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.

The goal of this mini-proposal is to investigate mode conversion current drive using the J-port antenna.

2. Background

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

Successful mode conversion electron heating has been demonstrated in D(\(^{3}\)He), H(\(^{3}\)He), and H(D) plasmas.[1-5] Mode conversion current drive (MCCD) was successfully demonstrated by Majeski et al using 2-strap antennas.[1] In this experiments, the driven current was estimated from the surface loop voltage evolution without measurement of the driven current profile. Recent simulations for C-Mod indicate up to 75 kA can be driven with 3 MW of power for near on-axis mode conversion (r/a < 0.2) at \(n_{e0}=1.5 \text{ m}^{-3}\) and \(T_{e0}=4 \text{ keV}\) in a D(\(^{3}\)He,H) scenario. For scenarios with the deposition further off-axis, the mode conversion scenario is complicated by trapping effects that decreases the driven current. Further complication arises from mode conversion into the ion cyclotron (ICW) wave whose impact on current drive has not been assessed.

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 order to optimize the driven current, target plasmas with high temperature and low density need to be prepared. In addition, near on-axis current drive will be pursued to minimize trapping effects. Some interesting upper single null target discharges achieved 4 keV with minimum impurity problems for ICRF power levels up to 4 MW. Another
potential target discharge is early ICRF injection during the current rampup. In both cases, co-current, ctr-current, and heating discharges will be compared.

For the upper single null discharges, the MSE analysis may allow the reconstruction of the driven current profile. Comparing co-current, ctr-current, and heating discharges should improve confidence in the measured profiles. The expected current relaxation time should be 0.3-0.5 sec ($2 < Z_{eff} < 3$ and $T_e = 4$ keV). Thus, comparing the surface loop voltage evolution for co-current, ctr-current, and heating discharges may provide an independent measure of the total driven current.

For the ramp-up discharges, the MSE analysis will be the primary method of determining the driven current. The expected current relaxation time is of order 0.6 sec ($Z_{eff} = 2$ and $T_e = 5$ keV) while the ramp-up phase is $< 0.3$ sec. Therefore the loop voltage analysis is complicated by current diffusion effects. Comparing the MSE measurements for co-current, ctr-current, and heating discharges should improve the confidence in the measured current profile.

Another means of inferring driven current is to attempt off-axis current drive near the q=1 surface and monitor changes to both the q-profile measured from MSE and sawtooth behavior. Again discharges with co-current, ctr-current, and heating phasing can be compared.

Although a variety of mode conversion scenarios are possible, the exact scenario depends on a number of other constraints. Among the scenarios are:

D(^3\text{He}, \text{H}) is a mode conversion scenario where the ion-ion hybrid layer can be located on axis for 78 MHz at 5.8 T (species mix is 35% D, 20% He3, and 25% H). The mode conversion heating and associated density fluctuations at the RF frequency were measured using PCI (1000623) using a similar scenario,[6] Using D and E-port antennas at 80 MHz additional electron heating is located off-axis at $R_{maj} = 64$ cm. One drawback is the addition of H requires some time invested to obtain the correct species mix and requires discharges to reduce the H fraction after the run.

Another MC scenario with central absorption is D(^3\text{He}, \text{H}) at 5.8 T with J-port at 53 MHz and D and E at 80 MHz. Here D and E-port antennas can heat the H minority near on-axis (5%). This scenario has an advantage that the H fraction is more compatible with other experiments; however, this frequency is unavailable for the present campaign. For 70 MHz, the field would be 7 T and the H cyclotron resonance, at 80 MHz, would be near the D and E-port antennas making them ineffective at heating the plasma.

D(^3\text{He}) and H(^3\text{He}) are other mode conversion scenarios requiring 8 and 6.4 T at 78 MHz, respectively. At this field, the FRECE is unavailable, the number of discharges is typically fewer than a 5.4 T run, and the MSE requires additional calibration data.

4. Resources
4.1 Machine and Plasma Parameters

Give values or range for:

**Toroidal Field:** 5.4-6 T

**Plasma Current:** scan 0.6-0.8 MA

**Working gas species:** variable levels of D, H and $^3$He

**Density:** $n_e < 1 \times 10^{20} \text{ m}^{-3}$

**Equilibrium configuration** (if possible, refer to database equilibria):
1) upper single null discharge like 1030509011 with 1 cm outer gap
2) lower single-null ramp-up discharge like 1021025017

**Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms: 1 sec current flat-top.

4.2 Auxiliary Systems

**RF Power, pulse length, phasing:** 2 MW to full power at 78 MHz, co-, ctr- and heating phasing.

2 MW to full power at 80 MHz.

Need to verify heating efficiency and impurity production of co-, ctr- and heating phasing prior to this experiment.

**Pellet Injection (species):** none

**Impurity blow-off injection:** none

**Diagnostic Neutral Beam:** Yes

**Special gas puffing:** H, $^3$He from separate valves

**Other:**

4.3 Diagnostics

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

FRECE, MSE, H/D, and PCI are particularly important.

Some spectroscopic measure of $^3$He concentration would be useful.

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 $5 \times 10^{13}$ 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.

1 run minimum.

\(^3\)He gas in B-side upper 16 psi
\(\text{H}_2\) gas in C-side
Overnight ECDC in H

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.

Develop an upper single null plasma similar to 1030509011 where the central density was \(1.5 \times 10^{20} \text{ m}^{-3}\) with at least 2.5 MW from D and E-port. Scan \(^3\)He and H concentration, density, and plasma current to maximize Te with minimum Zeff. (5 shots)

Scan phase (co-, ctr- and heating phasing) under the optimum condition and measure q-profile evolution for each phasing. (15 shots)

Depending on the current drive success we would devote time to MSE calibration discharges (up to 5 shots).

Vary the B-field to place mode conversion near the q=1 surface (on the high field side). Scan phase and evaluate effect on sawteeth. (5 shots)

Develop a lower single null plasma ramp-up discharge similar to 1021025017 where the central density was \(1.0 \times 10^{20} \text{ m}^{-3}\) with at least 2.5 MW from D and E-port. Again scan target density and current to maximize Te with minimum Zeff. (5 shots)

Scan phasing (co-, ctr- and heating phasing) will be carried out under the optimum condition. Measure q-profile evolution for each phasing. (15 shots)

Depending on the current drive success we would devote time to MSE calibration discharges (up to 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.

Complete Milestone 77 Demonstration of MCCD and evaluation of current drive efficiency.

Provide data for H. Yuh’s thesis.

Provide data for experimental comparison to simulation. The MSE data may provide the first indication of the MCCD profile width. The characterization of this width could impact upon the suitability of using MCCD to stabilize MHD modes.
7. References

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


