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Simulation of ITER first wall radiation heat load during the disruption

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1. Introduction

Investigation of the first wall materials behaviour under ITER off normal conditions is an important task for up to date reactor concept [1]. These investigations aimed at the evaluation of the first wall and the divertor armour damage need an estimation of the heat load at the first wall during ITER performance. Maximal heat loads are expected during the off normal events like the ELMs and the disruptions. For the simulations of disruptive radiation heat loads at plasma facing walls the FOREV-2D code has been used. The FOREV-2D code was originally developed for simulations of ELM influence upon plasma facing components including the thermonuclear core contamination with vaporized and ionised first wall materials [2,3].

Previous simulations revealed that the divertor armour heat load during the disruption is drastically reduced due to formation of the plasma shield produced from the evaporated armour material close to the separatrix strike position. The plasma shield, which protects the divertor armour, is also a significant source of radiation heat load distributed over surrounding structures. After the formation of plasma shield almost all disruption energy is deposited in the shield and reradiated backwards into the vacuum vessel. The simulations have shown the feedback influence of the cold and dense carbon plasma vaporised from the divertor armour on the disruption scenario. This study analysed how are the cold plasma penetrates inside the pedestal and irradiates the thermal energy of deuterium-tritium plasma directly from the pedestal and from the core, thus without heating the divertor.

2. FOREV scenario for ITER disruption

Simulation of disruptions in tokamak is a challenging problem for theoretical plasma physics. This problem cannot be solved using the modern FOREV-2D code originally developed for the simulations of ELM influence on the divertor targets, on the first wall of vacuum vessel and on the thermonuclear plasma itself. The code uses the assumption that the magnetic configuration of the simulated tokamak does not changed during the ELM. This assumption is not valid for the disruptions. Nevertheless, addressing the problem of the first wall radiation heat load during the disruption, the code can give an acceptable evaluation for the flux during the thermal quench of the disruption, when the magnetic field configuration could be approximated as unchanged with acceptable accuracy. For such a simulation it was assumed that the plasma transport across the magnetic field provided by increase of the effective diffusion coefficients D_{dis} for the thermonuclear plasma and for the heat transport. The scenario for the temporal and spatial variation of the diffusion coefficients proposed for the disruption is similar to those, used in previous FOREV-2D simulations of damage produced by ELMs [3]. In the scenario it was assumed that the heat load at the divertor surfaces during disruption is due to drastic temporal enhancement of the cross magnetic field diffusion in the ITER core, pedestal and SOL. The magnitude, the space and the time variations of enhanced plasma diffusion coefficient are fitted to reproduce the plasma fluxes anticipated for ITER disruptions. It is assumed that the value of D_{dis} grow linearly with time during 200 μs and then remains constant during all 3 ms of the simulation time. D_{dis} controls the rate of DT plasma injection into SOL during the disruption.

3. The simulation results

First simulations performed for disruptions of the ITER discharge used the same spatial and time dependences of the diffusion coefficients with four different amplitude values, which

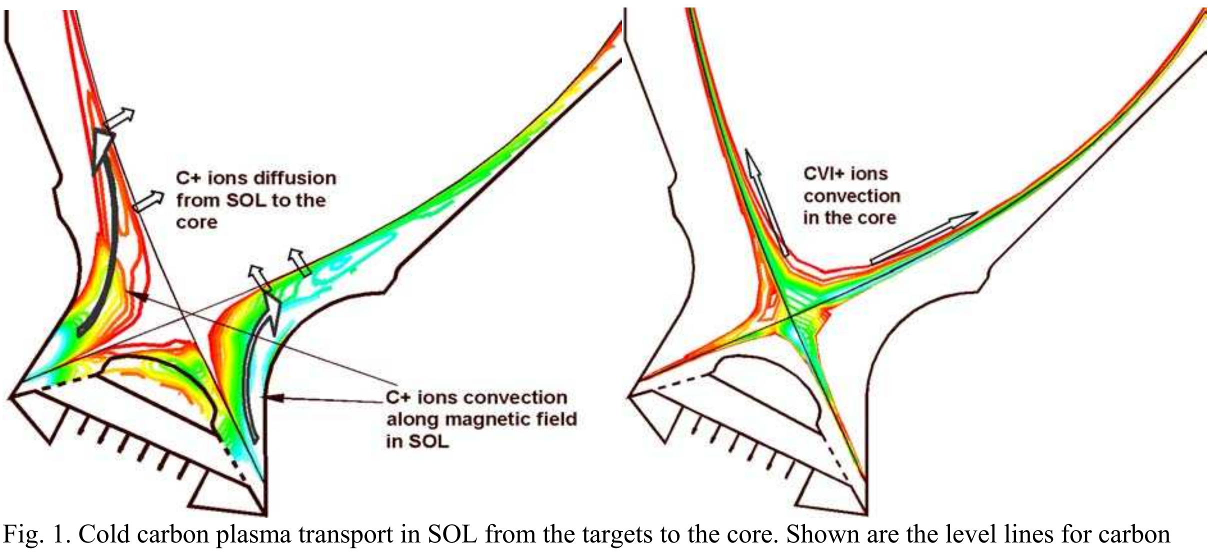

Fig. 1. Cold carbon plasma transport in SOL from the targets to the core. Shown are the level lines for carbon ions density. Red colour corresponds to the minimum density, cyan – to the maximum one. The plasma diffuses from SOL to the core close to the x-point mainly as C+ ions, then being heated with the thermonuclear DT plasma it ionised to CIV+ - CVI+ states and convects along the magnetic field in pedestal with much higher velocity than the C plasma in SOL. The absolute values for the plasma densities are seen from Fig. 2.

provided the release of 30, 43, 63 and 130 MJ/ms.

According to the simulations, the carbon divertor targets vaporization starts at 60-200 μs depending on the energy release rate. Then the carbon plasma transported along the SOL, filling it with the cold carbon plasma of a few eV temperature and of 10^{21}-10^{22} m^{-3} density depending on the release rate for the disruptive energy. After the disruption start the released energy is spent for the armour heating and vaporization. Then the thermonuclear energy flux ionizes the carbon vapour and converted into radiation in the plasma. The radiation flux is redistributed over the divertor surface decreasing peak heat load on the armour. Due to the plasma shield further divertor heating is maintained at the very low level providing permanent targets vaporization, which feeds up the shield. The carbon plasma from the shield expands along the SOL and diffuses across magnetic field to the core and to the vacuum chamber wall. The total amount of energy spent for targets vaporization is negligibly small, less than 1% of the released energy. That is,

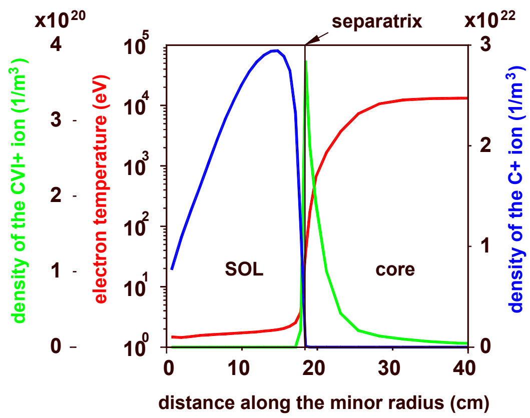

Fig. 2. C+ and CVI+ carbon ions density profiles along the minor radius close to the x-point. Due to different plasma temperatures the main ion species in the core is CVI+ and in SOL mainly C+ ions.

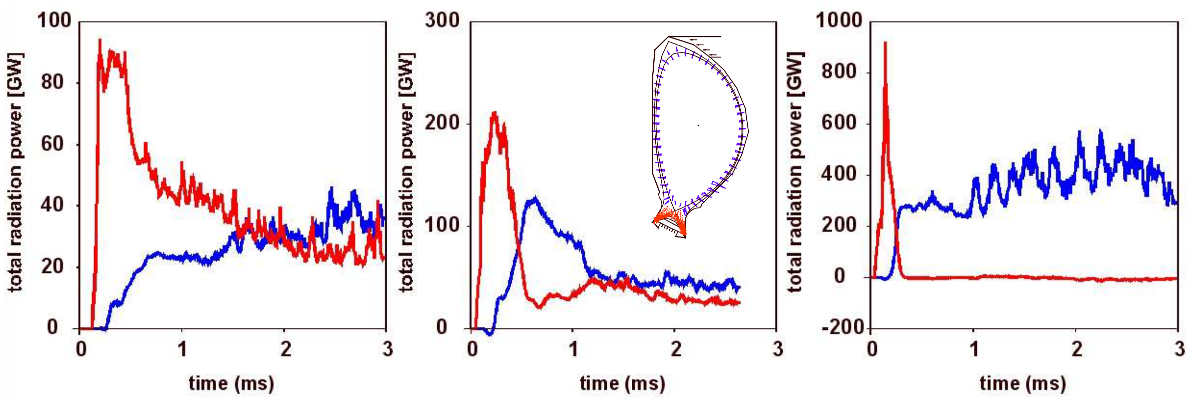

Fig. 3. FOREV-2D ITER disruption simulation results. Time dependences for total radiation power from the divertor region (red curves) and from the core (blue curves). Shown are the results of FOREV-2D simulations for disruptions with 30 MJ/ms (left panel), 63 MJ/ms (central panel) and 130 MJ/ms (right panel).

vaporized will be as much carbon as it needed for the shielding. The carbon shield consists of dense cold plasma, with 10^{21} – 10^{25} m^{-3} density and a few eV temperature, and of the corona with a few hundred eV temperature and less then 10^{20} m^{-3} density. The cold carbon plasma, consisting mainly of C+ ions reaches the x-point during few hundred microseconds and diffuses to the core in its vicinity, downstream from the x-point, see Fig. 1. Inside the core this plasma is heated up and ionized to CIV+ – CVI+ ions and transported along the magnetic field faster than in the SOL due to higher plasma temperature. As a result, the carbon plasma diffuses inside the core in vicinity of the x-point mainly. The density profiles for various carbon plasma ions are shown in Fig. 2. The carbon plasma penetration inside the pedestal causes radiation cooling down of the thermonuclear plasma there. The radiation produced in thin surface layer of a few centimetres thickness reach with the carbon plasma with density of 10^{19}-$4\cdot10^{20}$ m^{-3}. Comparison of the total radiation power from plasma shield in the divertor with the radiation from carbon plasma in pedestal is shown in Fig. 3. The disruption with small thermonuclear plasma energy release rate produces radiation mainly from divertor. With increasing of the energy release rate contribution of the pedestal carbon plasma to the total irradiated energy grow, reaching more than 85% for the disruption with 130 MJ/ms energy release rate. In the last case the pedestal plasma cooled down to a few electron-volts, when the carbon plasma cooling rate increased at least on two orders of the magnitude comparing with the higher temperatures of 30-100 eV, characteristic for the pedestal plasma in the disruptions with 30 - 63 MJ/ms energy release rate.

Conclusions

The first simulations of ITER disruptions using the FOREV-2D code aimed on evaluation of radiation heat load at the first wall have been done. An important peculiarity of the energy loss from the hot core during the thermal quench of the disruption has been revealed. According to the simulations, a considerable amount of carbon plasma vaporized from the divertor targets can penetrate into the core in the course of disruption. This plasma can irradiate up to 85% of the thermonuclear plasma energy to the first wall, thus reducing the divertor heat load.

References

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