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

The C-Mod Advanced Tokamak program depends on the unique capability of the C-Mod facility to operate with plasma pulse lengths corresponding to multiple skin times with high performance parameters. Specifically, pulse lengths with current and toroidal field flattops of order 5 seconds, with toroidal field of \( \approx 4 \) tesla, have been proposed. In the case of the AT program, these plasmas would have current sustained non-inductively, i.e. by a combination of RF current drive and pressure-driven current.

The purpose of the experiment proposed here is to investigate production of a long pulse plasma with parameters suitable for an AT target plasma, i.e. low-to-medium density, moderate-to-high heating power, and acceptable impurity radiation. With the future addition of a cryopump, we expect that the AT program will utilize plasmas of this kind as targets for current-drive experiments using the lower hybrid systems. In addition, these experiments will help to evaluate the divertor power handling as well as the prototype Tungsten brush divertor tiles presently installed.

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

Long-pulse, auxiliary-heated plasmas were produced in C-Mod in 2001 in order to test and demonstrate the long-pulse capability of the coils, power systems, control systems, etc., as well as to test the divertor power and particle handling performance under long pulse conditions. The 2001 experiments were proposed in MPs 283 and 283a and run on

Briefly it was found that
1) the coils, power systems, and control systems all performed adequately and in accordance with modeling,
2) plasmas of 3.2 sec duration were produced with 2 sec of 1 MW RF heating; this inductively driven plasma had a flattop current exceeding 2.5 L/R times (see Fig. 1);
3) particle sources/sinks associated with the vessel walls showed no signs of depletion/saturation up to the (longest) 3.2 second pulse length;
4) divertor temperatures near the strike points rose to ~700C with input power < 2MW;
5) the plasmas of longest duration were low density having less than L-mode confinement, presumably caused by the occurrence of locked modes due to coil misalignments;
6) plasmas of 2.5 sec duration with periods of ELMfree H-mode confinement were produced with 1 MW of RF heating (see Fig. 1);
7) non-optimized N₂ puffing was not effective in reducing the divertor heat load in these experiments (shots 1010803018 and 019).

Since those experiments, a number of salient upgrades have been made to the hardware and operational capability. The A-coils have been added to reduce the effects of the error fields and eliminate locked-modes. Tungsten Brush prototype tiles have been installed in to machine. Higher RF source power is available. We propose to utilize these upgrades to produce hotter (and thus possibly longer) plasmas, including plasmas with an EDA H-mode edge, while investigating the heating effects on the divertor, both its W and Mo tiles.

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.

In a well-boronized machine, start with plasmas like 1010803014 but with the A-coils operational to eliminate locked modes. In shot 1010803014, there were ELMfree H-mode periods from 0.7s to 2.0 s at a 1 MW RF power level for a target density of NL04≈4.2x10¹⁹ m⁻². However, EDA is the desired H-mode (as opposed to ELMfree), both in order to reduce the edge density (for current-drive efficiency), and in order to sustain the H-mode duration. Therefore, reducing the plasma current (from the 0.8 MA of 1010803014 to 0.6 MA) is warranted if shots similar to 1010803014 do not produce EDA. Currents of 0.6 MA have resulted in EDA H-mode in shorter pulse discharges, e.g. 1030612013 (see Fig. 1), with quite high Tₑ₀ (~ 4 keV). After obtaining the desired EDA discharge, we will extend the pulse length to the maximum in steps of 0.3 sec. The maximum length will probably be limited by flux swing on OH and EF1 coils. Initial RF power levels will somewhat above the H-mode threshold. Then we will increase RF power shot-by-shot in order to raise the temperature, thus lowering the loop voltage. We
estimate that RF power levels of up to 3 MW can be applied in H-mode plasmas, with RF pulse lengths as long as desired. For each discharge length and RF power we will evaluate divertor temperatures both at the W and Mo tiles using the IR camera, as well as evaluate Mo and W line intensities spectroscopically. We will do this for both cases where the strike points are fixed and for cases where the strike points are swept.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: 5.0 T
- Plasma Current: 0.6 and 0.8 MA
- Working Gas Species: D₂
- Density: NL04 approx 4.5x10¹⁹ m⁻²
- Equilibrium configuration (if possible, refer to database equilibria): LSN with strike point both fixed and swept, e.g. shot 1010803014 or 018, as well as shot 1030612013

4.2 Auxiliary Systems

- RF Power, pulse length, phasing: 78 and 80 MHz configuration is highly preferable, although if necessary this could be run in the 50 and 80 MHz configuration (with Bₗ=5.2 T, using somewhat off-axis He3 minority heating and somewhat off-axis 2nd harmonic H minority heating). The power level to be somewhat above the H-mode threshold with a duration as long as current flattop
- Pellet Injection (species):
- Impurity blow-off injection:
- Diagnostic Neutral Beam:
- Special gas puffing:
- Non-axisymmetric Coils (Connections, Current); Required, connections and currents as determined by S. Wolfe’s new control model
- Other: possible between shot boronization

4.3 Diagnostics

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

All diagnostics modified (as possible) to cover expected 3.5 sec pulse length
All coil temperature diagnostics
ECE and TS diagnostics
TCI
IR camera
Bolometry
VUV and visible diagnostics
Zeff
H/D ratio
Gas inventory diagnostics
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 day: Pre-run conditioning should include a well boronized vessel, as well as overnight ECDC in Helium to unload the walls of D₂.

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.

These long pulse shots typically have long re-cool times (between 20 and 35 min). Thus ~20 shots can be anticipated.

Start with a plasma like 1010803014. Flattop to 2.5 sec. Activate the A-coils to eliminate locked modes. This will use S. Wolfe’s new control model to determine the configuration and coil currents and should, in principle, require only 1 – 2 shots.

If EDA is not obtained, then lower the current to 0.6 MA (also with activated A-coils) in order to produce EDA H-modes (as in 1030612013).

Document the divertor temperatures with IR camera and Mo and W levels spectroscopically.

Extend the pulse length to the maximum in steps of 0.3 sec, until limited by flux swing on OH and EF1 coils. At this stage there is a tradeoff between pulse length and length of time in H-mode. We should have significantly more RF power than is necessary to access the H-mode. In any case, at each pulse length, we will increase power shot-by-shot in order remain in H-mode and to raise the temperature, thus lowering the loop voltage. We estimate that 3 MW of RF power will be available for H-mode plasmas. A decision will be made whether or not to use between-shot boronization at this point. Continue documenting divertor temperatures with IR camera, Mo and W levels, and gas inventories. It is unlikely that the maximum pulse lengths will be >3.5 sec, thus this should take ~10-12 shots.

At maximum pulse length and RF power compare divertor temperatures and impurity levels for the case where the strike points are fixed and for the case where the strike points are swept. (~5 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.

From C-Mod’s Field Work proposal for CY 05-06:
Page 16 – “The long term goals of the C-Mod AT program, as outlined in the Five Year grant

1. Demonstrate and develop predictive models for current profile control, leading to full non-inductive current drive, using LH and ICRF waves, in high density regime (>10^{20} m^{-3}) for pulse lengths long compared to current relaxation times.”

Page 19 - “Increased power, heat loads, and pulse lengths will also increase the challenge of power handling on the metal walls and divertor of C-Mod. Overall, our experiences in demonstrating integrated, near steady-state scenarios with high power density, high non-inductive fraction and high confinement, in regimes without particle and momentum input and with strongly coupled electrons and ions, will be extremely relevant to the development of advanced scenarios for ITER. We will continue to address the urgent research needs of ITER in this regard and to communicate results through active participation in all of the relevant ITPA groups.”

The work proposed here is a crucial step in attaining the goals outlined above.

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


and

C-Mod’s Field Work proposal for CY 05-06 at
Figure 1

<table>
<thead>
<tr>
<th>long pulse w/ H-mode</th>
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