Divertor heat flux mitigation with boron and boron nitride powders in DIII-D

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Injection of boron (B) and boron nitride (BN) in powder form into the upper closed divertor at DIII-D showed a substantial drop in divertor electron temperature from 30 eV to below 10 eV, increase in divertor neutral compression by up to an order of magnitude, and transition into stable detachment [1]. A decrease in wall fueling, main chamber neutral pressure, and the reduction of oxygen, carbon, and neutral deuterium line emission in the plasma edge and divertor demonstrated additional conditioning of the main plasma-facing components caused by the cumulative injection of the low-Z non-recycling materials.
Real-time wall conditioning with B and BN powders has been demonstrated before at AUG and DIII-D [2, 4]. Numerical modeling suggests that boron is, in addition to nitrogen, very suitable for reducing divertor peak heat loads at relatively low concentration and low core contamination [5]. To investigate this experimentally, B and BN powders of 65-150 um particle size were injected into the DIII-D closed small-angle slot divertor [6] in upper-single-null ELMy H-mode plasmas (I_p~1 MA, B_T=2 T, P_{NBI}~6 MW, f_{ELM}~80 Hz, $<n_e>$~3.6-5.0x10^{19}/m^3) in 2-s intervals at rates of 3-200 mg/s. BN powder at 50 mg/s showed transition into detachment while rates of 200 mg/s triggered n=2 tearing modes and a drop of up to 24% in energy confinement and a reduction in neutron rates. Plasma fluid simulations coupled with dust transport modeling were used to study the effect of the powder particle size on ablation and impurity migration in the divertor and scrape-off layer. The results show that larger powder particles can escape the divertor before they fully ablate, resulting in less localized boron fluxes advantageous for conditioning and more uniform power losses in the plasma boundary.
The experimental and modeling data suggest that boron and boron nitride injection provide an alternative approach for safe divertor power exhaust. Previous experiments have shown that using the BN powder impurity mix reduces the ammonia content by 90% compared to N2 gas injection [3]. Furthermore, real-time injection of B and BN powders brings the additional benefit of reduced recycling, better density control, and suppression of intrinsic impurity sources due to active conditioning of the divertor plasma-facing components during plasma operation. Thereby, powder injection could at least supplement conventional methods of impurity seeded power exhaust and wall conditioning, affecting the divertor integrity, performance, and operability of a fusion pilot plant.

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