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Impact of carbon and tungsten as divertor materials on the SOL conditions in JET

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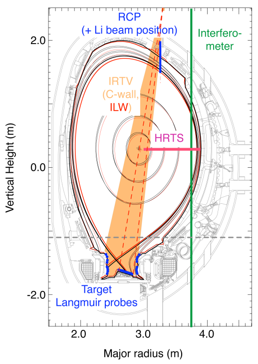
Motivation

- **Anticipation of increase in power loads and change in detachment characteristics** due to absence of carbon as dominant radiator in the divertor SOL of metallic devices

⇒ Assessment of hypothesis in the JET-ILW: replacement of JET CFC (JET-C) wall with beryllium in main chamber and tungsten in the divertor (JET ITER-like wall, JET-ILW) in **one single shutdown** [1]

- This poster: comparison of radiation pattern, and power and particle loads for **attached and detached conditions** in **JET-C** versus **JET-ILW L-mode reference plasmas** [2, 3]
- Predictive simulations with the EDGE2D/EIRENE code: are the code results QUALITATIVELY and QUANTITATIVELY consistent with the experimental observations, and does omission of carbon (and carbon chemistry) improve match to experimental data?

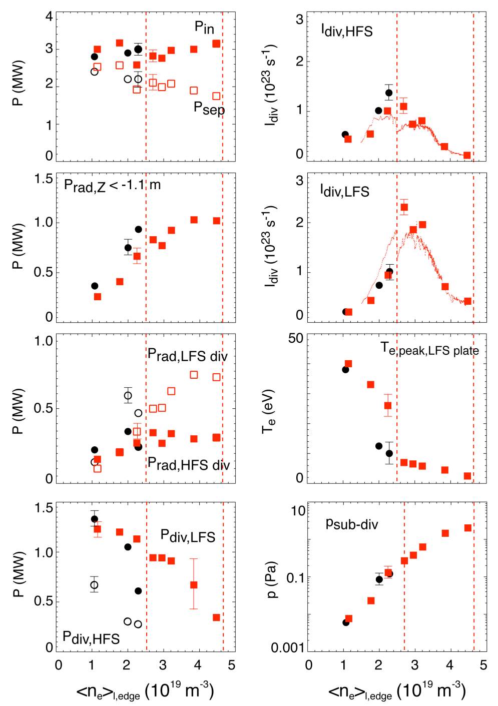


Plasma parameters and diagnostics

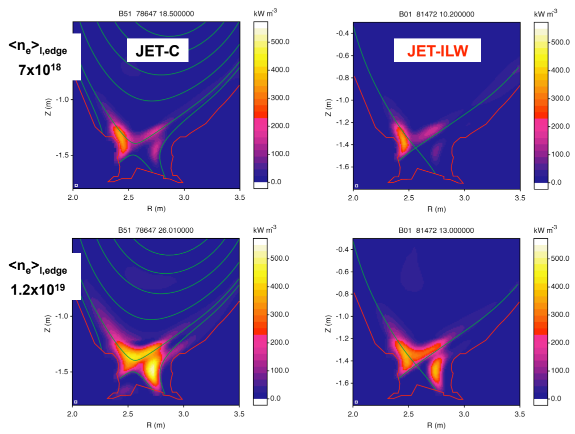
- Beam-heated L-mode plasmas: P_{NBI} = 1.6 MW
- Lower single null at 2.5 MA / 2.5 T: **B**x∇B toward device bottom
- Low (0.2) and high (0.4) upper triangularity ⇒ low-δ configuration larger (magnetic) clearance to top of device + permits radially more extended grids for edge modelling
- Highly resolved profiles of plasma conditions in main chamber SOL (n_e, T_e, T_i), and fluxes to HFS and LFS plates (j_{sat} → I_{div}, q_{plate} → P_{div}, n_e, T_e)
- Multiple radiation profiles for total and divertor radiation ($P_{rad,SOL}$) and line radiation (not shown):

Experiments: $P_{rad,div}$:= $P_{rad,Z}$ | Z < -1.1 m

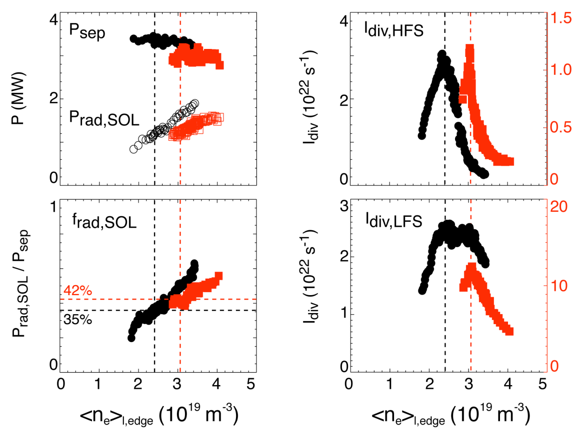
Power, currents and electron temperature in ATTACHED L-mode plasmas in JET-C and JET-ILW (low-δ)



Divertor radiation in ATTACHED L-mode-plasmas in JET-C and JET-ILW (low-δ)



Comparison of DETACHED L-mode plasmas in JET-C and JET-ILW (high-δ)



Principal results of comparison of MEASUREMENTS in JET-C and JET-ILW

- In sheath-limited conditions ⇒ nearly identical SOL plasmas
- **JET-C** → **JET-ILW**: decrease in $P_{rad,SOL}$ by 30% (for identical power crossing separatrix across SOL) ⇒ consistent with order-of-magnitude reduction in divertor carbon emission and C^{6+} density in the pedestal [4] ⇒ see also **Coenen et al., Ex/P5-4**
- Increase in $P_{div,LFS}$ and $T_{e,LFS}$ by factor of 2 (for same n_{up}) ⇒ conditions of $T_{e,LFS}$ < 10 eV achieved at lower n_{up}
- Similar magnitude and functional dependence of I_{div} on n_{up} in ATTACHED conditions ⇒ **rollover of I_{div} and density limit [5] at 30% higher n_{up} in JET-ILW**
  - –Rollover of I_{div} at HFS and LFS occurred at same n_{up}
  - –Order-of-magnitude reduction of $I_{div,HFS}$ past rollover in both JET-C and JET-ILW
  - –Saturation and 25% decrease of $I_{div,LFS}$ in JET-C; factor of 2 reduction in JET-ILW ⇒ **increase in density parameter space to operate in stable detached conditions**
  - –Similar radiative power fraction required to achieve $T_{e,LFS}$ < 10 eV and rollover of I_{div}: 35% in JET-C versus 42% in JET-ILW
- Similar neutral behaviour in LFS divertor (subdivertor pressure and D_α emission) ⇒ factor of 2 higher fuelling required to obtain same $n_{e,sep,LFS-mp}$

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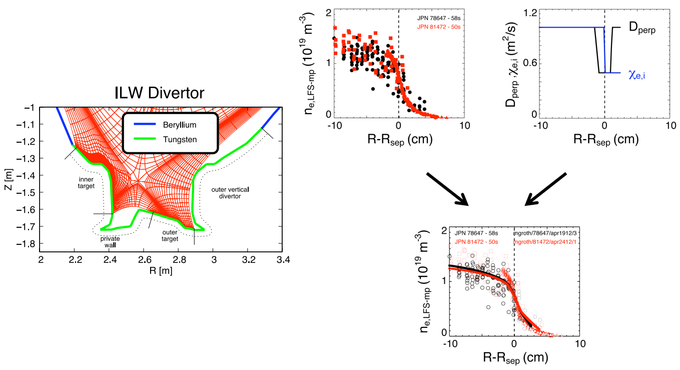
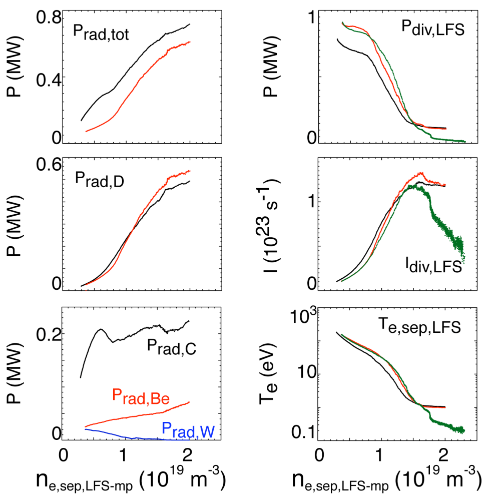
Setup of EDGE2D/EIRENE model

- EDGE2D = 2-D (poloidal plane) multi-fluid edge code for pedestal and SOL regions [6]
  - Parallel-**B** transport modelled by Bragiinski equations
  - Purely diffusive radial transport: $D_{\perp,eff}$ adapted to match measured $n_{e,LFS\text{-}mp}$ profiles; no cross-field drifts ⇒ focus on (better diagnosed) LFS divertor
  - Power flow from core into (density) pedestal from experiments: $P_{core\rightarrow ped} = P_{in} - P_{rad,E2D\ core}$ ⇒ power 10-20% higher at high upstream densities
- EIRENE = 3-D neutral code, deuterium atoms and molecules, impurity atoms [7] ⇒ iteratively coupled to EDGE2D [8]: standard (linearised) EIRENE model ⇒ **extended model, including elastic and inelastic collisions between plasma ions and molecules / molecular ions**
- Adapt JET-C and actual JET-Be/W wall configurations [9]: all divertor surfaces are assumed pristine W – Be migration into divertor not modelled
- Utilise two sets of simulation grids to test code results:
  - Pure-D, D+C, and D+Be+W on identical equilibrium / grid ⇒ compared predicted radiation, power to LFS plate, etc. for otherwise identical setup / boundary conditions
  - Separate grids corresponding to actual equilibria and walls ⇒ compare to experimental data
- Perform fuelling ramps from lowest upstream density case to density limit ⇒ quasi steady-state solutions + steady-state (> 500 ms) with density feedback on experimental $n_{sep,LFS\text{-}mp}$



EDGE2D/EIRENE predictions of power, currents and electron temperature for an identical grid and boundary conditions in JET-C and JET-ILW



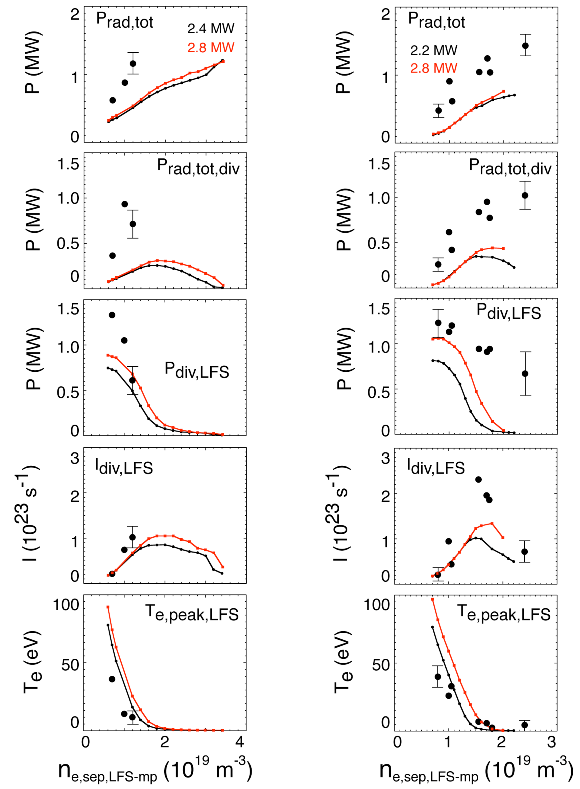
EDGE2D/EIRENE predictions for "generic" plasmas in JET-C and JET-ILW

- Simulations predict reduction of total radiated power by 50% uniformly across density range (c.f. exp. 30%)

⇒ **Reduction of radiation due to carbon being replaced by Be: $P_{rad,C} \approx 4\times P_{rad,Be}$**

- **Deuterium radiation** unaffected by change of wall materials, but **dominates radiation power balance**; tungsten radiation negligible for high-recycling and detached conditions
- 50% increase in conducted power to LFS plate for low-recycling conditions ⇒ difference is reduced to zero when LFS divertor plasma becomes detached
- Same $n_{e,sep,LFS\text{-}mp}$ for saturation or rollover of Idiv,LFS in assumed JET-C an JET-ILW
- No systematic effect on ion currents to LFS plates ⇒ **rollover of $I_{div,LFS}$ achieved when using EIRENE w/o ion-molecule collisions**
- T_e at LFS plate reaches 10 eV at 50% higher $n_{e,sep,LFS\text{-}mp}$ in assumed JET-ILW than in **JET-C** → w/ ion-molecule collisions, $T_{e,sep,LFS}$ is further reduced to 0.2 eV when fully detached

Predicted power, currents and electron temperature for ACTUAL L-mode plasmas in JET-C and JET-ILW



Comparison of EDGE2D/EIRENE predictions to experimental data

- **Simulations generally underestimate P_{rad} by factors of 2** ⇒ cannot be reconciled by raising $P_{core\rightarrow ped}$ or, for **JET-C**, the chemical sputtering yields for carbon:
  - Raising Y_{chem} for **JET-C** made predictions less consistent with divertor spectroscopy
  - Simulations generally predict saturation and rollover of divertor radiation ⇒ radiation front moved upstream of the divertor X-point and into the core
- In low-recycling conditions simulations for **JET-C** and **JET-ILW** predicted 50% lower $P_{div,LFS}$ than measured

⇒ Predicted $P_{div,LFS}$ < 250 kW in high-recycling and detached conditions are not supported by measurements

- **Rollover of $I_{div,LFS}$ observed for both JET-C and JET-ILW when using EIRENE extended to include ion-molecule collisions [10,11]**
  - Significant cooling of plasma directly adjacent to target plates when including ion-molecule interaction: T_e and T_i are reduced from 0.9 to 0.2 eV ⇒ reduction in I_{div}
  - Shallower rollover of $I_{div,LFS}$ for **JET-C** than for **JET-ILW**
- Raising $P_{core\rightarrow ped}$ generally preserves functional dependence of $P_{div,LFS}$, $I_{div,LFS}$, and $T_{e,LFS}$ with $n_{e,sep,LFS\text{-}mp}$, but increases their magnitude and shifts rollover of $I_{div,LFS}$ toward higher upstream densities
- Removal of uncertainties in modelling carbon chemistry when simulating JET-ILW does not necessarily improve the match to experimental data (e.g., radiative power) ⇒ Is deuterium radiation properly accounted for?

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