1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programatic relevance. Refer to any relevant program milestones or ITER R&D commitments.

Determine the existence and scaling of local thresholds, in particular edge temperature, density and pressure, during systematic scans of plasma density, current, field and RF power. At the same time, get good data on the global L-H and H-L power thresholds with small power steps. Use these data to compute dimensionless parameters in order to compare with theories and with other machines.

2. Background

Discuss Physics basis of the proposed research, Prior results at Alcator or elsewhere, and any related work being carried out separately.

It has become apparent from results on C-Mod and from databases including large numbers of experiments, that standard ‘global’ power scaling such as $P_{\text{threshold}} = 0.044 n B S$, while useful in predicting general trends and providing a basis for comparison of experiments, have a number of limitations. Even on given experiments, power thresholds typically vary by a factor of two or more/1/. The L-H and H-L power thresholds are different, by a factor of up to two, an issue which is of some concern for future machines. More fundamentally, they can provide little insight into the physics of the H-mode.

From the earliest H-mode experiments on ASDEX, it has been noticed that the edge temperature appears to play a role in initiating the H-mode/2/. The most obvious indication of this is that many transitions occur shortly after a large sawtooth crash, when the temperature is transiently increased by a small amount. On ASDEX, they also succeeded in delaying the onset of H-mode by cooling the edge with impurities.

On Alcator C-Mod, $T_e$ can be measured by ECE out to near the last closed flux surface. A database including a large number of shots confirmed the control room observation that $T_e(\psi = 0.95)$ is in a fairly narrow range for a given $I_p$ and $B_t$ when the transition occurs. Furthermore, the H-L transition typically occurs at about the same edge temperature,
despite the higher densities and apparent hysteresis in the global power threshold. The scaling of the threshold temperature with plasma current is not clear.

The proposed experiment would extend the edge threshold studies by carrying out systematic scans in a single run, with the plasma magnetic configuration held fixed. By stepping the power up slowly, we should be able to find the threshold more precisely. It is believed that a lot of the scatter in the present data set stems from difficulties in determining the exact time of transition when $T_e$ is changing rapidly both before and after the transition. Differences in the position of the LCFS can also be a factor, since we interpolate between channels and the profiles may not be linear.

Diagnostics other than ECE will be used to characterize the plasma parameters at and just inside the LCFS. Density profiles from the reflectometer and/or TTCI or edge Thomson will be needed to determine the electron pressure and gradient. If possible, ion temperature measurements from CXRS in the outer plasma region would allow us to determine whether $T_i$ and $T_e$ are similar, as has been assumed to date. Scanning probe and/or Helium beam data will provide boundary conditions at the SOL. By combining data from several diagnostics, we hope to be able to determine whether the actual threshold is in edge temperature, pressure or some related quantity such as a gradient or collisionality.

3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

The proposed approach is to run a series of diverted discharges with different densities and a few different fields and currents. For each discharge, the RF power will be stepped up in $\sim 250$ kW increments with about 75 ms between steps to allow temperatures to stabilize. The power range used at each density will be guided by our previous experience of the H-mode threshold. The scans will include discharges just below the expected low density threshold, to determine whether these discharges have different edge conditions. Particular attention will be paid to the position of the LCFS with respect to the edge GPC channels. RF position feedback will not be used. While this has given improved H-mode performance, the movements of the plasma around the time of the transition complicate the determination of thresholds and transient profile changes. This is one reason for proposing a dedicated experiment rather than simply using data obtained in other H-mode runs.

This miniproposal has now had one dedicated run day at 5.3 T (1/26/96). It yielded a good density scan at 800 kA, which showed a remarkably constant edge temperature threshold for the L-H transition. The proposed current scan was not achieved for operational reasons. As hoped, keeping the positions constant and using small increments did reduce the scatter in the data (Fig. 1). Particularly interesting results were obtained near the low density limit. These have generated some discussion in the community and were the basis for papers presented at the IAEA meeting in 1996 /3/ and H-Mode workshop in 1997 /4/. For one density, the probe was scanned on reproducible shots and measured SOL profiles both just before the L-H transition and late in the H-mode. As is usual,
however, the experiment raised new questions which it is hoped to adress with further run time.

1) How does the threshold condition vary with field?

Analysis of the present 7.9 T dataset indicates that the threshold Te is higher, at least in proportion to $B_t$. However, the scatter in the data is larger than one would like. Also, H-modes have only been seen over a limited density range, with a minimum nel 75% higher than the 5.3 T low density limit. It is not yet clear if this is a true difference in H-mode behaviour or just an indirect result of D-He3 heating efficiencies and limited run time. A dedicated run at 7.9 T (as suggested in the original MP) is proposed.

2) What is the global and local threshold for the H-L transition?

A surprising result of the boronized H-mode runs is that, in contrast to 1995 data, the edge temperature often remains high until the H-L transition. The original threshold experiment was not optimized to study this. By stepping up the power and leaving it at a high level, the termination was triggered randomly either by density/impurity rises or by the end of the RF pulse. This did not give good data on the hysteresis in the global threshold. We propose to do a run in which the power is stepped down in small increments once the H-mode is established. This will have to be performed at 5.3 T in order to have a long enough flat top, a range of power over the threshold, and well known absorbed power, and so cannot be combined with the 7.9 T run.

3) How general are the results near the low density limit?

The data from 1/26/96 showed that, near the low density limit, the edge temperature remained below the usual threshold (for reasons still unclear) until the L-H transition. In looking through a larger dataset, a few low density discharges have been found in which Te apparently rises well above the normal threshold while still in L-mode. This makes the explanation of the low ne limit less clear. The 7.9 T data show a similar trend, in that there is a tendency for more scatter in the threshold temperatures toward the low end of the H-mode density range. We plan to devote several shots in each of the 7.9 and 5.3 T run days to exploring the low density limit. Measurements of impurities and neutrals will be of particular importance.

4) What dimensionless parameters govern the H-mode threshold? Are these dimensionless thresholds the same on different machines?

The 1996 data, both from the dedicated scan and from random 8 T transitions, have been analysed in terms of dimensionless ballooning and diamagnetic parameters $\alpha$ and $\alpha_d$, with quite good agreement with simulations of Rogers and Drake /5/. As is the case in the raw data, the full dataset of random transitions shows a lot more scatter. We would like to get better documented profiles, at different plasma conditions, just before transitions. This would allow us to calculate $\alpha$ and $\alpha_d$, as well as the conventional $\nu_*$, $\rho_*$ and $\beta$, at various distances from the LCFS. While it is not the primary purpose of the MP, we plan to select conditions such that DIII-D could attempt to match our dimensionless parameters; they have indicated they will try to do this once we have obtained good quality edge profiles.
4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

**Toroidal Field:** 5.3 T, 7.9 T

**Plasma Current:** 0.8 - 1.2 MA

**Working gas species:** D2 (H minority at 5.3 T, He3 at 7.9)

**Density:** nel \(0.5 - 1.5 \times 10^{20} \text{m}^{-2}\)

**Equilibrium configuration** (if possible, refer to database equilibria): Lower null divertor (similar to 960126004)

**Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms:

4.2 Auxiliary Systems

**RF Power, pulse length, phasing:** 0.5 to 3.5 MW, 80 MHz

**Pellet Injection (species):** None.

**Impurity blow-off injection:** None.

**Special gas puffing:** H or He\(^3\) as required for ICRF, Argon for HIREX

**Other:**

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

All standard core diagnostics. Particular attention to ECE (Michelson and GPC/GPC2), reflectometer, Thomson Scattering, bolometry, CXRS if available, all looking as close to the edge as feasible. Scanning probe will be inserted on some shots.

4.4 Neutron Budget

Estimate the neutron dose rate at the site boundary. Give basis for estimate. (Once some experience has been gained a standard formula will be provided for estimating dose rates.)

5. Experimental Plan

5.1 Run sequence plan

extended run period (10 hours maximum), etc.

2 run days are proposed (in addition to the one already carried out). The day at 5.4 T is considered 'essential' for the '99 H-mode physics program. Data at 7.9 T are also very important, but are contingent on being able to obtain H-modes reliably over a range of conditions, and will probably require J-port RF in addition to D and E port.
5.2 Shot sequence plan
For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

Day 1 (completed 1/26/96. Parts 1 and 4 successful)

1). Density scan at 800 kA. (15 discharges)
Densities 0.5, 0.8, 1.0, 1.2 and 1.5 \( \times 10^{20} m^{-2} \) (allow 2-3 discharges at each \( n_e \) for good RF coupling) If still getting H-modes at extreme limits, try higher or lower \( n_e \) to establish density range.

2) Density scan at 600 kA. (6 discharges)
Densities 0.5, 1.0, 1.2 \( \times 10^{20} m^{-2} \) (allow 2 discharges per density) May curtail this scan if unable to get H-modes.

3) Density scan at 1.0 or 1.2 MA (depending on machine limits). (6 discharges)
Densities 1.0, 1.5 \( \times 10^{20} m^{-2} \), higher if successful.

4) Return to most reproducible H-mode (probably 800 kA, \( \times 10^{20} m^{-2} \)) and repeat 2 times, moving GPC grating angle to get more detailed profile. Will attempt scanning probe measurements on these discharges to match core and SOL profiles. (2 discharges).

Total: 29 discharges

Day 2:

1) Reference discharges at 5.4 T, 0.8 MA
Repeat L-H discharges from 1/26/96, with \( n_e = 1.0 \times 10^{20} \). This will allow us to compare directly with old threshold data, to check for any systematic differences in calibration etc, so that we will be sure of current scaling. Include scanning probe data and \( B_T \) sweep, just before threshold

(4 discharges).

2) Density scan at 5.3 T, 1.2 MA, both L-H and H-L transition
RF power will be stepped up in increments to get H-mode, then stepped back down to find H-L power threshold.

Density at the H-L transition, while difficult to program directly, will be varied by a) varying starting density over the H-mode range ( \( n_e = 0.6-1.5 \times 10^{20} m^{-2} \)), and b) changing the time at which the power is stepped down. Some trial and error will be required in programming the RF steps, we so expect to get 5 densities at \( \sim 4 \) shots each. Once the L-H threshold power is determined, will try to get scanning probe data and \( B_T \) sweeps for ECE for steady conditions, at powers just below threshold.

(20 discharges)

3) Low density limit shots at 5.3 T, 800 kA (6 discharges)
Density will be varied in small steps near the low density limit found previously (\(n_e \times 10^{20} \text{ m}^{-2}\)), to investigate further the global and local parameters near this limit. This will also allow us to check for consistency of calibrations, etc with the Jan '96 results and look for any current scaling of thresholds. Impurity, radiation and neutral behaviour will be of particular importance, and we hope to take advantage of neutral power measurements via bolometer and AXUV arrays.

4) High pressure H-L transitions (4 discharges)

Time and plasma conditions permitting, return to 5.3 T, 1.2 MA and do a few discharges where the RF power is kept as high as possible until the H-L transition. These typically exhibit higher edge \(T_e\) and a faster transition than those with low RF power. Use fast magnetics to look for evidence of MHD instabilities before transition. ECE (ideally with small \(B_t\) sweep), reflectometry, probes and Thomson scattering will be used to measure pedestal profiles so that MHD stability analysis can be carried out.

Total: 34 discharges

Day 3:

1) Density scan at 7.9 T, 1.2 MA (same \(q\) as 5.3 T, 800 kA scan)

Densities 0.5, 0.8, 1.0, 1.2 and 1.5 \(\times 10^{20} \text{ m}^{-2}\) (allow 2-3 discharges at each \(n_e\) for good RF coupling) If still getting H-modes at extreme limits, try higher or lower \(n_e\) to establish density range. Insert scanning probe at at least one density, before and after L-H. \(B_t\) sweep for ECE profile, both before and during H-mode, on at least a some densities.

(10-12 discharges)

2) Shots at 7.9 T, 800 kA, \(n_e \times 10^{20} \text{ m}^{-2}\), to check \(B\) vs \(I_p\) dependence. (3 discharges)

Total: 15 discharges

6. Anticipated Results

Discuss possible experimental outcomes and implications Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

The primary result of this experiment should be to provide more accurate data on edge parameters and thresholds at the L-H and H-L transition. Specifically, we expect to determine the dependence of the apparent \(T_e\) threshold on \(B_T\) and \(I_p\). There is the possibility of comparing data from different tokamaks, particularly DIII-D. This would be the basis of a new external collaboration. We also hope to provide high quality datasets relevant to theory collaboration with both U. Maryland (Drake and Rogers) and ORNL (Carreras and Owen).

Day 2 should provide systematic data on the global power threshold for the H-L transition, as well as check if the local threshold exhibits hysteresis. Much of the data obtained will be suitable for inclusion in the ITER H-mode threshold database and pedestal database.
7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.

2. ASDEX Team, Nucl. Fus. 29(11), 1989.