A Thrust for Integration of High-Performance Steady-State Burning-Plasma Behavior Relevant to Demo

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Fusion Research Themes (FESAC)

Theme A – Creating a High-Performance Steady-State Burning Plasma
(a heat source from magnetic fusion)

Theme B – Taming the Plasma Materials Interface
(interface between heat source and furnace wall, and extracting plasma exhaust power)

Theme C – Harnessing the Power of Fusion
(extracting neutron power, breeding tritium, remote handling, safety/environment)

- These themes follow a systems or process based approach, sometimes called Holistic approach to the R&D of complex systems - eg space craft.

- They form a natural overlapping sequence

Key Questions related to the Physics of a Demo Plasma

- A Demo plasma with high fusion gain, high neutron wall loading, high bootstrap fraction for efficient steady state and high power density plasma exhaust is a highly integrated plasma system. Some questions:
  - Is good confinement compatible with P_α defined profiles?
  - Does transport depend on non-linearly on the pressure profile?
  - Is high beta compatible with P_α defined profiles?
  - Does the plasma evolve to a stable self-organized state?
  - Will alpha heating drive a self-heating sawtooth?
  - Can the plasma be sustained and controlled with low power?
  - What are the optimum temperature and density regimes for simultaneous high Q, efficient CD and long life divertor operation?
  - Many more........
- Can we quantify the gaps between today, ITER and a Demo?

High-Performance Steady-State Burning-Plasma Issues

High Fusion Gain - attain good confinement with profiles defined by alpha heating(P_α/P_{ext} = Q/5), possible non-linear dependence of transport on gradients, coupled to edge plasma by pedestal, optimum temperature for fusion ~ 15 keV and high density but efficient current drive favors higher T ~ 30 keV and lower density.

Sustainment (100% NI) - produce large bootstrap current with pressure profiles defined by alpha heating and residual current driven efficiently by low power $P_{cd} \leq 5P_\alpha/Q$.

High Fusion Power Density ($\beta^2 B^4 <\sigma v>/T^2$) - to provide high neutron wall loading. Can near optimum β be attained for alpha-defined profiles?

Plasma Control ($P_{cd} + P_{cont} = 5P_\alpha/Q$) - maintain plasma control (esp. disruptions) with low power typically $< 0.15P_\alpha$. Will a burning plasma evolve to a self-organized state with good confinement, high bootstrap and high β?

Exhaust Power Density - can high exhaust power densities be handled while maintaining edge plasma for high Q and efficient CD with long PFC lifetime?

Self- Conditioned PFCs - will the PFCs self-condition that is consistent with high Q and β, and long PFC lifetime?

High-Performance Steady-State Burning-Plasma Metrics and Gaps

Table I. Individual Issue (Metric)	Today* ($>10\tau_E$)	ITER	ARIES-I	ARIES-AT	<Gap> IT to AR
Fusion Gain (Q)	< 0.2	5	20	50	7
Self-heating (%)	4	50	80	91	1.7
Sustainment (100% NI)** (P_{cd}/P_α)	>25	1	0.25	0.1	6
Current Drive fraction ($1-f_{bs}$) (%)	~30	~50	32	9	2.5
Neutron Wall Loading (MWm^{-2})	0.1	0.5	2.5	3.3	6
Plasma Pressure (atm)	1.6	2.5	10	10	4
Fusion Power density (MWm^{-3})	0.3	0.5	4	4.7	8
Plasma Control* (P_{cont}/P_α)	>25	1	0.25	0.1	6
Exhaust Power Density (P_{heat}/A_{ps} (MWm^{-2})	0.85	0.2	1	1	5
Self-Condition PFCs & FW f(t_{pulse}, T, ϕ,	No	?	Yes	Yes	?

* Not all simultaneous

** Current Drive Power + Plasma Control Power = 5 P_α/Q

Assumes ITER will be upgraded with addition of Lower Hybrid current drive for Scenario 4.

- ARIES-I And ARIES-AT span the range of a possible DEMO.

- Individual gaps between ITER (scenario 4) and ARIES range between 1.7 and 10

Description of integration issues

High-Performance Steady-State Burning-Plasma Integration Issue Gaps (an example)

Integrate Fusion Gain, Sustainment and Exhaust Power Density

Table I. Individual Issue (Metric)	Today* ($>10\tau_E$)	ITER	ARIES-I	ARIES-AT	<Gap> IT to AR
Fusion Gain (Q)	**< 0.2**	**5**	**20**	**50**	**7**
Self-heating (%)	4	50	80	91	1.7
Sustainment (100% NI) (P_{cd}/P_{α})**	**>25**	**1**	**0.25**	**0.1**	**6**
Current Drive fraction ($1-f_{bs}$) (%)	~30	~50	32	9	2.5
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Self-Condition PFCs & FW f(t_{pulse}, T, ϕ,	No	?	Yes	Yes	?

*   Not all simultaneous

** Current Drive Power + Plasma Control Power = 5 P_{α}/Q

Assumes ITER will be upgraded with addition of Lower Hybrid current drive for Scenario 4.

- The individual gaps are taken to be independent, therefore the Integration Gap is the product of individual gaps.
- **The Integration Gap for Fusion Gain, Sustainment and Exhaust Power density is ≈ 200**

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Key Objectives of Thrust

- Determine and understand conditions for attaining a Demo-relevant burning plasma.
- Determine and understand conditions for sustaining and controlling a Demo-relevant plasma that is dominately self-heated, with dominately self-driven currents and dominately self-conditioned PFCs.
- Test and Refine Predictive Modeling on a Demo relevant plasma.
- Together with ITER, and other Thrusts provide the knowledge basis for the design of a tokamak based Demo.

Strategy for Integrating Demo Relevant Plasma Issues

- Aggressively exploit simulation on existing DD facilities and computer models
  - target specific objectives/tasks with SC action teams
  - exploit Asian superconducting facilities
  - simulate burning plasma phenomena to the extent possible

- Begin a study of the Fusion Plasma Integration Facility that would address the integration issues of a Demo-relevant High-Performance Steady-State Burning plasma and serve as a D-T satellite tokamak for ITER.
  - refine key objectives and research requirements
  - define general characteristics of possible facilities (iterate with above)
  - since the cost will be significant, start with a plan that has a sequence of upgrades that spreads the cost and allows success to bootstrap funding for the next stage or objective.
  - begin the pre-conceptual design of a facility(s) within a year to assess technical feasibility and cost range.

Note: Not building a major Burning Plasma facility is very expensive

Since 1997 US MFE has spent $3.4B (≈ $4B in FY08 $)

Since 1989 US MFE has spent $6B (≈ $7.5B in FY08 $)