Heating, Current Drive, and Fueling: Overview

Heating and current drive technologies are essential for heating plasma to fusion-relevant betas and temperatures, and for manipulating plasma properties to access advanced operating scenarios (reversed shear, MHD stabilization, turbulence suppression). Physics and technology working groups at the Snowmass meeting emphasized the need for improved control of pressure and current profiles and transport barriers in order to access long-pulse advanced-tokamak scenarios. We need improvements in system reliability and flexibility, and a change from the present “blunt tool” capability for controlling profiles to a more refined ability to tailor profiles to access the high-beta, high-bootstrap-fraction plasmas needed for future research.

Significant progress has been made in developing and deploying high-power gyrotrons at the ~1-MW level at 110 GHz, and the development of 170-GHz prototype units for electron cyclotron heating/current drive (ECH/ECCD). Fast-wave (FW) antenna arrays in the >1-MW unit size for Ion Cyclotron Heating (ICH) and current drive (via direct electron heating) have been developed and tested. Progress is also being made in other countries on the development of negative-ion based, high power neutral beam injectors (NBI) (0.5–1.0 MeV). In line with the needs of the physics groups, the emphasis of the development of these heating and current drive technologies will concentrate on improving RF system reliability, robustness and performance; increasing power density (higher voltage limits for ICRF launchers), higher gyrotron unit power (1.5 to 2 MW), increased efficiency gyrotrons featuring depressed collectors, ICRF tuning and matching systems that are tolerant to rapid load changes, steady-state gyrotrons and actively cooled ICRF launchers for long-pulse/burning-plasma, next-step options, improved NBI sources, long pulse / CW lower hybrid (LH) antenna systems and basic research on helicity injection.

Fueling is another technology that is essential for achieving fusion-relevant plasma parameters and manipulating plasma parameters to achieve improved performance (peaking of the density profile for higher reactivity and reducing transport via turbulence suppression). Recent successes include sustained operation above the Greenwald density limit on DIII-D, high-field side launch with improved density profile peaking, internal transport barrier generation, the development of steady-state pellet injectors operating in the 1.5-km/s speed range, and the demonstration of core fueling in experiments using accelerated compact toroids (CTs). Pellet fueling technology has also been used recently to ameliorate the effects of major disruptions in tokamaks by delivering massive amounts of low- and high-Z material that rapidly quench the current in vertically unstable plasmas. It has been estimated that eliminating disruptions in tokamaks in the fusion energy development class would increase the lifetime of divertor plasma facing components by a factor of two. Reducing the severity of disruptions could allow the advanced tokamak to operate nearer its ultimate β potential. A critical issue for fueling in next-step device plasma regimes is the degree to which profile peaking is needed (for higher density operation and improved reactivity and confinement) and the technological requirements to meet that need (pellet speed, CT density and the physics of CT deposition). Advances are also needed in disruption detection, in developing low-Z mitigation techniques (i.e. massive gas-puff, liquid jet injector, etc.) and integrating detection and mitigation into the control system of an existing tokamak to test the full system and demonstrate reliability.