1. Purpose of Experiments

The input power required to enter H-mode has been found to depend nonlinearly on the density where it increases rapidly below some critical density that varies from machine to machine. On C-Mod, at $B_T = 5.4$ T, the observed critical density is about $8 \times 10^{19}$ m$^{-3}$, which is significantly higher than the L-mode target density foreseen in ITER. Other machines find a substantially lower critical density. The purpose of these experiments is to try to determine how this critical density scales with plasma parameters to better predict what the critical density might be in ITER. This has been approved as an ITPA joint experiment together with DIII-D, JET, and ASDEX-Upgrade, called CDB-10.

2. Background

The critical density in C-Mod below which the power required to achieve H-mode increases dramatically was found to be about $n_e = 8 \times 10^{19}$ m$^{-3}$ [1]. In other machines, the critical density was found to be considerably lower at about $n_e = 2.5 \times 10^{19}$ m$^{-3}$ [2]. Since ITER intends to run with an L-mode target density of $n_e = 5 \times 10^{19}$ m$^{-3}$ [3], if the critical density in ITER is as high as in C-Mod at the same toroidal field, then ITER may have difficulty achieving H-mode with the presently foreseen auxiliary heating power if the H-mode threshold power scaling correctly predicts the threshold power for nominal low threshold conditions [4]. While there is considerable uncertainty both theoretically and experimentally in the threshold power, the critical low density limit has been reproduced in C-Mod in recent experiments (Fig. 1). So, it appears to be a robust result and it remains to determine how this critical density depends on plasma parameters and how it will scale to ITER. This experiment has been approved as a joint ITPA experiment CDB-10 and there is interest on DIII-D, JET, and ASDEX-Upgrade to perform joint experiments to address this important physics issue for ITER.
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.

Achieving reproducible low density target plasmas for H-mode threshold studies should now be straightforward with the new cryopump. To make best use of the cryopump, reversed field upper single null plasmas may be required, but the miniproposal could be run with the normal field direction even if the cryopump is not as effective. The L-mode target density will be scanned from n_04 of $3 \times 10^{19} \text{m}^{-2}$ to $1 \times 10^{20} \text{m}^{-2}$ from shot to shot during an increasing ramp in ICRF power from 0.5 MW to as high as achievable, preferably $> 3.5 \text{MW}$. Ideally, such density scans would be carried out at a number of toroidal field values to see how the critical density scales with toroidal field, but with ICRF heating, this would require changing the heating scheme, which would also affect the heating efficiency and that would complicate the analysis as well as the operation. So, instead, we will stay at 5.4 T and vary the plasma current to see how the critical density scales with current or fraction of the Greenwald density limit, $n_G = I_P/(\pi a^2)$. If the critical density depends on the Greenwald fraction, then since ITER will operate at a significantly higher Greenwald fraction than present machines at the threshold target density, then this critical density will not be a problem for ITER. If we find that the critical density is independent of the plasma current, then it is not a function of the Greenwald fraction. Then, further experiments will be required together with other machines to determine how the critical density scales with other plasma parameters. In addition to the basic power threshold parameters, this experiment should also determine how the core and edge plasma rotation, edge temperature and density, turbulence and other MHD activity, radiated power, and $Z_{\text{eff}}$ change with the critical density to see if any of these parameters give some insight into the changes in physics near the critical density.

4. Resources
4.1 Machine and Plasma Parameters
Give values or range for:
- Toroidal Field: 5.4 T
- Plasma Current: 0.6 MA – 1.2 MA
- Working Gas Species: Deuterium
- Density: $3 \times 10^{19} \text{m}^{-2}$ – $1.0 \times 10^{20} \text{m}^{-2}$
- Equilibrium configuration (if possible, refer to database equilibria): 1070612025
Perhaps with adjustments to reduce SSEP to -5 mm to improve cryopump performance

4.2 Auxiliary Systems
- RF Power, pulse length, phasing: ICRF up to at least 3.5 MW
- Pellet Injection (species): None
- Impurity blow-off injection: None
- Diagnostic Neutral Beam: Yes
- Special gas puffing: No special puffing
- Non-axisymmetric Coils (Connections, Current); Standard configuration
- Other: Cryopump for density control

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

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Core and edge Thomson for temperature and density profiles. HIREX for ion temperature and rotation profiles. CXRS with DNB for ion temperature measurements. Bolometry for radiation profile measurements. Visible Bremsstrahlung for Z\textsubscript{eff} measurements. Fast scanning probes would be helpful for SOL flow measurements. Fast magnetic pick-up coils, PCI, and Reflectometry would be helpful for fluctuation measurements.

5. Experimental Plan
Both sections must be filled in.

5.1 Run sequence Plan
Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.
One run has been allocated this campaign. This should be sufficient to make progress on this proposal, but more run time will be required to completely scan the parameters.

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.

For all shots, the ICRF power will ramp up from 0.5 MW to as high as possible, at least 3.5 MW to scan the threshold power, ramping from 0.5 s to 1.5 s. Begin at I\textsubscript{p} = 0.9 MA with nl04 at 6 \times 10^{19} m^{-2} (1 – 2 shots). Reduce nl04 to 5 \times 10^{19} m^{-2} (1 – 2 shots). Reduce nl04 to 4 \times 10^{19} m^{-2} (1 – 2 shots). Reduce I\textsubscript{p} to 0.6 MA and repeat the density scan (4 – 8 shots). Increase I\textsubscript{p} to 1.2 MA and repeat density scan (4 – 8 shots). If time permits, repeat the 3 I\textsubscript{p} values at nl04 = 7 \times 10^{19} m^{-2} (3 shots). If time permits, repeat the 3 I\textsubscript{p} values at nl04 = 8 \times 10^{19} m^{-2} (3 shots).

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.
This experiment should indicate if there is a dependence of the critical low density for the H-mode power threshold on plasma current and Greenwald fraction or not. If so, this would suggest that ITER may be able to operate at its prescribed L-mode target density and achieve H-mode with the power level predicted by the H-mode threshold scaling. If the critical density is found to be independent of the plasma current, then more experiments will be required together with other machines to attempt to determine how the critical density scales with toroidal field or other plasma parameters. We may also find that core or edge rotation, edge temperature and density, radiation, Z\textsubscript{eff}, turbulence, or other fluctuations play a key role in the critical low density for the H-mode threshold.

7. References
Include references both to external and internal literature or communications which bear on this proposal. See Section 2.
Despite having 2.5 times the predicted H-mode threshold scaling power, the plasma only goes into H-mode after the density increases above about $0.8 \times 10^{20} \text{ m}^{-3}$. The plasma shape is JFT-2M-like and the ion $\nabla B$ drift direction is favorable toward the lower $X$ point. Type III ELMs begin just after the L-H transition indicated with the dashed line.