Simplifying the ST and AT Concepts

[1]R. Raman, [1]T. R. Jarboe, [2]J. E. Menard, [1]B. A. Nelson, [2]D. Mueller, [2]M. Ono, [2]T. Brown
[1]University of Washington, Seattle, WA, USA
[2]Princeton Plasma Physics Laboratory, Princeton, NJ, USA

A Fusion Nuclear Science Facility (FNSF) or a power plant based on the Spherical Torus (ST) or Advanced Tokamak (AT) concepts can considerably benefit from design simplifications that lead to reduced cost, increased system reliability and improved device performance due to reduced auxiliary power input. The need for this is identified under Theme A of the FESAC 'Priorities, Gaps and Opportunities (2007)' report.

Advanced Fueling and EBW Current Drive: Steady-state AT and ST scenarios rely on optimized density and pressure profiles to maximize the bootstrap current fraction. Under this mode of operation, the fuelling system must deposit small amounts of fuel where it is needed, and as often as needed, so as to compensate for fuel losses, but not to adversely alter the optimum density and pressure profiles. Compact Toroid (CT) fuelling, which involves the deep injection of small CT plasmas at the required frequency, has the potential to meet these needs, while simultaneously providing a source of substantial toroidal momentum input. This provides rotation capability, in alpha heated reactor discharges, needed for reducing transport and increasing plasma stability limits. For a ST-FNSF, A 5 MW CT system injecting 2 mg deuterium CTs at 20 Hz will impart the same momentum as a 69 MW, 500 keV neutral beam injector, while supplying 14 times more core fueling. A fuelling system based on CT injection has a simpler fuel cycle, without the need for tritium cryogenics, and should increase the tritium burn fraction and reduce tritium inventory in the fuel cycle. Under these operating conditions, in addition to a small amount of core current drive needed to control q(0) and q_{min}, the only other need is for a small amount of off-axis current drive. Electron Bernstein Current Drive (EBW CD) has the potential to meet these needs for these high-performance AT type discharges. Simulations for NSTX-like high beta geometry show that EBW CD power can provide up to 40 kA/MW of current drive for sustained operation. Developing these capabilities would require about 4 years of off-line experiments, followed by an additional 6 years of experiments on NSTX-U. The off-line experiments would start with an existing CT injector and improve the electrode configuration and injector operating frequency. EBW experiments would begin with a 1 MW gyrotron, initially for plasma start-up, which is part of the NSTX-U incremental budget plan, and during later years expand the capability to a 3 MW system to support current drive studies. Starting from YR5, experiments on NSTX-U would begin to provide the physics validation of both concepts. Sustained density profile control and sustained EBW current drive capabilities would be developed during YRs 6-10.

Solenoid-free plasma startup (SFPS): Methods for initiating the plasma discharge without reliance on the solenoid would remove an expensive component and provide greater flexibility in device aspect ratio optimization, which can lead to improvements in overall device performance. During the next five-years of NSTX-U operations, SFPS capability will develop an understanding of the current start-up requirements for FNSF applications. Coaxial helicity Injection (CHI) is the most developed system on NSTX. EBW CD and Local Helicity Injection will also be developed on NSTX-U. Design studies for a FNSF have identified new configuration features that simplify the CHI system design, but require experimental validation on STs. The goal towards the end of 5 years is to demonstrate the physics validation of at least one of these concepts, followed by the engineering validations by the end of the 10-years. The projected cost for this effort, that is well underway as part of the base and incremental budget, including cost for modeling support is about $7M for SFPS, largely for a 1 MW gyrotron that is needed for all three plasma start-up concepts. Unbudgeted cost is for sustained current drive studies during YRs 6-10 that would add two more gyrotrons at a total cost of $10M, and about $12M for a 20 Hz CT injector. Three FTEs are required for theory and modeling support for all these activities.