Physics and effectiveness of real-time boronization by B powder injection[1]

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Achieving wall conditioning via injection of non-toxic B powder presents considerable advantages over standard glow discharge boronization (GDB), which entails handling of hazardous gases and interruptions of experimental operation. Recent experiments on various tokamaks have shown that injection of B and BN in powder form can enhance and control the H-mode pedestal, as well as significantly improve wall conditions to facilitate operation at low density/collisionality scenarios. Injection of BN in AUG [1] resulted in a confinement improvement similar to N_2 injection; in KSTAR [2] and EAST [3] suppression of edge localized modes (ELMs) with negligible confinement loss has been observed with BN and B injection, respectively. Concurrent with these observations was an improvement of wall conditions in terms of reduced impurity sources, as well as reduced deuterium recycling and wall fueling. This effect was further investigated with dedicated DIII-D experiments, which demonstrated that B powder injection (BPI) in tokamak plasmas leads to similar improvements to wall conditions as GDB [4]. Injection of B powder in DIII-D H-mode discharges resulted in 50% lower impurity emission at breakdown and enabled better density control in the L-mode phase as result of reduced wall fueling. Reduced emission from the CD molecular band was also observed during BPI, indicating suppression of C chemical sputtering. *Ex-situ* surface analysis of graphite and W-coated witness samples exposed to BPI plasmas in the divertor and far scrape-off layer confirmed the growth of a B-rich films at rates of ~0.1 nm/s with surface composition B:C~1:1. Integrated modeling of powder transport and ablation (DUSTT), SOL transport (UEDGE), and sheath/surface processes (hPIC, F-Tridyn) indicate >95% powder assimilation by the plasma. For BPI at 10 mg/s, this leads to B fluxes to the divertor of $\sim 10^{20}$ $m^{-2}s^{-1}$ and a net deposition of B at rates consistent with measurements. The applicability of BPI for real-time wall conditioning of long pulse, next-step fusion devices will be discussed.

[1] R. Lunsford *et al*, Nucl. Fusion, 59(12), 2019, 126034
[2] E.P. Gilson *et al*, proceedings of the 33th EPS Conference, ECA, Vol. 43C, P5.1026
[3] Z. Sun *et al*, proceedings of 17th H-mode Workshop, 2019, Nucl. Fusion, to be submitted
[4] A. Bortolon *et al*, Nucl. Fusion to be submitted

[1] Supported by U.S. Dept. of Energy contracts DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FG02-07ER54917, DE-AC52-07NA27344, DE-NA0003525, DE-SC0018243, DE-FG02-06ER54852, DE-SC0019256 and DE-AC05-00OR22725.