Research on plasma wall interaction facilities for future fusion reactors

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Plasma material interactions will decisively determine the availability and thus the economy of a fusion reactor because of their impact on lifetime of the first wall (erosion) and on safety (tritium retention and dust production). Studies under the umbrella of the IEA implementing agreement on plasma wall interactions in TEXTOR have significantly contributed the understanding of PMI processes at high-Z plasma facing components with respect to erosion and deposition, material mixing and fuel retention, both in experiment and modeling.

In view of plasma material interactions in ITER and DEMO new challenges have to be met: extended operational regimes with respect to particle and heat flux densities onto plasma facing components, both steady-state and transient, the use of toxic first wall materials (Be in ITER), the presence of Tritium, and the impact of neutron irradiation onto first wall materials. Moreover, future fusion devices will – in contrast to most present day experiments – be characterized by long pulse operation, where issues related to large fluence predominate such as erosion / deposition, stability of co-deposits, surface morphology, dust accumulation, fuel retention, fatigue effects associated with transients and – last but not least – the impact of neutron damage on PWI processes and thermo-mechanical properties of plasma facing components.

To characterize plasma surface interactions under these conditions, dedicated plasma surface interaction facilities can be used, including linear plasma devices, which allow for detailed investigations not possible in magnetic confinement devices.

In this contribution we describe, how specialized linear plasma devices and open systems can contribute to fill the gaps which current toroidal devices show with respect to the challenges in ITER and DEMO. New devices are currently being constructed or planned at Forschungszentrum Jülich and its partners in the Trilateral Euregio Cluster. We introduce the JULE-PSI facility [1], a device proposed in Jülich and capable to expose neutron activated and toxic wall materials to reactor relevant particle fluence and ion energies. The new device in Jülich will be installed inside a new laboratory to study plasma-surface interactions with both toxic and neutron activated materials, which is planned in the Hot Material Laboratory of FZJ. The concept consists of:

- A target exchange and surface analysis chamber for activated and toxic materials equipped with laser aided diagnostics (Laser induced desorption, laser induced ablation and laser induced breakdown spectroscopy to determine fuel content and material composition [2]). Both the plasma device and the analysis chamber shall be located inside a Hot Cell.
- A linear plasma device equipped with the target exchange chamber to expose neutron activated and toxic PFC samples to reactor-relevant plasma fluence and ion energies (JULE-PSI).
- A non-nuclear twin device to JULE-PSI not located inside the Hot Cell but in the same building (a controlled area). Both twins share the high power diagnostic lasers and the power supplies.
To meet these objectives JULE-PSI will be a steady state linear plasma generator based on a low pressure high current arc discharge, which allows for reactor relevant particle fluence and ion energy. It is based the PSI-2 Berlin device [3] which has been moved from Berlin to Jülich and is assembled currently as PSI-2 Jülich to provide a test bed for JULE-PSI. The stationary plasma is produced between a cylindrical, heated cathode made from LaB6 (heating power of the cathode 6.5 kW, discharge current up to 1000 A, discharge voltage up to 200 V) and a hollow anode made of Mo. The use of a planar cathode is under consideration to improve the homogeneity of the plasma cross section. From the source region the plasma is guided by an axial magnetic field of 0.1 T (produced by copper coils) towards the target region. The particle flux density can reach up to $10^{23}$ m$^{-2}$ s$^{-1}$ (normal incidence with respect to the target and a factor 10 below the flux densities expected for the ITER strike points), the heat flux density up to 1 MWm$^{-2}$, the plasma diameter amounts to 50-150 mm. ITER relevant particle fluence of $10^{27}$ m$^{-2}$ (one ITER discharge in the Q=10 inductively driven scenario) can thus be obtained in about 3 h plasma duration in the PSI-2 device.

The targets will be heated to temperatures above 1000 deg C to investigate the effects of hot walls in a DEMO type reactor. In contrast and complementary to the high flux density device MAGNUM-PSI [4] with SC coils, which is currently being assembled at FOM, The Netherlands, JULE-PSI is not foreseen as a divertor simulator, as heavy particles are not magnetized in the moderate magnetic field and neutrals recycling at or eroded from the material surface are not ionized close to the target to a large extent. The non-nuclear twin device outside the Hot Cell aims at a more detailed plasma characterization with plasma diagnostics which cannot be integrated into the Hot Cell because of complexity and maintenance issues and to expose non-activated reference samples.

Such dedicated PSI experiments in linear plasma devices are complementary to studies in toroidal confinement devices and a coherent program on PSI topics in both configurations is essential for a successful development of concepts for future fusion reactors. On this basis, it has been proposed to widen the collaborative research on plasma wall interactions to dedicated PSI facilities (toroidal and linear) under a new heading “research on plasma wall interaction facilities for future fusion reactors” in extension of the current IEA implementing agreement on “plasma wall interactions in TEXTOR”.


