SOLPS modelling of W arising from repetitive mitigated ELMs in ITER.

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Abstract

SOLPS simulations of ELMs are performed for ITER to model the impact of sputtered tungsten on the plasma. Without prompt redeposition, the impact on the core is found to depend on the nature of the ELM event: if it is modelled by a diffusive process, contamination of the core is possible; if it is modelled by a convective process, contamination of the core can be avoided. With prompt redeposition, W contamination of the core seems to be unlikely as a result of the very high prompt redeposition fraction predicted by both simple and more complicated models.

Key words: SOLPS, Divertor Modelling, Edge Modelling, ELM, Erosion & Deposition
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1 Introduction

The issue of tungsten contamination of the main plasma is an important one for ITER. In order to clarify some of the issues, SOLPS modelling has been performed for ITER with a species mix of D+T+He+Be+Ne+W: D+T as the primary hydrogenic species, He produced by fusion reactions, Be and W produced by sputtering from the main wall and targets, and Ne as a control parameter to increase the power radiated.

In addition to steady state calculations where a scan in electron density and Ne concentration was performed, ELM simulations were also performed for a range of conditions. The steady state calculations included an edge transport barrier that gave rise to a pedestal, and the

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ELMs were modelled by a temporary increase of the transport coefficients across the pedestal into the SOL, and both small (1 MJ ELMs produced by just increasing the particle transport) and large (10 MJ ELMs produced by increasing both particle and heat transport) ELMs were simulated.

In previous work, the flux of W across the separatrix as calculated by SOLPS arising from a single ELM was used in combined ASTRA-STRAHL calculations to simulate the impact of a series of ELMs on an ITER plasma, as well as to explore the effect of ELM frequency on plasma performance. Some of the results of the steady state SOLPS simulations, as well as the single ELM calculations, can be found in [1]. The ASTRA-STRAHL simulations can be found in [2].

In the work reported here, the SOLPS results are extended to include a series of ELM simulations. The cases so examined include a "standard" case where ELMs were simulated by enhancing just the particle diffusivity for 1 ms without prompt

Table 1
Cases considered in the extended ELM simulations.

label	description
diffusive	ELM modelled by enhancing the particle diffusivity (without prompt redeposition)
convective	ELM modelled by enhancing the outward particle convective velocity (without prompt redeposition)
diffusive/redep	ELM modelled by enhancing the particle diffusivity (with prompt redeposition)

redeposition, the same ELM prescription but including the effects of prompt redeposition, and a case where the ELM was simulated by enhancing the outward convection of particles for 1 ms. In all three cases, the enhancement of the transport coefficients was chosen to provide approximately 1 MJ ELMs.
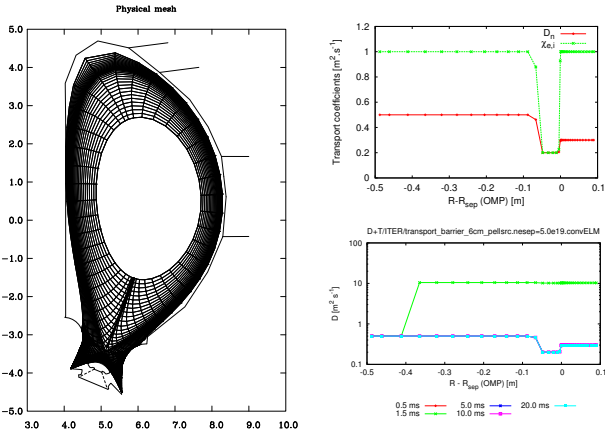
2 Results

Fig. 1. Left, SOLPS simulation domain. Right: top, anomalous radial transport coefficients used to establish the edge transport barrier, and bottom the enhanced transport coefficients used to simulate an ELM, both plotted at the outer mid-plane with 0 at the separatrix.

As described in [1], the 2d edge plasma fluid code SOLPS5.0-B2[3] was used to simulate a region of the ITER plasma extending from about 50 cm inside the closed flux surface (correspond-
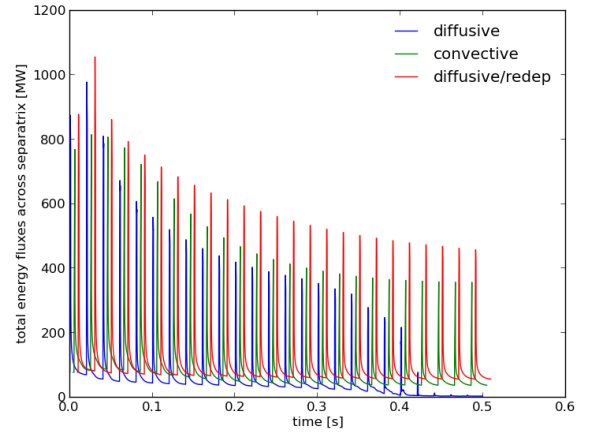

Fig. 2. Power crossing the separatrix as a function of time. The three cases are described in table 1.
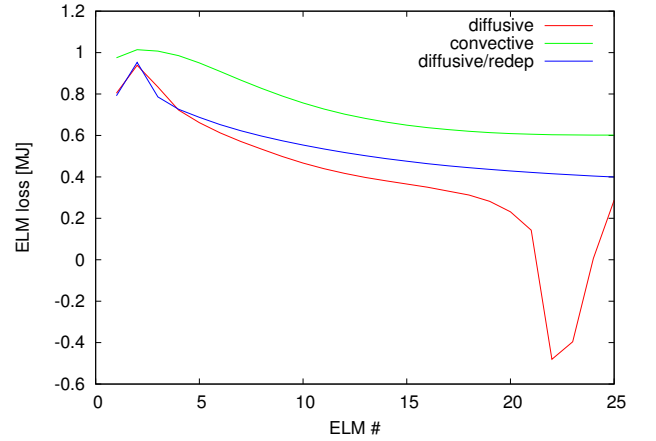

Fig. 3. Loss of core energy per ELM event.

ing to r/a = 0.75) out into the SOL, including the divertor regions, figure 1 left. A reduction of the anomalous transport coefficients was used to establish a pedestal. The pre-ELM case was chosen to have a steady-state heat flux of less than 10 MW.m^{-2} and had an upstream separatrix electron density of just under 5×10^{19} m^{-2} and had a core Zeff (mostly from the Ne) of 2.5. ELMs were simulated by enhancing transport coefficients (either the radial particle diffusivity or the radial convective "pinch" velocity) for a short time (1 ms), figure 1 right, and the simulations were performed with a time-step of 0.01 ms. Three cases were chosen in which 25 ELMs were simulated (a total of 0.5 s) — these are described in table 1. The power fluxes across the separatrix are shown in figure 2, and the core energy loss per ELM (size of the ELM) is shown in figure 3. For the "diffusive" case the plasma has es-

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sentially collapsed by the 22nd ELM. Neither of the other cases has truly reached a steady-state in the ELM size, though the "convective" case is closest. (Previous ELM simulations for AUG ([4]) covered 2 s of ELMs and took more than 0.25 s to reach a quasi-steady-state.)
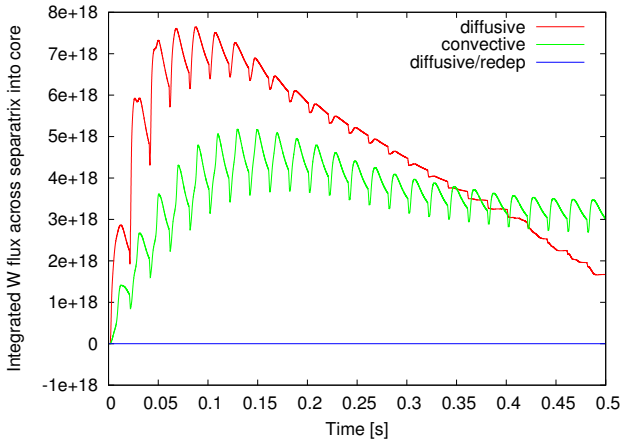

Fig. 4. Time integral of the W flux across the separatrix into the core.
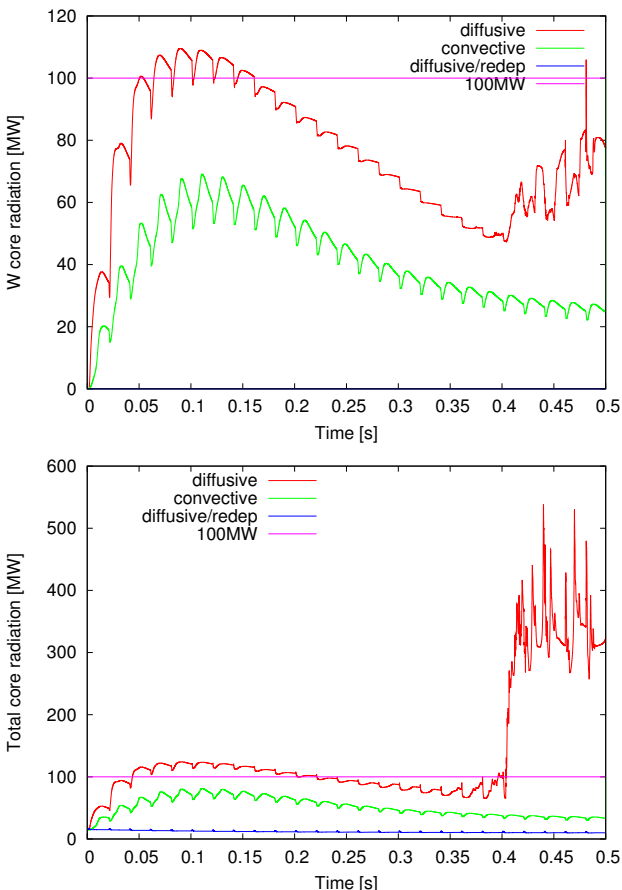

Fig. 5. Core radiation as a function of time: top for W, bottom total radiation.

Figure 4 shows the time integral of the W flux into the core from the SOL. The "diffusive" case shows an initial large influx, and later the drop is because the whole simulated plasma has become colder. The "convective" case shows a quasi-steady state, and the "diffusive/redep" case shows very little W reaching the core. The radiation from W and summed over all species in the core is shown in figure 5. The difference between the "diffusive" and "convective" cases arises because diffusion acts to move particles down density gradients (which, in the case of W produced at the targets would be from the SOL into the core), and convection as implemented is always outward from the core into the SOL.

The resultant W concentration (as a fraction of the electron density) profile at the outer mid-plane is shown as a function of time in figure 6. The fast penetration of W into the core for the "diffusive" case is clearly seen — W is produced at the targets and then moves into the SOL. Between ELMs the reduced transport coefficients slow the penetration into the core, but the enhanced particle diffusivity during the ELM event allows for fast penetration in the ELM affected region. After about 0.15 s, the entire simulated closed field line region has a W concentration in excess of 1×10^{-4}, and after that the simulated edge region cools, and then collapses. For the "convective" case, a quasi-steady-state is established by about 0.35 s where the influx from the separatrix is balanced by the ELM expulsion. The "diffusive/redep" cases shows hardly any W in the core.

3   Discussion

The results presented in this paper extend the results of the earlier SOLPS calculations where only one ELM was simulated, as well as confirming the overall results of the ASTRA-STRAHL calculations which took a source of W derived from the single-ELM SOLPS simulations. (Note that the ASTRA-STRAHL simulations also includes additional sources and neoclassical transport which makes the detailed comparison between the two approaches difficult.)

Performing a true coupled run of ASTRA-STRAHL and SOLPS for this sort of time-dependent problem is a challenge which we
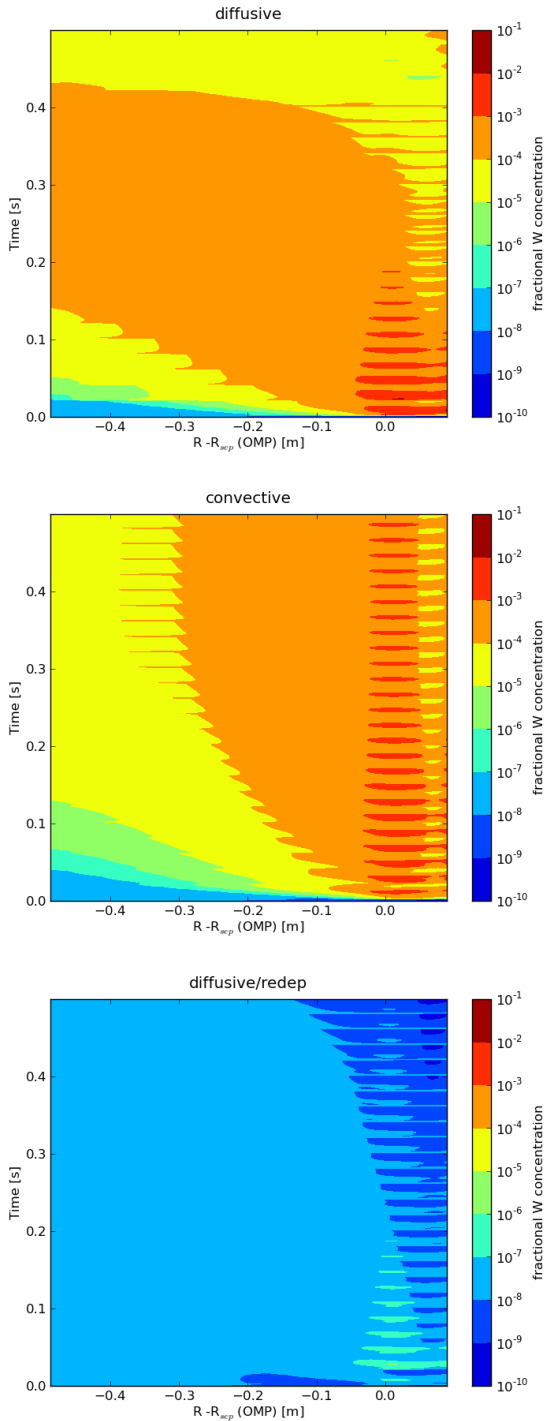
Fig. 6. W fractional concentration (as a fraction of the electron density) plotted as a function of position at the outer mid-plane and time.

avoided by essentially replaying the sources from the SOLPS single ELM simulation in the ASTRA-STRAHL simulation for all simulated ELMs. This is valid only if all of the ELMs are the "same". The SOLPS multi-ELM simulations showed that the second and subsequent ELM sources are not exactly the same as those shown in the first ELM, but the differences are not that big. The significant advantage of the ASTRA-STRAHL calculations is that 0.5 s of plasma time can be simulated in a few hours, whereas the SOLPS simulations took about 2 months. This huge disparity makes examining a range of scenarios easy with ASTRA-STRAHL and very cumbersome with a SOLPS only approach.

Key results from this and the earlier work:

(1) under conditions where the engineering target heat flux limit of 10 MW m^{-2} was achieved, steady state W contamination is usually not an issue ([1]);

(2) that, in such conditions, the neoclassical transport of W in the pedestal transport barrier leads to hollow W density profiles in this region due to the associated pinch of W being directed outwards from the plasma ([2]),

(3) that, if a simple model for the prompt redeposition of W is included[5], W contamination of the core plasma during ELMs is strongly reduced ([1] and this work);

(4) including additional effects into the prompt redeposition model[6] will give a similar strong reduction of W in the core plasma ([1] and this work);

(5) that, without prompt redeposition, the ensuing contamination of the plasma by ELMs depends strongly on the model for W expulsion by ELMs due to the edge W profiles between ELMs being hollow; for "diffusive" ELMs (where W expulsion by ELMs is modelled by an increase in the particle diffusion coefficient) the core W concentration increases with ELM frequency while for "convective" ELMs (where W expulsion by ELMs is modelled by an increase in the outwards plasma velocity) the core W concentration decreases with ELM frequency (this work and [2]).

Since prompt redeposition is so effective in reducing the W contamination from sputtering in the target region, other sources of W might become important (e.g. dust; blobs or filaments hitting the upper parts of the targets). Modelling these effects will require other codes.

4 Acknowledgments

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