# Density Scaling of the H-Mode Power Threshold in JET

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## 1. Introduction

Analysis of the ITER Threshold Database revealed a linear dependence of the H-mode power threshold on the plasma density [1]. However the JET database has never been conclusive on the subject, although there was the indication of a density dependence of the H-mode power threshold, as well as of the lower threshold of H-modes produced by Ion Cyclotron Resonance Heating (ICRH) in single null X-point configuration on beryllium target plates. Since one of the crucial issues for the design of ITER is to establish field, size and density scaling of the power threshold, the ITER Confinement and Transport Expert Group has asked JET, DIII-D, ASDEX-U, JT60-U, COMPASS, C-MOD, JFT-2M, and PBX-M to carry out a series of experiments in a given ITER-like configuration with $q_{95} \cong 3$ at the transition. This paper presents results obtained on the JET tokamak using both Neutral Beam Injection (NBI) and ICRH.

## 2. Experimental parameters

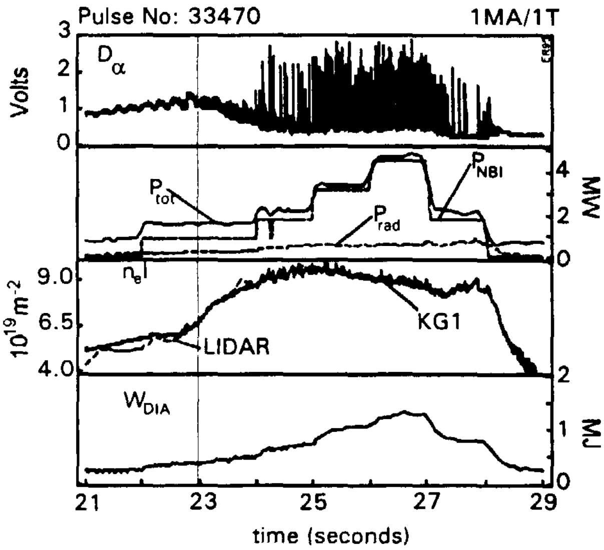

*Fig.1 Transition into H-mode for a discharge in the database. KG1 here indicates the FIR interferometer.*

The experiment was carried out in a single null X-point JET standard fat configuration, with X-point height of about 25cm and plasma distance from both the inner and outer walls of about 8cm. The ion ∇B drift was towards the target plates, while triangularity was kept constant at $\delta \cong 0.15$. At the transition the edge safety factor was $q_{95} \cong 3$, which allowed us to work at different combinations of toroidal field and plasma current, namely 1MA/1T, 2MA/2T, 3MA/3T. Density was increased by both gas puffing and controlled

NBI fuelling, with the cryopump at the LHe temperature. Two heating schemes were used, namely $D^0$ NBI and H minority ICRH in D plasmas. The present paper is focussed on the results obtained with CFC divertor target tiles and NBI. However, preliminary analysis of experiments using a Be target are reported, as well as very recent ICRH-only H-modes on Be at 3MA/2.9T. All data were taken about 30msec before the L-H transition and were validated against a dataset of L-modes.

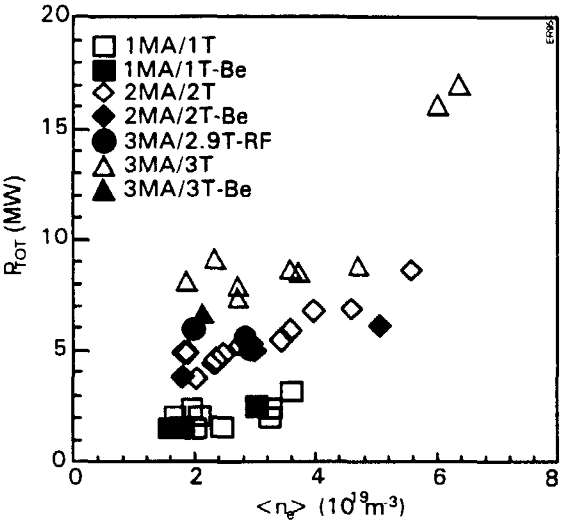

*Fig 2 H-mode power threshold scaling with volume averaged density. Data have been obtained with NBI and CFC target (open symbols), Be target (filled symbols), and ICRH on Be (filled circles).*

## 3. Density scaling of the power threshold

The power threshold $P_{th}$ was determined at the L-H transition as total power coupled to the plasma,

$$P_{TOT} = P_{AUX} + P_{OHM} , \qquad (1)$$

where $P_{AUX}$ is the power of the auxiliary system used (ICRH or NBI), while $P_{OHM}$ is the Ohmic power input; or as power flux through the separatrix,

$$Q_{NET} = (P_{TOT} - P_{RAD}^{bulk} - dW_{DIA} / dt) / S , \qquad (2)$$

with $P_{RAD}^{bulk}$ total radiation emitted by the bulk plasma, while $dW_{DIA} / dt$ is the slope of the diamagnetic energy, and $S \cong 140\ m^2$ is the plasma surface area. As shown in Fig.2, the threshold has an approximately linear dependence on $< n_e >$. Departure from the linear scaling is evident for the 3MA/3T data at low and high densities (Figs.2,3). Analysis is in progress to estimate in the low density range the amount of NBI shine through, which could reduce $P_{TOT}$ by up to 20%. Note also that the ICRH data indicate a power threshold somewhat lower, in agreement with results from the 1991-92 database [2]. Also,

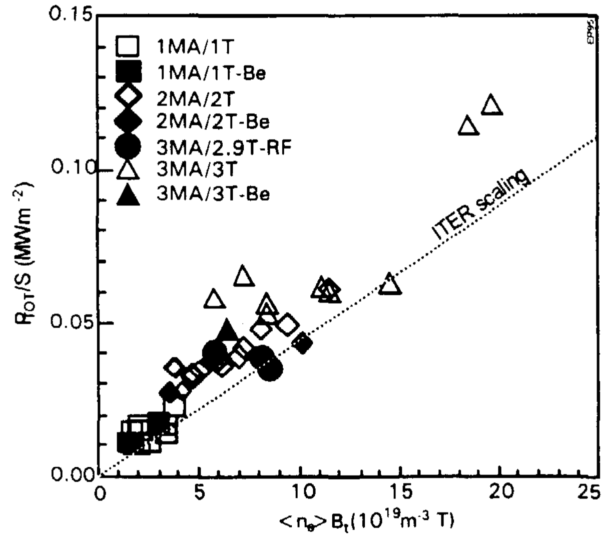

*Fig.3 The data roughly agree with the ITER scaling [1], with the exception of some of the 3MA/3T data.*

there is no appreciable difference in $P_{th}$ with either Be or CFC tiles and NBI heating, although at high $< n_e >$ no data exist. The dependence of $P_{th}$ on $B_t$ and $< n_e >$ has been determined through nonlinear regression analysis:

$$P_{TOT} \propto B_t^{1.19} < n_e >^{0.74} , \tag{3}$$

$$Q_{NET} \propto B_t^{0.63} < n_e >^{0.88} , \tag{4}$$

similar to dimensionally correct forms of the H-mode power threshold [3,4].

## 4. Edge measurements

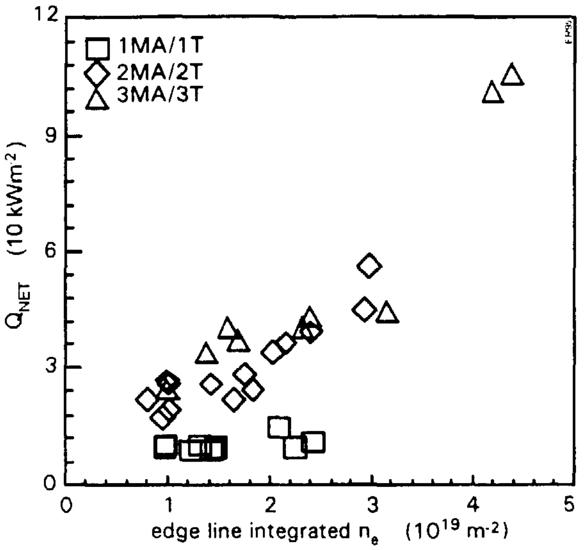

*Fig.4 Net power flux through the separatrix as a function of edge line integrated density (CFC data).*

In this section are summarised the first partial results obtained from the measurement of edge electron density and temperature, and neutral flux at the divertor, thought to be relevant to the understanding of H-mode transition physics. Line integrated electron density at the plasma edge (R=3.75m) was obtained and cross-checked using both the LIDAR Thomson scattering diagnostic and the Far Infra Red (FIR) interferometer. These measurements show that the power flux $Q_{NET}$ depends roughly linearly on the edge density $n_{ea}$ for the 2MA/2T and 3MA/3T data, while the 1MA/1T series shows a much weaker dependence (Fig.4). Moreover, the $B_t$ scaling at the plasma edge is not so clear-cut as in Fig.2: in particular, there is no clear distinction between the 2MA/2T and 3MA/3T data. On the other hand the dependence of $Q_{NET}$ on the neutral flux, obtained with pressure gauges in the divertor [5,6], is weaker than that with $n_{ea}$, while that on $B_t$ is clear.

The electron temperature was measured at R=3.6m, for $B_t$=2,3T with the heterodyne radiometer, and at R=3.75m, for $B_t$=1,2,3 T with LIDAR. $T_{ea}$ shows a nonlinear dependence on both $n_{ea}$, and $B_t$, the latter indicating the importance of Larmor radius.

## 5. Conclusions and future analysis

The power threshold, expressed both as $P_{TOT}$ and $Q_{NET}$, depends roughly linearly on $< n_e >$ and on $n_{ea}$, although there are deviations from linearity at low and high densities. Scaling with $B_t$ is evident with $P_{TOT}$, not so much with $Q_{NET}$. The database is roughly in agreement with the ITER scaling, although deviations exist for low and high densities (Fig.3).

Results of regression analysis are similar to dimensionally correct forms of $P_{th}$ [3,4].

Similar discharges carried out on CFC and Be divertor target plates show no significant difference in the power threshold. No data however were obtained at high densities ($<n_e> \cong 6\times10^{19}$ m$^{-3}$) with Be.

ICRF-only H-modes on Be target show a lower power threshold. Future analysis will compare ICRH and NBI produced H-modes to clarify the reasons for the different $P_{th}$.

$Q_{NET}$ shows a mildly nonlinear dependence on the neutral flux as measured at the divertor, and a roughly linear scaling with $B_t$. However a link needs to be established between L-H transition and recycling conditions at the edge, of which the particle flux is only a partial measurement.

Measurements of electron temperature at the plasma edge show a nonlinear dependence on the the edge density and the magnetic field. Further analysis in this direction will include the scaling of $T_{ea}$ with $B_t$ at the plasma edge.

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## References

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