Results from the ITER H-Mode Threshold Database

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Abstract. The ITER H-mode Threshold Database, which presently includes data from 9 divertor tokamaks is presented. The results obtained for single devices and for the combined dataset are given. The similarities and differences between the different devices are shown. Possible expressions for the H-mode threshold in agreement with the data are given and the extrapolation to ITER is discussed.

1. Introduction and present status of the database

The H-mode, a regime with good confinement envisaged for ITER, is reached above a power threshold (P_{thres}) which depends on plasma conditions and machine size. Whereas the threshold dependencies on plasma parameters have been studied in single devices, the determination of the size dependence requires inter-machine studies. Therefore the ITER Threshold Database, including initially 5 tokamaks, was initiated by the ITER H-Mode Database Working Group in 1992 [1]. The database has been considerably extended since, with new data and contributions from 4 additional devices, totally now from 9 divertor tokamaks: Alcator C-Mod, ASDEX, ASDEX Upgrade, COMPASS-D, DIII-D, JET, JFT-2M, JT-60U and PBX-M. The database is described in section 2. Results from single devices and from the combined database are presented in sections 3 and 4 respectively. Finally, section 5 is dedicated to discussion and conclusion. A detailed report of this work will be available shortly [2].

The database contains 143 variables to describe both the core plasma, basically those used in the confinement database [3], and edge plasma believed to be important in H-mode physics. Due to the experimental difficulties of routinely measuring edge data, the latter group of variables is presently rather sparse. This is expected to improve soon with specific threshold experiments. The plasma shape and position are described by several variables. Information on vessel coating and material of device components are also included. The threshold database has been released to the public in September 1995 and is available on FTP servers at IPP-Garching and San Diego JCT.

2. Threshold features in single devices

In earlier studies made in several devices, the H-mode power threshold showed the following common global features (see [2] for references):

- Ion ∇B drift: the threshold power is $\approx$2 times lower for SN configuration with the ion ∇B drift towards the X-point than for the opposite direction
- Isotope effect: the threshold is $\approx$1.8 lower in deuterium than in hydrogen
- Plasma-wall distance: if the distance between separatrix and machine components is smaller than 2-3 cm the threshold is increased
- Wall conditions, recycling, divertor properties: Boronization and He glow discharge cleaning, both reduce recycling and lower the H-mode threshold. Similarly divertors with good retention of neutrals also lower the threshold. Therefore, a low threshold requires low neutral density.

As we are interested in low thresholds, we discuss in the rest of this paper data obtained from discharges which fulfil the above conditions. A corresponding selection variable exists in the database. In this section we concentrate on two threshold features important for ITER: the dependencies on line-averaged density (NEL) and magnetic field (BT).

Studying the threshold behaviour with NEL, at constant BT, is complex because it apparently varies from device to device and because the NEL ranges vary. The situation can be summarized as follows: the devices show a non-monotonic variation of P_{thres} with NEL, with a minimum at the same $NEL_{min} \approx 0.25\ 10^{20}$ m^{-3}, except for Alcator C-Mod where $NEL_{min} \approx 0.8\ 10^{20}$ m^{-3}. This difference is attributed to an operational low density limit specific of high field compact tokamaks and characterized by the production of run-away electrons [4]. Above NEL_{min}, the threshold increases with NEL. However the increase is weak in ASDEX and JFT-2M and somewhat stronger than linear in ASDEX Upgrade, DIII-D and JET. The density dependence clearly deviates from linear at high gas puffing rates. It is therefore speculated that the neutrals directly influence the threshold in such cases. Subtracting the power radiated inside the separatrix make the density dependence weaker.

Finally, we are aware that the edge density might be a better scaling than NEL but NEL is routinely available in all the devices while the edge density is not. However, the relation between NEL and edge density in the L phase prior to the L-to-H transition, where the time slices are chosen, depends only weakly on NEL, except in cases with pellets or strong gas puffing. Therefore, for the data in the database, using NEL may be justified

The BT dependence at constant NEL is rather clear. The tokamaks with sufficient BT range show a linear threshold increase with BT. New results from Alcator C-Mod [4] confirm this behaviour up to 8T.

In summary, in all the devices NEL×BT yields coherent existence diagrams, suggesting a rather linear threshold dependence on this product above NEL_{min}.

3. Analysis of the combined database

As the H-mode is triggered at the plasma edge one assumes that the power flux through the plasma edge P_{tot}/S, where S is the plasma surface area, is a sensible global parameter for determining the threshold. Starting from this consideration one can derive threshold expressions using dimensionless plasma variables (ρ^*, ν^*, β). Taking into account the experimentally observed threshold dependencies on NEL and BT as constraints, leads to 2 dimensionally correct expressions compatible with the data: (1) $P_{thres} \approx 0.3 NEL \times BT \times R^{2.5}$ and (2) $P_{thres} \approx 0.016 NEL^{0.75} BT \times S$, in m, T, 10^{20}, see Fig. 1. The data shown in this figure correspond to discharges which reached the H-mode and we consider the threshold to be the lower boundary.

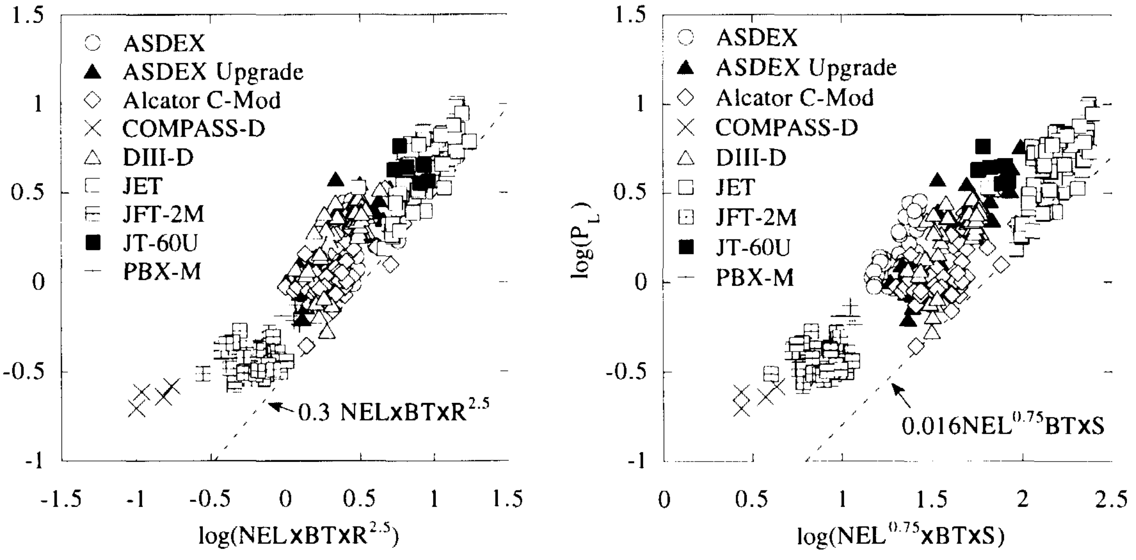

Figure 1. *Threshold results from the combined database for expressions (1) and (2) given in the text with* $P_L = P_{tot} - dW/dt$.

The extrapolation to ITER at a NEL = 0.5 10^{20} m^{-3} gives about 150 MW and 65 MW for (1) and (2), respectively. Expression (1) which gives the best agreement with the data, yields the highest prediction because of its stronger size dependence.

Discriminant analyses including a quadratic interaction model between NEL and S to reproduce the non-monotonic behaviour of the density confirm the BT dependence and yield a size dependence which is at most as strong as $R^{1.5}$ [2] and giving $P_{thres} \approx$ 70MW for ITER. In addition the threshold is predicted to decrease with increasing elongation.

4. Discussion and conclusion

The data presently included in the database show a large scatter in P_{thres} for reasons not clearly identified, possibly not measured. Possible candidates are the neutral density just inside the separatrix, where the transition occurs, the ergodization of the magnetic edge field lines by error fields and the coupling between electron and ions. If one assumes that the scrape-off layer also plays a role in the transition physics [5], further candidates are possible. As explained above we have considered the threshold being represented by the lower points of the existence diagrams. In addition one assumes, for extrapolation to ITER, that the known and unknown low threshold conditions of present devices will be achievable in ITER. The presently known conditions, listed in section 2, are discussed as follows. ITER will have the favourable ion ∇B drift direction. ITER will operate in D-T for which the threshold is expected to be at least as low as in D. Concerning, wall conditioning, neutrals and divertor properties, ITER will have a divertor with good retention and plasma facing components with low recycling. ITER should also avoid error fields because of the risk of locked modes. Therefore, ITER should have the presently known conditions necessary for a low threshold.

The extrapolation from JET to ITER for BT and NEL seems to be linear and involves at most a factor of 2 for each parameter. However, the results of the previous section suggest that the threshold dependence on machine size lies between $R^{1.5}$ and $R^{2.5}$ and therefore extrapolation from JET to ITER yields factors of about 5 and 14, respectively. Thus, the machine size clearly causes the strongest increase of threshold power when extrapolating to ITER.

References

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