

Alcator C-Mod Mini-Proposal

MP No. 490

Subject: Assessing LHCD in ICRF-Heated L and H-modes

From: Amanda Hubbard, Greg Wallace, Paul Bonoli, Chuck Kessel, Yijun Lin, Ron Parker, Andrea Schmidt, Dave Terry, Randy Wilson, Steve Wukitch

Group: LH

Date: May 24, 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.

Establish the limits and optimal conditions for coupling, accessibility and current drive efficiency of LHCD into ICRF-heated discharges for the 2007 campaign. While the hope is to find and document good operating conditions, understanding the issues to the extent that remediation measures can be taken following the campaign is also important. Results from this experiment will be critical for other LHCD experiments and particularly several high priority Advanced Scenario proposals. One of these will inject early ICRF and LH with slower I_p ramps so that we can elevate q and produce different plasma conditions as we enter flattop.

2. Background

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

In the 2006 campaign, and the pre-boronization phase of the 2007 campaign, many successful experiments have been conducted with LHCD¹. Conditions for good coupling, tied in particular to sufficiently high density at the grill mouth, have been identified and agree fairly well with modeling².

However, the majority of experiments have been into ohmic, L-mode target plasmas. For better LHCD localization, it is critical that LHCD be combined with ICRF to raise $T_e(r)$ and ensure single-pass absorption. For high performance advanced scenarios, which are expected to be the primary application of LHCD, the high confinement of H-mode plasmas is also desired. Both ICRF and H-mode are expected to make LH coupling more difficult by lowering SOL density. Limited results this campaign, obtained during

Wilson's MP 473 ("RF Checkout and initial operation") have indeed shown the challenge; drops in grill density are pronounced with D and E port ICRF, which are magnetically connected to the grill, and present but less strong with J-port. LHCD-induced H-modes, on 1070523, also produced changes in coupling but good net reflection coefficients were maintained.

H-mode operation poses the additional challenge that core densities rise, making accessibility worse and efficiency lower; this was also observed on 1060523. Now that boronization has commenced, LHCD into longer, higher performance H-modes can be studied which has not been tried to date. LHCD into H-modes has been identified as a critical issue for application on next step devices.

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.

This experiment proposes to systematically study LHCD coupling and efficiency in a range of ICRF-heated targets. While ICRF and H-mode typically go hand-in-hand, the proposal includes some RF-heated L-modes to separate the two effects for better understanding.

The proposed experiment has two parts:

- 1) Low power coupling experiments (~150 kW) over a range of parameters, to establish limits of plasmas for which LHCD can be used in combination with ICRF. We expect current to be a key variable since it affects the mapping between antennas.
- 2) High power LHCD into a more limited range of plasmas, to assess LHCD localization and efficiency.

These aims are separated into two run days. However, it may prove more efficient to increase power and pulse length on Day 1 in conditions where coupling appears good.

The outline of the plan is as follows:

Day 1:

- Coupling studies into J-port ICRF heated L-modes (USN, shape optimized for coupling). Limited scans of plasma current, J-port power, target n_e . Add E and D port ICRF to part of some discharges.
- Coupling studies into J-port-heated, steady EDA H-modes (LSN, shape from MP 464).

Day 2: Revisit the coupling conditions which showed reasonable reflection coefficients, ideally including both L-mode and H-mode plasmas. Increase power to maximum available, and extend pulse length to achieve steady LHCD. Document LHCD through loop voltage, MSE, and non-thermal diagnostics, for comparison with models.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 T

Plasma Current: 0.5-1.2 MA

Working Gas Species: D, H-minority.

Density: Target 6-9e19 m⁻².

Equilibrium configuration (if possible, refer to database equilibria): *Start with LSN, 1070427008*

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: J-port essential, 2 MW. D and/or E desirable, 1 MW.

LHCD Power, pulse length, phasing: Day 1: At least 200 kW, variable phase, short pulses. Day 2: 600 kW-1 MW, mainly 90 degrees, long pulse.

Pellet Injection (species): no

Impurity blow-off injection: no

Diagnostic Neutral Beam: Highly desirable, esp Day 1

Special gas puffing: NINJA (with D2) should be available. Argon permitted subject to H-mode effects.

Non-axisymmetric Coils (Connections, Current); Yes; optimized to reduce locked modes.
Other:

4.3 Diagnostics

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

Essential: Thomson, Magnetics, Hard x-rays, ECE, TCI, probes in LH grill.

Desirable: MSE, CXRS, SOL probes.

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.

2-3 run days. Well conditioned machine (ie recent boronization, demonstrated steady H-modes) is desired. A well conditioned J-port antenna (1 MW min, 2 MW desired) is essential; should these prove mutually exclusive, the priority will be on J-port particularly for the L-Mode portions of the campaign.

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 (may well carry into second day, see below):

For the coupling studies, LH power will be kept to a low level (typically 100-200 kW) and pulse lengths reduced so that the system can be safely operated without the full

coupler protection circuitry. This enables a wider parameter range to be explored, to find optimal conditions for later higher power experiments.

1. Reestablish good LH coupling into ohmic, moderate density targets. I_p 800 kA, B 5.5T, n_{el} $7e19$ m^{-2} . Start with equilibrium from 1070427008. Add ~ 1 MW J-port ICRF late in LH pulse. *1-2 shots*.
2. Produce USN ohmic plasma with optimized shape for coupling, in order to enable L-modes with significant ICRF – *3 shots* to optimize shape, reduce LH reflections.
3. Return to USN, L-modes. Add 1 MW J-port ICRF followed by 1 MW E-port. Vary I_p from 1.2 MA to 0.5 MA to assess sensitivity of ICRF density reduction from each ICRF antenna to this. *6 shots*
4. USN. Determine most promising I_p from step 4 (expected to be higher currents since these map least to C-port). J-port power scan, shot to shot. 60, 90, 120 degree LH. 1.0 MW, 1.5 MW, 2.0 MW. Add moderate (0.5-1 MW) D or E-port ICRH towards end of J-port pulse to see effect on coupling. *3 shots*.
5. Return to LSN, target $n_{el}=7e19$ m^{-2} . Determine optimum I_p and J-port power from preceding shots. Should give steady, moderate density, H-mode. Add LHCD, measure coupling, assess accessibility. *4-shots*.
6. Puff D_2 from NINJA into H-mode. Assess effects on coupling, and on plasma density and confinement (note that fuelling efficiency is generally lower into H-mode pedestal than L-mode, may be able to handle more gas without raising core n_e). *2 shots*.
7. Time permitting, carry out limited scans of target density in L and/or H-mode plasmas, and current in H-mode plasmas, depending on prior results. Expect there will be tradeoffs between RF effects (lowest at higher I_p) and H-mode density (lowest at lower I_p).

Total: 23-30 shots.

Day 2: (Details will depend on results of first day)

Top priority is to couple as much LHCD power as possible into promising ICRF heated discharges from Day 1.

1. LSN, H-modes. Select a target ICRF-heated discharge and phase (likely 90 degrees or higher, $N_{//} \geq 2.2$) with acceptable reflection coefficient and pedestal accessibility. Progressively increase LH power to maximum available or which can be coupled without excessive trips. (0.6-1 MW?). Pulse length ~ 200 ms. Measure change in loop voltage, and non-thermals via Hard x-rays and ECE. MSE

measurements are highly desirable. These measurements will be used in later modeling runs (CQL3D, TSC, perhaps ACCOME) to benchmark observed vs predicted $j_{LH}(r)$.

- 6 shots.

2. USN, L-modes. Similarly, select most promising L-mode target discharge and phase (likely 60 degrees, since density can be lower). Increase power, pulse length and diagnose as above. One might expect more off-axis LH deposition than in ohmic targets if $T_e(r)$ is higher.

- 6 shots.

3. Complete parameter scans in L and H-mode from “Day 1”, in particular variations of the target density, plasma current and perhaps gas puffing. These would start at lower power, with power increased for selected ‘low R’ conditions.

4. Time permitting, try adding modest amounts of D and/or E-port ICRH to successful LHCD+ICRH discharges above, to see if T_e can be further increased while maintaining adequate coupling.

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 results will contribute to the thesis research of G. Wallace and to multiple APS and EPS talks, in particular Ron Parker’s EPS presentation and an invited APS nomination of Paul Bonoli. Just as importantly, they will provide crucial information for use of LHCD in 2007 Integrated Scenario experiments. Positive results (ie success in combining LH and ICRF), will lay the foundation for several experiments in the 2007 campaign (eg, Hybrid Scenarios, LH into I_p ramp), contributing to a Sept. 2007 Program Goal and largely fulfilling a non JOULE milestone **“B.3 Operate LHRF into L-Mode and H-Mode plasmas, and investigate combined LHRF and ICRF”**– due June 2007. Negative results will help up understand what hardware changes need to be made during the next opening. Either will help inform our five-year plan.

7. References

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

¹ R. Parker, APS Invited talk 2006.

² G. Wallace, APS 2006, 2007 RF Conf, and MP 464 results presented at C-Mod group meetings.