Densification of the peripheral scrape-off layer by CD_4 puffing in JET

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1. CD_4 puffing and SOL density

CD_4 puffs at the outer mid-plane (OMP) were found to raise the peripheral SOL electron density as compared to deuterium puffs with the same deuteron rate (Fig. 1a). The integrated electron density rise was linear with CD_4 puffing rate (Fig. 1b). The effect has only been seen when the OMP gas valve and the fast reciprocating probe (FRP, see Fig.2) used to measure the electron density lie on the same flux tube.

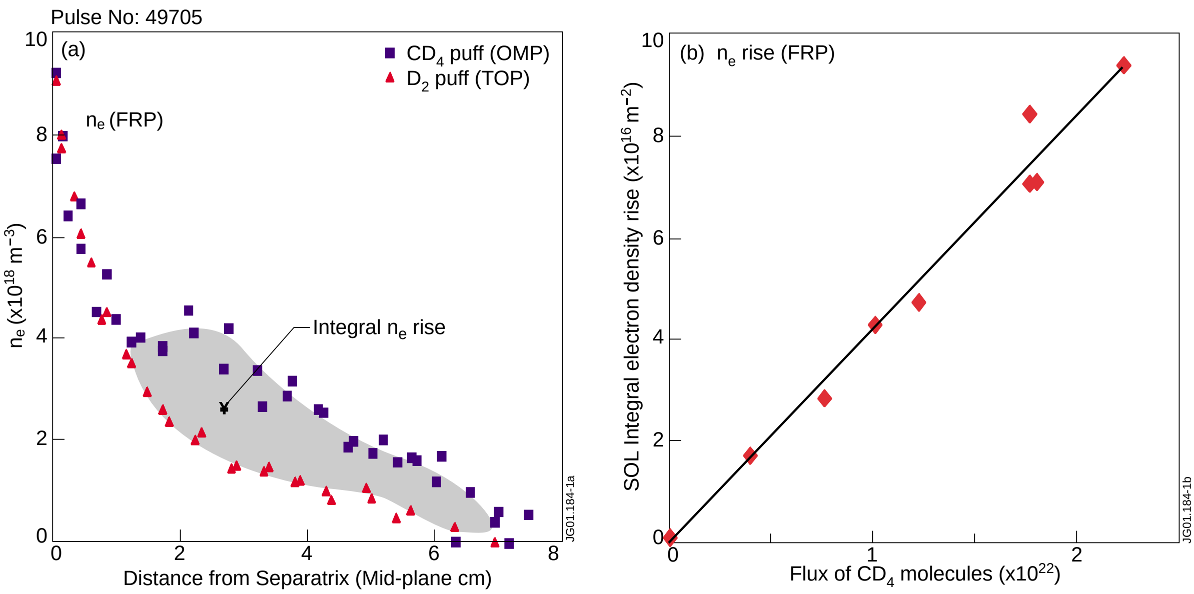

Fig. 1(a) SOL density profiles measured in an L-mode at two times: 58.4s when CD_4 is puffed from the outer mid-plane and 62.4s when D_2 is puffed from a top valve to give the same line averaged density (b) linearity of peripheral density rise with CD_4 puff rate over a series of pulses.

2. Application of CD_4 puffing to the LHCD coupling problem

Early attempts to use lower hybrid current drive in optimised shear plasmas during ITB phases were not successful due to the low plasma density in front of the antenna. Raising the density with deuterium puffing caused the ITBs to collapse. Guided by the data of Fig.1, CD_4 puffing close to the LH antenna was proposed as a solution and has produced the longest ITB phase to date, due to the reduced power reflection coefficient for LH [1].

3. Possible causes of peripheral density modification

3.1 First hypothesis - direct effect of ionisation source

Our first hypothesis was that the peripheral density rise was a direct consequence of the short ionisation mean free path of CD_4 compared to D_2 leading to a rise in the peripheral density and an increase in parallel flow.

To test this idea EDGE2D-U/NIMBUS [2] multi-fluid code simulations were carried out with arbitrary assumptions chosen to maximise the chances of reproducing the peripheral density rise due to the peripheral ionisation source:

- Wide grid (5.5cm OMP), Fig. 2
- Puff of 1×10^{21} C atoms s^{-1} (0.36eV) and 4×10^{21} D atoms s^{-1} to mimic CD_4
  D atoms arbitrarily assumed thermal
- Transport ballooning like $(B/B_{mid})^{-2}$ to give stagnation point near outer mid-plane (OMP)
- $D_{\perp C} = D_{\perp D}/3 = 0.07 m^2 s^{-1}$ (at OMP)
  - another arbitrary assumption

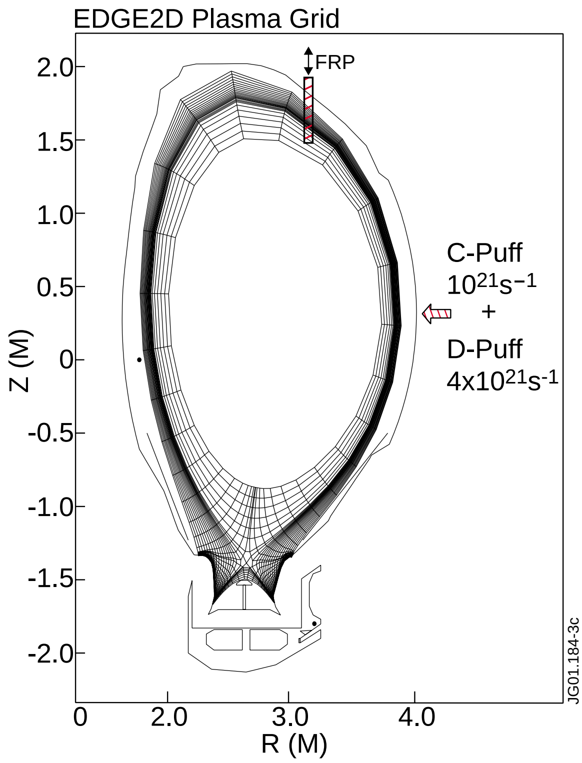

Fig. 2 EDGE2D grid used in the simulations

The EDGE2D results showed that carbon puff is ionised 1-2cm (mid-plane) from the separatrix where the density perturbation is seen in the experiment, Fig. 3a, and the carbon concentration is raised in the periphery, Fig. 3b. However, the peripheral electron density is practically unchanged, Fig. 3c, even with the unrealistic assumption that the deuterium atom puff is thermal which increases the peripheral ionisation. In the code calculation, the additional particle sources are exhausted by a rise in the parallel flow to the divertor, Fig. 3d.

3.2 Second hypothesis – A rise in SOL transport

EDGE2D simulations indicated that, even with favourable assumptions, carbon and deuterium sources associated with CD_4 puffing can not explain the peripheral density rise so we turned to another possibility - that our assumption of constant radial transport between the two cases is incorrect. Measurements of radial transport due to **E**×**B** micro-turbulence were available from the probe that measured the peripheral density rise [3]. The key results are:

- The turbulent radial flux increases with CD_4 puffing
- Implied $D_\perp$ is increased in CD_4 ionisation zone - see Fig. 4.

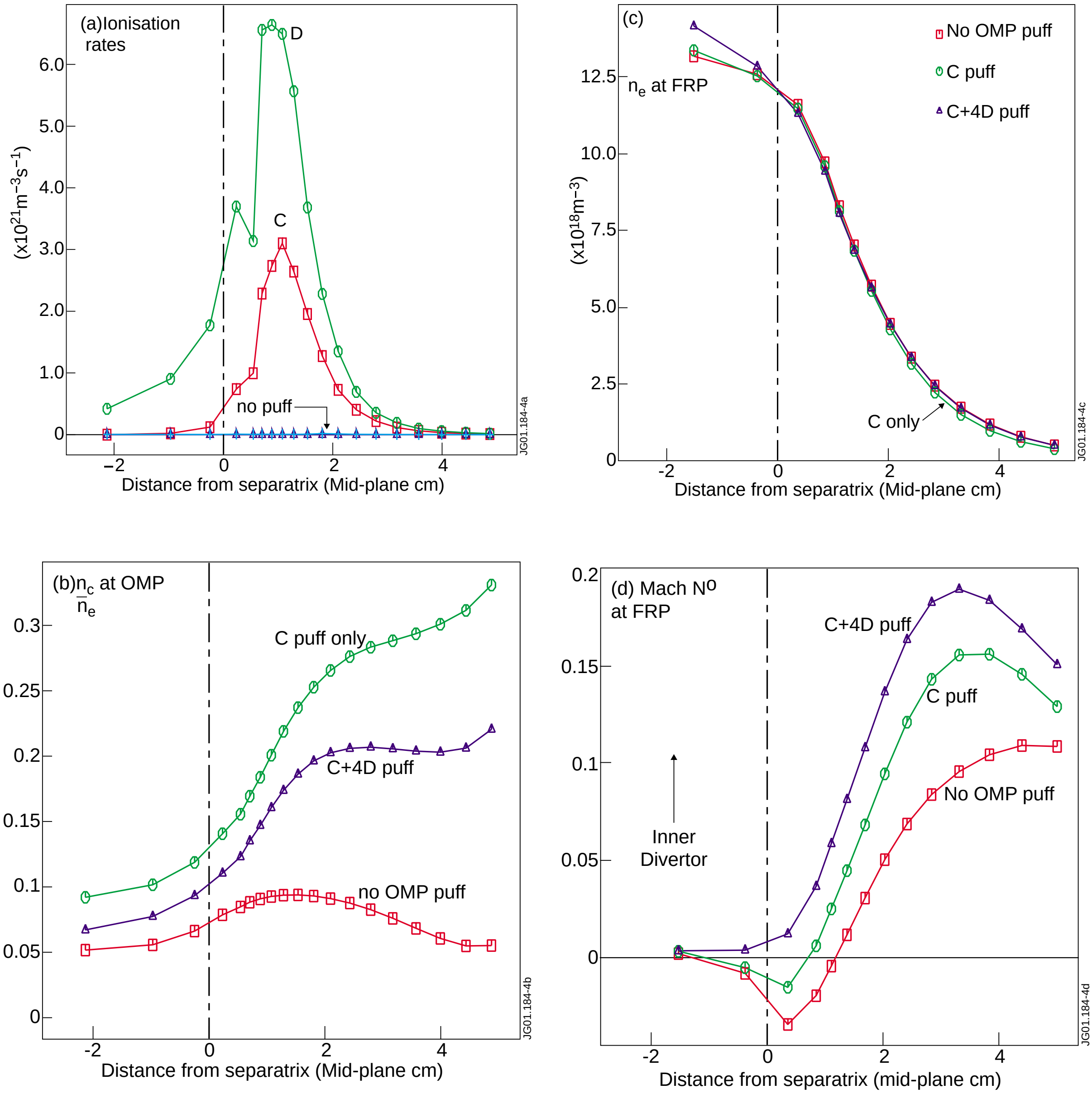

Fig. 3 EDGE2D-U/NIMBUS simulated profiles with and without OMP C- puff: (a) OMP carbon and deuterium ionization sources, (b) carbon concentration at FRP, (c) electron density at FRP and (d) Mach number at FRP

3.3 SOL Flow

Empirical profiles for $D_\perp$ can be used in EDGE2D but are too large by a factor ~5 to reproduce the observed density profiles. It is also the case that the FRP measurements of parallel flow exceed those predicted by the code by a similar factor[4].

Since radial decay lengths result from competition between parallel and perpendicular losses these two discrepancies may be related. If we employ the empirical $D_\perp$ profiles of Fig. 4 in EDGE2D then the observed peripheral density rise can be reproduced, Fig. 5, but the absolute values of $D_\perp$ have to be reduced by a factor of 5 to match the observed decay lengths.

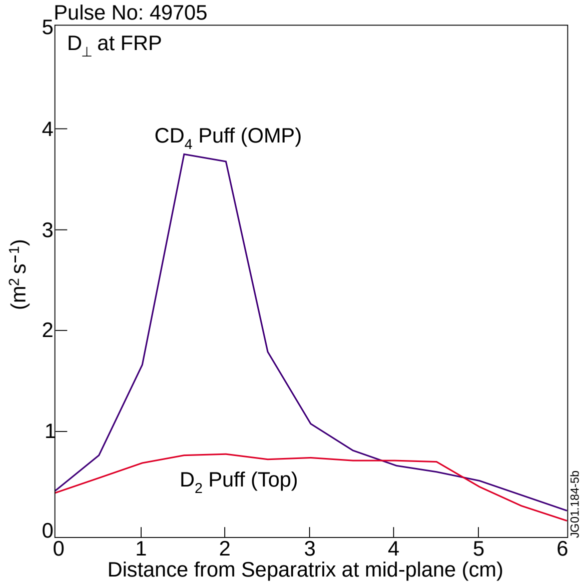

*Fig. 4 $D_\perp$ derived from measured radial flux driven by **E**×**B** micro-turbulence [3]*

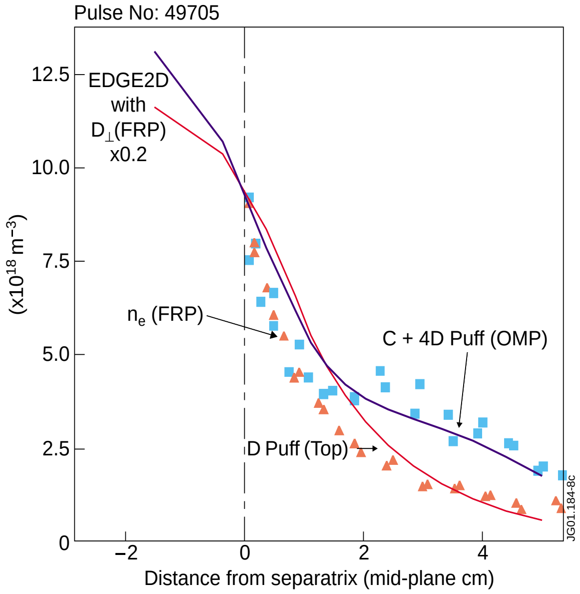

*Fig. 5 EDGE2D simulated density profiles assuming transport of Fig. 5 * 0.2 compared with FRP data*

4. Conclusions

- CD_4 puffing at the outer mid-plane can raise the peripheral plasma density relative to the separatrix in L-modes on a flux tube connected to the valve
- CD_4 puffing improves LHCD coupling into optimised shear via reduced power reflection
- EDGE2D shows that the peripheral density rise is not a direct result of local ionisation
- Observed changes in peripheral transport can explain the L-mode results

CD_4 would not be suitable for enhancing LH or ICH coupling in ITER due to co-deposition of tritium. However, impurity gases such as N_2 may have similar effects on the periphery.

References

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