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Demonstration and analysis of helium exhaust enhancement during resonant magnetic perturbation field application at DIII-D[1]

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It is shown for the first time in a diverted tokamak that key metrics for continuous fusion, effective helium particle confinement time $\tau_p{}^*{}_{,\mathrm{He}}$, and its ratio with energy confinement, $\tau_p{}^*{}_{,\mathrm{He}}/\tau_E$, were reduced by more than a factor of two during suppression of edge localized modes (ELMs) by resonant magnetic field perturbations (RMPs) over the unperturbed ELMy case. Reduced $\tau_p{}^*{}_{,\mathrm{He}}$ during RMPs was observed in the core, edge, and pump plenum, where higher helium pressure and concentration were also found. Elevated ionized helium line emission during ELM suppression, with a decay time matching $\tau_p{}^*{}_{,\mathrm{He}}$, was measured at the inner strike point, suggesting more helium in the unconfined region. These observations suggest that processes during application of RMPs better retain helium at the edge, in excess of that expected from deuterium 'pumpout,' where it is pumped more quickly. A multi-reservoir model, derived from a finite volume approximation of the continuity equation with diffusive and convective transport, fits the helium time evolution at each of the above-mentioned measurements well. Transport parameters obtained from these fits indicate the data are consistent with strongly increased transport of helium in the separatrix region during RMP application, although higher core transport is also found. EMC3-EIRENE modeling suggests magnetic field stochastization near the separatrix reduces the upstream thermal force relative to the friction force, enhancing outward transport in the edge. These findings, which were obtained in ITER-shaped plasmas, provide evidence that application of RMP ELM suppression in future devices such as ITER may be capable of matching or exceeding the helium impurity exhaust produced by the ELM events themselves, thereby helping to avoid helium ash buildup in a burning regime, and maintain high fusion gain.

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