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Steps in validating scrape-off layer simulations of attached and detached plasmas in the JET ITER-like wall configuration

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* *See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia.*

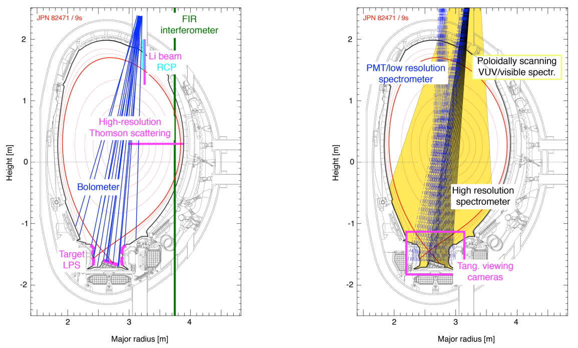
Motivation

- Predictions of scrape-off layer conditions, and particle and heat loads to divertor plates in ITER and DEMO rely on validated simulations ⇒ edge fluid codes are presently the state-of-the-art tools
- EDGE2D-EIRENE simulations for **JET ITER-like (ILW) wall plasmas without extrinsic impurity seeding** show **shortfall in predicted vs. measured radiation** ⇒ observed in low confinement mode (L-mode) [1] and high confinement mode (H-mode) plasmas [2]

⇒ What are the primary radiators in JET-ILW plasmas, and which radiators cause the shortfall?

- This poster: assessment of radiation shortfall in L-mode plasmas as described in [1] utilising the full suite of JET spectroscopic and imaging suite of diagnostics and EDGE2D-EIRENE [3]
  - Deuterium fuelling/upstream density scan ⇒ LFS divertor plasma in **low-recycling**, high-recycling, **partially detached** and fully detached conditions; T_e at HFS plate < 10 eV for all n_{up}
  - As pure as possible deuterium plasmas: Z_{eff} decreased from 1.4 at low density to 1.1 at the density limit; intrinsic impurities beryllium and carbon: core $c_{Be4+} \approx 1\%$ and $c_{Be4+} \approx 0.1\%$ [4]
  - Absence of ELMs ease data analysis and EDGE2D-EIRENE simulations
- Complementary studies for JET-ILW L-mode plasmas with EDGE2D-EIRENE [5] and SOLPS [6]

Comprehensive plasma and spectroscopic analyses in a divertor plasma configuration with LFS strike point on horizontal plate



- Vertical and horizontal (not shown) bolometer array for **total radiation**
- Poloidally scanning VUV/visible spectrometer [7]: **Ly-α, D-α, low charge state Be and C**
- **Mirror-link**, high-resolution visible (LFS) divertor spectrometer [8]: **low-n and high-n Balmer lines, low charge state Be and C**
- Photo-multiplier and low-resolution spectrometer, HFS and LFS [9]: **low-n Balmer lines, low charge state Be and C**
- Tangentially viewing cameras [10] and poloidal image reconstructions for divertor emission [11]: **low-n Balmer lines, low charge state Be and C**

EDGE2D-EIRENE simulations

- EDGE2D [12] = 2-D (poloidal plane) multi-fluid edge code for pedestal and SOL regions
  - Parallel-**B** transport modelled by Bragiinski equations, including D, Be, C, and W
  - Purely diffusive radial transport ($D_{\perp,eff}$); coefficients adjusted to reproduce measured profiles of n_e and T_e at LFS midplane; currently, cross-field drifts for pure-D plasmas only
  - Power flow from core into (density) pedestal from experiments: $P_{core \rightarrow ped} = P_{in} - P_{rad,\rho<0.9}$
  - **Upstream profiles shifted radially inward: force electron pressure balance between LFS midplane and LFS target for lowest n_{up} case [13] ⇒ apply same shift to all n_{up} cases**
- EIRENE [14] = 3-D neutral code, deuterium atoms and molecules, impurity atoms; iteratively coupled to EDGE2D [3] ⇒ here, use most complete EIRENE package [15]
- Actual Be/W wall configurations; here, no attempt to model material evolution of divertor walls
- Carbon injected as diffusive source from PFR, assumed recycling species to further diffuse carbon distribution ⇒ actual source not known, but present ⇒ use carbon also a diagnostic for T_e
- Code output: $P_{rad,SOL+ped}$, $j_{sat,div}$, $T_{e,div}$, **synthetic diagnostics for bolometers and spectrometers**

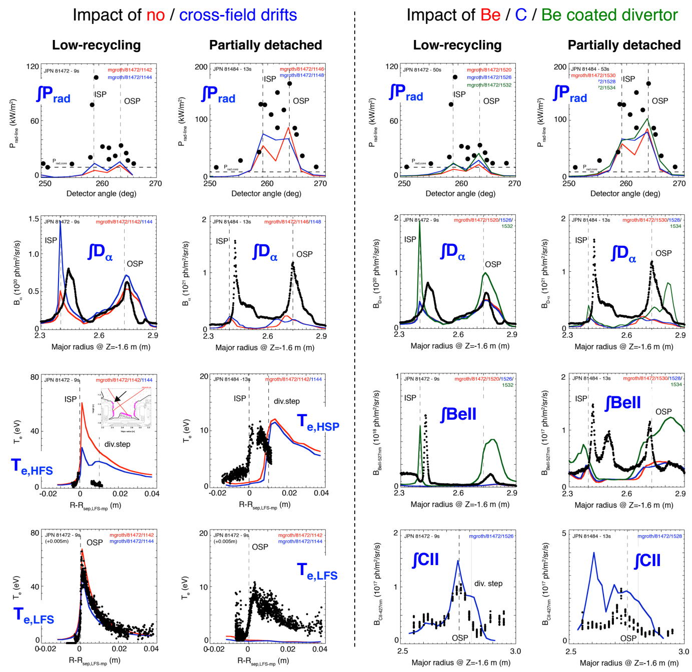
Global assessment of radiating species and processes [1, 16]

Line radiation from D	**Ly-α ~85-90%, Ly-β ~10% and other lines ~3%**
D line radiation due to direct recombination	**< 10^{-5} of total D line radiation**
Line radiation from D2	**~10% of total D line radiation**
Line radiation from $D2^+$	**~3% of total D line radiation**
D CX recombination	**Negligible**
Radiative recombination to D followed by cascading + Bremsstrahlung	**< 10^{-2} of total D radiation at low n_{up}, rising to ~30% at high n_{up}**
Be impurity radiation	**~50% of total D radiation at low n_{up}, decreasing to <10% at high n_{up}**
C impurity radiation	**~50% of total D radiation at low n_{up}, decreasing to <10% at high n_{up}**
W line radiation	**~10% of total D radiation at low n_{up}, zero at high n_{up}**

⇒ **In attached conditions, Be and C emission line contribute 50% to total radiation; in detached conditions total radiation is dominated by deuterium Ly-α line emission**

Comparison of EDGE2D-EIRENE predictions to measured profiles

Impact of no / cross-field drifts | Impact of Be / C / Be coated divertor



Conclusions from comparison experiment vs. EDGE2D-EIRENE predictions

- In attached divertor conditions (LFS plate), EDGE2D-EIRENE reproduced measured j_{sat} (not shown), T_e and D-α emission within 20% (**when forcing electron pressure balance along SOL!**)
- Inclusion of cross-field drifts reduces T_e at HFS plate and raises D-α across HFS divertor leg ⇒ HFS divertor conditions still predicted hotter and less dense (more weakly detached) than inferred experimentally
- In detached conditions, predicted T_e < 1 eV at the plates, yet predicted total radiation and D-α emission factors of 3-5 lower than measurements ⇒ divertor plasma recombining, but not sufficiently cold to produce radiation (radiation rates highly non-linear below 1 eV)
- Be sputtered at main chamber walls and transported into divertor too low to reproduce measured BeII emission ⇒ part of HFS divertor covered with Be, consistent with post-mortem analysis [17]
- Artificially increasing BeII emission by assuming fully Be coated divertor (and reduced sputtering yields) increases total radiation by 150% at low n_{up} and 30% at high n_{up} over pure-D case ⇒ over-predicts measured BeII emission
- Introducing C as radiating species, at a rate to match measured CII emission across LFS divertor leg, may contribute about 50% at low n_{up} and 10% at high n_{up} over pure-D case

⇒ Radiation shortfall likely not be produced by Be and C line emission ⇒ **more likely deuterium radiation and divertor plasma temperature and density, and their exact distributions**

⇒ Further radiative loss / temperature reductions may be via molecular deuterium: vibrational-rotational activation, molecular ions

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