Evolution modelling of ASDEX Upgrade shots with B2-EIRENE.

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1 Introduction

We have used the coupled plasma multi-fluid[1, 2], Monte-Carlo neutrals[3] code, B2-Eirene[4, 5] to explore the density limit in ASDEX Upgrade. A two pronged approach has been taken. The first, relying on the observation by Borrass[6, 7] that the density limit is associated with the onset of volume recombination, used a feedback loop to add or remove particles by varying the target recycling coefficient to achieve a specified value of volume recombination. The second more closely follows the experimental procedure in a density ramp of puffing in gas and following the time evolution of the plasma.

2 Volume recombination feedback

This approach is based on the observation by Borrass[6, 7] that the density limit is associated with the onset of volume recombination. With this assumption we define the density limit density as the separatrix density when volume recombination accounts for about half the total recombination flux. We ran B2-Eirene with a feedback loop that varied the target recycling coefficient to achieve a specified volume recombination rate. This was done for a range of input powers, and for pure hydrogen (H) as well as hydrogen combined with carbon (H+C). Hydrogen rather than deuterium was used to match the choice in a particular set of experimental shots where it was chosen so that high power L-mode shots could be achieved (the lower L→H threshold of D would have meant that we would have had to deal with a transition out of H-mode as well as the density limit). Borrass argued that the critical parameter was the net input power, P_{net} (input power less the power radiated by impurities), rather than the input power, P_{in}, or the power crossing the separatrix, P_{sep}. The carbon runs allowed us to distinguish between these cases. By plotting the density limit density as a function of P_{in}, P_{sep} and P_{net} Borrass' result was confirmed — P_{net} gave the clearest ordering of the data. Figure 1 shows the plot for P_{net}, together with experimental results for H and D, as well as the density limit found using the density ramp scenario described in the next section.

The code results seemed to indicate a power dependence for the density limit density at low P_{net}, but a saturation at higher P_{net}. The data were further analysed by fitting simple power laws to the H and D experimental data, and to the volume recombination feedback data (with the highest power point exluded because of the density limit saturation). The experimental data showed an approximately square root dependence, with the code results demonstrating a somewhat weaker dependence (approximately cube root). This might be influenced by the choice of transport law, which was to have constant transport coefficients.

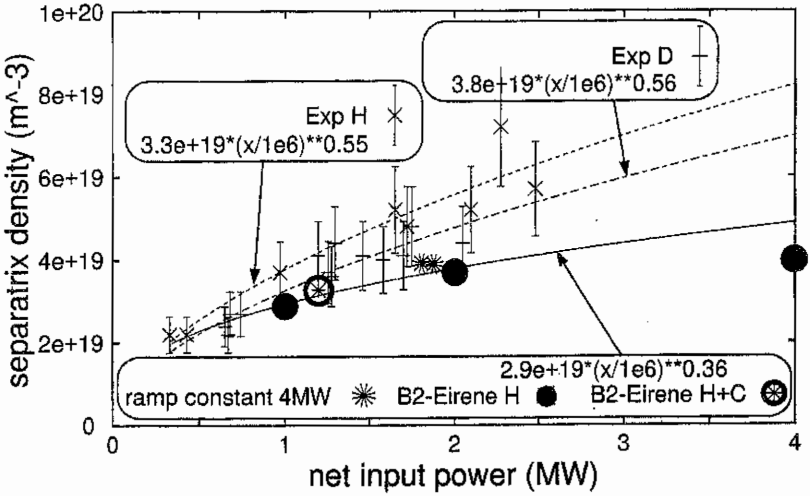

Figure 1: *Midplane separatrix density at the density limit versus net input power for the experiment (both H and D), and the results from the simulation, for the H and H+C feedback calculations, and for the density ramp case. Simple power laws were fitted to the experimental data (separately for H and D), and to the feedback code results (excluding the highest power point as there seemed to be a saturation in the density limit at higher input powers). The code shows a somewhat weaker power dependence.*

3 Density ramp simulation

Here we tried to more closely model the experimental scenario. B2-Eirene was used in the time-dependent mode to model the plasma together with a gas puff. To compress time-scales so that the computation was feasible, the gas-puff rate was considerably higher than that used in the experiment, and this was partially compensated by using an artificial time enhancement for the Monte-Carlo treatment of the neutrals, as well as by puffing in the divertor region (despite this, about 2 months of cpu time on a high end work station was used). Four different transport laws were used: **constant** transport coefficients, **Bohm**-like, transport coefficients that were globally scaled by **1/n** measured in the midplane, and **flux-scaled** transport coefficients (with constant values in flux space resulting in higher real space numbers on the inboard side).

With the exception of the flux-scaled transport case (whose transport coefficients placed the starting plasma in a regime close to detachment at the beginning), these runs matched the experimental runs qualitatively, and in some cases gave good quantitative matches as well. The constant, Bohm and 1/n runs all showed detachment starting on the inner divertor leg, followed at a later time by the outer divertor leg detaching, and then the appearance of a MARFE. During the entire period a steady rise in fractional contribution of volume recombination to total recombination was seen. The experiment showed the same development with respect to the bolometer, and, in a different but similar shot, showed the increase in volume recombination.

Experimental results for the H-α diagnostic viewing the inboard divertor are compared to the constant transport case simulation in figure 2. The constant, Bohm, and 1/n cases were all similar, with the flux-scaled case showing a shift in the maximum in the later stages to the left. The bolometer reconstructions were also compared: the Bohm and 1/n cases showed the most stable positioning of the MARFE, though the constant transport case could not be eliminated as a candidate. On this basis it is not yet possible to reject one of these transport laws.[1]

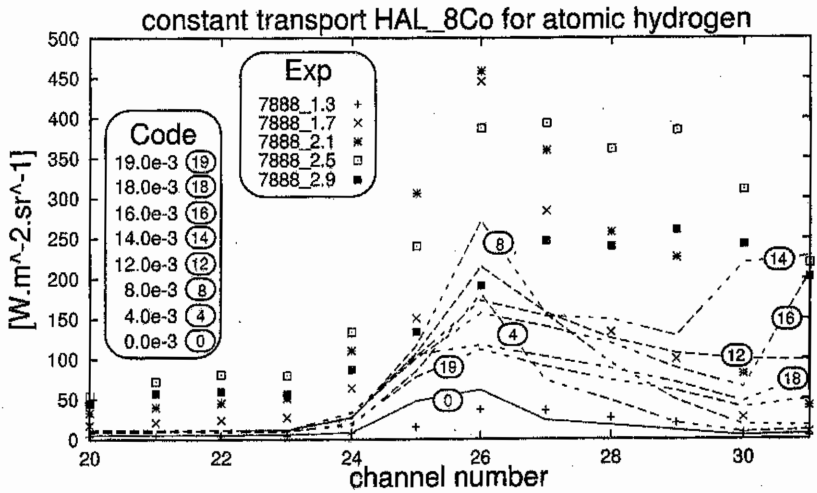

Figure 2: *Comparison of the H-α signals for the constant transport case with the experiment. Both show a rise and then a fall with time in the vicinity of channel 26, and a broadening at later times to the right. There is a systematic discrepancy for the lower numbered channels which might be related to recycling from the inner heat shield.*

4 Ongoing code developments

The introduction of the new LYRA divertor configuration on ASDEX Upgrade[8] has demanded modifications in the current SOLPS package so that the new baffle structures can be properly treated. Some calculations were done with a narrower grid that does

[1]The constant transport density ramp simulation (which was started first) has proved to be useful as results from it have been used in other work presented at this conference (Napiontek *et al.*, Gafert *et al.*, Verbeek *et al.*, Krieger *et al.*).

not treat recycling at the top of the baffle, but this grid is probably not sufficient when exploring detachment and the flattening of profiles that occurs close to detachment. We have just started calculations with a new, broader grid.

We are also in the process of upgrading from the current SOLPS4.0 to SOLPS5.0 by replacing the version of B2 that has been in use by a newer version of B2.5 from Braams[9]. We also hope to replace the current version of Eirene with a version capable of treating neutral-neutral collisions. In the coming months we plan to move from a staggered mesh treatment of the parallel momentum equation to a cell-centered version, and then to implement 1d addressing so that mesh refinement can then be introduced. In work done with Braams, the coding for drift terms has already been introduced into the new B2.5, but remains to be debugged.

5 Conclusions

These modelling results seem to confirm the analytic work of Borrass[6] that the net input power rather than the total input power or the power crossing the separatrix is the correct ordering parameter in examining the density limit. We seem to see a power dependence for the density limit for low powers, but a saturation at higher powers.

We have demonstrated that we can model the time evolution of the plasma by following the experimental procedure of having a gas puff. One problem that still remains is the long computation times that are required — efforts have started to parallelize B2 and Eirene.

On the basis of the density ramp scenario, 1/n- and Bohm- are favoured over constant-transport law scenarios, though the latter cannot be ruled out.

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