Combined Onion-Skin Method, OSM, and EIRENE Modeling of the DIII-D Edge

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Summary

- Density control via pumping is required to obtain adequate non-inductive current drive in Advanced Tokamak plasmas
- The effectiveness of the pump is dependent on the transport of neutral particles into the pumping plenum
- For the lower outside pump on DIII-D, it has been shown that this transport can be well estimated using a simple First-Flight Neutral Model, F-FNM [1]
- A complimentary study has now been carried out using the EIRENE Monte Carlo neutral code in combination with a DIVIMP Onion-Skin Method, OSM, plasma model
- When the outer strike point, OSP, is located close to the plenum entrance, both OSM+EIRENE and the F-FNM agree closely with experiment
- As the strike point moves further from the entrance, the F-FNM progressively underestimates the plenum pressure, while OSM+EIRENE maintains agreement

Importance of neutral hydrogen

- The location of ionization can control whether the SOL is in the sheath-limited ($\nabla_{||}T \approx 0$) or conduction-limited ($\nabla_{||}T \neq 0$) regime.

- Energetic charge-exchange neutrals cause sputtering

- Ion-neutral friction on SOL plasma flow is involved in detachment

- Efficient coupling of neutrals to pumps is necessary to control volatile impurities such as He, e.g. using puff and pump

The particular importance of pumping

- Density control is required to obtain adequate non-inductive current drive in Advanced Tokamak plasmas

- In pursuit of its Advanced Tokamak program, DIII-D has installed 3 cryogenic pumps: one at the bottom (modeled here) and two at the top

- The plenum apertures to the pumps were designed based on estimates provided by the First-Flight Neutral Model, F-FNM

- The importance of pumping warrants reassessment using a more complete analysis

In general, we want to know…

- 2D (or 3D) distributions of D and D_2 densities and energies throughout the plasma and non-plasma volumes
- Particle and energy fluxes of D and D_2 onto all solid surfaces
- D_2 throughput of pumps and bypass leaks
- Unfortunately, much of this can not be directly measured
- Fortunately:

  All these quantities can be calculated using Monte Carlo neutral hydrogen codes, e.g. EIRENE and DEGAS

  All known atomic and molecular processes can be included

  Monte-Carlo codes are obedient bookkeepers that keep track of the cumulative effects of a very large number of basic, well-understood processes

  $\therefore$ they should be reasonably reliable

EIRENE neutral code

- A Monte Carlo neutral hydrogen code developed by D. Reiter [3]

- EIRENE includes:

    1. Transport of atoms and molecules
    2. All known ionization and dissociation processes for hydrogen
    3. Surface backscattering model based on TRIM code results, and particles that are not backscattered are released according to a thermal emission model
    4. Charge exchange collisions
    5. Neutral-neutral and neutral-ion scattering collisions
    6. Thermalization processes for atoms and molecules due to wall and particle collisions

However, the validity of the output is controlled by the fidelity of the 'plasma background' - the 2D (or 3D) distributions of n_e, T_e, T_i, $v_{||}$ - which is needed as input by EIRENE

Onion-Skin Method, OSM, analysis

- Solve the 1D, along-B, plasma conservation equations using across-B boundary conditions from experiment, e.g. Langmuir probe measurements of $\mathbf{I^{+}_{sat}}$ and $\mathbf{T_e}$ across targets to produce a 2D solution

- The plasma solver is iterated with the EIRENE 2D neutral code to provide the particle, momentum and energy terms associated with hydrogen recycling

- $D_{\perp}^{SOL}$ and $\chi_{\perp}^{SOL}$: **not** required as input since the cross-field information is implicitly contained in the cross-field boundary conditions

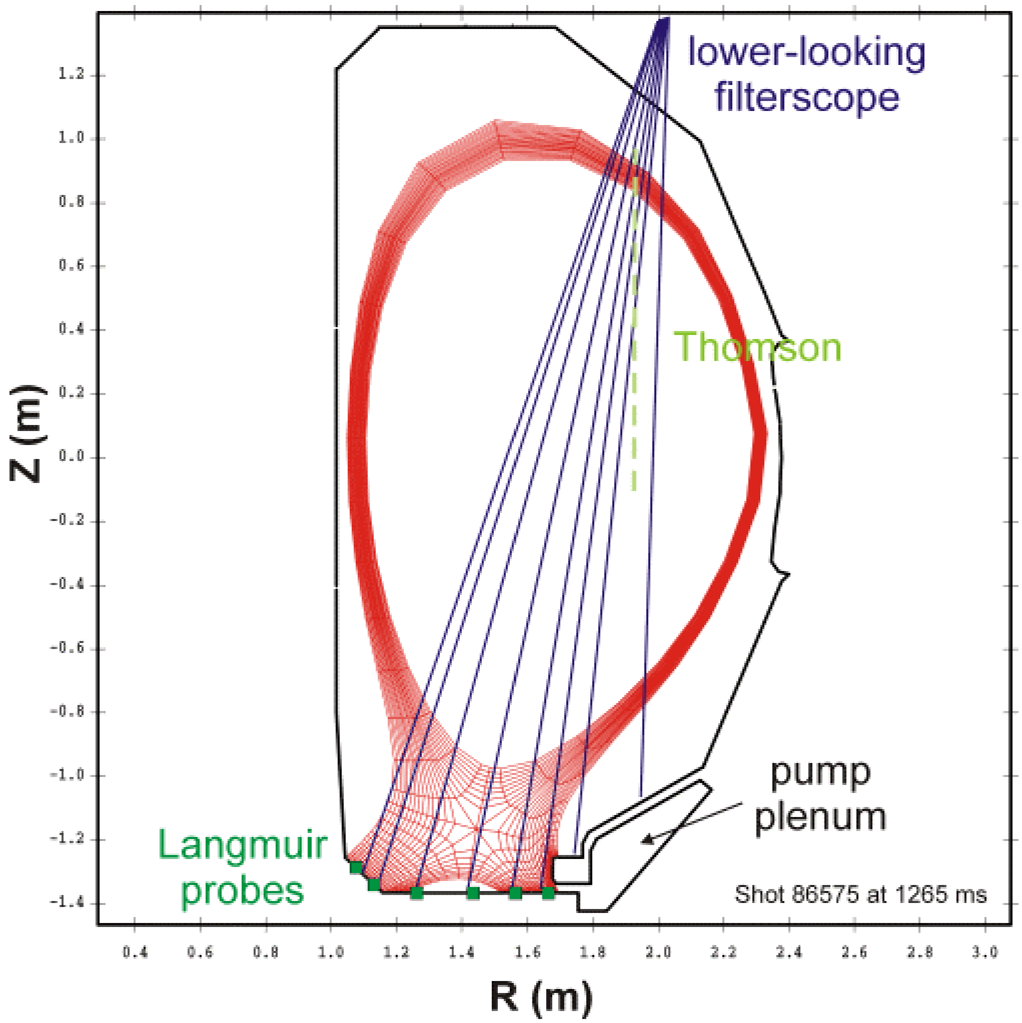
- In fact, $D_{\perp}^{SOL}$ and $\chi_{\perp}^{SOL}$ can be extracted from OSM analysis (⇒ 'Edge TRANSP')

- OSM has been tested using input (target conditions) from the EDGE2D 2-D edge fluid code [5], successfully replicating the rest of the 2-D fluid code solution

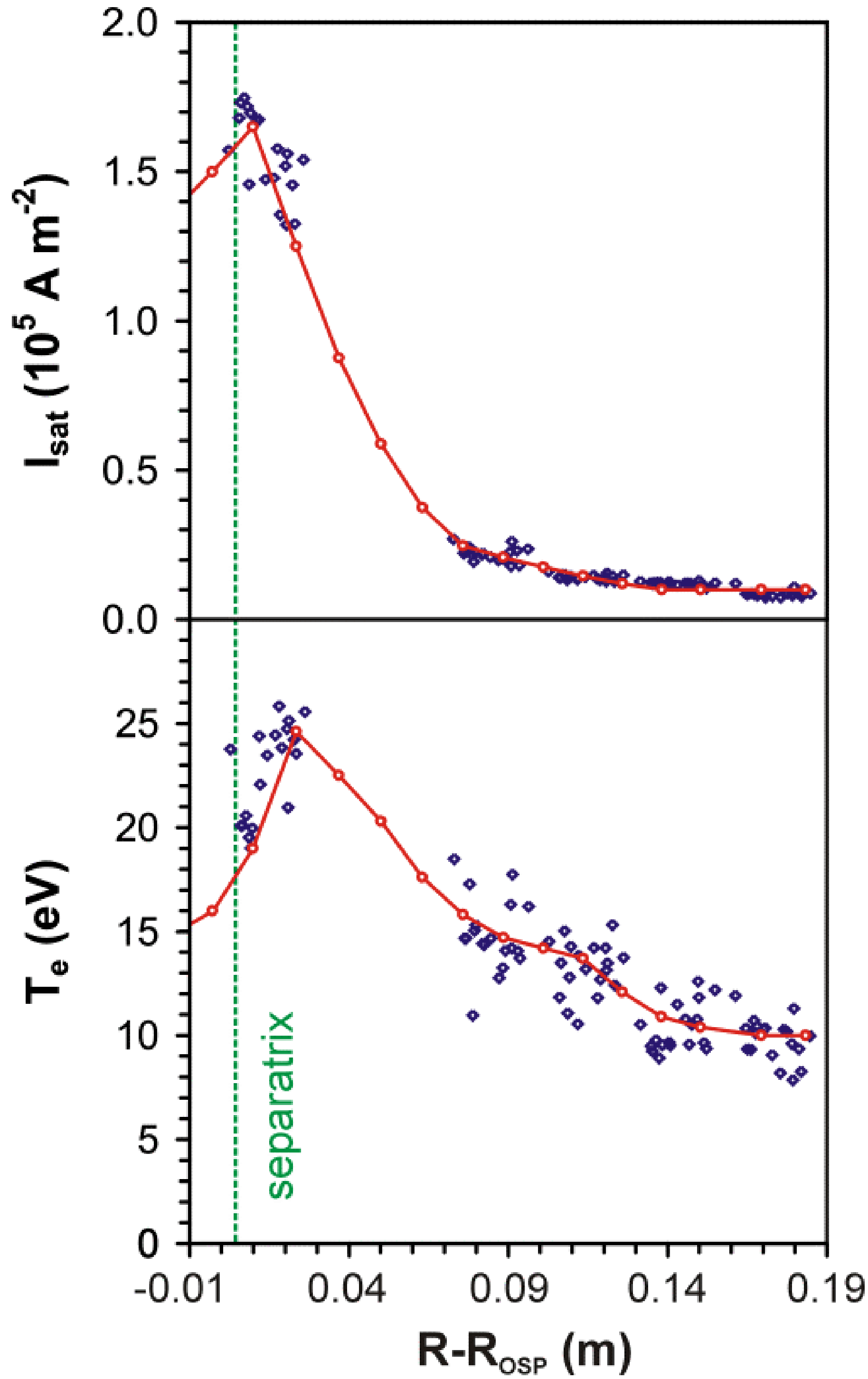
OSM+EIRENE analysis of a DIII-D L-Mod discharge

- DIII-D shot no. 86575: lower single null, L-mode, P_{NB} = 0.85 MW, $\langle n_e \rangle = 2.1 \times 10^{19}$ m^{-3}
- An array of Langmuir probes built into the divertor targets measured T_e and I^+_{sat} across the targets
- Gas pressure measured in pumping plenum
- The poloidal distribution of D_α light across the divertor was measured by a calibrated ‘filterscope’
- An Upstream Thomson Scattering System measured n_e and T_e across the SOL and main plasma
- The UEDGE 2D fluid edge plasma code (Gary Porter, Tom Rognlien[4]) was also used to model the plasma

Diagnostics and magnetic equilibrium for shot 86575



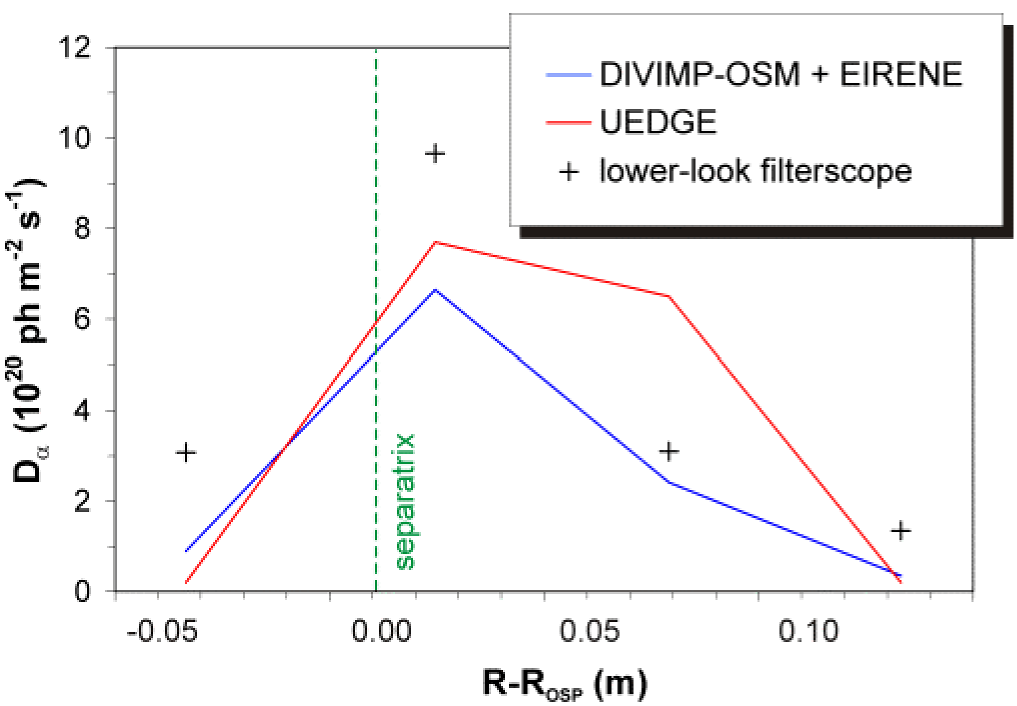
Outer target Langmuir probe data for 86575 at 1650 ms



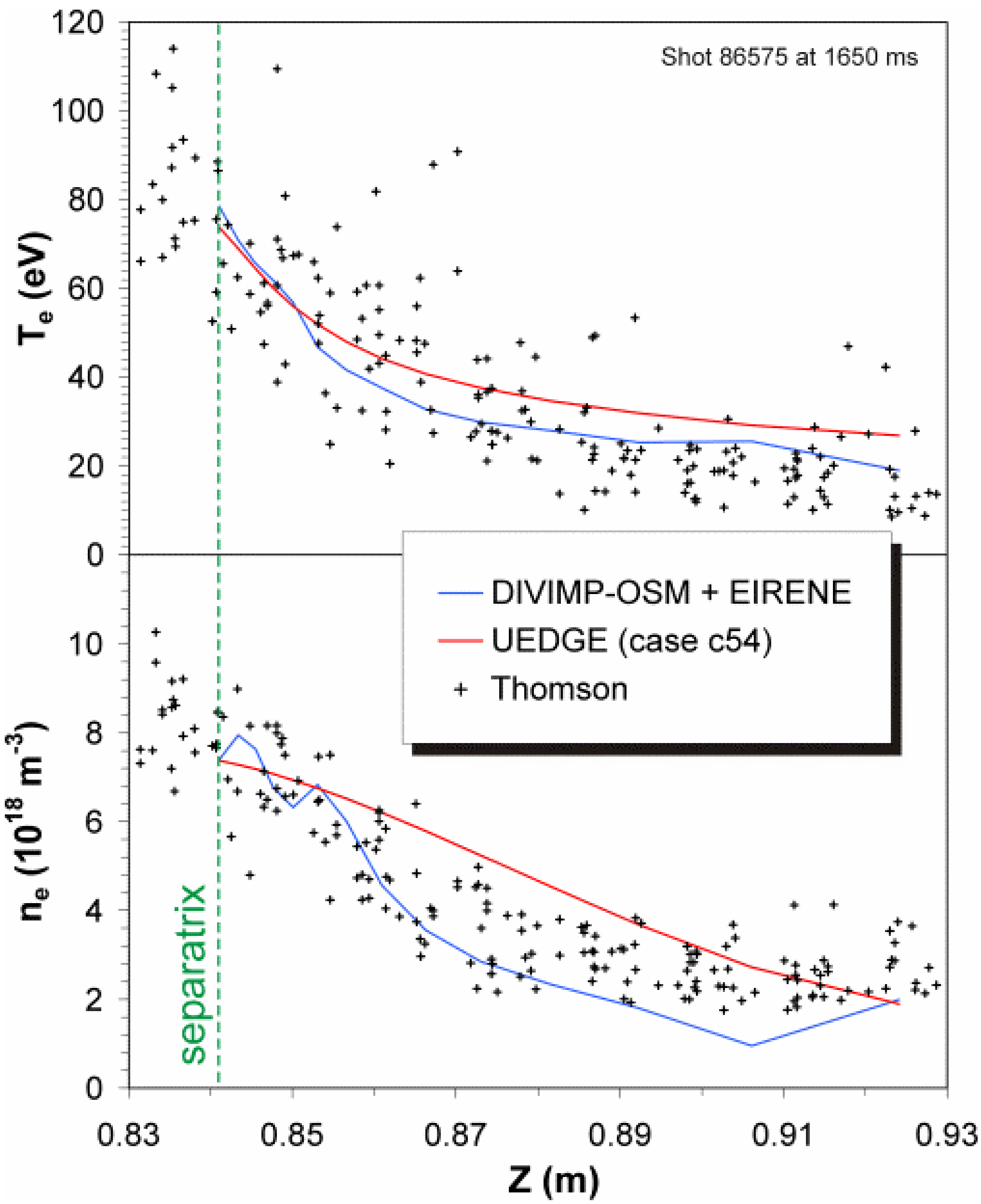
Comparison of OSM+EIRENE results with experimental measurements

- Details of comparison were presented at PSI 2000 Conference, Rosenheim, Germany

Filterscope D_α emission



Upstream Thomson T_e and n_e profiles



- The Z coordinate is measured vertically, along the line of the Thomson laser

First-Flight Neutral Model, F-FNM

- A simple, First-Flight Neutral Model has been developed to calculate the dependence of pump plenum pressure on divertor plasma parameters and the magnetic geometry [1]

- Principal model assumptions:

  1. 25% of recycled neutrals are backscattered as atoms with half the ion impact energy, and 75% as 3 eV (Frank Condon) atoms (estimates based on TRIM); isotropic spatial distribution

  2. Free-flight atoms are attenuated by ionization

  3. Plasma conditions are measured by divertor target Langmuir probes and are assumed to depend only on R (no variation with height above target, Z)

  4. No molecular transport

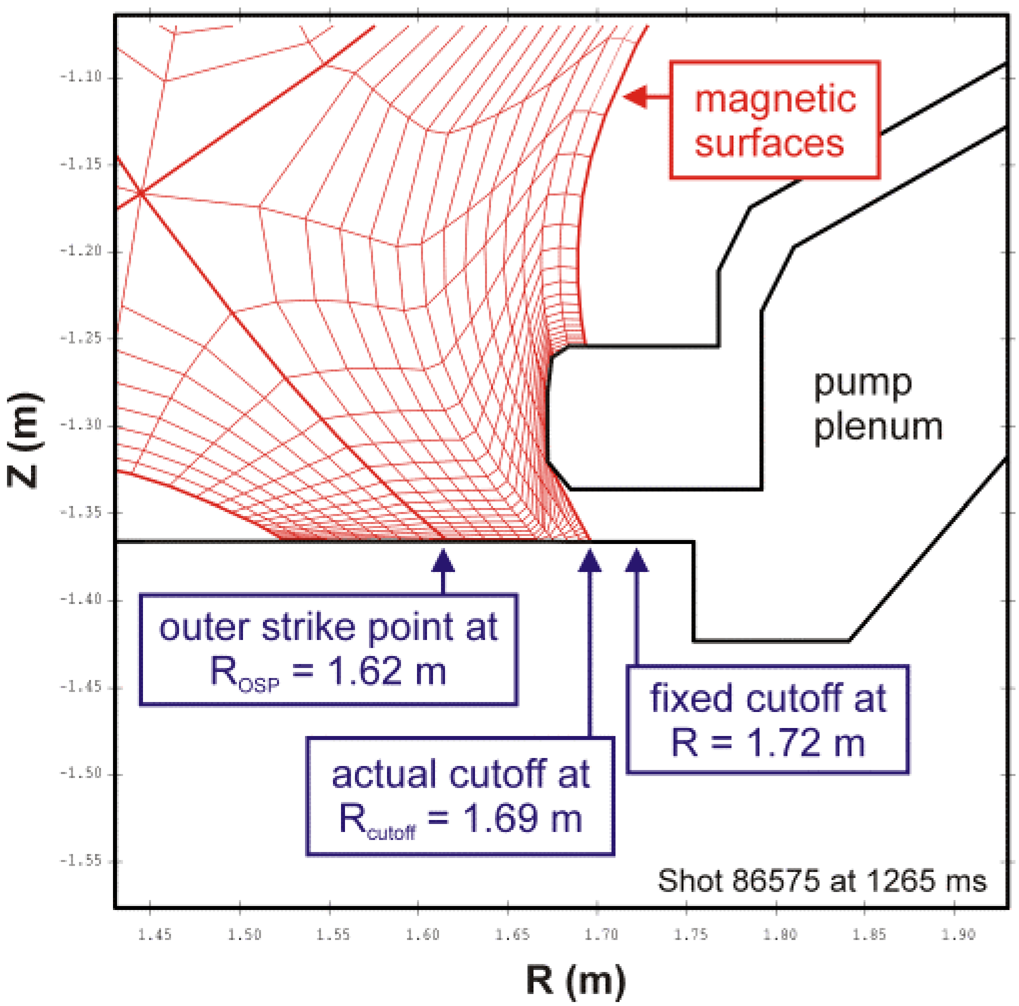
  5. No reflection from surfaces

  6. No charge exchange

  7. No atom-atom or atom-ion scattering

Penetration of the "plasma foot" into the plenum opening

- The actual penetration of the "plasma foot" into the plenum opening is dependant on the magnetic geometry, which varies with the location of R_{OSP}



The importance of the neutral source near the plenum entrance

- The plenum pressure is very sensitive to I^{+}_{sat} near the plenum entrance
- It is therefore important to take I^{+}_{sat} from **experiment**, which is the approach used in **both** the First-Flight Neutral Model and OSM+EIRENE
- Neutral flux reaching the plenum depends strongly on how far the ‘plasma foot’ penetrates into the plenum opening
- Assumption of the F-FNM in [1]: toe penetrates to R = 1.72m, independent of location of outer strike point, R_{OSP}
- The effect of this important assumption is assessed below

Calculation of plenum pressure for different values of R_{OSP}

- The divertor plasma was ‘swept’ magnetically, causing R_{OSP} to vary from 1.51 m to 1.67 m

- Fixed divertor plasma conditions

- The penetration of the toe of the plasma foot into the plenum opening, R_{cutoff}, varied with R_{OSP}:

R_{OSP} (m)	R_{cutoff} (m)
1.51	1.67
1.57	1.69
1.62	1.70
1.67	1.71

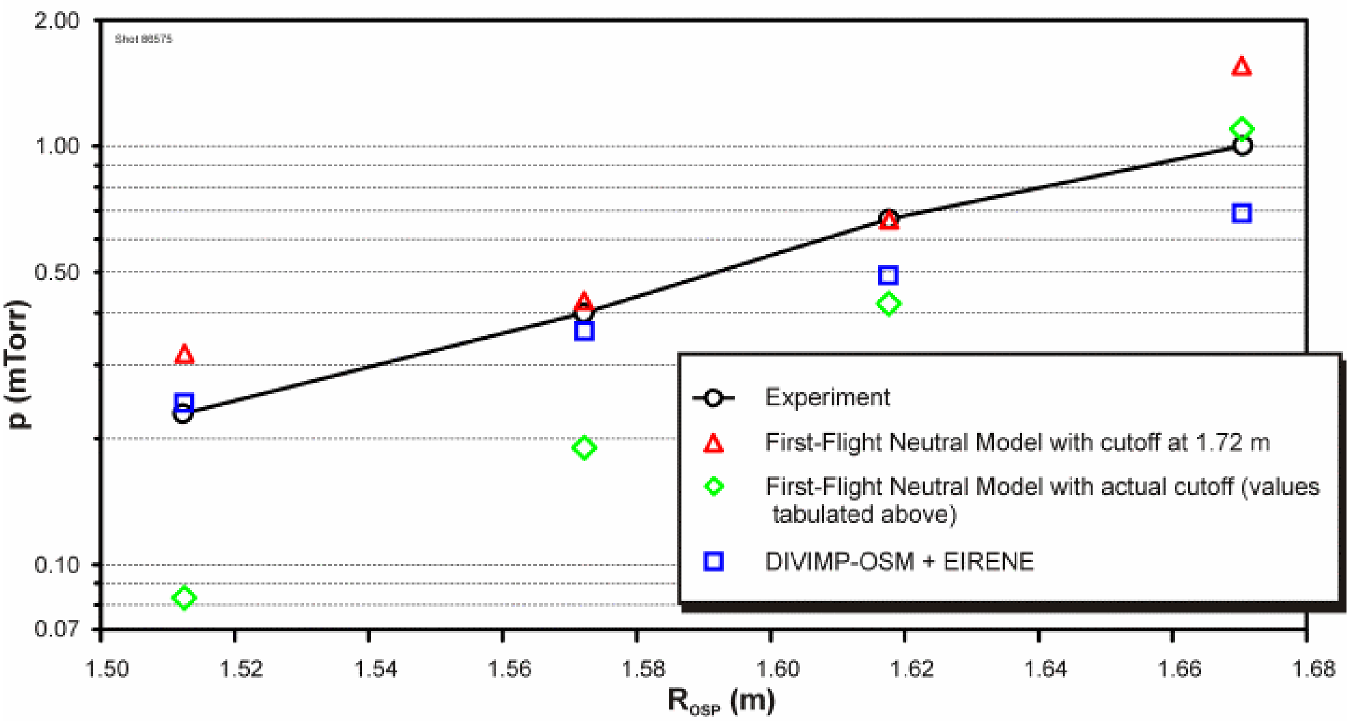
- The First-Flight Neutral Model was used to calculate the plenum pressure for both:

  1. A fixed R_{cutoff} = 1.72m, as in *Maingi et al.* [1], and

  2. The actual values of R_{cutoff}, as defined by the magnetic and plenum geometries

- The OSM+EIRENE analysis was based on the actual values of R_{cutoff}

Lower pump plenum pressure versus outer strike point location



Discussion

- When the cutoff is fixed at R = 1.72m, the First-Flight Neutral Model matches the experimental values of plenum pressure very well, a similar result to that reported by *Maingi et al.* [1] for another discharge

- When the actual cutoffs are used, the First-Flight Neutral Model does less well, although it still provides a good first estimate, particularly when the strike point is close to the plenum entrance

- The tokamak shot analyzed here is low density ($\langle n_e \rangle = 2.1 \times 10^{19}\ m^{-3}$); for higher density cases the more complete treatment may be required even for a first estimate

- The OSM+EIRENE analysis, using the actual cutoffs, matches the experimental measurements well for the full range of R_{OSP}

- Fortunately, it is not much more effort to apply the OSM+EIRENE analysis than the F-FNM analysis, and the required input is the same, i.e. the plasma profiles across the target and the magnetic plenum geometry

Conclusions

- The particle flux reaching the pumping plenum is sensitive to the precise depth of penetration of the ‘plasma foot’ into the plenum opening, and therefore it is necessary to allow for the actual cutoff of the peripheral flux tubes by magnetic and plenum geometry

- The F-FNM of *Maingi et al* [1], provides a good first estimate of the plenum pressure

- The F-FNM gives the correct general behavior, and illustrates the sensitivity of the plenum pressure to the system parameters, e.g. R_{cutoff}

- This problem can be dealt with by employing a more complete treatment of the geometry, the divertor plasma, and the neutral transport - as illustrated here using OSM+EIRENE

- For other edge studies where the details of neutral hydrogen transport are important, OSM+EIRENE analysis may also be useful

References

[1] Maingi, Watkins, Mahdavi, Owen*, Nuc. Fusion*, 1999

[2] Stangeby, Watkins, Porter, Elder, Lisgo, Reiter, West, and Whyte, PSI 2000

[3] D. Reiter, *J Nucl Mater* **196-198** (1992) 80

[4] T.D. Rognlien *et al*., *Contrib Plasma Phys* **34** (1994) 362

[5] Fundamenski *et al*., PSI 2000

Acknowledgments

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