Thrust 12:
Demonstrate an Integrated solution for plasma-material interfaces compatible with sustainment and control of an attractive core plasma

Presented by A. Leonard

With contributions from R. Goldston, B. Lipschultz, D. Whyte, and C. Wong

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Demo's boundary will go where no magnetic fusion device has gone before

- Power: More than four times ITER's power in a similar size device
- Pulse length: More than 75% duty cycle for years
- Temperature: Greater than 500°C for efficient electrical energy production
- Fuel: Tritium must be self-sustaining
- Neutrons: More than 25 x ITER's neutron fluence

We need a validated model of the boundary plasma and plasma-material interactions for Demo conditions

- **Key Thrust 12 challenges for Demo boundary design:**
  - Aggressive steady-state and transient heat flux control compatible with a robust edge pedestal and good core confinement
  - Erosion, migration, redeposition and dust formation from PFCs compatible with long term operation, fuel control and core plasma contamination
  - Effects of high temperature PFC surfaces (metal and liquid) on fuel recycling/retention and core density control
  - Core plasma sustainment and control compatible with edge plasma (coupling to core) and power handling requirements (survivability)

Thrust 12: Validate solutions for these challenges with conditions relevant for Demo

- **Possible solutions will arise from a number of thrusts**
  - Thrust 1: Diagnostics for long pulse boundary characterization
  - Thrust 2: ELM and disruption control
  - Thrust 5: Plasma sustainment and control
  - Thrust 9: A model of the boundary plasma and PFCs
  - Thrust 10: Plasma PFC materials and PMI
  - Thrust 11: Heat flux control techniques and components
  - Thrust 14: PFC materials
- **No existing, or planned, facility is capable of validating these solutions for Demo boundary relevant conditions, AND illuminating issues that these other thrusts must address**

Thrust 12 will examine comprehensive solutions for Demo's boundary

- **Heat flux control**
  - Examine a variety of approaches to reduce upstream heat fluxes of ≥ 1 GW/m^2 to tolerable levels for material surfaces, ≤ 10 MW/m^2
  - Compatibility of such approaches with a robust pedestal and good core confinement
  - Transient heat flux control (ELMs and disruptions) compatibility with robust pedestal and heat and particle flux control
- **Material erosion, migration and redeposition for relevant boundary plasmas**
  - Characterization and control of erosion rates and redeposition (lifetime and dust)
  - Compatibility of various PFC materials with optimal core plasma operation (impurity influxes)
  - Role of redeposition in T retention

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Thrust 12 objectives (cont.)

- **High temperature effects on PFCs, boundary plasma and core**
  - Changes in erosion rates (e.g. evaporation of Li) and impurity influxes
  - Fuel retention/recycling with control of the pedestal
  - Fuel permeation and trapping in the PFC
  - Operational window of the PFC (e.g. above DBTT but below recrystallization)
- **PFC component testing**
  - Long term reliability of high heat flux PFC components in a steady state high heat flux tokamak environment
  - Compatibility of liquid metal PFC components with tokamak conditions
  - Properties of neutron irradiated components in tokamak conditions
- **Steady state plasma control**
  - Coupling and efficiency of heating & current drive through 'thick' SOL
  - Interactions of SOL with current drive launching structures
  - Achieving equilibrium (e.g. T profile in PFC) requires no disruption

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Thrust 12 objectives (cont.)

- **Model validation (multiple diagnostics required) under Demo-like conditions**
  - Boundary plasma characteristics (T, n, flows….)
  - Plasma-material interactions (3D fluxes of particles and power)
  - The PFC (material erosion & redeposition, material characteristics, T permeation and trapping)
  - Neutron effects, largely separable from plasma interactions, to be integrated in DT device

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Thrust 12 facility design objectives

- **An experimental facility is needed to validate models and solutions at Demo relevant conditions**
- **High power density**
  - For all normalizations (P/A, P/R, P/R^2) Demo power density is greater than all existing or planned facilities
  - Work underway (e.g., 2010 JOULE milestone) for better estimates of divertor heat flux area in Demo
- **Robust pedestal**
  - Heating power many times greater than H-mode power threshold
  - A low collisionality pedestal with Demo's bootstrap current profile
  - Centrally fueled (SOL opaque to neutrals)

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Thrust 12 facility objectives (cont.)

- **Long pulse at high power**
  - All components at thermal equilibrium for recycling and fuel retention
  - Long term erosion rate profile, migration and redeposition and dust formation
  - PFC component reliability
  - Current sustainment integral part of design
  - Short, high duty cycle, pulses not equivalent to long pulse due to thermal and particle cycling
- **High temperature, 500°C – 1000°C**
  - He gas, or potentially liquid metal, cooled components
  - Temperature variability for optimizing fuel retention and permeation

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Thrust 12 facility objectives (cont.)

- **Explore current drive options**
  - Variety of options may include LH, ECCD, and NBI
  - Capability for studying coupling through dense high power SOL
  - Core current profile control
- **Complete diagnostic coverage**
  - Measurements are key for understanding and validation of boundary models, components and techniques
  - Complete coverage of boundary plasma parameters; density, temperature, impurities, neutrals, heat flux
  - Comprehensive plasma-material interaction measurements; erosion and deposition rates and profiles
  - Fuel retention and permeation rates and profiles
  - Dust formation; rates, locations and transport

Thrust 12 facility objectives (cont.)

- **Flexibility is essential**
  - A wide variety of components and techniques must be installed and tested; divertor configurations and components, first wall materials, ELM control hardware, current drive actuators
  - Quick installation of test components
  - Access for regular maintenance and replacement of failed components
  - Diagnostic access
- **Design objectives more readily obtained without requirement of a nuclear (DT) mission**
  - Machine design flexibility and lower cost by not requiring high gain
  - Faster component change-out
  - Diagnostic flexibility
  - Synergy with a parallel CTF program

Thrust 12 will build on results from a number of thrusts, but also provide feedback to them

- **Thrust 1; Diagnostics for long pulse boundary characterization**
  - Validate diagnostic techniques for boundary characterization
  - Validate diagnostic reliability in harsh boundary plasma environment
  - Demonstrate steady-state diagnostic operation
- **Thrust 2; ELM and disruption control**
  - Demonstrate ELM transient control techniques compatibile with steady-state heat flux control
  - Provide additional requirements for ELM transient control
  - Disruption control required for steady-state operation
- **Thrust 5; Plasma sustainment and control**
  - Current drive is required for continuous operation
  - Test compatibility, coupling and efficiency, of current drive techniques with dense, high power SOL

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Thrust interactions (cont.)

- **Thrust 5, 9; Model development of boundary plasma and PMI**
  - Validate boundary models in new regimes
  - Highlight new physics that must be included in model
- **Thrust 10; Plasma-material interactions science**
  - Validate results in Demo relevant conditions
  - Highlight PMI physics for further dedicated research
- **Thrust 11; Improve power and particle handling**
  - Validate developed techniques at Demo relevant boundary conditions
  - Highlight problems for further dedicated research
- **Thrust 14; Material development**
  - Test compatibility of new materials in Demo relevant boundary plasma

Scoping and design of a Thrust 12 facility can begin soon

- **An experimental facility is needed to validate solutions for Demo's boundary;** High power, long pulse, high temperature, excellent access, configuration flexibility
- **A facility designed to achieve Demo-relevant boundary plasmas will build on, but not culminate a number of thrusts**
  - A test bed for developments from a number of thrusts; 1, 2, 4, 5, 9, 10, 11
  - New physics will drive further dedicated research in these thrusts
- **A thrust 12 facility will be complementary to and accelerate results from a DT facility; Thrusts 8, and 13**
  - A preceding or parallel effort allows for quicker validation of PFC concepts and study of problems encountered in CTF
  - Cost, device flexibility, remote access requirements for H, D and T options need quantitative evaluation

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