Physics design of a Spherical Tokamak Advanced Reactor (STAR)*

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Compact high-field superconducting tokamaks are being proposed in the U.S. as a means of potentially reducing the capital cost of a fusion pilot plant (FPP). Systems code analysis of steady-state tokamak FPPs with varied aspect ratio and fixed net electric power of 100 MWe (and other constraints) indicates that $A \approx 2$ could significantly reduce the toroidal field and central solenoid coil volume and mass [1], which are major drivers for the fusion core cost [2]. Further, if the favorable confinement regimes observed in NSTX, MAST, and other spherical tokamaks scale to larger reactors, the auxiliary power, neutron wall loading, and blanket replacement volume will also be reduced. Recent access to ion temperatures of 100 million degrees Kelvin in the ST-40 spherical tokamak (ST) device show that the ST configuration can access fusion-relevant ion temperatures [3] in a compact low-aspect ratio tokamak. These and other factors have motivated the design and development of next-step spherical tokamaks, for example the Spherical Tokamak for Energy Production (STEP) facility [4].

This presentation will describe physics design activities for a fully nuclear A=2, R=4-4.5m Spherical Tokamak Advanced Reactor (STAR) [5,6] targeting 100-500MWe net electric power, tritium breeding ratio > 1 and including integrated vertical maintenance, power exhaust, and neutronics analysis. See Figure 1 for

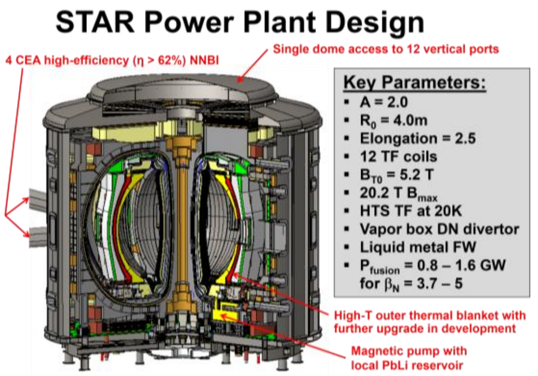

Figure 1 - Key design features and parameters for STAR

additional design and parametric information for STAR. STAR operational scenarios have emphasized full non-inductive current drive with approximately 80% bootstrap current fraction with the remaining current drive provided by electron cyclotron current drive (ECCD) and/or negative neutral beam injection (NNBI) with injection energies of 0.7MeV or above. These scenarios have elevated safety factor profiles with minimum q > 2. The no-wall stability limit is set by the n = 1 pressure-driven kink mode at normalized beta $\beta_N \leq$ 3.5-3.8 with a weak dependence on q provided $q_{min} > 1$. These scenarios support fusion powers of 0.5-1GW with a nominal operating point of 800MW. With wall stabilization ($b_{wall}/a = 0.5$), $\beta_N \sim 5$ is accessible with fusion power = 1.5-2GW.

Local Alfvenic instability analysis finds that Toroidal Alfven Eigenmodes (TAEs) are unstable due to high central ion temperature $T_i > 30$keV. Global 2D ideal MHD NOVA calculations identify ~300 radially extended TAEs and Reversed Shear AEs (RSAEs) at n=1-20. However, these modes are found to be stable with kinetic effects included in NOVA-K due to global structure and strong thermal ion Landau damping.

Gyrokinetic analysis of the H-mode pedestal finds that the widths are approximately twice the values typically found at conventional aspect ratio. The impact of this broadening is to provide a higher pedestal MHD stability limit with weak or absent edge localized modes (ELMs) for aspect ratios A = 2.2 and below. If valid, such wide pedestals with intrinsic ELM stabilization may be transport limited rather than MHD stability limited which would be a significant advantage relative to conventional aspect ratio pedestals.

Extensive analysis using SOLPS-ITER has been dedicated to lithium-based capillary porous system with flow (CPSF) divertor plasma facing components to mitigate very high edge power and heat fluxes. In a system also including Neon for enhanced divertor radiation, favorable solutions are found with CPSF peak temperature < 700C, peak divertor target heat flux < 5MW/m^2, upstream lithium concentrations below 2% of the electron density, $Z_{eff} < 2.5$, and separatrix densities below the estimated threshold for H-mode back-transitions to L-mode. These and other important results will be described.

References

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