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Plasma chamber PMI –Linear plasma facilities (implantation, retention, erosion, first wall)

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Tritium (T) retention in plasma facing components (PFCs) subjected to burning plasma-material interactions (BPMI), defined here as simultaneous plasma exposure and 14 MeV neutron irradiation at reactor-relevant temperatures, will materially impact the in-vessel T inventory, achievable tritium breeding ratio (TBR), and performance limits of PFCs in fusion pilot plants (FPPs). Validated model predictions of these issues in FPP PFCs are needed to support FPP designs but require a deep understanding of PFC material evolution under BPMI conditions.

Experiments on linear plasma devices are contributing to the development of this understanding in several ways. First, these experiments show that PFCs exposed to mixed D-He plasmas undergo profound surface and near-surface morphology changes, including formation of He-nanobubble layers at the surface, development of arrays of micron-scaled cone-shaped features and, at high surface temperature, spontaneous growth of a dense interwoven nano tendrils that emerge out of the underlying substrate. Experiments then show that these changes have a profound impact on fuel retention within the PFCs, and that these changes lead to macroscopic changes in transport of eroded surface material within the surrounding scrape-off layer plasma; thus, any model of redeposition and material migration must account for these microscopic morphology changes. Second, ion-beam based studies show that the displacement damage from energetic particles leads to defects that can greatly enhance fuel retention. When exposed at reactor-relevant temperatures, interstitial-vacancy recombination in W-based materials occurs quickly enough to largely eliminate this elevated retention. However, recent sequential ion-beam/linear plasma device PMI experiments clearly indicate that trapping of plasma-implanted hydrogen isotopes within these defects can stabilize vacancy-interstitial recombination, and thus may largely stop this beneficial annealing. Finally, recent experiments show a clear degradation of material thermomechanical properties from plasma exposure and from displacement damage, and thus PFC operational limits in an FPP will likely be profoundly impacted by BPMI effects.

After presenting these existing results, we close with thoughts on future linear device and confinement device BPMI experiments that can help develop the validated predictive multi-scale PFC models needed to guide the design of any magnetic confinement based FPP device.

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