Impact of tungsten charge state bundling on scrape-off layer transport simulations in JET L-mode

H.A. Kumpulainen[1], M. Groth[1], M. Fontell[1], A. Jarvinen[2], G. Corrigan[3], D. Harting[3] and JET Contributors*

[1]*Aalto University, P.O.Box 11000, FI-00076 AALTO, Finland*

[2]*Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*

[3]*CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK*

**See the author list of Overview of the JET preparation for Deuterium-Tritium Operation by E. Joffrin et al. to be published in Nuclear Fusion Special issue: overview and summary reports from the 27th Fusion Energy Conference (Ahmedabad, India, 22-27 October 2018)*

Abstract. The bundling of the 74 tungsten ion charge states into 6 fluid species in the coupled multi-fluid plasma/kinetic neutral code EDGE2D-EIRENE is shown to decrease the predicted average tungsten charge in the JET main chamber scrape-off layer by up to 40%, compared to mutually consistent predictions using the Monte Carlo impurity transport code DIVIMP and 22 tungsten fluid species in EDGE2D-EIRENE. The tungsten concentrations predicted by DIVIMP in the pedestal region are consistently ~50% higher than by EDGE2D-EIRENE with 6 tungsten fluids under attached divertor conditions, whereas under partially detached conditions the stochastic errors exceed the systematic disagreement between the two codes.

1. Introduction

The use of tungsten (W) as the divertor plasma-facing material for ITER, and for the JET ITER-like wall [1], is motivated primarily by its low tritium retention, high melting point, and low erosion [2]. The accumulation of W in the core plasma must be suppressed to ensure that the plasma-cooling effect due to W radiation does not prevent fusion-relevant plasma operation [3]. W transport from the divertor source into the main scrape-off layer (SOL) is critical since it determines the rate at which W enters the core plasma.

2. Simulation setup

The studied plasma scenarios are based on the JET L-mode discharge #81472 (2.5 MA plasma current, 2.5 T toroidal magnetic field) in a vertical HFS/horizontal LFS strike point configuration. The W transport simulations using the coupled 2D multi-fluid plasma/kinetic

neutral code EDGE2D-EIRENE [4, 5] are based on earlier work [6]. The 74 W ion charge states were bundled [7] to 6 fluid species representing charges 1, 2-6, 7-12, 13-22, 23-73 and 74. Particle and energy transport across flux surfaces was treated as purely diffusive with no pinch velocity or cross-field drifts. A range of attached and detached divertor conditions was obtained by altering the prescribed electron density at the LFS mid-plane separatrix while keeping the input power, transport parameters and boundary conditions constant.

In the DIVIMP [8, 9] 2D Monte Carlo simulations, tungsten test particles were injected in a singly ionized state based on the neutral W ionization profile calculated by EDGE2D-EIRENE. The background plasma was imported from EDGE2D-EIRENE. The settings and boundary conditions were selected as close to those used in EDGE2D-EIRENE as possible.

3. Comparison of the DIVIMP and EDGE2D-EIRENE predictions

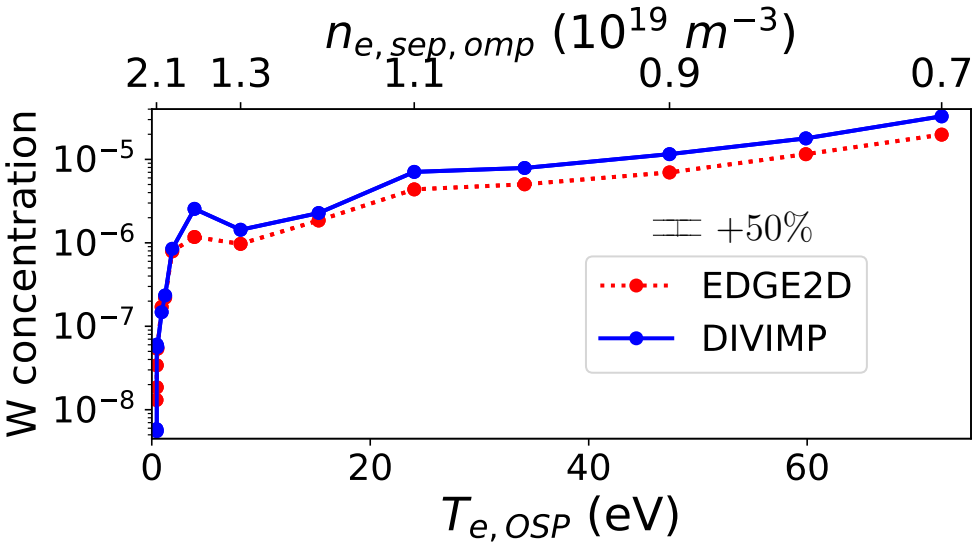

Figure 1. Spatial average of the tungsten concentration in the pedestal region (closed flux surfaces at $r/a > 0.8$) predicted by DIVIMP and EDGE2D-EIRENE as a function of electron temperature at the LFS strike point (bottom axis) and electron density at the LFS mid-plane separatrix (top axis).

DIVIMP predicted consistently ~50% higher W concentration in the pedestal region than EDGE2D-EIRENE under low- and high-recycling divertor conditions (Fig. 1). In partially detached cases with pedestal W concentration below 10^{-6} ($T_{e,OSP}$<5 eV), the systematic disagreement was low compared to the Monte Carlo noise in the W source. With very low W concentration (<10^{-7}) in EDGE2D-EIRENE, the error terms in the W particle

and momentum conservation equations became greater than most other terms, essentially rendering the obtained solutions unphysical. Therefore, the conclusions of this work are based on the cases with W concentration $> 10^{-6}$.

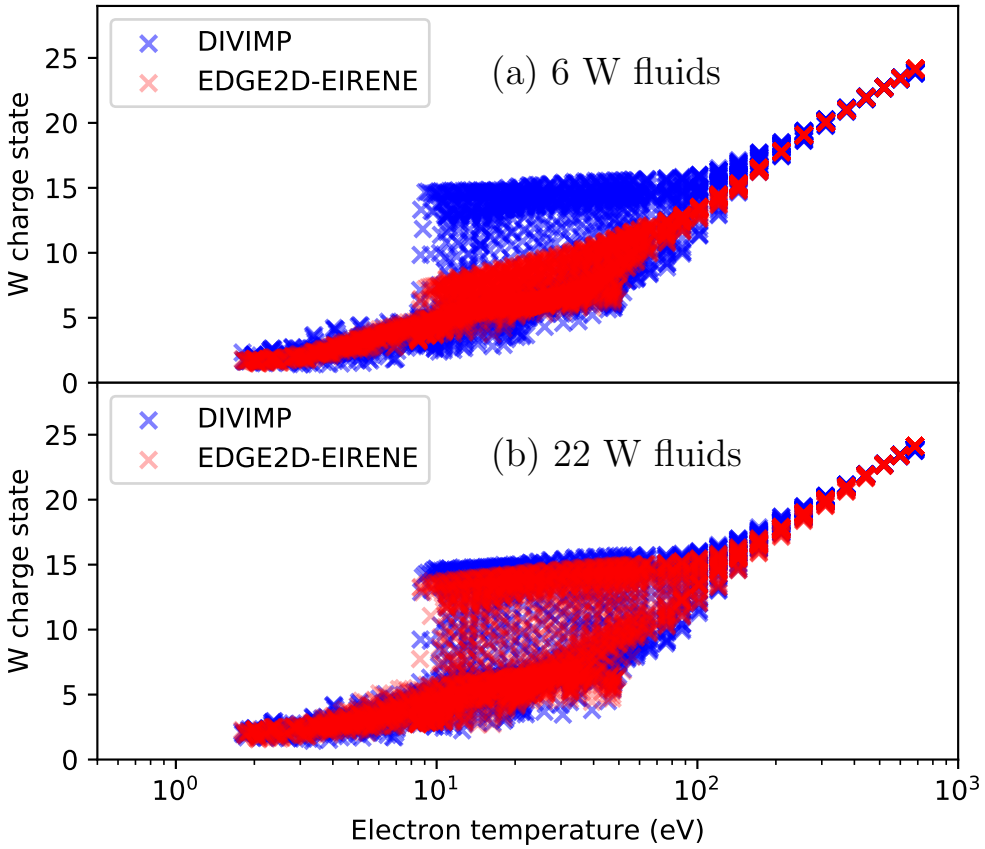

Figure 2. Mean charge state of W ions in each grid cell plotted against electron temperature for DIVIMP and EDGE2D-EIRENE. The 74 W charge states are bundled in EDGE2D-EIRENE into (a) 6 and (b) 22 fluid species.

The bundling of W charge states into 6 fluid species in EDGE2D-EIRENE decreased the average W charge in the upstream SOL region by up to 40% compared to DIVIMP (Fig. 2a). The predicted W charge profiles matched in the divertor (1 eV< T_e <60 eV, 1< Z_W <6) and in the pedestal region (T_e >100 eV, Z_W >13).

Including all the individual W charge states from 1+ up to 20+ as separate fluid species in EDGE2D-EIRENE (the 22-fluid scheme, Fig. 2b), the W charge profiles predicted by EDGE2D-EIRENE and DIVIMP matched within a few percent. The momentum conservation equation, however, was not satisfied due to numerical issues as the EDGE2D-EIRENE runs became unstable. Due to violations of the momentum balance, the 22-fluid scheme did not reproduce the DIVIMP W density profiles despite matching the W charge

profiles.

4. Conclusions

A decrease of 40% in the average charge of W in the main chamber SOL was observed due to the bundling of charge states into 6 fluid species in EDGE2D-EIRENE compared to DIVIMP. This explains the 50% higher W concentration predicted by DIVIMP than by EDGE2D-EIRENE in the pedestal region. Using a more elaborate bundling scheme with 22 W fluids instead of 6, EDGE2D-EIRENE reproduced the W charge profile predicted by DIVIMP within a few percent. However, the increased amount of fluid species in EDGE2D-EIRENE led to larger error terms in the momentum balance. Thus, the 6-fluid W scheme can be considered more appropriate for EDGE2D-EIRENE than the 22-fluid scheme, despite its less realistic W charge profile.

Acknowledgments. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] G. Matthews et al. 2011 *Phys. Scripta* **T145** 014001

[2] R.A. Pitts et al. 2009 *Phys. Scripta* **T138** 014001

[3] T. Pütterich et al. 2010 *Nucl. Fusion* **50** 025012

[4] R. Simonini et al. 1994 *Contrib. Plasma Phys.* **34** (2-3):368-373

[5] S. Wiesen 2006 EDGE2D-EIRENE code interface report, `http://www.eirene.de/e2deir_report_30jun06.pdf`

[6] M. Groth et al. 2013 *Nucl. Fusion* **53** 093016

[7] J.D. Strachan et al. 2011 *J. Nucl. Mater.* **415** S501-S504

[8] P.C. Stangeby et al. 1988 *Nucl. Fusion* **28** 1945

[9] P.C. Stangeby et al. 1995 *Nucl. Fusion* **35** 1391