ITER Engineering Design Activities - Overview

ITER Technical Characteristics

Performance

Fusion power amplification > 10 with inductive current drive (ignition not precluded).
Fusion power amplification > 5 using non-inductive current drive.
Typical fusion power level ~ 500 MW.

Testing

Integrate and test all essential fusion reactor technologies and components.

Design

Use existing technology and physics database to give confidence but be able to access advanced operational modes.
Operation equivalent to a few 10000 inductive pulses of 300-500 s.
Average neutron flux ≥ 0.5 MW/m².
Average fluence ≥ 0.3 MWa/m².

Operation

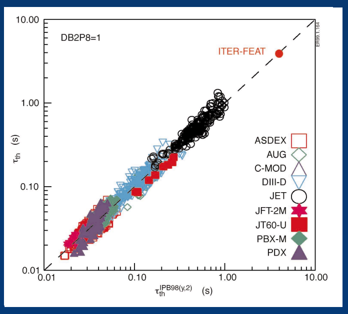
Address all aspects of plasma dominated by alpha particle (helium) heating through burning plasma experiments.
Low fluence functional tests of DEMO-relevant blanket modules early; high reliability tests later.
Device operation ~ 20 years. Tritium to be supplied from external sources.

Main Plasma Parameters and Dimensions

Total fusion power	500 MW *(700MW)*
Q = fusion power/auxiliary heating power	≥ 10
Average neutron wall loading	0.57 MW/m² *(0.8 MW/m²)*
Plasma inductive burn time	≥ 300 s
Plasma major radius	6.2 m
Plasma minor radius	2.0 m
Plasma current (I_p)	15 MA *(17.4 MA)*
Vertical elongation @95% flux surface/separatrix	1.70/1.85
Triangularity @95% flux surface/separatrix	0.33/0.49
Safety factor @95% flux surface	3.0
Toroidal field @6.2 m radius	5.3 T
Plasma volume	837 m³
Plasma surface	678 m²
Installed auxiliary heating/current drive power	73 MW *(100 MW)*

Inductive Operation

Experimental Basis



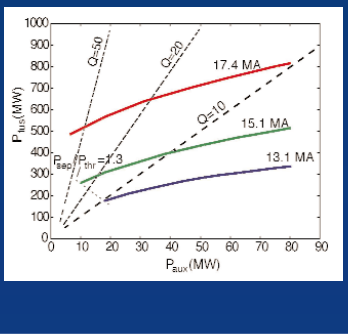
The figure shows observed energy confinement time (s) in various experiments versus value derived from the scaling law:

$$\tau_{E,th} = 0.0562\, H_H\, I_p^{0.93}\, B_T^{0.15}\, P^{-0.69}\, n_e^{0.41}\, M^{0.19}\, R^{1.97}\, \varepsilon^{0.58}\, K_a^{0.78}$$

where I_p = *plasma current (MA)*
B_T = *on-axis toroidal field (T)*
P = *internal + external heating power (MW)*
n_e = *electron density (1019m-3)*
M = *atomic mass (AMU)*
R = *major radius (m)*
ε = *inverse aspect ratio (a/R)*
K_a = $S_o/\pi a^2$, S_o *being plasma cross sectional area.*

H_H, the confinement time enhancement factor, measures the quality of confinement (= 1 for the dotted line in the figure).

Range of Performance



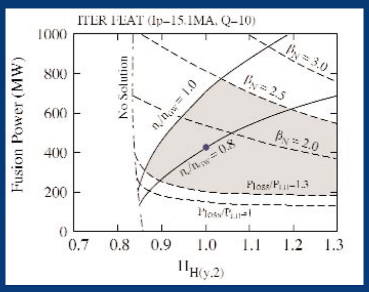
Fusion power (P_{fus}) versus auxiliary power (P_{aux}) for a range of currents and for H_H = 1 and $n_e/n_{Greenwald}$ = 0.85. Minimum fusion power is limited to a factor 1.3 above the expected power at which transition to L-mode would occur, namely:

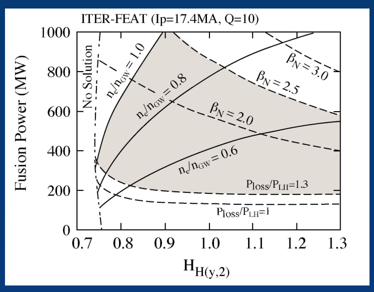
$$P_{LH} = 0.75\, M^{-1}\, B_T^{0.82}\, n_e^{0.58}\, R^{1.00}\, a^{0.81}$$

Flexibility in Reaching Q=10

The combination of a range of plasma parameters will allow Q=10 to be obtained. The figures below show the operational domain in terms of fusion power and H_H, plus the various limiting boundaries that are thought to apply.

Q=10 is maintained within the shaded region by adjusting auxiliary power and density.





The results

- *show the flexibility of the design,*
- *show the capacity to respond to factors that degrade confinement,*
- *show the ability to maintain the goal of extended burn Q=10 operation,*
- *imply the ability to explore higher Q operation,*

provided energy confinement times consistent with the confinement scaling are maintained.

Steady State and Hybrid Operation

Two operational scenarios are under consideration for steady-state operation:

- *high current (12 MA) with monotonic q or shallow shear - this requires all the current drive power (100 MW) available, but the requirements on confinement (H_H~1.2) and beta (β_N ~3) are modest;*
- *modest current (9 MA) with negative shear - this requires more challenging values of confinement improvement (H_H~1.5) and beta (β_N~3.2-3.5).*

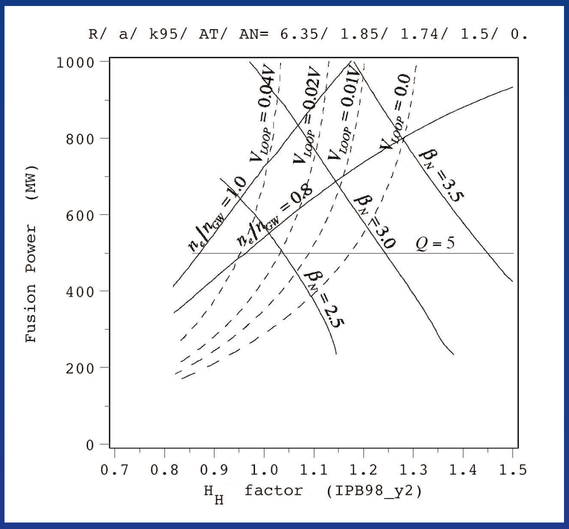
Performance predictions for these modes of operation are much less certain than for inductive operation.
In particular, the operating space is sensitive to assumptions about current drive efficiency and plasma profiles.

The potential performance of hybrid modes of operation is being evaluated as a promising route towards establishing true steady-state modes of operation. There, in addition to inductively driven current, a substantial fraction of the plasma current is driven by external heating and the bootstrap effect, leading to extension of the burn duration. This form of operation would be well suited to systems engineering tests.

The figure shows the operation space for I_p = 12 MA and P_{CD} = 100 MW, in terms of fusion power versus confinement enhancement factor, and the transition from hybrid to true steady-state operation.

For a given value of fusion power (and hence Q), as the confinement enhancement factor, H_H, increases (simultaneously decreasing plasma density and increasing β_N), the plasma loop voltage falls towards zero.

For example, operation with V_{loop} = 0.02 V and I_p = 12 MA, which corresponds to a flat-top length of 2500 s, is expected at H_H = 1, Q = 5, $n_e/n_{Greenwald}$ = 0.7, and β_N = 2.5. True steady-state operation at Q = 5 can be achieved with H_H = 1.2 and β_N = 2.8.



This analysis indicates that a long pulse mode of operation is accessible.