

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 $\geq 1 \text{ GW/m}^2$ to tolerable levels for material surfaces, $\leq 10 \text{ MW/m}^2$
 - 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

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

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

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)

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

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 compatible 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

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