Exploring Capability to Calculate Heat Loads on Divertors and Walls

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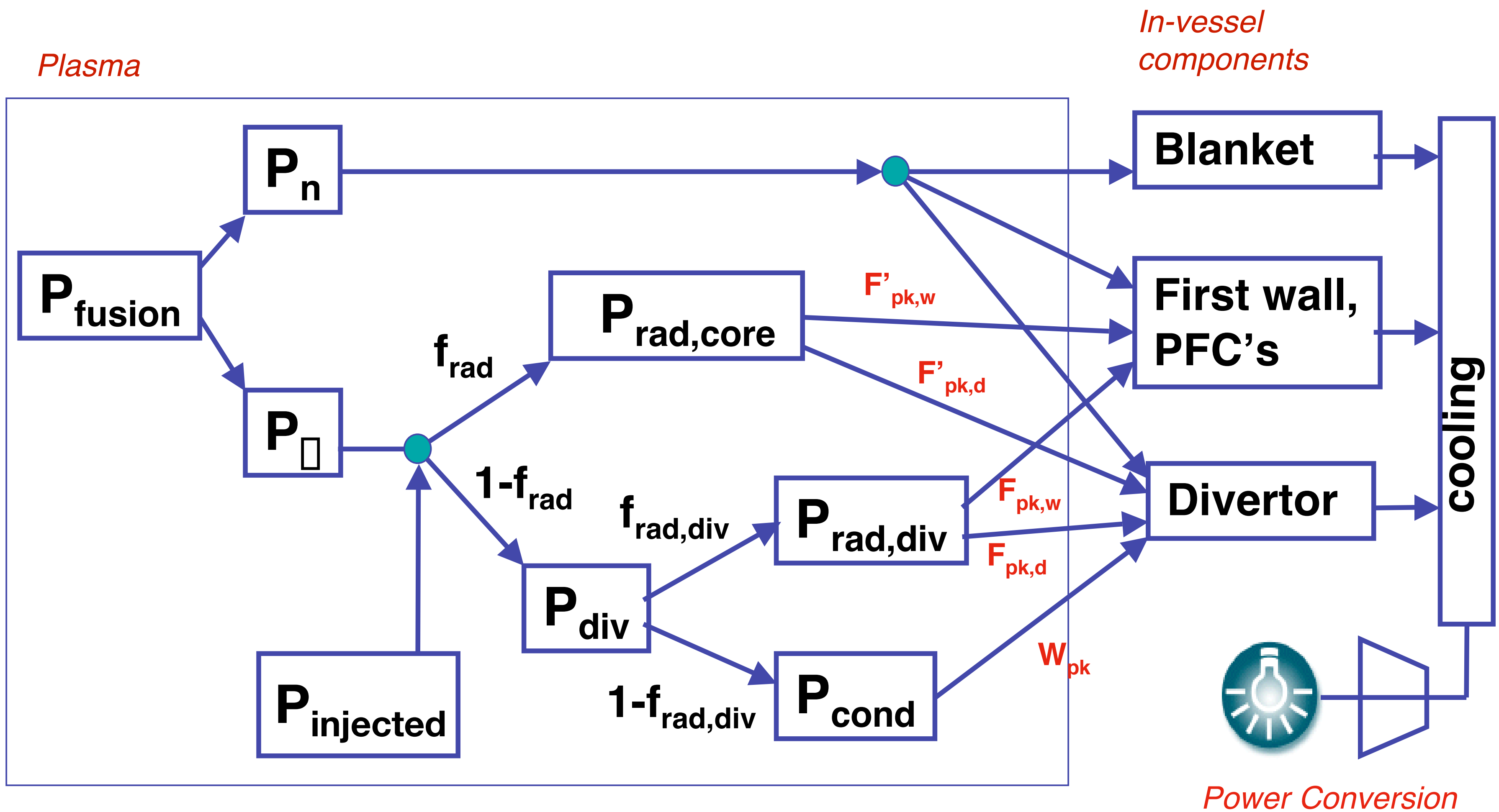
Need for Heat Load Analysis Tool in Power Management and Plant Operation

- Power and particle handling is a key element in the power management and plant operation consideration for the ARIES Pathways Study.
- Peak heat loads on PFCs (divertor targets, first wall) are empirical output parameters from the system code that have implications for target/wall engineering design and material/coolant selection.
- Edge plasma physics determines the distribution of particle heat and radiation fluxes to the target/wall, with or without impurities.
- To validate divertor heat load empirical scalings used in the system code, and to help design the next-step device, we need state-of-the-art physics analysis tools
- Propose to acquire the capabilities for the ARIES project to evaluate self-consistently the particle and radiation heat loads on the PFCs, using ARIES-AT as a starting point.

What are the Quantities We Want to Calculate?



- Particle peak heat loads on divertor plates (W_{pk})
- Radiation peak heat loads on first wall and divertor plates that originate from core and SOL/divertor region (F_{pk}'s)

Codes that We May Require

- For heat loads that originate from SOL/Divertor regions,
  - 2D plasma edge physics code + neutral and radiation transport
- For heat loads that originate from the plasma core, including edge radiating mantle,
  - 1-D Impurity transport code + heat load calculation for individual first wall design

The UEDGE Edge Physics Code

- There are three codes, B2-Eirene, EDGE2D and UEDGE, that have very similar capabilities. These all solve the multi-species plasma fluid transport equations in the SOL, coupled with a Navier-Stokes model for neutral, and an impurity transport and line radiation package.

- We choose to work with the UEDGE code, for the following reasons:
  - A relatively friendly code widely used and accepted in the US fusion community
  - The code is up-to-date with the latest physics developments
  - Code has existing capabilities that suit our needs
  - Well maintained by Tom Rognlien at LLNL, who is very supportive
  - Good working relation established with LLNL during ARIES-CS study
  - Familiarity with the platform and Linux cluster at LLNL
  - Sasha Pigarov at UCSD can provide occasional local support and advice

- However, it will take a while to become fully proficient with the workings of the code. Some consultation with LLNL will help.

Regions in Tokamak Poloidal Cross Section for Divertor Analysis

Boundary conditions are set in between various regions.

UEDGE solves set of equations in all regions except the core.

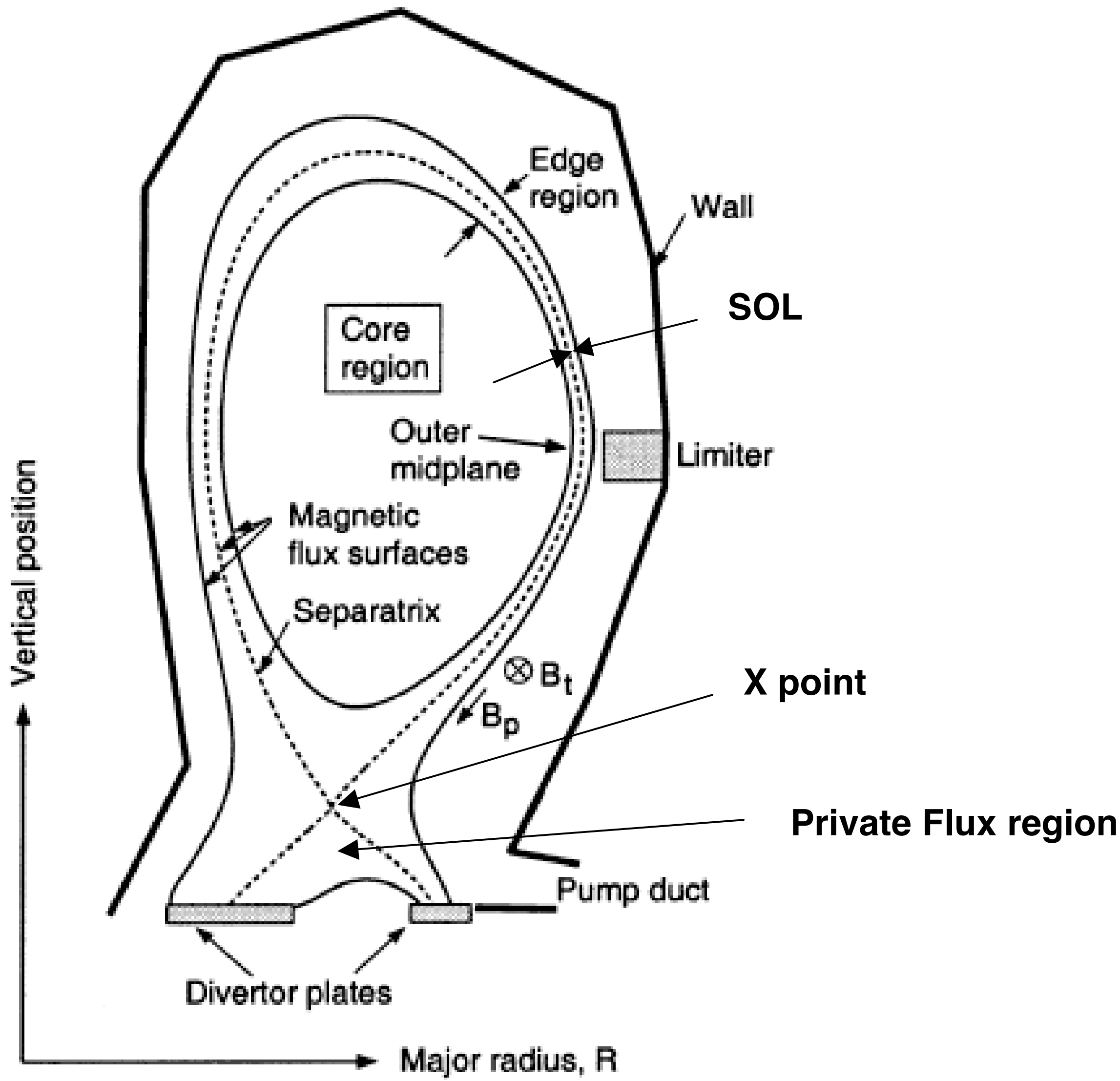


Fig. 1. The poloidal cross-section of a single-null divertor tokamak show various regions and boundaries.

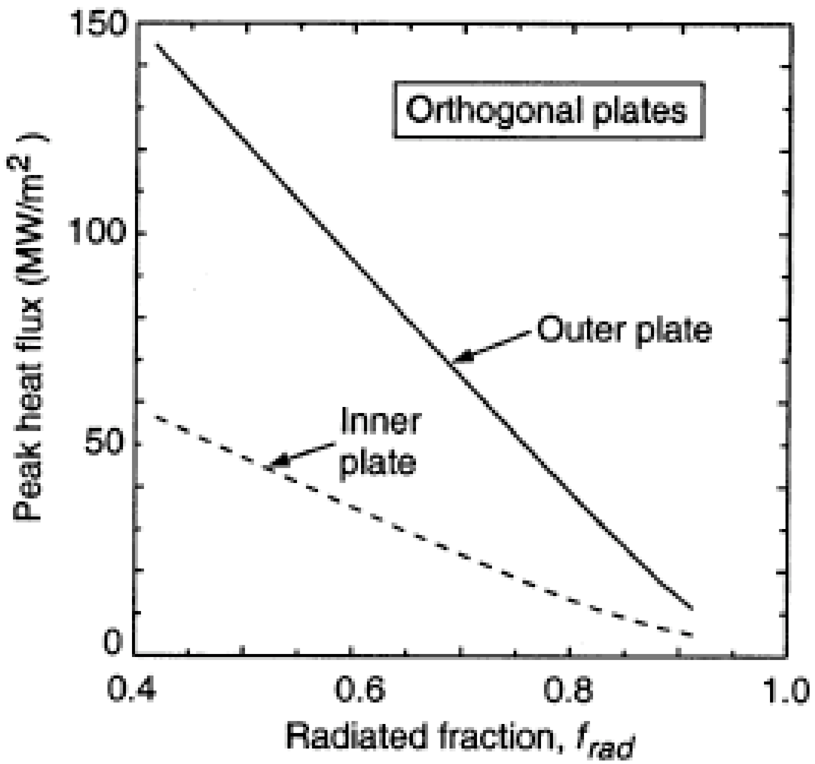
UEDGE Calculations for ARIES-AT and FIRE

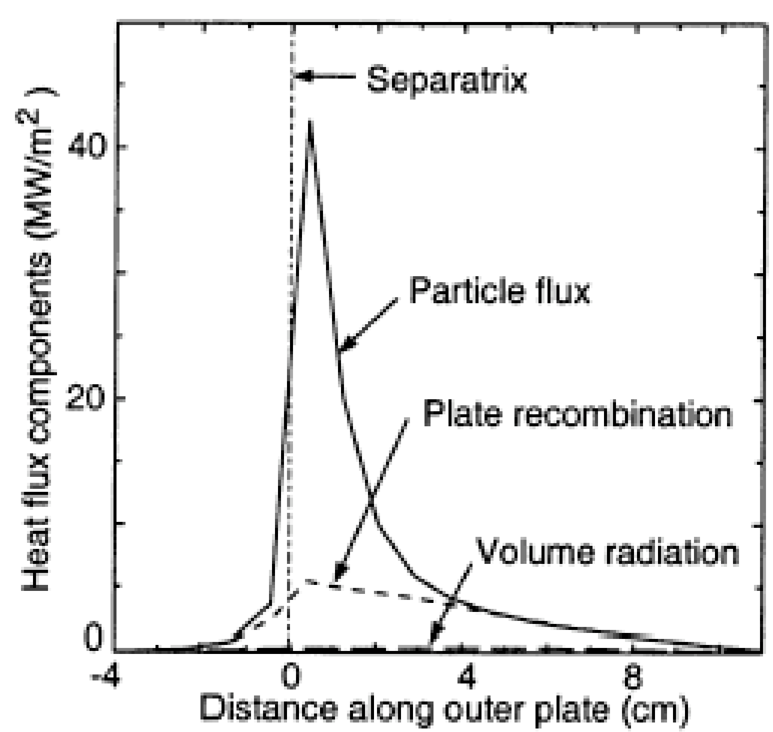
- Rognlien and Rensink have documented UEDGE calculations of heat loads for ARIES-AT and FIRE examples. [FED **60** (2002) 497]
- The parameters used are:

Parameters	ARIES-AT	FIRE
Fusion Power (GW)	1.76	-
Net heating power (MW)	343	40
Edge ion density (10^{20} m^{-3})	0.5	1.5
Particle diffusivity D (m^2/s)	0.33	0.33
Thermal diffusivity χ (m^2/s)	0.5	0.5
Surface energy trans, coeff. $\gamma_e(\gamma_i)$	4(2.5)	4(2.5)
Divertor configuration	DN	DN
Plate tilt angle at separatrix	30^o	60^o
Recycling coeff. at plate and wall	1.0	1.0
Core radiation fraction f_{rad} assumed	0.77	-
Ne injection rate (10^{20} s^{-1})	0	11.0-12.5

Heat Loads at Orthogonal Divertor Plates in ARIES-AT

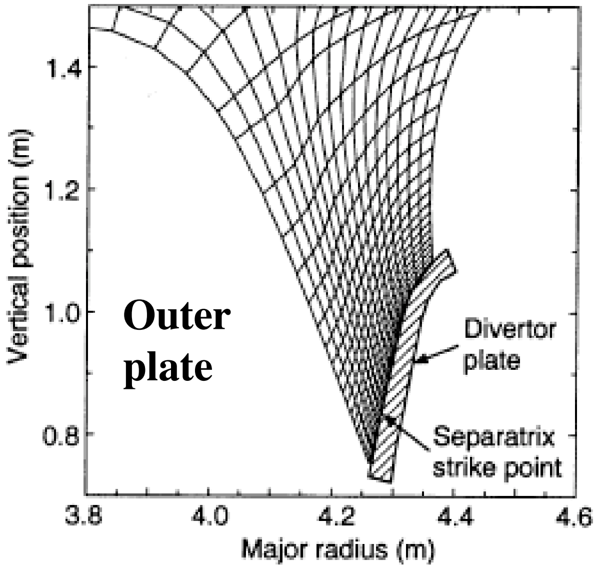
- Net particle power into SOL = 80 MW @ $f_{rad} = 0.77$
  Total peak heat flux = 47 MW/m^2 at outer plate
- **Peak heat flux is too high** (> 10 MW/m^2) for conventional targets when $f_{rad} < 0.9$
- Total heat flux at inner plate is 36% of that at outer plate because of
  - ✓ smaller surface area of outer plate
  - ✓ more closely spaced flux surfaces on the OB side
- Heat flux to OB-side (private-flux) wall is 0.1 (0.01) that of outer plate.





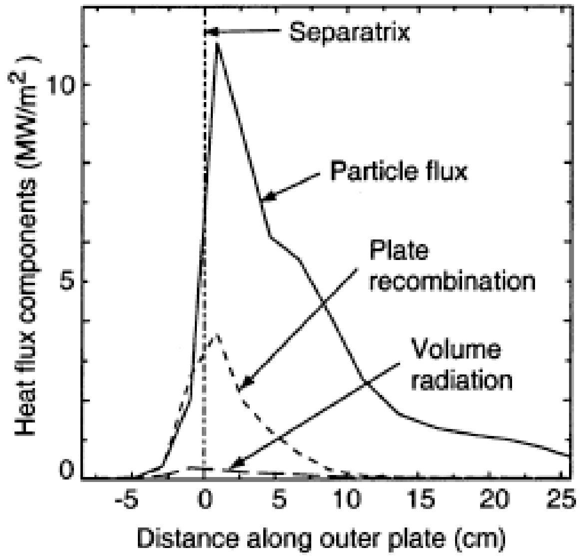
Tilted Divertor Plates (60°) Significantly Lower Heat Load

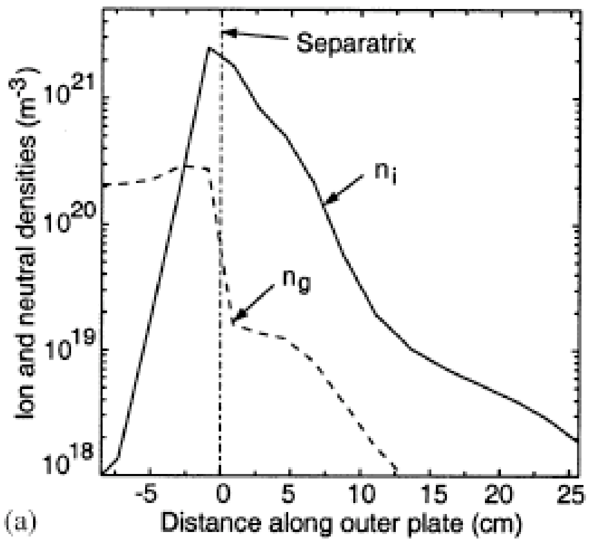
$f_{rad} = 0.77$ P_{net} into SOL = 80 MW



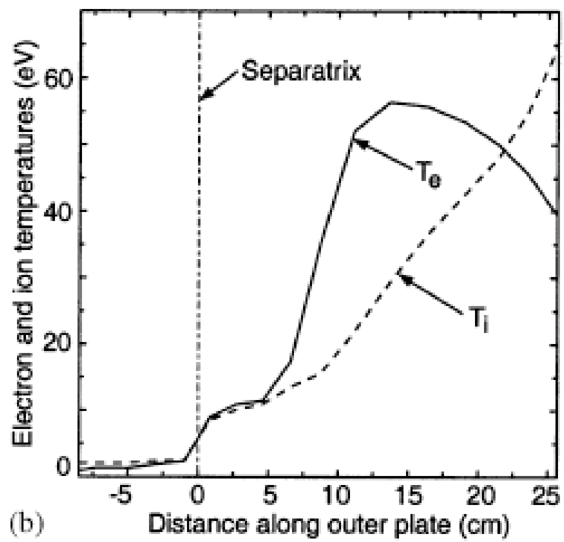
Total peak load = 15 MW/m^2

Heat flux is much lower and broader than orthogonal case.





(a)

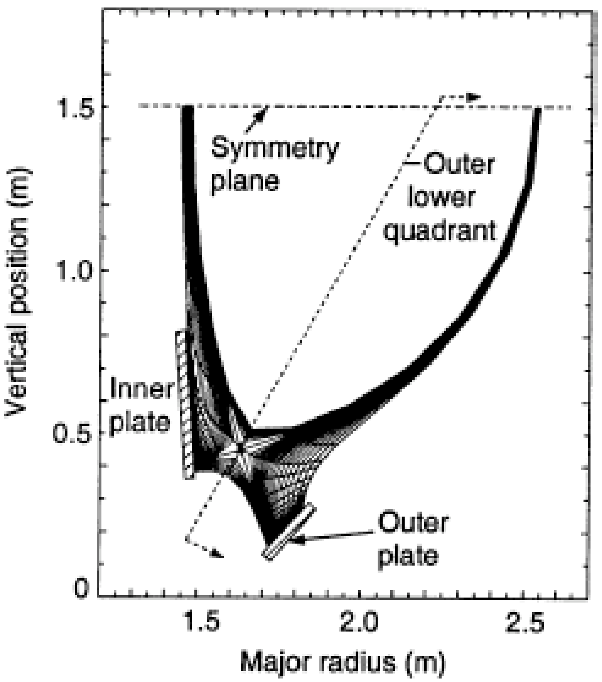


(b)

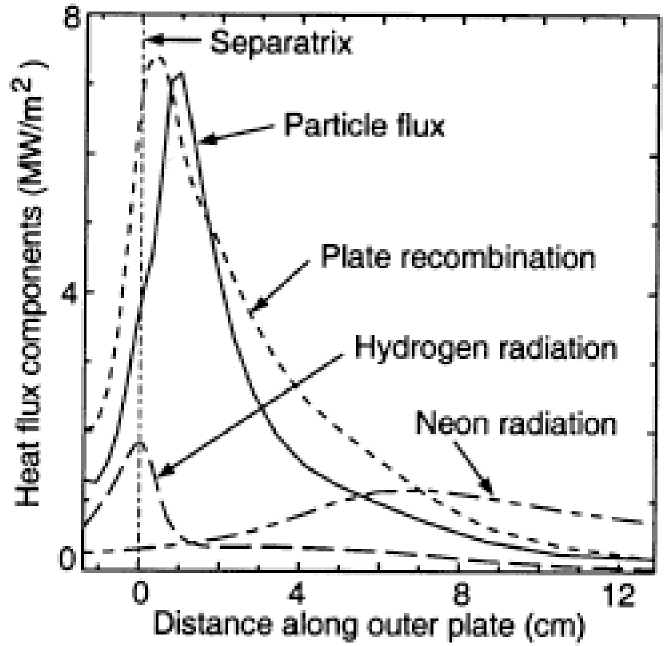
UEDGE Results for FIRE with Ne Impurity Injection

- Here Ne is injected from OB midplane and included in the calculation.
- Ne injection rate = 1.10 x 10^{21} s^{-1}.
- Peak ion density at the plate is 1.8 x 10^{22} m^{-3}.
- Heat load is equally divided between particle and radiation fluxes.

Power radiated by Ne is 7.9 MW out of 14 MW going into the SOL.



High recycling mode

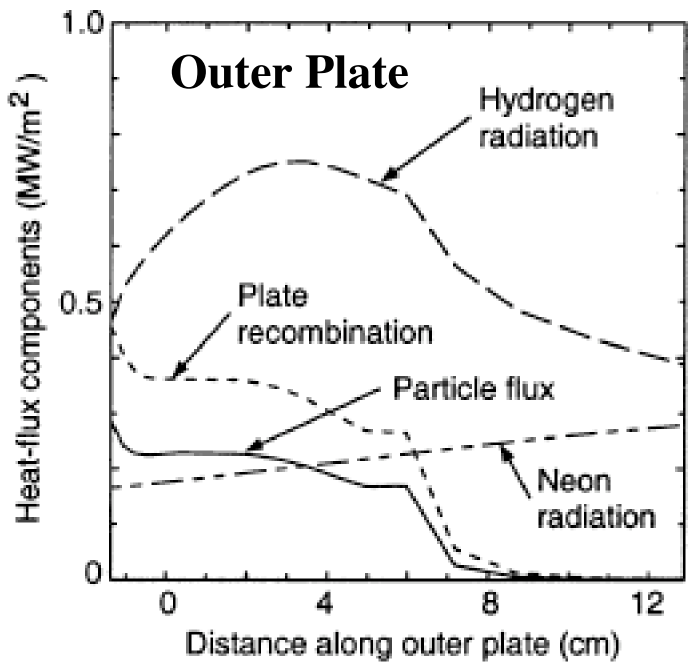


Peak heat load = 14 MW/m^2,

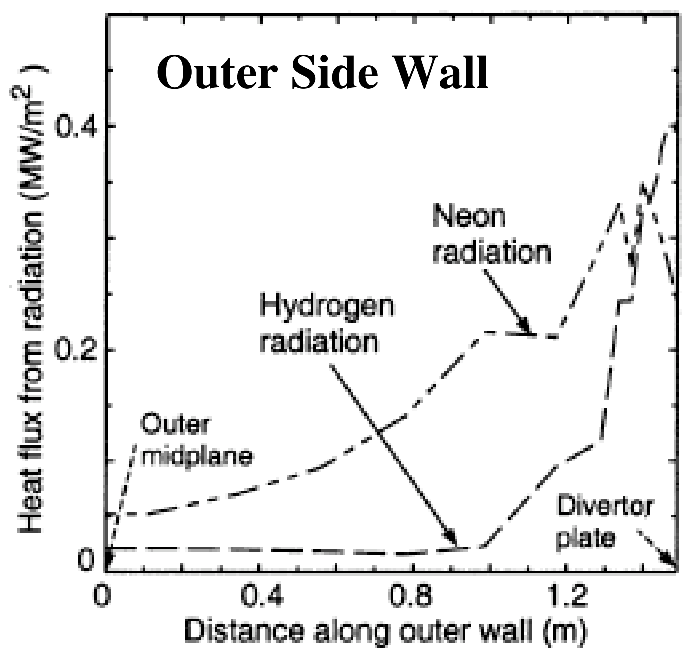
Divertor in Detached Mode with Large Ne Injection

- In this case, Ne injection rate is 1.25×10^{21} s^{-1}.
- Ionization front moves up close to X-point.
- In divertor region, $T_e \sim 1$ eV, $n_i \sim 1 \times 10^{21}$ m^{-3}, and $n_g \sim 7 \times 10^{21}$ m^{-3}.
- Almost all power into SOL is radiated by Neon and hydrogen.
- Substantial radiation heat flux in private flux region: 0.5 - 1.5 MW/m^2.

Peak heat flux = 1,5 MW/m^2.



Peak heat flux = 0.7 MW/m^2



Calculation of Core Radiation Heat Loads

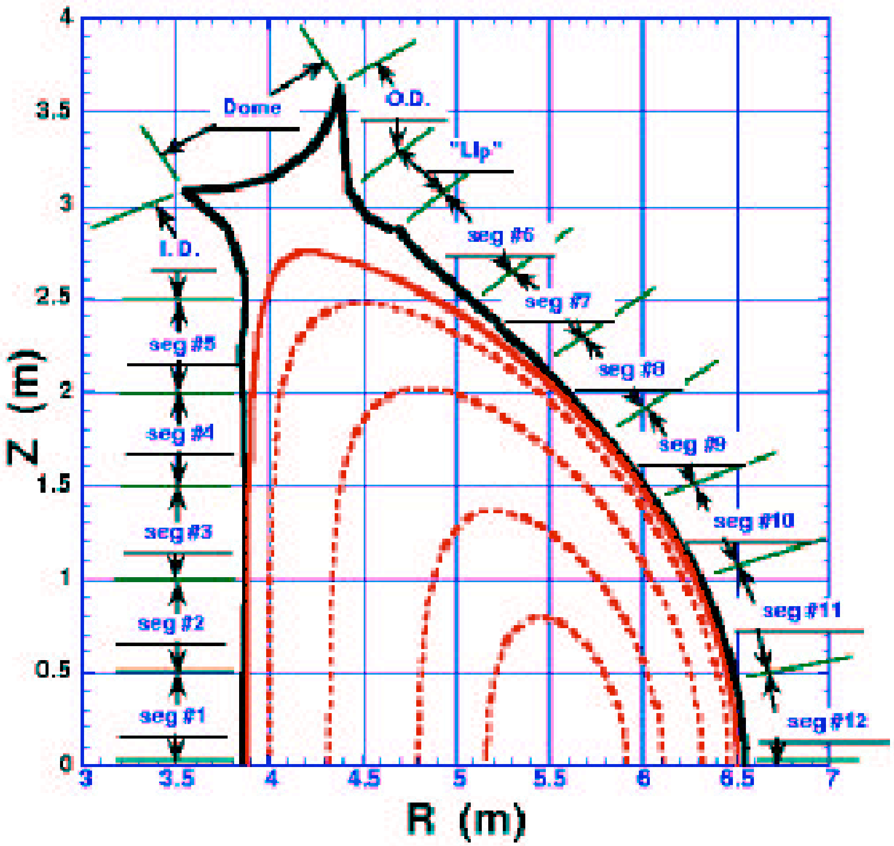
- Core radiation (including Bremstrahlung and line) can be calculated using the multi-species, multi-charge-state impurity transport codes:
  - MIST: anomalous transport for all species
  - STRAHL: neoclassical transport for ions inside transport barrier and anomalous elsewhere

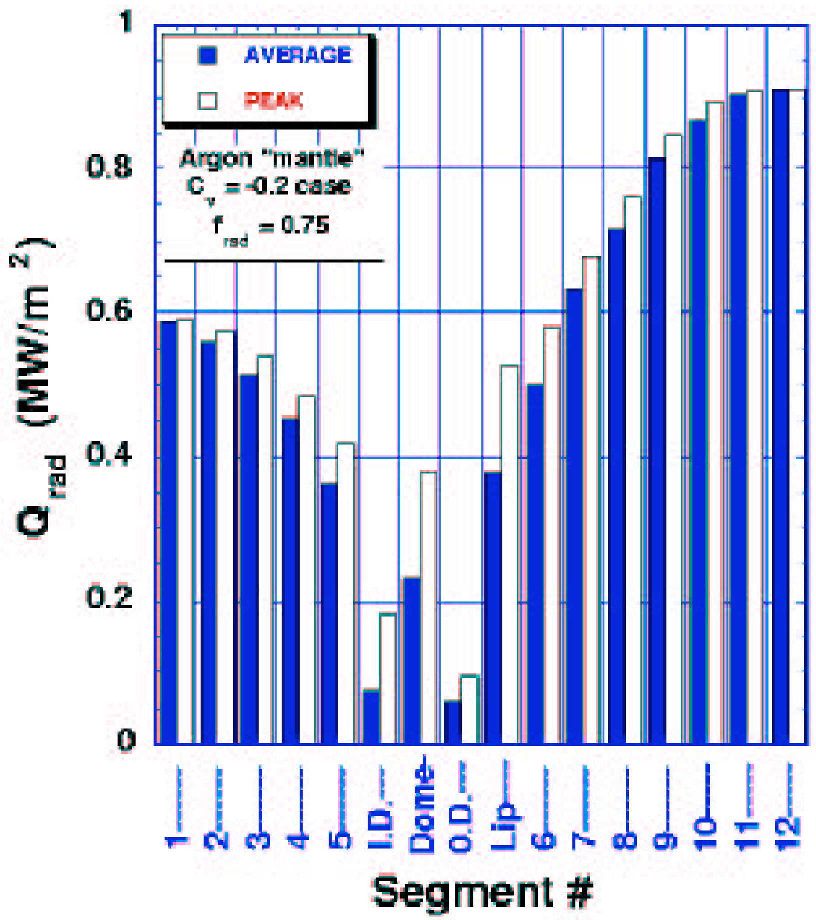
- Using core radiation sources, we calculate the first wall heat load using the code RADLOAD.

- These codes have been used by the GA Group for the ARIES-AT design studies and results were reported in FED paper.

MIST/RADLOAD Result for an Ar Radiating Mantle with f_{rad} = 0.75 for ARIES-AT

- Peak heat load on first wall is 0.9 MW/m^2 on OB mid-plane.





Progress of Work with UEDGE

- A working, up-to-date version of UEDGE exists on the Linux cluster at LLNL. Tom Roynlien is the curator of the code.

- Have worked with Tom to do some simple runs with sample input packages, in particular, with a D3D test case.

- Sample runs include setting up UEDGE grids, 32x16, using data set that are known to work. Code runs to end without problem.

- Varied some input parameters to see how results vary.

- Really need to make a short trip to LLNL to get familiarized with post-processing the results for graphic display.

Summary and Conclusions

- It is important to self-consistently evaluate the distribution of heat loads on the divertor plates and first wall for power management in the ARIES Pathway studies.

- We choose to use the UEDGE code to calculate heat loads for power fluxes originating in the SOL and divertor region. This code has been demonstrated to yield heat loads on plates and surrounding walls that are consistent with parameter variations, for ARIES-AT and FIRE.

- Heat loads on the first walls arising from the core (and radiating mantle) can be evaluated using the MIST/RADLOAD or STRAHL/RADLOAD combination. This was done in the ARIES-AT study.

- Work on exercising the UEDGE code for the ARIES Pathway project is on-going. Closer consultation with LLNL will be very helpful in producing useful results soon.

Future Work

- Work with Tom Roynlien to restore the UEDGE cases for ARIES-AT.
- Set up the files to run ARIES-AT case with impurity injection, i.e., include impurities in UEDGE calculations.

  What impurities will be relevant for ARIES-AT?

  Emissivity data available?
- In longer term, try to run variations from ARIES-AT. Need a way to create corresponding input EQDSK files.