1. Purpose of Experiments

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

In reactor devices such as ITER, $\alpha$ particles born with velocities above the Alfvén phase speed can resonantly excite the Toroidal Alfvén Eigenmodes. Unstable TAEs can in turn cause increased transport of the non-thermalized alphas, leading to decreased burn performance and first wall damage.

Hydrogen ion velocity distribution tails with energies above $v_A/3$ generated by ICRF or NIB can also excite TAEs. Studies of the TAE instability threshold in H minority plasmas have led to well known behavior of the low $n=1,2$ modes. However moderate $n=6-14$ modes are speculated to be most problematic in ITER, and their interaction with energetic ions has not been thoroughly explored in experiment. The dependence of the stability threshold of moderate $n$ modes on ICRF resonance localization and ion distribution tail temperature in Alcator will be established. Dependencies extending to ITER will be attempted to quantify the likelihood and feasible mediation of unstable TAEs.

2. Background

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

TAEs are driven unstable by a strong peaking of energetic minority ion pressure gradient in Alcator. Unstable modes have also been attributed to peaked $\alpha$ densities in JET DT plasmas [1], demonstrating that the phenomena on should be expected in ITER.

The response of low-$n$ TAE stability thresholds to ion velocity distribution above $v_A$ has been thoroughly studied in JET. For example, the stability threshold for low $n=1,2$ TAEs was demonstrated to increase as the heating deposition was broadened [1]. With neutral beam heating below 3MW, the damping rate of $n=1$ TAEs was found to decrease
with increasing $\beta$. [2] The sudden reduction of the distribution tail energy by increasing the H/D ratio was quantified by neutral particle analyzer measurements and observed to quench unstable TAE activity [3]. Similarly, the flattening of the fast particle pressure gradient by a saw tooth crash was observed to coincide with the end of unstable low-n TAE activity. The damping rate of n=TAEs was observed to decrease nearly to zero as ICRF power increased to 5MW [4].

Moderate-n TAE dependence on fast particle distribution was preliminarily explored on Alcator during the 2006 campaign. Initial studies with low (<3MW) ICRF heating found no dependence of the damping rate on ICRF power, and hence on the velocity distribution tail temperature or density gradient. However the heating resonance, localized in the core, may have been spatially separated from the peak of the radial eigenmode structure, a conjecture supported by TRANSP and NOVA-K simulations.

It is expected that by moving the ICRF resonance off axis, the stability threshold (eg damping rate) of moderate-n TAEs will decrease with increasing ICRF power. Then the dependence of TAE stability on tail temperature and density gradient will be observable by the Active MHD diagnostic and the CNPA (or antenna modelling codes).

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 ICRF resonance will be moved up to 7cm off axis by increasing $B_T$. RF power will be stepped from 0 to 5MW or until TAEs appear spontaneously. When fast particle contributions to the drive of TAEs are less than the damping rate of a particular eigenmode, the mode remains stable (ie it does not spontaneously appear). Then the Active MHD diagnostic can identify the characteristics of these modes in Alcator, most notably their net damping rate. The Active MHD diagnostic will be used to observe the effect of increased RF power on the moderate-n TAEs. The compact neutral particle analyzer, if available, will be used in conjunction to quantify the high energy tail temperature and density. TRANSP/TORIC and AORSA/CQL3D simulations will estimate the fast ion density gradient.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field**: -5.7 to -6.2 T
- **Plasma Current**: 0.6 MA
- **Working gas species**: $D_2$
- **Density**: NL04 $> 7.5 \times 10^{19} m^{-2}$
Equilibrium configuration (if possible, refer to database equilibria): 1060526032

Pulse length, typical current & density waveforms, etc. Refer to database or sketch desired waveforms: 1060526032

4.2 Auxiliary Systems

RF Power, pulse length, phasing: up to 5MW, H/D < 5% attempt monster sawtooth phasing, 80 MHz

Pellet Injection (species): -

Impurity blow-off injection: -

Diagnostic Neutral Beam: -

Special gas puffing: Argon for HIREX

Non-axisymmetric Coils (Connections, Current): -

Other: -

4.3 Diagnostics

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

CNPA, Active MHD, DPCS_ftae2 implemented, HIREX, H/D

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.

Day 1: High field to move ICRF resonance off-axis. Low Ip to increase q95 and move q=1.5 towards the axis (as in shot 1050824013). Lowish density to increase fast ion tail energy. Limited configuration, L-mode. ICRF power scan from 0 to 5 MW or until unstable TAEs are observed.

Day 1.5: Same target field, current and density, but now diverted and H-mode, as in shot 1051202011.

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.

* Set Ip to 0.6 MA, P_{ICRF} to 3MW, B_T to -5.7. Increase B_T to -6.2T while searching for TAEs and monitoring fast ion tail with CNPA. (6 shots)

* At highest B_T with sufficient T_{Hfast}, scan RF from 0 to 5MW in 0.5 MW increments, with two shots at each power. (22 shots)
* Increase Active MHD frequency to correspond to \( q=1 \) and lower \( B_T \) to -5.4 for higher \( T_{H_{fast}} \). ICRF power scan, one shot at each power. (9 shots)

* In H mode at \( B_T=-5.9 \text{T} \), repeat ICRF power scan starting at highest power and stepping down to H mode threshold power. Two shots for each power level. (18 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.

The dependence of moderate-\( n \) TAEs on the ICRF power and correspondingly on the energetic particle distribution tail and density gradient will be established. Moderate-\( n \) modes are speculated to be the most threatening of TAEs to ITER performance. Therefore experimental evidence of their behavior and an extension to ITER operation and strategies for mitigation of the modes will be valuable. This research will be the main focus of a Ph.D. thesis.

7. References

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