Development and Validation of a Plasma Boundary Model

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GENERAL ATOMICS

A Variety of Options Can Be Utilized for a DEMO Boundary Plasma Solution

- **Requirements of a DEMO boundary plasma**
  - Surface heat flux ≤10 MWm^{-2}
  - Adequate particle control , pumping
  - Minimize surface erosion
  - Maintain robust core confinement
- **Wide variety of boundary plasma design options**
  - Magnetic configuration; double-null, flux expansion, Super-X
  - Surface geometry; target plate shaping, divertor baffling
  - Radiative dissipation; high density, injected impurity radiation
- **Issue: Our models have not been sufficiently qualitatively validated to design future boundary plasma operation with confidence**

A Comprehensive Boundary Plasma Model is Required to Design a Boundary Solution for DEMO

- **Too time consuming and costly to optimize DEMO boundary operation empirically in real time**
- **A comprehensive model is needed because different physical mechanisms are tightly coupled**
- **Physical processes in model may be described either by fundamental theory or empirical scaling**
- **Physical process that should be included and validated include:**
  - Plasma transport; Parallel and perpendicular, particles and energy, steady state and fluctuation driven, all species…
  - Kinetic effects; Ions, electrons and neutrals
  - Drifts; ∇B and E-field drifts
  - Atomic physics; Radiation, ionization, recombination, C-X,…
  - Surface boundary conditions; Sputtering, recycling,…
  - Compatibility with core plasma; Pedestal degradation, current drive,…

A Comprehensive Boundary Model Must be Validated

- **All physical processes can be, and are being incorporated into codes**
- **Currently our codes must adjust free parameters to match experimental measurements, and some measured conditions cannot be reproduced (flows)**
- **Validation of physical processes, or robust empirical scaling, in the comprehensive boundary model will require significant experimental resources**
  - Configuration flexibility
  - Access to wide range of plasma parameters
  - Extensive diagnostic set

Validation Should be Carried Out Over a Wide Range of Conditions

- **Proposed divertor solutions cover a wide range of configurations, geometry and materials whose effects must be known**
  - Configurations; Double-null vs. single-null, core separatrix shaping, flux expansion (Snowflake), divertor length and volume (Super-X),…
  - Surface geometry; Divertor baffling, private flux dome, target plate geometry,…
  - Surface material; Low Z (carbon), High Z metal, Liquid metal
- **The underlying physics, or scaling, of the model needs to be tested over a wide range to provide confidence in scaling those processes to DEMO**
  - Divertor and SOL parameters; Density and temperature of the divertor and SOL, neutral densities, power densities, impurity density, detachment,…
  - Core parameters; Pedestal density, ELM suppression, high beta, current drive

US Tokamaks Cover a Wide Range of Conditions

- **Configuration flexibility**
  - Shaping, configuration (DIII-D)
  - aspect ratio (NSTX)
  - divertor shaping (C-mod, DIII-D, NSX)
- **Materials**
  - High-Z (DIII-D)
  - Low-Z (C-mod)
  - Li, Liquid metal (NSTX)
- **Divertor SOL parameters**
  - Toroidal field, particle density, power density (C-mod vis. DIII-D and NSTX)
  - Impurity density (C-mod, DIII-D, NSTX)
- **Core plasma parameters**
  - High beta (DIII-D)
  - RF heating (C-mod)
  - ELM suppression (DIII-D)

An Extensive Diagnostic Set is Required to Validate Boundary Plasma Models

- **Extensive diagnostic implementation on a single device**
  - Because physical processes are coupled many parameters must be measured to isolate a single physical effect
- **2D measurements**
  - The boundary constitutes a complex 2D pattern of densities, temperatures, flows, fluctuations and E fields
  - Existing diagnostic techniques can be scaled up large arrays of measurements
  - Imaging techniques may be extremely useful
- **Several parameters measurements are especially sparse**
  - Ion temperature; Ion temperature may be very different from electrons, Non-Maxwellian features also important
  - Neutral density; Ionization rate fundamental to particle balance
  - Erosion rates; Boundary condition for studying impurity transport

A Boundary Plasma Diagnostic Thrust Would Enable Validation of a Boundary Model

- **Boundary plasmas are currently inadequately diagnosed to examine boundary plasma processes**
- **A diagnostic thrust should be accompanied with an enhanced boundary plasma modeling effort**
- **DIII-D could accommodate a significant boundary diagnostic effort**
  - Extensive existing diagnostic set
  - Open geometry for imaging, diagnostic installation
  - Flexibility for installing innovative divertor geometry
  - Wide range of configurations and divertor parameters
  - Access to advanced tokamak operating scenarios