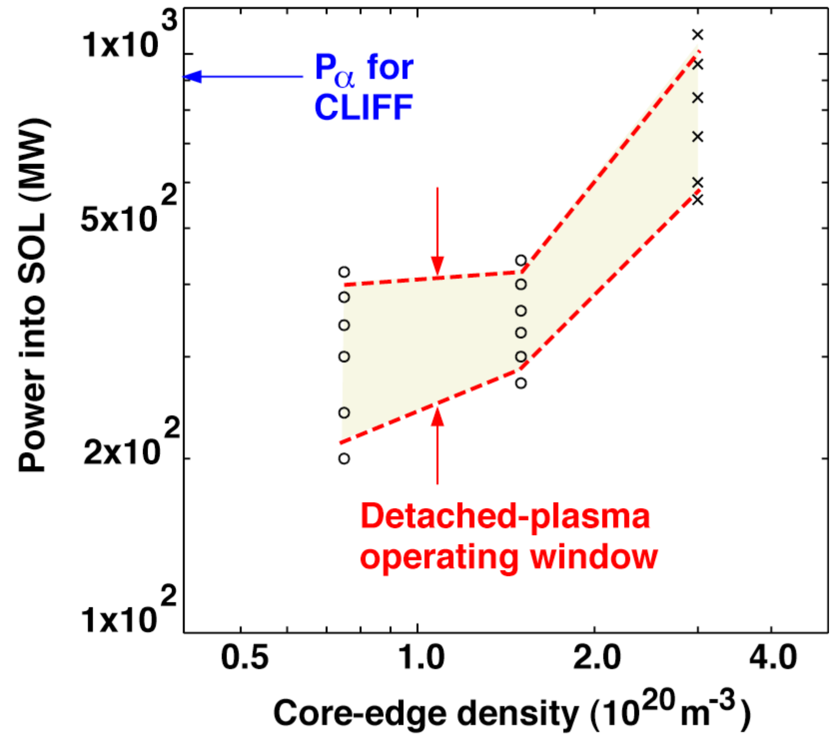
Edge Plasma Model is 2-D Fluid

- Parallel transport is classical
- Radial transport is anomalous
- Two impurity models:
  - a) fixed concentration
  - b) individual charge states
- Heat flux to surfaces includes both particles and radiation
- Important input parameters are n_{core} and P_{core}



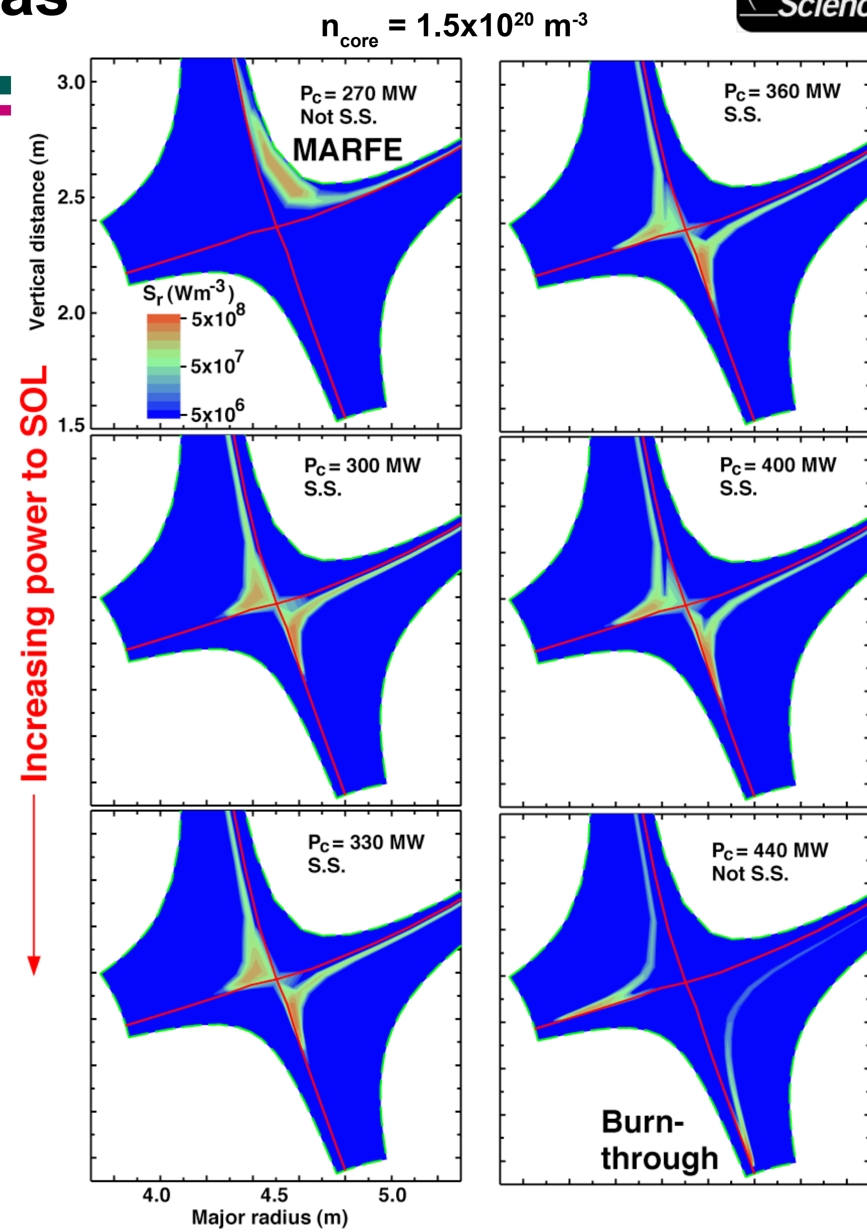
Substantial operating window exists for highly-radiating SOL plasmas

- Radiating plasma prefers high density owing to $P_{rad} \sim n_{imp} x\ n_e$
- Upper limit is burn-through to divertor plate
- Lower limit is thermal collapse of the core – a MARFE
- Fluorine/Neon impurity species



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

- 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



Heat Flux on Divertor Plates includes Contributions from Particles and Radiation

- **Base Case:**

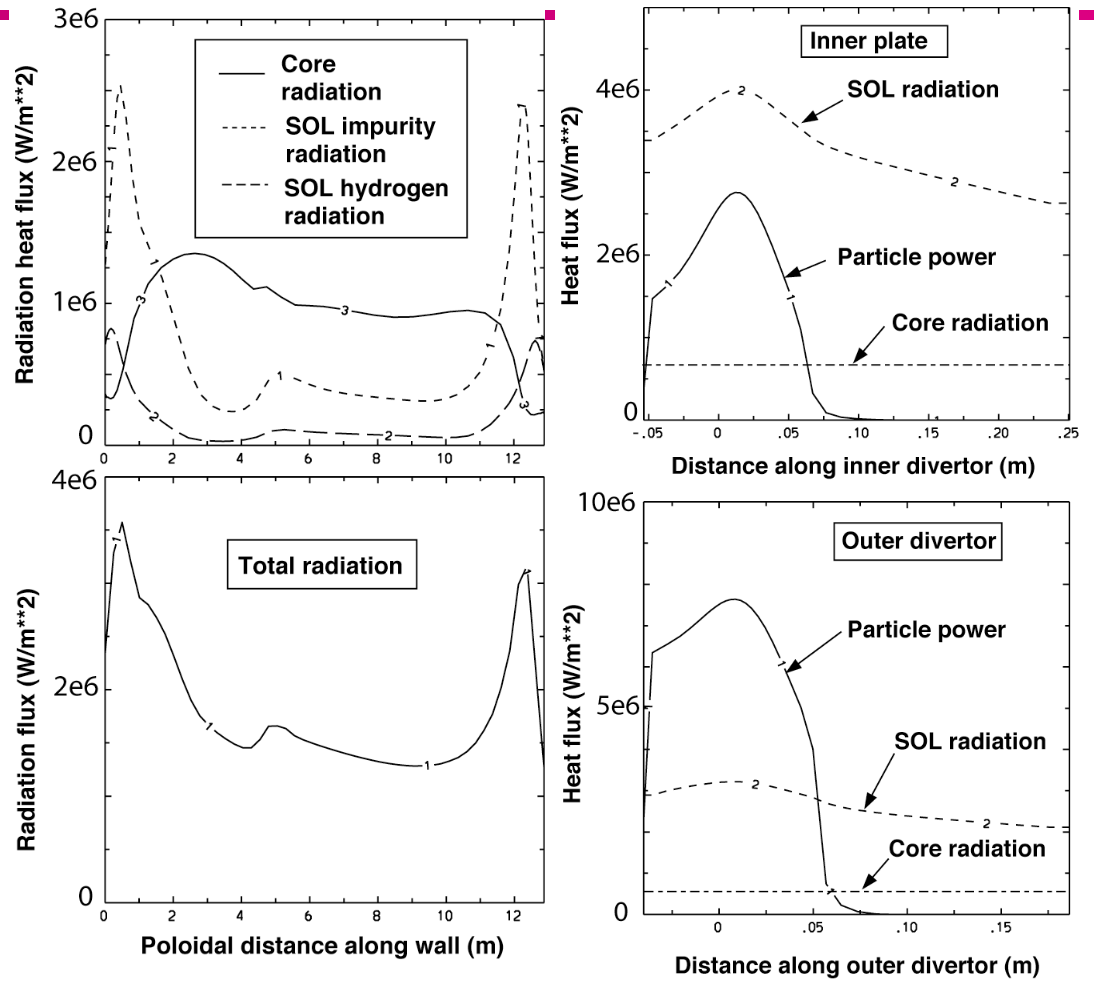
  $n_{core} = 1.5\text{x}10^{20}\ m^{-3}$

  $P_{core} = 360\ MW$

- **Particle power peaked near separatrix, depends on radial transport**

- **SOL radiation emitted isotropically, yields broad profile at plate**

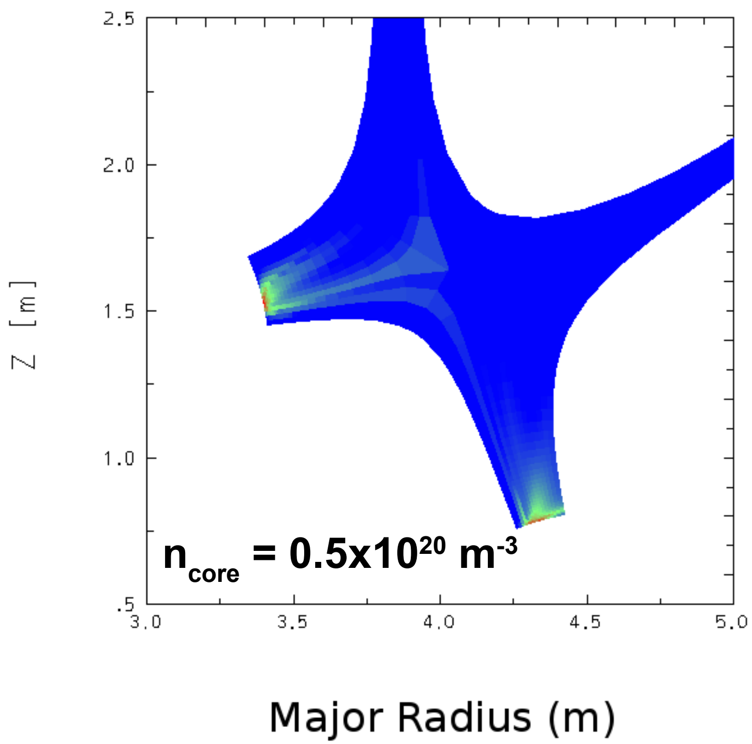
- **SOL radiation includes both hydrogenic and impurity contributions**



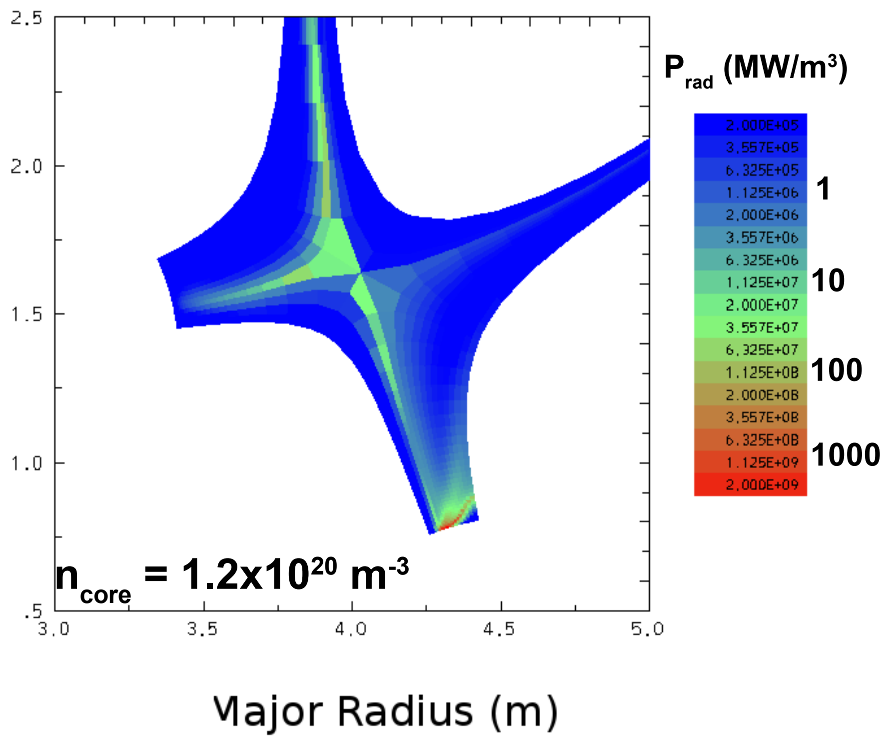
Plasma Simulations with Fixed-Concentration Impurities Exhibit Detachment in ARIES-AT Geometry

- f_{Ar} = .0006, P_{core} = 2 x 150 MW

- P_{rad} = 2 x 20 MW
- inner leg attached



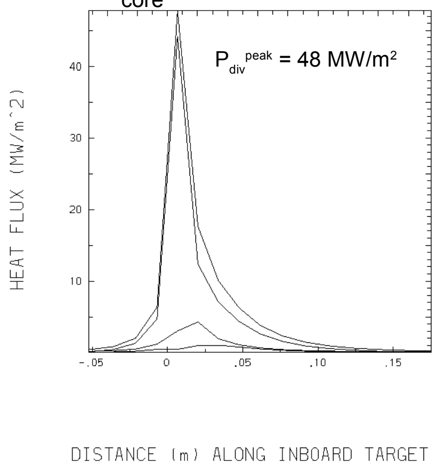
- P_{rad} = 2 x 70 MW
- inner leg detached



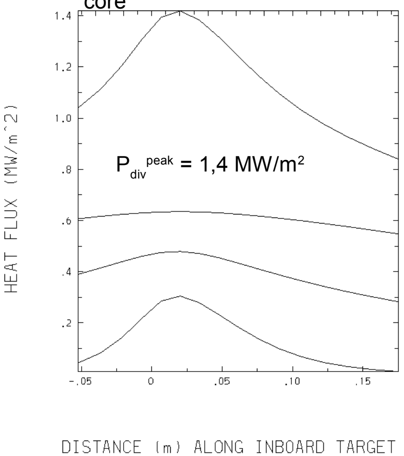
Fixed-Concentration-Impurity Model Simulations (cont'd)

Heat flux on detached inner divertor plate is reduced and broadens

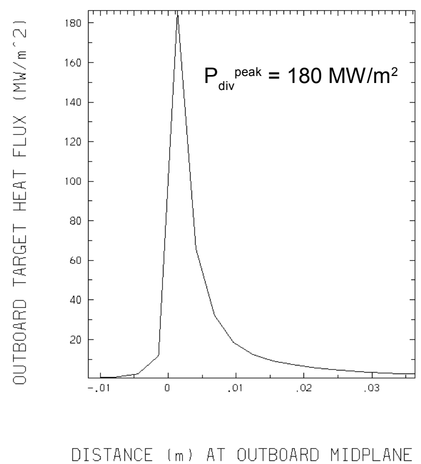
$n_{core} = 0.5 \times 10^{20}\ m^{-3}$



$n_{core} = 1.2 \times 10^{20}\ m^{-3}$



- Heat flux on outer divertor plate (mapped to midplane)
  - simulation (atdnbot23) λ_{pow} = .005 m
  - ARIES heat flux scaling (systems code case 91) λ_{pow} = .004 m



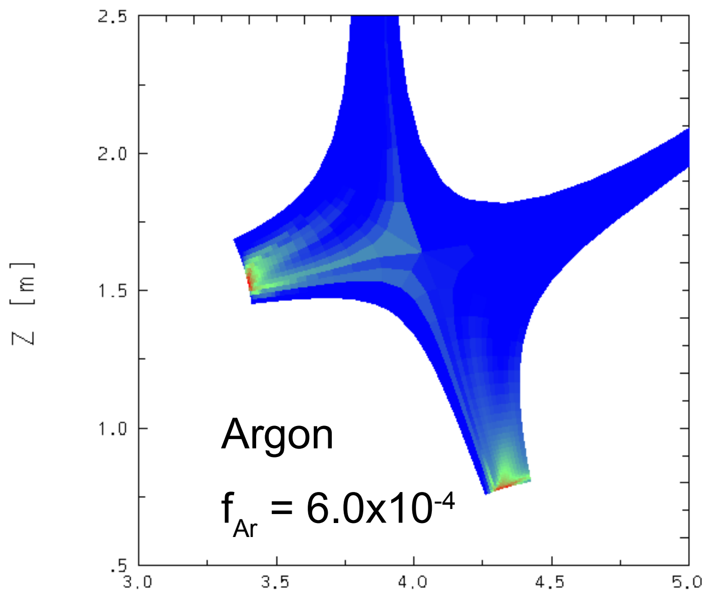
Divertor Radiation Varies with Impurity Species

- Pcore = 2 x 150 MW
- same $Z_{eff,core}$

$P_{rad,z}$ = 2 x 20 MW

$P_{rad,h}$ = 2 x 8 MW

$P_{div,in}$ = 24 MW, $P_{div,out}$ = 90 MW



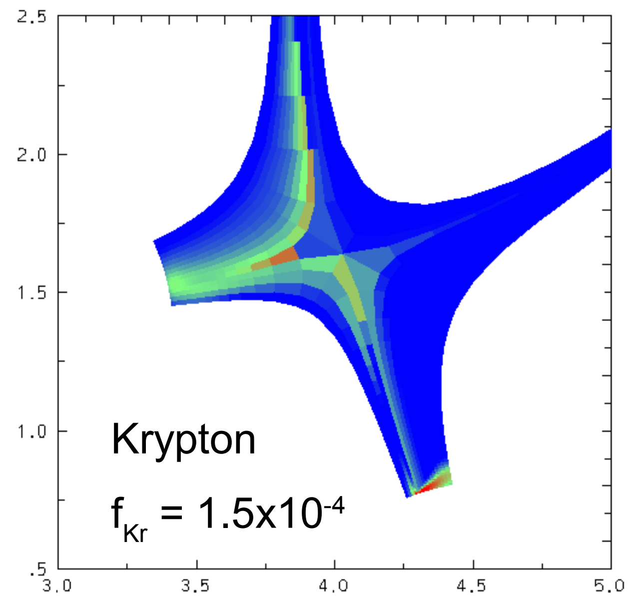
$P_{div,out}^{peak}$ = 185 MW/m²

R [m]

$P_{rad,z}$ = 2 x 90 MW

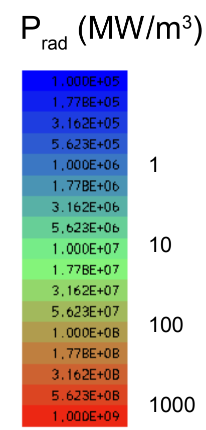
$P_{rad,h}$ = 2 x 17 MW

$P_{div,in}$ = 1 MW, $P_{div,out}$ = 46 MW



$P_{div,out}^{peak}$ = 120 MW/m²

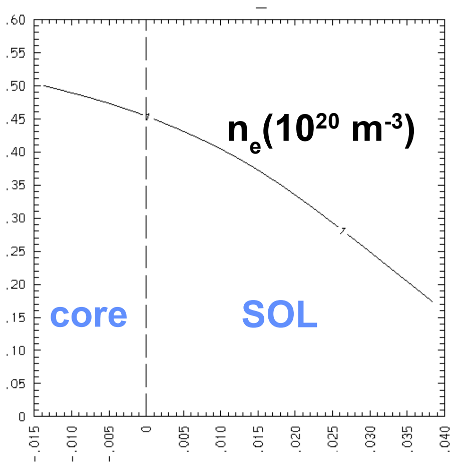
R [m]



Mantle Radiation Modeling Requires More Detailed H-Mode Pedestal Profiles

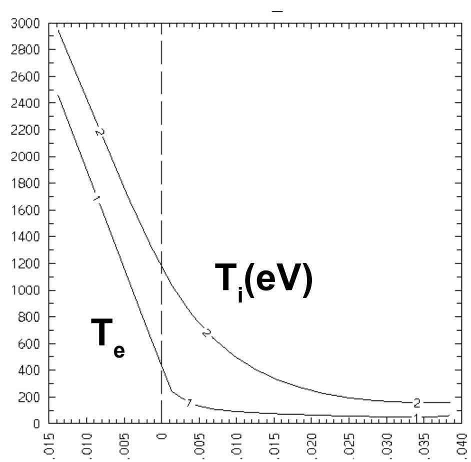
- **Low edge T_e desirable for strong radiation, but may degrade H-mode**

- **Only thin layer of mantle region is included in preliminary cases**



Distance (m)

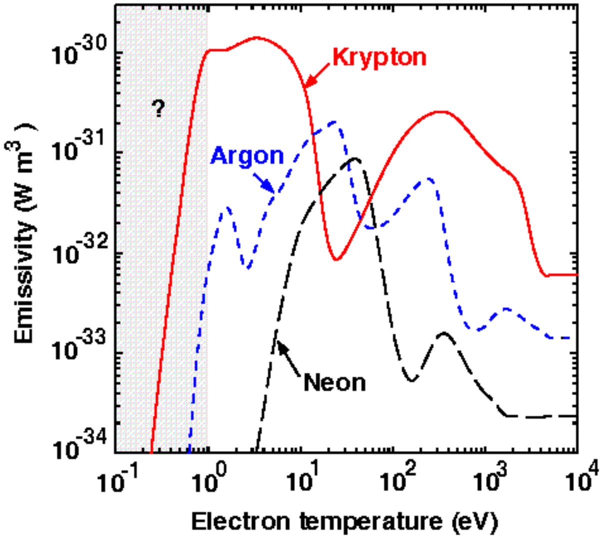
at Outboard Midplane



Distance (m)

at Outboard Midplane

- **Emissivities are sensitive to T_e**



Summary

- **Simulations demonstrate high radiative fraction in SOL-divertor**
  - Operating window in n_{core} and P_{SOL}
  - Detached plasma
- **Spatial distribution of radiation could be a problem**
  - Radiation localized near divertor plate unless detached
  - Detached ionization front tends to x-point MARFE
- **Detached plasma might work**
  - Pumping may be needed for stability
  - Not well understood or explored