

Alcator C-Mod Mini-Proposal

MP No. 496

Subject: High Performance Operation at $I_p > 1.2$ MA

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Group: Integrated Scenarios: H-Mode Baseline

Date: July 2, 2007

Approved by:

Date Approved:

1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programmatic relevance. Refer to any relevant program milestones.

The purpose of these experiments is to explore the confinement, transport, pedestal scaling and divertor behavior as plasma current is scanned above 1.2 MA using hydrogen minority heating, with maximum power available. Ideally, these experiments will be carried out using the nominal ITER shape, with a target to reach 1.6 MA, which should yield the ITER q_{95} at the ITER magnetic field. If we can access these parameters with 6 MW of input power (ICRF + Ohmic), and good H-Mode confinement ($H_{89} \sim 1.8$), the resulting plasma will have the same absolute pressure and β as the baseline ITER H-Mode discharge target. Exploration of this territory should significantly expand our parameter ranges for studies of confinement (particularly scaling with I_p), the H-mode pedestal, including ELM character, and spontaneous rotation. These experiments will directly contribute to one of the C-Mod *plain English* goals for FY2008, *Confinement at High Plasma Current*. Elucidation of these results for extrapolation to ITER will be a major goal of these studies.

2. Background

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

The dimensional parameter with the strongest effect on global tokamak energy confinement is the plasma current, with τ_E typically increasing approximately linearly

with I_p (for both L-Mode and H-Mode edge). C-Mod is capable of running to 1.6 MA at 5.4 Tesla, and has operated to 2 MA at 8 Tesla. Even higher currents should be accessible at 8 Tesla, but are not the subject of this MP. The existing C-Mod database includes exactly 2 discharges with $I_p \geq 1.4$ MA, $B_T < 6$ T and $P_{ICRF} \geq 3$ MW (1050624032 and 1050624033), both of which were 5.4 Tesla, 1.45 MA shots with $P_{ICRF} \leq 3.1$ MW. Each shot went into H-Mode, but confinement enhancement was low ($H_{89} \sim 1$). We obtain a wide range of H-Mode confinement for nominally similar discharge conditions, usually correlated to impurity content (especially Mo) and boronization history. Figure 1 shows a plot of $20 \cdot W_{MHD} / (P_{in}^{0.5} \cdot I^{0.85})$ as a proxy for the H_{89} confinement enhancement, versus I_p for all time slices in the traces database with B_T between 5 and 5.7 Tesla, $I_p \geq 0.8$ MA, and $P_{ICRF} \geq 2$ MW. This has not been filtered for H-Mode, and includes both L- and H-mode shots. It is clear that the parameter space above 1.25 MA is very sparsely populated. Scaling from the baseline ITER H-Mode target, aimed at $Q=10$ burning plasma studies, the corresponding operating point on C-Mod is at $B_T = 5.3$ Tesla, $I_p = 1.6$ MA, SNL topology. This MP is aimed at utilizing H minority ICRF heating, with all sources close to 80 MHz, where we normally find our best single-pass absorption and heating efficiency.

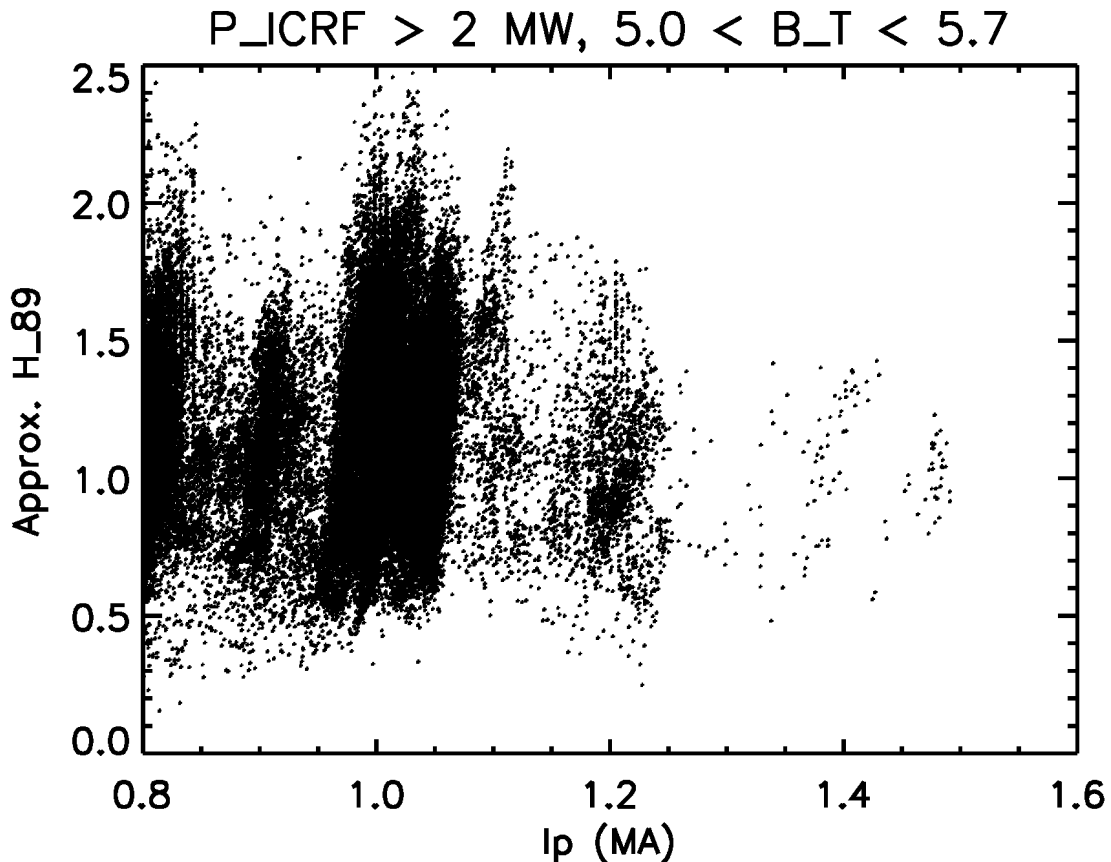


Figure 1: Approximate H_{89} enhancement vs. plasma current for nearly 57,000 time slices from the C-Mod traces database.

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 machine must be in a well-conditioned state and recently boronized. ICRF systems must be operating reliably at high power.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 to 5.7 Tesla

Plasma Current: 1.2 to 1.6 MA

Working Gas Species: D₂

Density: $n_{l04} = 1.0$ to $1.4 \times 10^{20} \text{ m}^{-2}$ (L-mode target)

Equilibrium configuration (if possible, refer to database equilibria): lower single null configuration in the ITER shape ($\kappa=1.85$, $\delta_x=0.49$). Start with parameters similar to 1040127010, but decrease I_p to 1.2 MA. If a better shot is developed during 2007 run(s) on MP362, use that instead.

4.2 Auxiliary Systems

RF Power, pulse length, phasing: maximum power available, at least 3.5 MW required, 5.5 MW desired, .5 seconds, heating phase, ~80 MHz

Pellet Injection (species): not required

Impurity blow-off injection: N/A

Diagnostic Neutral Beam: yes

Special gas puffing: standard valves; argon for HIREX; ninja for GPI (but coordinate closely with session leader because of perturbations to z-meter profiles, and possible effects on plasma and neutral densities.)

Non-axisymmetric Coils (Connections, Current): standard config for optimal error field suppression, operating in feedback

Other: Between shot boronization may be needed.

Disruption mitigation?

4.3 Diagnostics

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

Require: HIREX, H/D, Thomson (core and edge), ECE, neutrons, bolometry, TCI, CXRS (poloidal and toroidal, core and edge as available), Chromex, McPherson, fast magnetics.

Edge Thomson alignment should be optimized for high elongation.

Desire: PCI/Reflectometry/GPI (monitor EDA-ness, QC mode, broad-band turbulence), MSE, IR divertor imaging.

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.

Requires at least one standard run. Since we might require between-shot boronization to maintain or recover low radiation conditions, we should consider a 10 hour run day. We plan to scan plasma current, requiring about 19 good shots after the desired shape has been established, with high RF power.

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.

Start from a high elongation discharge, using the best feedback programming developed under MP362 and MP471 (1040127010, with I_p lowered to 1.2 MA, is a possible starting point, but something better should be developed under MP362 and/or MP471 prior to operation for this MP). (3 shots)

At $I_p = 1.2$ MA, n_{l_04} target = $1.0 \times 10^{20} \text{ m}^{-2}$, establish EDA H-Mode at $P_{RF} = 3.5$ MW. (3 shots)

$I_p = 1.5$ MA, n_{l_04} target = 1.25×10^{20} , $P_{RF} = 3.5$ MW. (2 shots)

If promising, increase RF power to max available at 1.5 MA, in .75 MW steps (4 shots)

$I_p = 1.6$ MA, n_{l_04} target = 1.35×10^{20} , $P_{RF} = 3.5$ MW. (3 shots)

If promising, increase RF power to max available at 1.6 MA, in 0.75 MW steps (5 shots)

If time permits, go back to $I_p = 1.35$ MA, n_{l_04} target = 1.1×10^{20} , $P_{RF} = 3.5$ MW, to help fill in the current scan data. (2 shots)

Throughout the day, keep a close watch on radiated power, and impurity content (particularly Mo). Signs of problems include: $Prad/Pin > 50\%$, dropping confinement ($H_{89} < 1.5$), increasing density and Prad during the H-mode, weakening of QC mode/heading toward ELM-free. If deemed appropriate, do between-shot boronization, in whatever mode (EC resonance position, with/without vertical field, fill pressure) is considered most effective based on studies that we have done under MP430 and are doing under MP 470. The length of time will also be decided based on those studies, but should not

exceed 30 minutes, and might be as short as 10 minutes. To date, 1050705018 was the best we've done in this regard.

If we think the high current shots are heading toward ELM-free because q_{95} is too low, try increasing the toroidal field to 5.7 Tesla; this will take us somewhat away from the ITER target, and so should only be done if necessary to get steady H-Modes for $I_p \geq 1.5$ MA. If we end up doing this, we will probably want to repeat the 1.2 MA case at the higher field before doing 1.35 MA.

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.

These experiments should determine plasma performance under H-mode conditions at high power in C-Mod, in the ITER shape, close to the ITER q_{95} , and potentially at the ITER β and absolute plasma pressure. This should yield important results in a number of areas: high β effects on the H-mode edge, including fluctuations and the boundaries between ELM-free, EDA, small- and large-ELM regimes; confinement scaling; pedestal scaling; toroidal rotation. We will not purposely provoke disruptions, but should they happen, we could learn important things about halo currents, and wall effects from disruptions at high current and stored energy.

7. References

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