MF-I57

1st Asia-Pacific Conference on Plasma Physics, 18-23, 09.2017, Chengdu, China

Modelling of Plasma-Wall Interaction and Impurity Transport in Magnetic Fusion Devices

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The interaction of plasma ions and neutral particles with the wall components in magnetic fusion devices is unavoidable and has severe consequences for the machine availability. First of all, impinging particles can erode material from the wall components, which limits their lifetime. Replacement demands a time-consuming shut-down and thus should be minimised. Furthermore, eroded particles reaching the main fusion plasma will cause dilution and in particular strong cooling of the plasma in the case of high-Z particles. Both processes reduce the probability of fusion reactions and therefore the performance of the fusion reactor. Finally, deposition of eroded particles on wall components comes along with co-deposition of fuel atoms. Fusion reactors will use a 50/50 mixture of deuterium (D)/ tritium (T) as fuel to benefit from the large cross section of the D-T fusion reaction. However, the maximum allowed amount of radioactive T retained in the wall components is limited by safety and fuel cycle reasons. After having reached such limit (e.g. 1kg for ITER) further operation has to be suspended to allow for elaborate cleaning procedures. Hence, T retention should be minimised to enhance machine availability.

Therefore, development of future fusion devices like ITER or DEMO requires reliable prediction of the lifetime of wall components and T retention. For this purpose, present experiments in combination with modelling are indispensable. The contribution at hand introduces the three-dimensional Monte-Carlo code ERO [1], which is used to model plasma-wall interaction and impurity transport in a large variety of fusion experiments including tokamaks and stellarators as well as linear devices. The basic physical processes implemented in ERO will be described. These include physical sputtering, chemical erosion and transport of such eroded particles through the edge plasma. Physical sputtering yields are typically calculated according to the so-called Eckstein fit [2]. Chemical erosion of carbon (C) and beryllium (Be) is based on data from literature, see e.g. [3, 4]. For the particle transport, modelled in the traced impurity approximation, the Lorentz force due to electric and magnetic fields is considered. The friction forces between the impurity ions and the background plasma flow are also taken into account. Anomalous cross field transport is treated on the basis of effective diffusion coefficients. Finally, atomic processes like ionisation, dissociation or recombination are included using rate coefficients mainly based on ADAS [5] data. The plasma background is a necessary input for the ERO simulations and can either come directly from measurements or from plasma simulation codes like SOLPS [6]. Modelled impurity light emission and erosion/deposition pattern are output data, which can be compared and benchmarked with experimental observations.

In the present contribution the application of ERO is demonstrated on various examples mainly focused on JET. First, the impurity transport in the divertor of JET-ILW with Be main wall and tungsten (W) divertor is studied (experimental findings are summarised in [7]). The resulting deposition at remote areas is compared with post-mortem analysis. It is seen that the main deposition is due to Be eroded from the main wall. Comparison with observed deposition in the full C wall of JET-C reveals that the erosion of the Be main wall in JET-ILW is much smaller (factor about 10) than the erosion of the C wall in JET-C. This also leads to a significantly reduced T retention in deposited layers.

Another example is the erosion of the Be main wall in JET-ILW [7], which has been studied in dedicated experiments with limiter configurations. ERO modelling has been performed to validate the sputtering data for Be with respective passive spectroscopy during the plasma parameter scan, which determines the sputtering ions impact energy.

Finally, predictive modelling of the wall lifetime for ITER will be shown. The modelling reveals that lifetime issues of the Be wall are much less critical with respect to machine availability than W erosion in the divertor.

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