# EDGE2D-EIRENE study on tungsten fluid vs. tungsten kinetic

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## Introduction

New materials for plasma facing components in the next generation tokamak ITER are beryllium for the main chamber, CFC and a tungsten divertor. This combination will be tested at JET during the ITER like wall project, the current status of which is summarised in [1]. Recently the edge modeling code package EDGE2D-EIRENE [2] at JET has been extended to handle the new wall materials. First tungsten transport studies with EDGE2D-EIRENE, where the impact of bundling charge states on impurity screening has been analysed, have been presented [3]. Bundling schemes are important for W transport modeling with EDGE2D, because simulating all 74 charge states is computationally extremely expensive and numerical artefacts can occur. Thus bundled charge state schemes are introduced to reduce the number of charge states in the computation. The bulk plasma as well as the impurity ions are described within EDGE2D as fluids, which requires the assumption of full thermalisation of the particular ions. From ionisation rates of W taken from the ADAS data base [4] and assuming $n_e \sim 10^{13}/cm^3$ and $T_e = 10eV$ (near the divertor) the lifetimes of the lower charge states of tungsten $W^{1-4+}$ is below $10^{-4}$s and can be even shorter further upstream in the JET SOL where temperatures reach more than $200eV$. In contrast equilibration of heavy W ions released into a $10eV$ plasma at wall temperature takes approximately $150\mu s$, thus only $W^{5+}$ and higher ionised W charge states can be fully thermalised, hence the criteria of full thermalisation, which is required for a fluid description, might be violated for $W^{1-4+}$. Only recently the kinetic Monte Carlo code EIRENE has been expanded with a new trace ion option, referred to as trace ion module (TIM). The new module comprises the numerical algorithms required to solve the drift kinetic equation in the tokamak geometry with Monte Carlo approach. The EIRENE code has become an integrated

code package which unifies kinetic neutral particle dynamics with kinetic trace ions in one single code. Beside other kinetic impurity transport codes, e.g. DIVIMP or DORIS, the trace ion module utilises finite element methods, which is new and allows calculating drifts on unstructured grids. Moreover the Coulomb collision operator has been further extended compared to e.g. DORIS. The details of the trace ion module are summarised in [5]. Currently EIRENE is used by many plasma transport codes, e.g. EDGE2D, SOLPS and EMC3, for describing the dynamics of neutrals in the divertor region. With the trace ion module transport of W ions is described kinetically and can be benchmarked against the fluid transport model of EDGE2D and other fluid codes. This approach allows to solely compare the nature of the transport models, because in both cases (fluid or kinetic) the same EDGE2D plasma solution for the bulk plasma is used, the boundary conditions are the same as well as the atomic physics and the grid.

**The JET Modeling Case with full W wall**

The present simulation scenario is an artificial JET case, where in contrast to the ILW project (no W in the main chamber) the first wall and the divertor has been specified as W in the simulations. The equilibrium solution from discharge 53140 has been used, for which a corresponding grid has been available. The atomic physics of W is described with a bundled charge states scheme, composed as $W^{+}$, $W^{2-7+}$, $W^{8-12+}$, $W^{13-16+}$, $W^{17+}$, $W^{18+}$, $W^{19-20+}$, $W^{21-26+}$, $W^{27-73+}$, $W^{74+}$. This scheme has been chosen for practical reasons, because of convergence considerations for the simulated W gas puff. More simulations with another bundling scheme, where the first 10 charge states of W are not bundled and the remaining one is bundled into one massive superstate, are under preparation. The plasma was an ELM-free SOL plasma with an input power of 6MW entering the edge and a separatrix density of $n_{sep} = 10^{13}/cm^3$. Transport coefficients for typical H-Mode plasmas have been specified. Sputtering has been turned off in the simulations and the gas flux of W atoms was located at the outer midplane.

For simulating W ions kinetically with the new trace ion module for EIRENE the corresponding grid and plasma solution from EDGE2D has been reused. The EIRENE grid extends the EDGE2D grid to the first wall and covers the vacuum region. For simulating trace ions in this region it was necessary calculate the magnetic field on this extended grid. $B_r$ and $B_z$ has been calculated using the FLUSH code at JET. The toroidal magnetic field component, $B_t$ has been derived assuming $B = B_0 R_0/R$. Recombination in the vacuum region has been treated by setting a constant plasma with parameters $n_e = n_i = 10^{12}/cm^3$ and $T_e = 0.1eV$, because otherwise lifetime of $W^{x+}$ is infinity.

**First Simulation Results**

First it has been observed that the steady state distribution of the very short living $W^+$ calculated with the fluid code EDGE2D is nearly the same as the distribution obtained by EIRENE with the kinetic approach. Corresponding profiles at outer midplane are shown in figure 1. For both cases the same atomic physics has been used and it seems the distribution of $W^+$ is more affected by the source profile (ionisation of W) than by transport model. The present calculation with EDGE2D has delivered a density distribution of the bundled charge state $W^{2-7+}$, which does not allow a direct comparison of the single charge states of W with the kinetic results from EIRENE. Though it appears that the kinetic approach, where $W^{2-7+}$ are not bundled, delivers much more localised density profiles. An example is shown in figure 2, where the fluid result for the bundled charge state $W^{2-7+}$ is compared to the kinetic result for $W^{6+}$. The most probable explanation is the missing effect of anomalous diffusion in the kinetic EIRENE-TIM code, which does not allow to specify additional transport coefficients for W ions. This effect will be incorporated into EIRENE-TIM in the near future. In the vacuum region a strong recombination has been enforced by setting an artificial electron density and temperature, which is a strong particle sink in the simulation. In contrast particle orbits of $W^{x+}$ show that particles can reenter the SOL from the vacuum region. For studying this effect the grid in the vacuum region will be refined and a more realistic plasma model will be applied by setting an appropriate e-folding length.

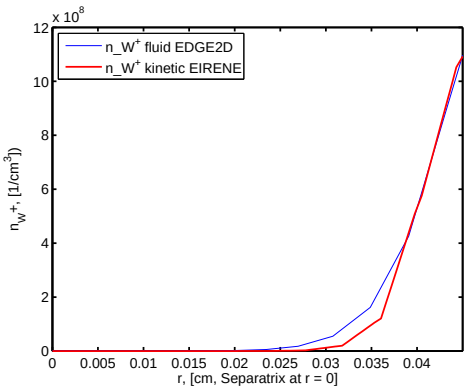


Figure 1: Density profile calculated with fluid and kinetic approach of $W^+$ at Outer Midplane

**Conclusion**

The new trace ion option for EIRENE has been applied to benchmark the fluid description of W impurity ions in the JET SOL with EDGE2D against the kinetic approach with EIRENE. The development of the required interfaces and code structure for performing these simulations is finished. Bulk plasma, magnetic field and grid from any EDGE2D run can be used with EIRENE, where kinetic trace ions of any kind can be simulated (if atomic physics data is available). One advantage of the kinetic treatment of impurity ions with the trace ion module is the straightforward incorporation of drift effects in the simulations. In contrast simulating drift effects with fluid codes can be highly complex and often numerical stability problems occur. The

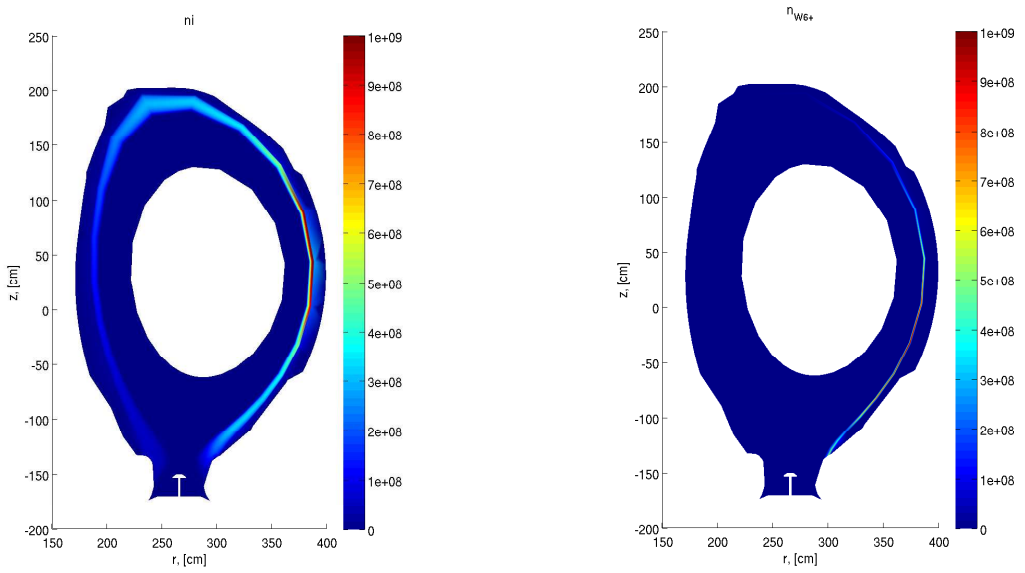


Figure 2: $W^{6+}$ density profiles from EDGE2D (fluid description) and EIRENE (kinetic description). So far anomalous diffusion is missing in EIRENE-TIM kinetic modelling of tungsten, which explains the rather narrow radial layer of the W6+ density distribution. Neoclassical drift effects as ExB, $\nabla B$ and curvature drift have been included in the kinetic simulations.

first simulation results have at least allowed to compare the density profiles of the lowest charge state $W^{+}$ and the localisation of the $W^{1-7+}$ impurity ions. More EDGE2D simulations with other bundling schemes are under progress as well as corresponding EIRENE-TIM trace $W^{x+}$ cases for gaining more understanding of the differences between fluid and kinetic transport. The results of this analysis will be published elsewhere.

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