

Alcator C-Mod Mini-Proposal

MP No. 544

Subject: Optimizing LHCD in “improved L-mode” scenarios

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Group: Advanced Integrated Scenarios

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Approved by:

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1. Purpose of Experiments

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

This experiment seeks to demonstrate, optimize and document experimental scenarios with significant LHCD in ICRF-heated L-mode plasmas, for increased confinement and plasma temperature without the strong density increases associated with H-mode. This will serve to strengthen the basis for future higher LH power, majority non-inductive scenarios which are part of the five-year plan.

2. Background

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

Most of the LHCD experiments to date have been into low density, ohmic, target plasmas which maximize the LHCD. However, these tend to have relatively cool electron temperatures, which can lead to low single pass absorption and to broad or two-peaked deposition profiles. They also have low energy confinement and stored energy, and thus small bootstrap current.

For future use in advanced scenarios, we need to combine LHCD with ICRH, and use target plasmas with higher confinement and bootstrap fraction. We have had some operational experience, on MP 490 and other experiments, that show we can combine LH with ICRH, from J and E-port antennas, up to about the 3 MW ICRH level [1]. There was evidence of broadening of the hard x-ray emission as Teo increased from 2 to 4 keV. However, there has not been an attempt to optimize the heating and confinement of the L-mode target, and LH power was relatively low (~0.5 MW) in most of these experiments.

Two modes of operation are possible: L-mode and H-mode. The latter has highest confinement but also higher plasma density, reducing LHCD. This will be the subject of a separate MP. To achieve high power L-modes with good confinement, one can run with the ion BxgradB drift away from the active x-point, raising the L-H power threshold. Past experiments show that a temperature pedestal can develop, without a density pedestal, an ideal situation for LHCD [2,3]. A related proposal, MP 539 by Lipschultz *et al*, will seek to optimize the parameters of the “Improved L-mode”, and understand its physics better, by varying density and topology to find conditions which maximize the L-H threshold power, and the confinement of the L-mode plasma. The ‘forward field’ run day of that MP should be scheduled if possible before this one.

Modelling of an L-mode like discharge, with 2.5-3 MW of LHCD as eventually planned, shows that strong off-axis LHCD, up to 450 kA, could be obtained (see Figure 9.9 of current C-Mod five-year proposal). The objective of the current experiment is to maximize the non-inductive current drive with the LH presently available, about 1 MW. This will be a good check/demonstration that such scenarios are feasible, and be used to benchmark integrated modeling. In particular, it would be a good test of whether parasitic absorption by energetic ions, which is not included in most of our current integrating modeling, will be a problem in these ‘standard’ C-Mod conditions (see new MP by Wukitch et al, and references therein).

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.

Since no reversed field operation is planned this campaign, this experiment will use the normal field, upper null configuration. Target discharges will start from those demonstrated in MP 539, with moderate density and hopefully about 3 MW of power from E and J-port (at 78 MHz); the power used will depend on the L-H threshold. We will start with $I_p=800$ kA, as in MP 539, and later reduce to 600 kA, $q_{95}\sim 5$ to increase non-inductive current fraction. LHCD will be added during the steady L-mode phase of the discharge, and brought up to maximum available power. Small scans of LH phase will be carried out to find the value which maximized the current drive (generally, just above the accessibility limit). We will then repeat at other density values, and possible raise B_T slightly to improve accessibility. Time permitting, we would also try at higher I_p .

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field:	5.4-6 T.
Plasma Current:	0.6-0.8 MA

Working Gas Species: D2
Density: nel 4-8 e19 m⁻²
Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.): Should be fairly recent, but need not be the previous night.
Equilibrium configuration (if possible, refer to database equilibria): USN, 1070817021 (with Ip, nel adjusted), or preferably a more recent example from MP 539.

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: YES. J and E, up to 3 MW total, in flat top. 78-80 MHz.
LHCD Power, pulse length, phasing: YES, start with 90 degrees, 0.5 s, up to 1.1 MW.
Pellet Injection (species): no
Impurity blow-off injection: no
Diagnostic Neutral Beam: YES
Special gas puffing: possible Argon, to extent it does not compromise confinement.
Cryopump: YES
Non-axisymmetric Coils (Connections, Current); standard config to avoid locked modes.
Other:

4.3 Diagnostics

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

Need Thomson scattering, LH probes and cameras, ECE (non-thermal settings), hard x-ray camera, with appropriate shielding for ICRF-related effects, bolometer, magnetics and other standard core and pedestal diagnostics. Divertor probes, to assess SOL conditions in this regime. MSE highly desirable, to see current drive effects! Also CXRS, CNPA, HIREX-Sr desirable.

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.

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.

Starting plasma parameters will be selected based on results from MP 539. Expect to use 800 kA, target nel = 6e19 m⁻², (nebar ~ 10²⁰ m⁻³). ICRF power about 3 MW.

1) Establish high power, steady, “Improved L-mode”. Raise ICRF power to maximum value which gives steady L-mode conditions, monitor confinement and core and edge T_e.

(3 shots).

2) Add LHCD during steady ICRF heated period. Select $n_{//}$ to be lowest accessible value (75 or 90 degrees?). Raise power progressively to maximum available. It is likely that we will need to reduce ICRF power correspondingly to stay in L-mode. Monitor plasma response: MSE angles, V_{loop} , ECE, x-rays, etc.

(6 shots).

3) Limited phase scan to establish optimum $N_{//}$, for maximum effect (eg, 75-100 degrees).

(4 shots)

4) Reduce plasma current to 600 kA, repeat with the $N_{//}$ which gave most current drive. Monitor plasma confinement as well as LHCD.

(2 shots)

5). Repeat lowest phase at slightly increased field (6.0 T). (2 shots). Monitor changes in $T_e(r)$, which may flatten, as well as non-thermals.

6) Repeat steps 1-3 at reduced plasma density, for higher T_e and current drive.

(n_e range will be guided by prior experience with L-H threshold and L-mode confinement)

(8 shots).

It is possible we will find that L-mode plasmas cannot be maintained with substantial ICRF and LHCD in the USN configuration. If this occurs, a fallback would be to use the inner wall limited configuration. This would not be expected to give improved confinement, but should allow L-modes with full ICRF from J and E-port and thus high temperatures.

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, an ITER request, or an external database.

If successful, these experiments would be an important demonstration of LH current drive in hot, ICRF heated discharges, which we expect to give strong single-pass damping and far off-axis deposition. While this is L-mode, the density range is comparable to that expected in ITER H-modes. This will thus be a useful benchmark of CD models (TSC+LSC, CQL3D, others) both for ITER and for planned C-mod scenarios. Significant LHCD at 1 MW would give greater credibility to our plans at higher P_{LH} , and would support our five-year proposal. Significantly less LHCD than expected would point to other effects such as parasitic absorption which need to be included in our modeling and considered (avoided) in optimizing our scenarios.

Would contribute to presentations at EPS (Parker), IAEA (Wilson) and other conferences, and likely be presented at SSO ITPA meeting in April, and other future venues and publications. Should contribute to the thesis work of Greg Wallace and Andrea Schmidt.

7. References

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

- [1] A. Hubbard et al, poster at 2007 APS-DPP meeting, Orlando, Florida.
- [2] F. Ryter, W. Suttrop *et al*, Plasma Phys. Control. Fusion **40**, 725-729 (1998).
- [3] A. E. Hubbard. J. W. Hughes, *et al*, Physics of Plasmas **14** (5) 056109 (2007).