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Prospects for a compact high-beta burning plasma

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The low aspect ratio "spherical" tokamak (ST) has previously been identified as a potentially attractive candidate for a fusion nuclear science facility (FNSF) ultimately leading to a Component Test Facility (CTF). ST-based FNSF/CTF design studies have focused on very compact plasmas with major radius 1.2m and A=1.5 capable of producing neutron wall loadings = 1-2MW per square meeting at DT fusion gain Q(DT) = 1-3. In the present work, we consider larger ST device size and assess the possibility of exploiting the modularity of the ST to enable a single facility to: (1) achieve FNSF/CTF-level neutron wall loading, (2) access higher fusion gain for accelerated component testing, (3) investigate ST burning plasma physics, and (4) achieve engineering breakeven Q(engineering) = 1. To begin assessing such possibilities, a core plasma systems-code has been extended and benchmarked against reactor design studies. It is found that with ARIES-ST-level stability and increased confinement, the smallest possible ST pilot plant capable of electrical self-sufficiency has major radius in the range of 1.5m, i.e. roughly half the size of ARIES-ST. The achievement of reactor-like normalized parameters is clearly very challenging, and the impact of further increased device size and reduced confinement and stability on fusion performance will also be described. Using the same plasma geometry as an ST pilot plant, CTF-like scenarios with neutron wall loading = 1-4MW per square meter are achievable over a wide density range by operating with reduced normalized beta and increased NBI current-drive fraction. While non-inductive start-up to ~150-200kA has recently been achieved, start-up remains a challenge for the ST. NSTX and MAST Upgrades are planned to assess non-inductive start-up/ramp-up at the ~1MA level, and substantial progress has also been made in partial-inductive ramp-up in present STs using early H-mode and NBI heating resulting in OH Ejima coefficient = 0.3-0.35. This result implies that a A=1.7, R=1.5m device could utilize a single-swing solenoid to provide 9MA of ramp-up current to quickly access and assess ST-CTF-like regimes. Overall, a modest increase in device size in a ST-CTF appears to substantially enhance fusion gain, wall loading, operational flexibility, and options for the center-stack.

This work supported by U.S. DOE Contract # DE-AC02-09CH11466