Alcator C-MOD
Mini-Proposal

Subject: D(H) Minority and Mode Conversion Heating
Date: October 3, 1997

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

This mini-proposal is to explore the RF absorption efficiency and heating effectiveness (change in stored plasma energy/RF power) in D(H) plasmas, over a range of H concentrations up to \( n_H/n_e \approx 0.4 \). At small H concentration, the absorption should be dominated by minority absorption, but as the H concentration increases mode conversion to ion Bernstein waves becomes important. By examining the power split between ions and electrons as a function of hydrogen concentration and as a function of plasma density, a calibration of full-wave ICRF models such as TORIC can be established and provide a systematic study comparing minority and mode conversion heating. Results from this study can also provide an evaluation of the viability of D(H) mode conversion for off axis heating and current drive.

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

Mode conversion electron heating has been observed in both \( H(\text{^3He}) \) and \( D(\text{^3He}) \) plasmas on C-Mod and Tore Supra, and in \( D(\text{^3He}) \) and D-T plasmas on TFTR. Observation of D(H) mode conversion is limited to one discharge on ASDEX-U and some limited data was collected by P.J. O'Shea on C-Mod. An interesting physics feature of mode conversion in D(H) plasmas is that the two cyclotron layers which bound the region containing the mode conversion layer are farther apart than in \( H(\text{^3He}) \) and \( D(\text{^3He}) \) scenarios. Furthermore the cutoff resonance pair is more widely separated in D(H) than either \( D(\text{^3He}) \) or \( H(\text{^3He}) \). Both impact the absorption physics.

To date, D(H) minority heating has been used extensively in C-Mod at hydrogen concentrations of typically \( < 2\% \) where ion absorption dominates. However, mode conversion requires larger minority concentrations. For the ASDEX-U, the hydrogen concentration was \( \approx 7\% \) and \( \approx 20\% \) of the power was measured to be absorbed by mode conversion. A
careful H concentration scan with RF power modulation should provide an opportunity to experimentally observe mode conversion in D(H) plasmas. The higher concentrations will be the best suited because the H and D cyclotron resonances will be in the outer half of the plasma.

TORIC simulations of D(³He) and H(³He) show good agreement in profile shape and absorbed power density with experimental measurements. This suggests the potential use of TORIC to accurately predict and model the ICRF power deposition profiles routinely. Work is underway to couple TORIC with TRANSP. An H concentration scan should provide an opportunity to benchmark the code against experiment, particularly at low H concentrations where C-Mod typically operates.

Experimentally, the heating effectiveness (change in stored plasma energy/ RF power) is larger with ion minority heating compared with direct electron heating. The source of this difference can be that the ion minority heating energy is stored in well confined fast ions compared to direct electron heating which injects its power into thermal electrons. By scanning H concentration the transition from minority to mode conversion dominated heating can be characterized.

This proposal also addresses an issue raised at the National Tokamak Workshop. DIII-D proposed to use D(H) mode conversion for localized heating and current drive for advanced tokamak scenarios. Preliminary calculations indicate that it may be difficult to achieve effective mode conversion in the DIII-D D(H) plasmas. Theory and modeling calculations (CARDS and METS95) indicate that mode conversion decreases as the major radius and operating density of the device increase. Physically, this dependence arises because the incoming fast waves must tunnel through a cutoff layer to reach the mode conversion layer. The compact size and density range of C-Mod provides us with an opportunity to clarify the physics issues surrounding D(H) mode conversion.

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 guiding principle is to center the absorbed power profile about the magnetic axis. For low H concentrations (0.5-10%), the magnetic field will be 5.4 T. As the H concentration is increased, \( B_T \) will increase. To optimize mode conversion heating at high H concentration, the ion resonances will be shifted off-axis and the minority ion concentration will be adjusted to maximize mode conversion.

4. Resources

4.1 Machine and Plasma Parameters
Give values or range for:

**Toroidal Field**: 5.4 - 6.5 T; shot to shot scan
Plasma Current: 1.0-1.2 MA

Working gas species: D, H minority (variable concentration)

Density: \( n_e = 1-2 \times 10^{20} \, \text{m}^{-3} \)

Equilibrium configuration (if possible, refer to database equilibria): Lower single-null with 1 cm outer gap

Pulse length, typical current & density waveforms, etc. Refer to database or sketch desired waveforms: current flat-top of at least 0.4 sec.

4.2 Auxiliary Systems

RF Power, pulse length, phasing: 2 MW to full power, with power modulation.

Pellet Injection (species): none

Impurity blow-off injection: none

Special gas puffing: none

Other:

4.3 Diagnostics

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

All available diagnostics. CX for H/D ratio and H ion acceleration, U. Md. spectroscopy for H/D ratio, ECE polychromator with appropriate grating (prefer to have the new 19 channel GPC), and Ti measurements.

4.4 Neutron Budget

Estimate the neutron dose rate at the site boundary. Give basis for estimate. (Once some experience has been gained a standard formula will be provided for estimating dose rates.)

Less than \( 10^{13} \) per shot.

5. Experimental Plan

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.

Full 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.

A mixture of hydrogen and deuterium will be used for prefill and gas puff. The main parameter scans are D/H concentration and electron density. The RF power will be 2 MW
(or maximum power that can be run reliably) with 0.5 MW power modulation. Recently installed tuned arc detectors should prevent antenna cross-talk as was the case in H($^3$He) experiments.

1) Moderate density, H concentration scan in H-mode. (12 Discharges)

1.0 MA, 5.4 T discharges with target density 1.0x10^{20} m^{-2} [H] = 0.5%, 1%, 2%, 5%, 7%, 10% Ti profile at 1%, 5%, and 10% (3 discharges each)

2) Moderate density, H concentration scan in H-mode with the power deposition profile centered. (7 Discharges)

1.0-1.2 MA, 5.4-6.5 T discharges with target density 1.0x10^{20} m^{-2} [H] = 10%, 15%, 20%, 30%, 40% Ti profile at 20% (3 discharges)

3) Locate the mode conversion on axis and perform a density scan. (4 Discharges)

[H] will be probably 20-40% and $B_T \approx 6.5T$ target densities of 0.6, 0.9, 1.2 and 1.5 x10^{20} m^{-2}

4) Locate mode conversion on axis and maximize RF power

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.

Demonstration of D(H) mode conversion electron heating.

Benchmark TORIC against experiment.

A detailed comparison of minority and mode conversion heating.

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