Thrusts #1-4, led by Theme 1:
Achieving and Understanding the Burning Plasma State in ITER

Theme 1 leadership:

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Role of Theme 1 in ReNeW

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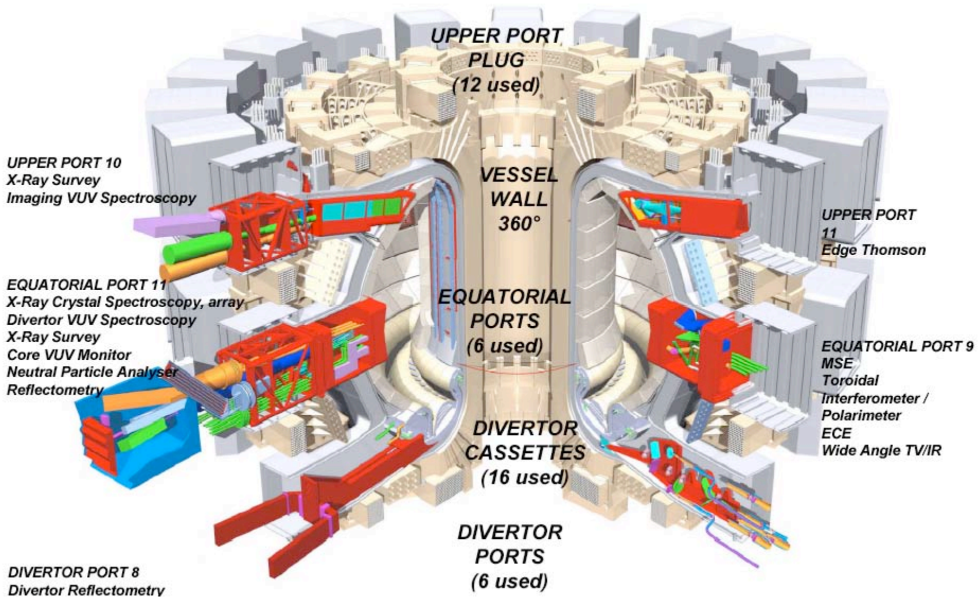
- **Burning plasma regime is next frontier for fusion energy science**
  - ITER will now open the way to study thermonuclear self-heating for the first time in a magnetically confined burning-plasma facility
- **Burning plasma scientific issues**
  - Many are similar to issues on present-day tokamaks; hence, BP science is embedded in larger US/world research program
  - However, BP research requirements are challenging (e.g., nuclear environment), and there are new issues (e.g., alpha particles, autonomous profiles)
- **Large US commitment to burning plasmas**
  - US will spend ≥$1.3B to provide this scientific capability
  - US program is increasingly focused on ITER as flagship facility
- **Six Theme 1 panels, of which 3 have been joint with Theme 2**
  - Four thrusts of Theme 1 focused on ITER; four of Theme 2 on beyond

Mapping to Research Thrusts

THEME 1 PANELS	RESEARCH THRUSTS
Understanding Alpha Particle Effects	**Thrust 3:** Understand the role of alpha particles in burning plasmas
Extending Confinement to Reactor Conditions	**Thrust 4:** Qualify operational scenarios and the supporting physics basis for ITER
Creating a Self-Heated Plasma	**Thrust 4** (see above)
Controlling and Sustaining a Self-Heated Plasma	**Thrust 5:** Expanding the limits for controlling and sustaining fusion plasmas
Mitigating Transient Events in a Self-Heated Plasma	**Thrust 2:** Control transient events in burning plasmas *[also **Thrust 3** (see above) for alpha bursts]*
Diagnosing a Self-Heated Plasma	**Thrust 1:** New measurement techniques to understand and control burning plasmas

Thrust 1: New measurement techniques to understand and control burning plasmas

- **Issues:**
  - Diagnostics are vital for understanding plasma behavior & control
  - Many present diagnostics may fail in burning plasmas (e.g., due to hostile nuclear environment)



- **Research requirements:**
  - Need improved and new diagnostics usable in the burning plasma environment: (1) to support different requirements of both scientific discovery and real-time plasma control; (2) to meet the harsh environmental needs of ITER and even harsher demands expected in subsequent devices, e.g., DEMO
  - Need techniques to measure unique properties of burning plasmas, e.g., behavior of fusion alpha particles

Thrust 1: New measurement techniques to understand and control burning plasmas

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- **Thrust action items:**
  - Evaluate ITER measurement needs, capabilities, and risks
  - Prioritize burning plasma measurement issues, including those for DEMO
  - Carry out phased diagnostic developments targeted to high-priority needs, including prototyping on present devices
  - Evaluate the success of the developments and, for those applicable to ITER, work with the ITER Project to implement qualified techniques
- **Thrust assumes USIPO will develop and deliver ITER-credited diagnostic systems**
  - US diagnostic community could contribute to broader coordinated burning plasma diagnostic development program
  - High leverage to maximize US investment in ITER research and to contribute to preparations for DEMO

Thrust 2: Control transient events in burning plasmas

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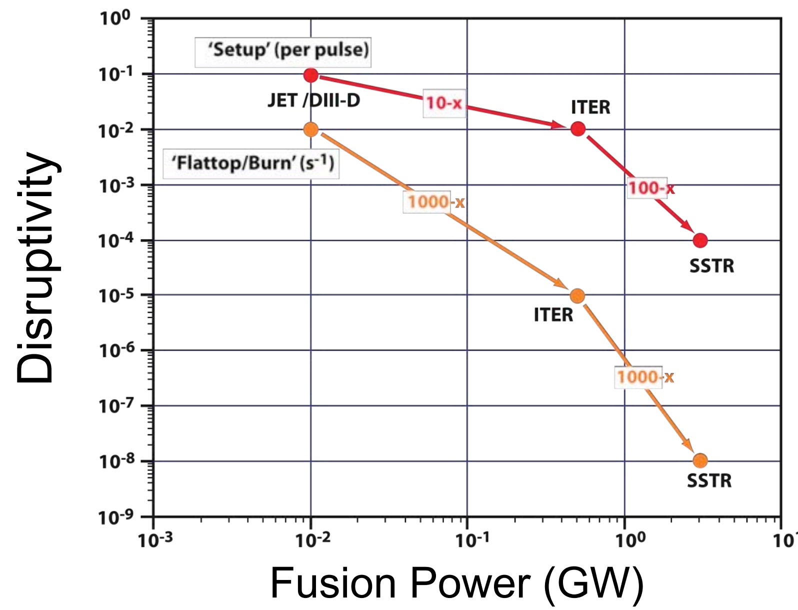
- **Issues:**
  - Transient events (disruptions with runaway electrons, ELMs) cause heat loads & EM stresses and jeopardize steady operation
  - ITER requires reduced disruption frequency, to prevent PFC melting (10X per pulse, 1000X per second)
  - Transient alpha particle bursting events covered in Thrust 3



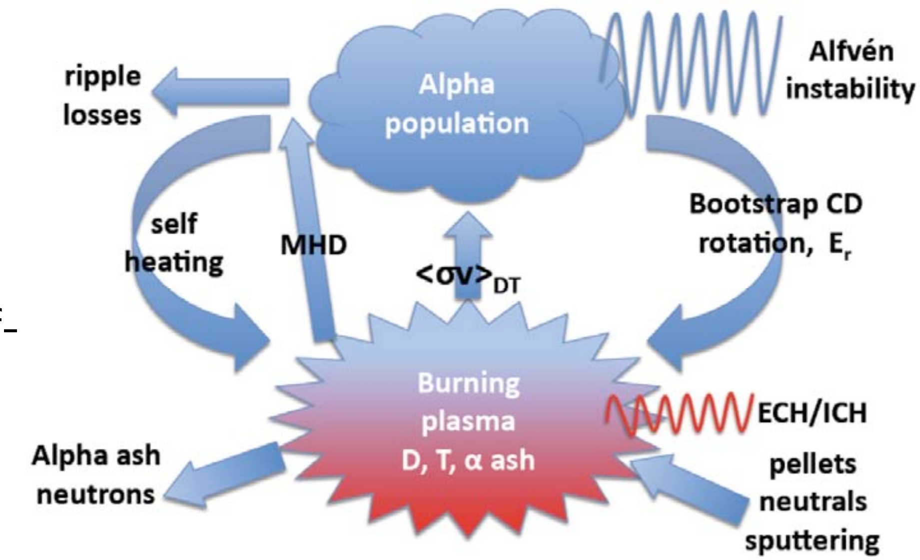
- **Research Requirements:**
  - Need to be able to predict and avoid disruptions
  - Need to minimize impact of disruptions
  - Need robust means to avoid or suppress ELMs

Thrust 2: Control transient events in burning plasmas

- **Thrust action items:**
  - Develop integrated control of plasma stability: e.g., real-time determination of plasma stability, actuators for control of internal profiles & direct suppression of instabilities, and well-tested control algorithms to steer operating point away from impending instabilities. Also, demonstrate these in new superconducting tokamaks.
  - Develop methods of disruption mitigation: e.g., actuators for rapid but benign shutdown, high-heat-flux survivable wall configurations, and magnetic configurations that reduce or eliminate disruption impact. Also, demonstrate solutions in medium & large tokamaks for extrapolation to ITER.
  - Develop control of edge plasma transport and stability: e.g., roles of 3D fields, radial electric field shear, and local particle fueling. Also, demonstrate ELM suppression in range of devices and operating conditions, for extrapolation to ITER.

Thrust 3: Understand the role of alpha particles in burning plasmas

- **Issues:**
  - Burning plasmas (e.g., ITER) will contain new, ultra-high-energy population of fusion-product alpha particles
  - Alphas will provide dominant self-heating
  - Alphas modify plasma behavior in various ways



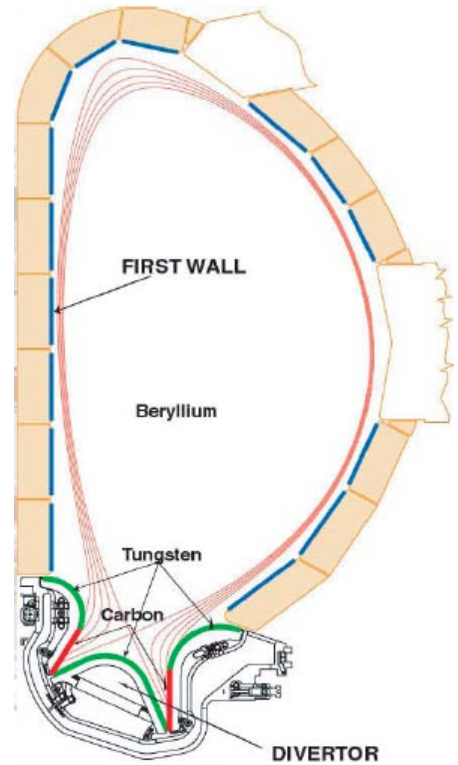
- **Research requirements:**
  - Need experimental scenarios to expand access to energetic particle behavior at high fast-particle pressure, to explore their dynamics and interaction with instabilities, losses, and current drive
  - Need new, advanced diagnostics to measure fast ion properties and phenomena in burning plasma conditions
  - Need integrated, global simulation tools for burning plasmas (e.g., small wavelength/multi-mode, flow, interaction with core turbulence)

Thrust 3: Understand the role of alpha particles in burning plasmas

- **Thrust action items:**
  - Develop experimental scenarios to expand access to energetic particle behavior at high fast-particle pressure
  - Identify burning plasma operational regimes stable to alpha-driven instabilities; assess if alpha transport is tolerable in unstable regimes (e.g., alpha particle losses and their impact on first-wall integrity)
  - Predict the alpha heating profile, alpha-driven currents, and impact on current drive requirements.
  - Incorporate experimentally validated alpha physics transport models into integrated plasma simulation tools for the entire plasma [link to Thrust 6 (predictive modeling)]
  - Develop innovative high-resolution spatio-temporal measurements of the alpha particle energy distribution and instability mode structure [link to Thrust 1 (measurements)]
  - Use Alfvén wave excitation as spectroscopic diagnostic tool
  - Invent control techniques to expand operating regime, remove helium ash, and possibly directly transfer alpha energy to core ions

Thrust 4: Qualify operational scenarios and the supporting physics basis for ITER

- **Issues:**
  - Accessing high performance in ITER will require forming, heating, controlling, and safely shutting down a high-temperature plasma



- **Research requirements:**
  - Plasma initiation (wall cleaning, tritium removal)
  - Transient phases (energy/particle transport during ramp-up/down)
  - H-mode access (in hydrogen, helium, deuterium, and DT operation)
  - H-mode sustainment
  - Heating (e.g., ICRH effective for ITER)
  - Fueling (e.g, pellet ablation and fuel deposition)
  - H-mode pedestals (integrated w/ core heat & momentum transport)
  - Pulse length extension (hybrid and steady-state operation)

Thrust 4: Qualify operational scenarios and the supporting physics basis for ITER

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- **Thrust action items:**
  - Develop wall cleaning methods for strong stationary toroidal field
  - Measure/characterize transport during transient phases
  - Assess minimum P_{aux} to obtain (1) H-mode during ramp-up/down, (2) steady Type III H-mode, (3) steady H_{98}=1 H mode
  - Minimize ICRH antenna interaction with edge plasma
  - Develop models for particle transport and pellet fueling in ITER
  - Test models of H-mode pedestal structure against experiment, determine effect of pellet fueling and low flow/torque, and couple to core models
  - Understand physics of hybrid scenario to determine applicability to ITER; develop predictive understanding of steady-state modes of operation and define requirements for implementation in ITER
  - Integrated experimental campaign in ITER-like conditions (i.e., H-mode with low input torque, $T_e = T_i$, low collisionality): use upgrades (heating & current drive, particle control, heat flux mitigation) on existing tokamaks and, possibly, a new facility