Taming the Plasma Material Interface

RF Antennas, Launching Structures, and Other Internal Components

Richard W. Callis – General Atomics

Issues

In order to achieve the conditions needed for high performance core, edge and SOL plasmas in steady-state with the combined performance characteristics required for Demo, methods need to be developed and applied that can modify plasma parameters using external means. The parameters that need to be modified include plasma temperature, current, density, current profile, pressure profile, stabilization of instabilities, shape and rotation.

A variety technologies have been exploited over the years to produce external plasma manipulation. These can be grouped into the categories of Plasma Heating, Current Drive,, Shaping, and Edge Control. Technologies utilized are high velocity neutral particles, microwaves, radio waves, magnetic coils, and high speed switching power supplies. The extrapolations of these technologies to meet the needs of Demo range from extensive development needed to readily available commercially. All technologies will have to be evaluated for robustness, reliability and compatibility in the Demo environment. For steady-state performance the systems will need to be operated in a feedback mode based upon information gathered by real-time diagnostic measurements,

Many of the diagnostics presently employed will be unavailable or much more difficult in Demo. These issues are already exposed in the diagnostics planned for ITER. These issues are accentuated in Demo. Generally it is believed there will be less access to the plasma, while at the same time control of profiles, monitoring of material erosion, accounting for tritium inventory, etc. will be essential. The neutron fluence in Demo will be several-fold larger than in ITER, restricting material choices for nearby diagnostics components. Like many other components, diagnostics will need to be remotely maintainable. The robustness of the measurements will need to be greater than presently achieved in order to maintain plasma control over long periods of time.

The continuous operation of Demo demands a degree of measurement robustness that has not been required to date. Not only does the data need to be continually reliable, but a gradual change in the instrumentation physical characteristics from neutron and radiation damage must be accounted for. At the same time, the near steady-state operation of the device will limit access to diagnostic hardware and its ability to operate during diagnostic maintenance.

Functional internal components (antennas, sensors, mirrors, control coils, etc.) must meet the criteria of other plasma facing components in terms of resistance to high (~1-10 MW/m2) heat and neutron fluxes and acceptable levels of impurity production, while in addition maintaining the capability to perform heating, diagnostic, or control functions. Internal RF antennas and microwave launch structures or mirrors present special challenges, as these components are energized with high intensity electromagnetic fields with amplitudes ~ 10-100 kV/m. These fields can accelerate particles along field lines and create DC plasma sheath structures: both these phenomena can lead to focused particle and energy fluxes on the antennas or launchers themselves, as well as other components or surfaces intersected by the field lines.

Development Requirements

The key capabilities required for the development and deployment of effective and durable internal components in fusion reactors were identified in the Greenwald report as:

a. *Reliable and verified techniques for predicting particle, heat, and neutron fluxes on passive components (e.g. sensors, mirrors, etc) in realistic geometry in both normal and off-normal operating conditions.*

b. Reliable and verified techniques for computing self-consistent heat and particle fluxes to high-power, energized components (RF antennas, microwave launchers, etc) which interact with and alter the edge plasma.

c. *Structural, shield and coating materials with which to construct internal components, and appropriate joining/bonding technologies. These materials must be able to withstand the intense heat, particle and neutron fluxes of a fusion reactor for reasonable operation lifetimes, without excess impurity generation, and will need to be fully qualified in materials testing facilities.*

d. *Verified 3-D design concepts and techniques for cooled internal components*.

Research Thrust

All of the internal components to be used in DEMO must pass through a rigorous development cycle of modeling, testing, validation and extrapolation, using computer code analysis, test bed confirmation, and implementation on present and future non-DT tokamaks. However, to obtain the performance capability of internal components under high neutron fluxes, in a hostile plasma environment, requires that integrated tests be performed in a Component Test Facility, where, reliability, availability, maintainability and inspectability (RAMI) criteria can be established.

The Fusion Development Facility (FDF) is an ideal device to validate the internal components needed for DEMO. With neutron fluence at the outer midplane of 1–2 MW/m^2 and a goal of a duty factor on a year of 0.3, FDF can produce fluences of 3–6 MW-yr/m^2 in ten years of operation onto complete internal component prototypes. With these fluences FDF can make a significant contribution on relatively large, fully integrated and engineered components. It should be noted that close to DEMO relevant internal components will be needed to operate the FDF tokamak from day one, with the expectation that over the lifetime of FDF these components will evolve into designs with more capability and robustness. Other components can be validated in the test ports provided as part of the FDF mission, which will allow the testing of different designs for extended periods, and under different temperatures and cooling methods. Both liquid metals and gas cooling can be explored, with temperatures as high as 900°C.

For RF antennas and microwave launchers there is a concern on their lifetime owing to erosion of plasma facing surfaces. With ten times greater plasma fluence onto surfaces than ITER, FDF will make a major contribution to evaluating the robustness of conducting layers needed for launching high intensity electromagnetic fields.