

# ITER FUSION PERFORMANCE PROJECTIONS FOR INDUCTIVE ELMY H-MODE AND NON-INDUCTIVE REVERSED SHEAR SCENARIOS

**D. Boucher**

*ITER Joint Central Team and Home Teams*

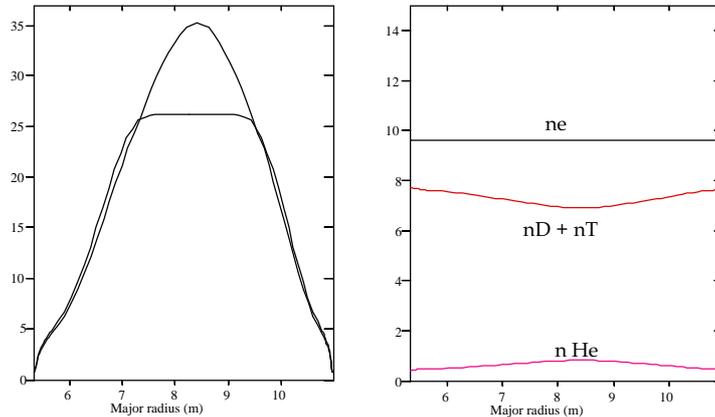
## Abstract

Addressing ignition in a next step devices implies operating away from empirical limits: on density, beta or on the power needed to sustain H-mode operation while satisfying the power balance imposed by transport losses. This paper presents the ignition domain predicted for ITER under inductive operation as a function of the energy confinement time normalized to the latest ELMy H-mode global scaling expression. The method used to study inductive operation is generalized to non-inductive operation by consistently computing the driven and bootstrap current with the plasma parameters. The operating space in reversed shear regime, with a fixed amount of current drive power is presented and shows that significant improvement of confinement ( $HH > 1.3$ ), operation at high normalized beta ( $> 3$ ) and high ratio of  $\langle n_e \rangle / n_{GW}$  are required to reach fusion power levels similar to that obtained by purely inductive operation.

## 1. Operating diagrams for inductive operations

The study of fusion performances presented in the paper is performed by deriving a self-consistent ignited reference point using the 1-1/2D transport code PRETOR [1] which computes the particle and power sources consistently with assumed transport coefficient profiles and physics dependence on local plasma parameters. The device parameters and computed profiles are shown in Fig. 1:

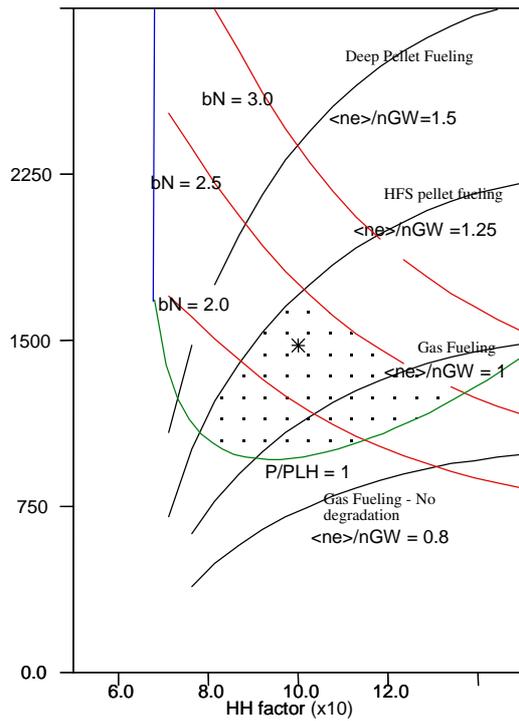
R (m)	:	8.14
a (m)	:	2.80
Bt (T)	:	5.68
I <sub>p</sub> (MA)	:	21
$\kappa_X$	:	1.7
$\delta_X$	:	0.24



**Figure 1.** Temperature and density profiles for a ignited point at  $HH=1$  and 1.5GW fusion power.

The magnitude of the transport coefficient is chosen so that the global energy confinement follows the value given by the ITERH97-P(y) [2] ELMy H-mode scaling expression. A divertor model [3] is used for the boundary conditions: edge temperatures, densities and Helium and Argon levels compatible with the pumping speed and divertor target heat loads.

Empirical fits and scalings of the global plasma parameters given by the 1-1/2D transport code are used to extrapolate the plasma parameters as the quantities ( $HH$ ,  $\langle n_e \rangle / n_{GW}$ ,  $\beta_N$ )

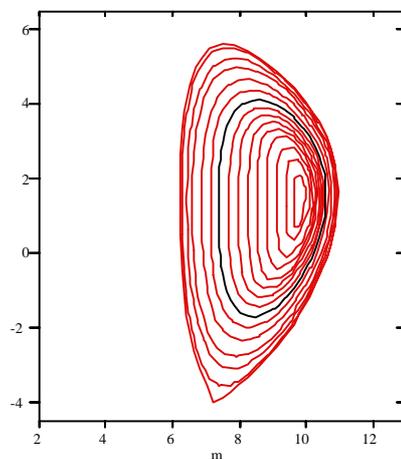


**Figure 2.** ITER Ignited Operation Diagram.

## 2. Operating diagrams for Non - Inductive operations

In absence of inductively driven current the total plasma current is maintained solely by bootstrap and current drive. Because the current drive is limited to about 100 MW, the total plasma current is in practice also limited to less than 12 MA. At such low current recovering a significant amount of fusion power implies significantly improved confinement which respect the ELMy H-mode operation and operation at significantly higher  $\beta_N$  values. Operation in reversed magnetic shear has been shown experimentally to offer the prospect of satisfying simultaneously both requirements. This is turn implies that the plasma will operate at simultaneously low  $i_i$  and high  $\beta_p$ . Fig. 3 indicates the plasma and surface geometry which is obtained by the ITER Poloidal Field System for a typical reversed shear discharge [4].

R (m)	:	8.59
a (m)	:	2.36
Bt (T)	:	5.38
$I_p$ (MA)	:	9 - 12
kX	:	2.0
dX	:	0.5



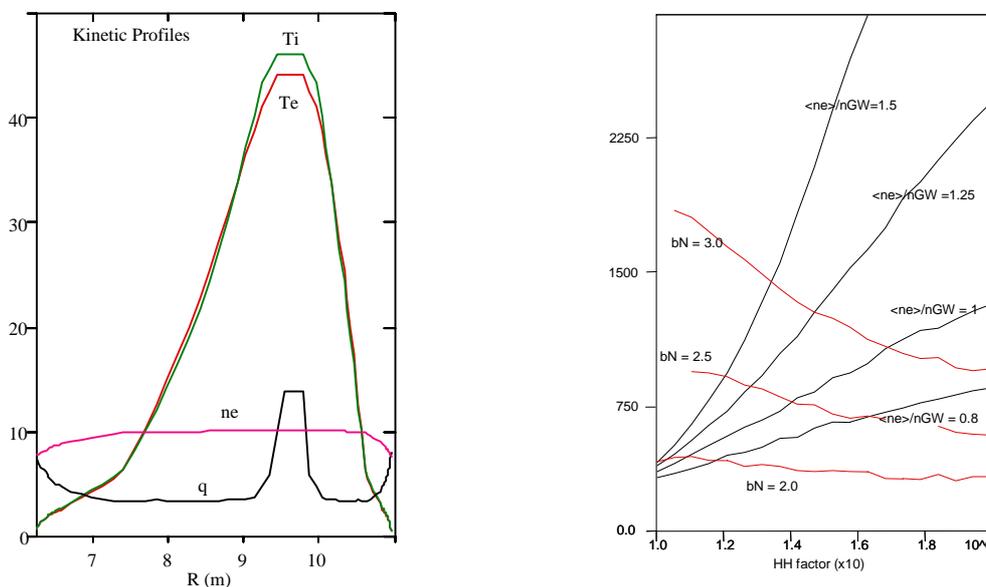
**Figure 3.** Non-inductive magnetic geometry.

are varied, where HH is the ratio of the global energy confinement time to ITERH97-P(y),  $\langle n_e \rangle / n_{GW}$  is the volume average electron density normalized to the Greenwald value and  $\beta_N$  is the normalized toroidal beta including energetic particle contributions. Fig. 2 shows the fusion power as a function of the confinement represented by the HH factor for ignited operation ( $P_{aux} = 0$  MW). The lines of constant  $\langle n_e \rangle / n_{GW}$ ,  $\beta_N$ , and  $P_{loss} / PLH$  are indicated. (PLH is the H-mode power threshold given by:  $PLH(\text{MW}) = 100 (n_{19} / 5)^{0.75} B_t R^2 2/A$  ).

The diagram indicates that the ignition domain for ITER extends from HH  $\sim 0.78$  to 1.35 and is limited at low power - for a given HH factor - by the L- to H-mode transition, at higher fusion power by the beta limit.

The plasma boundary moves naturally to a high elongation, high triangularity configuration which does not allow the plasma to closely fill the vacuum. In addition a large shift of the magnetic axis is observed. A confinement transport barrier in the 1-1/2D transport simulation is imposed when the local magnetic shear becomes equal or less than 0. It is found that imposing a significant amount of off-axis current drive, 80 MW of ECCD with an assumed efficiency of 0.25 MA/MW/m<sup>2</sup>, is required to stably maintain the position of the reversed magnetic shear. In addition, 20MW of 1MeV NBI is used to drive the current on axis.

Fig. 4 shows the profiles obtained for HH=1.3, 1.5 GW of fusion power and the 80 + 20 MW of current drive power. Empirical fits using the profiles obtained by the 1-1/2D transport code are then used to extrapolate the plasma parameters when the confinement and amount of fusion power are varied at fixed current drive power. The operating diagram showing the lines of constant  $\langle ne \rangle/nGW = 0.8, 1.0, 1.25, 1.5$  and  $\beta_N = 2.0, 3.0, 4.0$  are shown in Fig. 4. Each point on the diagram satisfies:  $P_{loss} > PLH$ .



**Figure 4.** Profiles and operation diagram in ITER for non-inductive operation with 100 MW (80MW off-axis, 20 MW NBI) current drive power with an assumed current drive efficiency of 0.25 MA/MW/m<sup>2</sup>.

### 3. Conclusions

A systematic exploration of fusion performance is shown which documents the range of plasma parameters normalized to appropriate operation limits: density, beta, L-H mode transition representing ignition in ITER under driven operation. The method is generalized for non-inductive operation by self-consistently computing the driven and bootstrap currents for each combination of (HH,  $\langle ne \rangle/nGW$ ,  $\beta_N$ ) that corresponds to a given current drive power.

### References

- [1] D. Boucher et al.: in Design Description Document of ITER EDA
- [2] ITER Physics Basis, Chapter II, *submitted to Nuclear Fusion*.
- [3] M. Sugihara: J. Nuclear Material, **241-243**, 299 (1997)
- [4] W. Nevins et al.: in IAEA-CN-64/FP-22, *16th IAEA Conference*, Montreal, 1996.