Integrating Plasma-Material Interaction with Fusion Nuclear Science

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Fusion reactors will produce unprecedented heat, particle, and neutron fluxes which will alter the properties of plasma facing materials (PFMs) and components, significantly impacting reactor lifetime, performance and safety. Defect production caused by these fluxes during plasma-material interactions (PMI) in the near-surface region will induce stresses and produce stress-induced vacancies, which can then migrate deeper into the material and act as trap sites for gas atoms, driving material degradation and leading to large scale erosion processes. Neutrons will create further defect production by energetic particle-induced displacement damage cascades, He production, and transmutation in the near surface region and in the bulk of the PFM. Study of the combined effects of neutron irradiation damage with PMI is an emerging scientific focus as the diffusion, trapping/de-trapping of dissolved gas atoms within the complex of defects, and migration, merging, and annihilation of vacancies, voids, and larger defects, is unclear. The combined effects will change the tritium retention and the thermal conductivity, and will lead to embrittlement and enhanced erosion. New experimental capabilities are required to understand this PMI science and the potential impact it might have on tritium self-sufficiency, the evolution of the thermomechanical properties of the PFM and underlying component lifetime. The Material Plasma Exposure eXperiment (MPEX, see figure 1), currently in construction at the Oak Ridge National Laboratory, is designed to address these outstanding science gaps. Its concept provides the capability to expose *apriori*-neutron irradiated material samples to fusion reactor divertor grade steady-state plasmas [1]. This is achieved with a novel plasma source and heating system, which makes use of a high-power helicon (200 kW, 13.56 MHz) to create a high-density plasma which will be heated by waves in the electron cyclotron resonance frequency range (400 kW, 70/105 GHz) and in the ion cyclotron resonance frequency range (400 kW, 6-9 MHz). The MPEX concept is expected to produce electron and ion temperatures of up to 15 eV, electron densities of up to 10^{21} m^{-3} and parallel heat fluxes of up to 40 MW/m^2 in front of the target without target biasing. The device will operate in steady-state and make use of superconducting magnets to reach the required magnetic fields of 1 T at the target. This is essential to be able to investigate the strongly-coupled plasma material interaction regime expected in tokamak divertors, where erosion products (atoms, molecules and even nm-sized dust particles) will be confined, mimicing (as realisticly as possible) material erosion and re-deposition and its effect on the surface evolution. Long term exposures of up two weeks non-stop are planned to achieve a reactor relevant ion fluence of 10^{31} m^{-2} on the target. A surface-analysis station, which will allow *in vacuo*, inter-shot material characterization with a large set of surface diagnostic tools, is an integral part of MPEX. This will allow tracking of the surface evolution throughout the very long pulses.

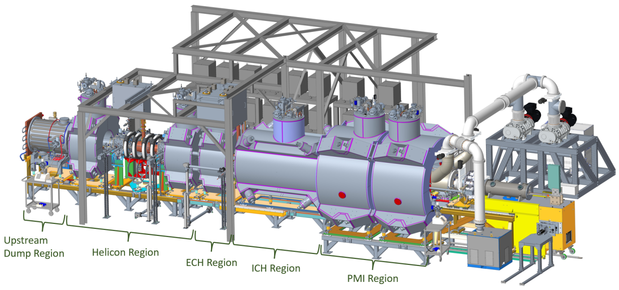

Figure 1: Final design of MPEX

MPEX will be complementary to other linear facilities, like PISCES-RF [2], which is able to investigate the material changes due to simultaneous plasma exposure and irradiation damage by high-energy ions. First experiments on PISCES-RF elucidate this new field of PMI Science and recent data will be presented. Furthermore, in this contribution the outstanding science gaps and the planned PMI science program will be discussed. It will be shown how MPEX with its unique capabilities will be essential for closing the outstanding science gaps. Details of MPEX's unique capabilities will be explained, such as the high power helicon antenna, the Electron Bernstein Wave heating technology, the ion cyclotron beach heating scheme, the target exchange chamber with its automated docking machinery, and the surface analysis diagnostic suite for unraveling the science of the evolving surfaces in long pulse exposures. This presentation will include aspects of the previous R&D establishing the MPEX physics basis and also describe the ongoing MPEX Science program to prepare for the MPEX exploitation phase.

References
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