9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Review of prompt redeposition in fusion devices with focus on tungsten-based plasma-facing components

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Plasma-wall interaction is one of the crucial issues in magnetic confinement fusion research. The unavoidable erosion of wall components in fusion devices due to plasma-wall interaction or energetic charge-exchange neutrals reduces the lifetime of the wall components. Moreover, eroded material can migrate into the plasma core, potentially leading to radiation cooling and plasma dilution of the fusion plasma. Due to its high melting point and low physical sputtering yield, tungsten is the preferred wall material for future devices. Also ITER, the international next-step fusion experiment, will be a full-tungsten device with a tungsten divertor and tungsten first wall [1]. However, as high-Z material, tungsten has a large ability to cool the plasma for which reason the concentration of tungsten in the plasma core has to be kept at very small values. The net tungsten erosion, which finally determines the plasma contamination, is the result of gross erosion minus the amount of redeposition. For high-Z materials, redeposition can be significantly enhanced due to so-called prompt redeposition. In a simplified view, prompt redeposition of an eroded particle can be seen as deposition during its first gyration motion after erosion. Thus, with larger ratio of gyration radius to ionization length, the effect of prompt redeposition becomes more pronounced, which therefore can be expected to be an important process in particular for high-Z materials. The amount of tungsten prompt redeposition can reach large values of nearly 100% under certain plasma conditions and thus is a key factor to reduce the gross erosion to tolerable net erosion sources. Understanding of all the involved processes under various plasma conditions is indispensable and hence modelling in combination with experimental findings is important. Predictive modelling for future devices like ITER and DEMO will depend on robust modelling tools, which have to be benchmarked against experiments. The present contribution reviews the current knowledge and understanding of prompt redeposition physics with focus on modelling but also discusses experimental studies.

The process of "prompt redeposition" has been already addressed by Fussmann, Naujoks et al. in the 1990s. The fraction of eroded particles, which can be redeposited within the first gyro-orbit, has been calculated with a simplified treatment [2]. Consideration of the electric field and multiple ionization has been done with the 3D Monte-Carlo code ERO [3]. Further ERO simulations have been performed with various refinements, for instance considering an improved description of the sheath characteristics [4]. This includes the electric field itself but also the density and temperature profiles within the sheath. These improved sheath characteristics are based on Particle-in-Cell (PIC) simulations [5], which also have been used to estimate the fraction of prompt redeposition. A 1D-semi-empirical model for prompt redeposition is presented in [6] based on the separation of the electric field effect from the gyromotion.

Experimentally prompt redeposition has been studied in various fusion devices. As examples, experiments at ASDEX-Upgrade [2, 3], JET [7] or DIII-D [8] are mentioned. Prompt redeposition can be observed in-situ via spectroscopy or post-mortem by means of ion-beam analysis of gross- and net-erosion. Successful benchmarking e.g. with the 3D code ERO has been done, see for instance [3, 8].

ERO code based studies of the main parameters influencing the amount of prompt redeposition like plasma density and temperature, sheath electric field or anomalous cross field diffusion will be discussed. The amount of tungsten prompt redeposition can vary between a few percent and almost 100% (see figure). Thus, for future devices like ITER or DEMO it is extremely important to have a good knowledge of the specific plasma parameters to make reliable predictions of the tungsten net erosion sources.

References

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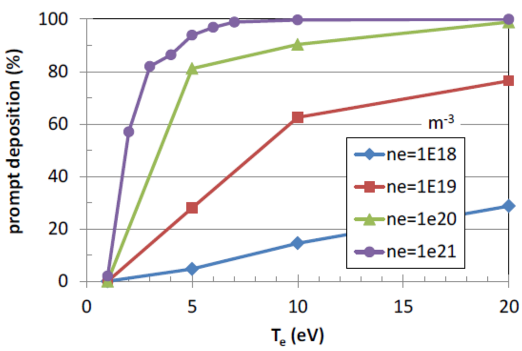

Simulated amounts of W prompt redeposition (ERO)