Detachment physics in SOLPS simulations.

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Abstract

Since the divertor for ITER has been designed to operate in a partially detached mode on the basis of SOLPS calculations, the understanding of the physics of detachment is crucial. The results of SOLPS calculations with fluid and Monte-Carlo neutrals; with pure deuterium and with carbon impurities; with and without drifts; with horizontal and vertical targets; and with and without ELMs will be presented. In addition, the possible role of fast electrons which can be expected to strongly modify the ionization rates without much affecting the recombination rates, will be investigated. Initial calculations with SOLPS indicate a strong enhancement of the volume recombination rate in the inner divertor leg arising from the enhanced ionization by the fast electrons of the volume recombination produced neutrals, producing an enhanced "volume recycling". This can then increase the volumetric losses in the inner divertor region.

Key words: SOLPS, Divertor Modelling, Edge Modelling, Detachment
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1 Introduction

SOLPS[1](and references therein), the combination of a fluid plasma code, B2, and a Monte-Carlo neutrals code, Eirene, has been used to explore detachment. This work does not attempt to match specific experimental results, but explores trends.

A number of measures of detachment have been used in the literature — here we will be concentrating on the behaviour of the integrated particle flux to the two divertors as the upstream density is increased.

One of the differences between typical experimental results for detachment and the results from code simulations, is the onset of detachment at the inner divertor at significantly lower densities than for the outer target in the experiment, whereas the code results tend to be more symmetric[2].

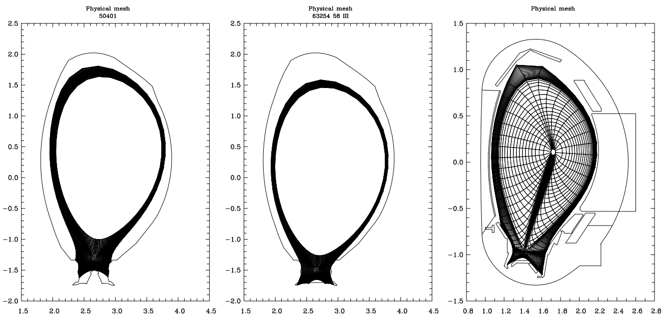

Fig. 1. The three geometries used in this study. On the left, a vertical target configuration based on the geometry of a JET shot (50401), in the centre a horizontal target configuration based on the geometry of a JET shot (63254), and on the right a vertical target configuration based on an AUG shot (17151).

In this work we explore a variety of modifications to the code setup to try and reproduce this feature. We explore the role of geometry by using two possible divertor configurations, a vertical target and a horizontal target (figure 1), the

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effect of kinetic versus fluid neutrals, the role of impurities, and the role of kinetic electrons.

In the simulations, two main approaches for simulating detachment can be pursued. The first is to perform a density ramp within one simulation, most easily by including a gas puff in the simulation that continuously adds particles at a rate faster than they can be pumped. The second is to do a series of point simulations for a range of density levels.

In this work we start by presenting results from the first approach, and them move on to the second approach.

2 Results

Figure 2 shows the results of simulating the vertical target configuration for three different time-steps (upper part) and three different gas puff rates, all with pure D plasmas and 2.5MW of heating power, using kinetic neutrals. Also marked on the figure are the point of maximum integrated particle flux for the inner and outer targets. For this case, the maximum at the inner target was reached at an upstream separatrix electron density of $1.62 \times 10^{19}\mathrm{m}^{-3}$ and for the outer target at $1.95 \times 10^{19}\mathrm{m}^{-3}$. The ratio of these two densities is 1.20 and it is this ratio that we will be using to characterize the influence of various processes on detachment asymmetry.

In figure 3, the results from a series of code runs under feedback control of the upstream separatrix density are overlayed on one of the puff cases. Here the rollover densities are $1.7 \times 10^{19}\mathrm{m}^{-3}$ and $2.2 \times 10^{19}\mathrm{m}^{-3}$ giving an asymmetry ratio of 1.29. Figure 4 shows the same vertical target, D only, kinetic neutrals cases for 5 different power levels. Table 1 gives the asymmetry ratios for these cases.

Analyzing the vertical target, kinetic neutrals, D+C+C+He drift cases presented in [3], the rollover asymmetries are 1.12073, 1.22437 and 1.47354 for the reversed, no drift and forward field cases.

Figure 5 shows the results for the horizontal and

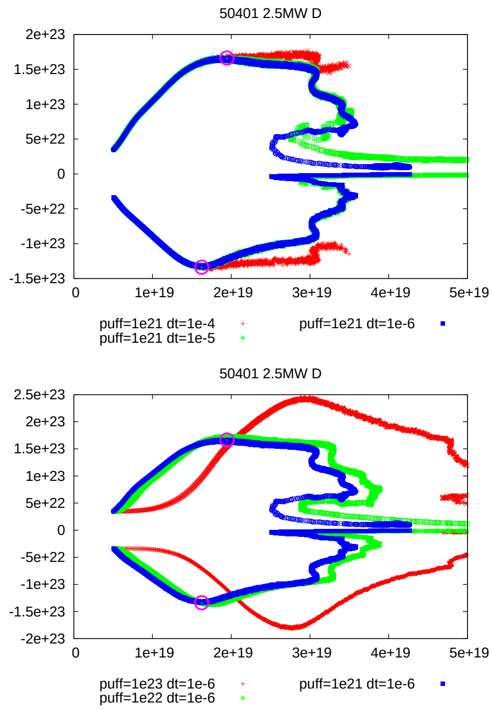

Fig. 2. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density. In the upper figure, 3 sets of curves are plotted for varying time-steps in the code. In the lower figure, the three curves are for the same time-step, but for three different puff rates. The relatively good agreement between the two smaller time-step cases, and between the two smaller gas puff rates indicates that we can trust the dt= 1×10^{-6}s, puff=1×10^{21} particles per second case. (The running time for these cases is proportional to the inverse of the product of these two numbers.)

Table 1
Upstream densities at rollover for the inner $ne_{r,i}$ and outer targets $ne_{r,o}$ and the rollover asymmetry ratio R_r for the power scan shown in figure 4

Power [MW]	$ne_{r,i}[m^{-3}]$	$ne_{r,o}[m^{-3}]$	R_r.
1.25	1.50e+19	2.00e+19	1.33
2.50	1.70e+19	2.20e+19	1.29
5.00	2.20e+19	2.50e+19	1.14
10.00	3.20e+19	3.70e+19	1.16
20.00	5.19e+19	5.19e+19	1.00

vertical geometries for both fluid and kinetic results. The fluid neutrals seem to result in earlier detachment. This effect was traced to the assumption in the fluid neutral model that all of the recombination energy is radiated. When this

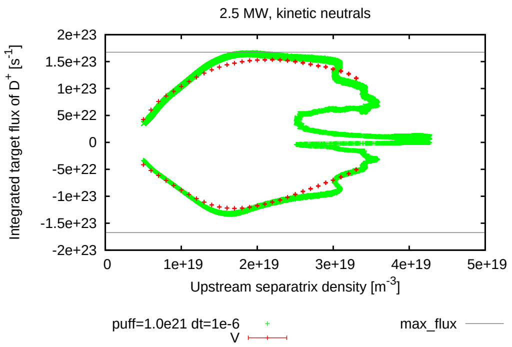

Fig. 3. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density. Here the puff results are compared with a series of runs under feedback control for the upstream separatrix density. Also plotted are two lines giving an indicative maximum flux to be expected based on the assumption of 25eV of radiation per ionization event, 1eV temperature at the targets, and equal splitting between the two targets.

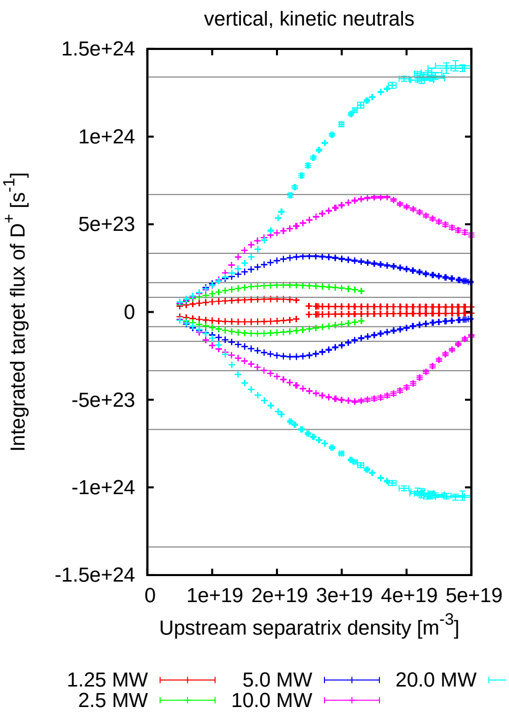

Fig. 4. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density for a power scan in the vertical target configuration with kinetic neutrals. For an explanation of the additional horizontal lines, see the caption for figure 3.

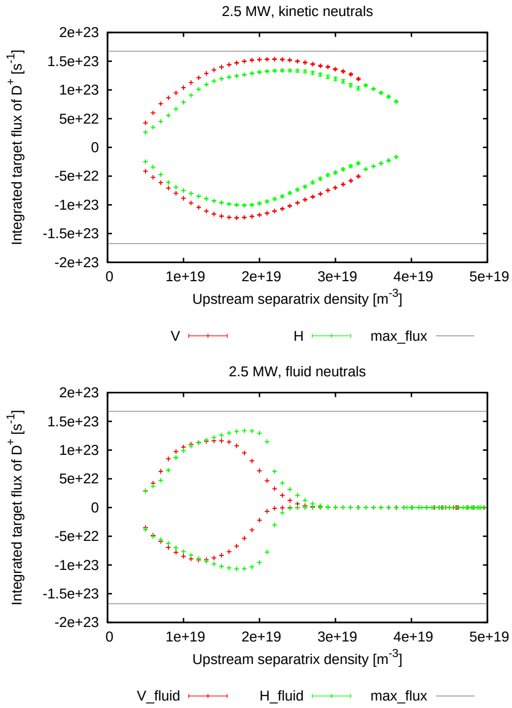

Fig. 5. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density. Comparison of the vertical (50401) and horizontal target (63254) configurations with kinetic neutrals (upper figure) and fluid neutrals (lower figure).

model was improved taking into account the effects of 3-body recombination, the fluid results are closer to the kinetic results, figure 6.

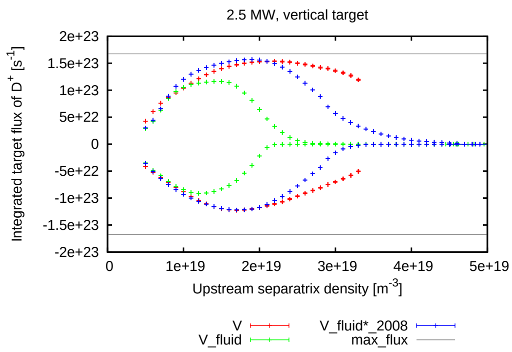

Fig. 6. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density, for the vertical target configuration. The results with the improved neutral model are labelled "fluid*"

Another effect that might influence the rollover or detachment asymmetry is an increase in the transport coefficients as the density increases. Figure 7 shows cases where the transport coefficients are scaled with density to the 0.5, 1.0 and

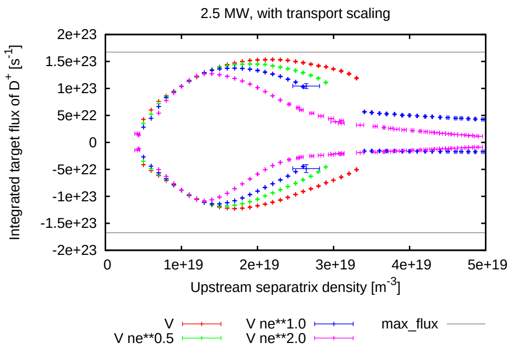

Fig. 7. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density for vertical target, kinetic neutrals cases where the transport coefficients were scaled by the upstream separatrix density to the 0.5, 1.0, and 2.0 powers.

2.0 powers.

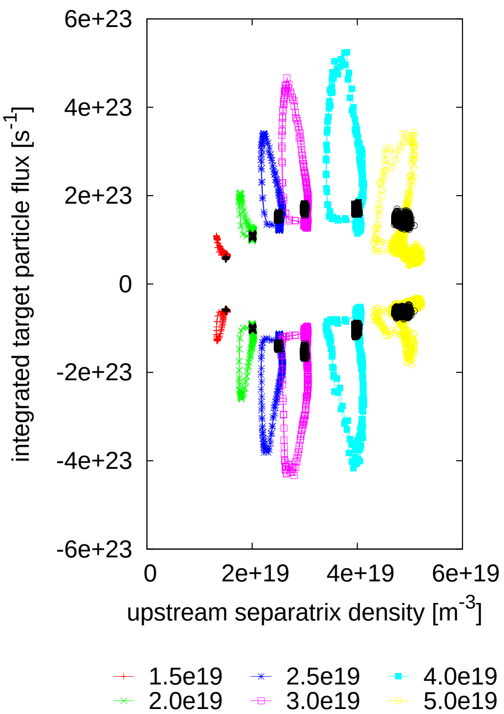

Fig. 8. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density for time dependent simulations of ELMs in AUG with a vertical target configuration. Also plotted are the results from no-ELM cases.

ELMs might also be expected to have some effect. Figure 8 shows the results for the density scan presented in [4]. No strong differences with the no-ELM results can be seen.

So far, the only cases that have showed a systematic effect have been the drift cases, with the forward (usual) field giving the largest rollover asymmetry ratio.

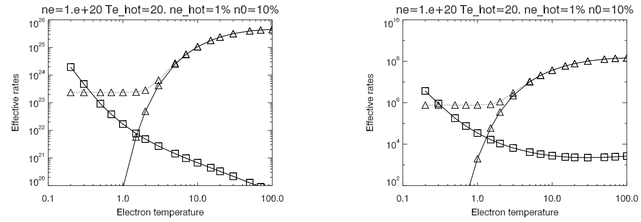

Fig. 9. Rates for ionization and recombination (particle and energy) are calculated on the assumption of a 1% 20 eV electron population.

Additional effects could be expected if a population of hot electrons in the divertor is postulated. This preferentially affects the ionization rates, as can be seen in figure 9 where a 1% population of 20 eV is assumed. Figure 10 shows that the hot electrons indeed have a large effect, giving a very pronounced difference in the rollover densities.

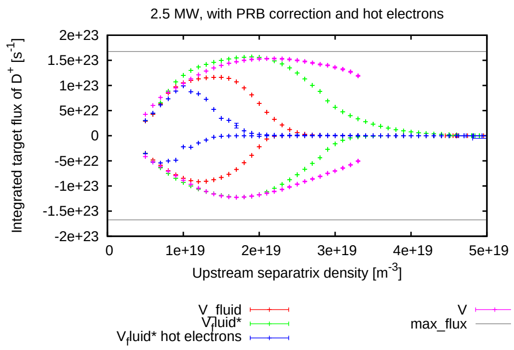

Fig. 10. Integral particle fluxes to the outer (positive) and inner (negative) divertor plates as a function of the outer midplane separatrix density where the hot electron results are compared with the other vertical target results.

3 Summary, conclusions and future work

Figure 11 indicates the main result of this work. The presence of hot electrons produces the largest effect in the middle power range. The variation of transport coefficients does not show a strong effect. As indicated earlier, drifts also show an effect.

The hot electron model used here is not self-consistent in that no physics model is used to predict the hot-electron population. In that sense,

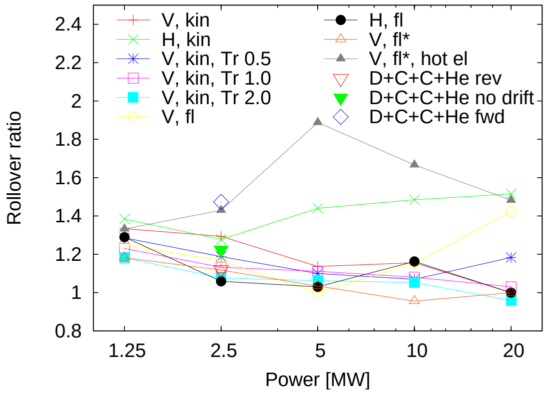

Fig. 11. Rollover asymmetry ratios as a function of power for the density scans performed.

the model is more of a sensitivity study that indicates a strong effect. To improve the results, a model for the hot electron population needs to be developed, or fully kinetic calculations need to be performed.

References

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