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Physics Basis Development for Spherical Torus p-^{11}B Plasma Fusion

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Research toward commercial p-^{11}B fusion power in a Spherical Torus (ST) [1] takes advantage of the aneutronic reaction to permit a relatively slender toroidal field coil center-post, and retain high performance (e.g., plasma β), compact size and modular design [2]. Compared to the DT tokamak, the challenges of reaching ~100keV plasma temperatures, sufficient densities for adequate fusion power, and high energy confinement times must be overcome. A mid-size ST p-B experiment, EXL-50, was initiated at ENN in October 2018 to explore the physics of ECRH current initiation, ramp-up, heating and sustainment without a central solenoid [3].

Progress in physics basis so far included an improved equilibrium model [4] for p-B plasmas to reproduce the observed plasma conditions [5,6], which contain populations of un-equilibrated supra-thermal (~200keV) electrons of very low densities (~several$\times 10^{16}$/m^3) [7,8]. Under ECRH power, these plasmas exhibit transitions (Figure) to a quiescent state. Transition in ST p-B plasmas becomes a viable research goal aimed at improving ion turbulence and confinement, given strong auxiliary and/or internal fusion alpha particle heating [9].

These transitions are likely to change the ST p-B plasma properties of equilibrium; supra-thermal particle kinetics; macroscopic stability; neoclassical transport; microscopic turbulence and transport including isotope effects; heating and current drive via ECRH, LHCD, ICRH, NBI and the fusion alphas; plasma-material interactions of limiter and divertor configurations involving boron; and charge separation mechanisms at the plasma edge. Upcoming research will develop a p-^{11}B physics basis toward igniting the plasma and allowing the centralized fusion α heating and auxiliary heating to exceed the local Bremsstrahlung radiation and transport losses, with margins to reach fusion burn.

The EXL-50U [3,10] is being built to raise in 2024 its operational capabilities to test the p-B plasma properties at 0.5MA current, several-keV central temperatures, and ~10^{20}/m^3 central densities. This will provide opportunities for addressing new physics issues encountered. The EHL-2 [1] will follow to produce plasmas of 3MA current and 3T toroidal field at 1.05m major radius, to achieve substantial p-^{11}B fusion reactions for the first time.

Research aimed at raising plasma performance and improving the physics basis of these new ST p-^{11}B experiments [1,3,10] will be reviewed, including new performance analysis based on the *open, thermally un-equilibrated plasma system* model [11].

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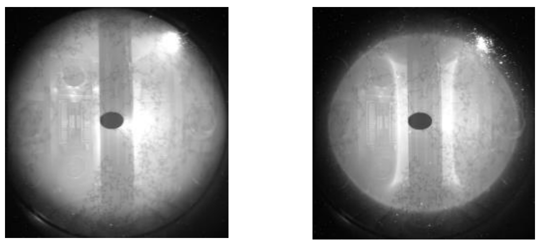

A self-organized transition from a turbulent state (left, 1.18s, 28 + 50GHz) to a quiescent state (right, 1.80s, 50GHz) of the EXL-50 ECRH-only p-B plasma under boron powder fueling (Ip~100kA, nel~1.5$\times 10^{18}$/m^2)