1. Purpose of Experiments

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

Determine if losses or redistributions of RF tail ions due to actively excited TAE modes can be measured in C-Mod, and whether these are large enough to reduce the ICRF heating efficiency.

2. Background

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

High priority ITPA experiments are presently planned on TAE-induced losses of fast ions from neutral beam injection in JET and ASDEX Upgrade. Experiments demonstrating Alfvén eigenmodes driven by ICRF beat waves were first performed on JET [1]. Theoretically, significant fast particle losses are expected for local magnetic perturbations with $\tilde{B}_r/B > 10^{-3}$ [2]. Measurements on C-Mod indicate that poloidal field perturbations at the wall with $\tilde{B}_\theta/B > 3 \times 10^{-5}$ have been observed in the frequency range 490 kHz $< f <$ 510 kHz during high power ICRF heating with D and E port antennas generating a beat wave at 500 kHz. Exactly how large this perturbation may reach in the core is not known, but some effect on the fast ions might be expected for large enough beat waves. TAE induced fast ion losses are a high priority research area in the ITPA MHD group and may be important for ITER.

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.

$\tilde{B}$ drive: Ideally one would like to use the active MHD antennas to provide the drive, since the frequency and amplitude would then be controllable. But typical values of $\tilde{B}_\theta/B$ driven by the active MHD antennas are only $4 \times 10^{-7}$. A much stronger $\tilde{B}$ drive is produced by
the beat wave from the D and E antennas. This is usually at 500 kHz (80.5 MHz and 80.0 MHz), but it can be changed to 400 kHz (more typical of our TAE modes) if we want. An analysis of a number of shots from 2004 and 2005 when D and E were operating well have shown cases where $\tilde{B}/B$ of the 0.5 MHz beat wave is larger than $3 \times 10^{-5}$, which is about two orders of magnitude higher than from the active MHD antenna. Therefore we propose to use this beat frequency (maybe at 400 kHz) as the drive.

To excite TAEs with a broad radial structure across the plasma core, very low or reversed shear would be best and initial analyses indicate that the largest beat wave perturbations occur with ICRF heating in the current rise or in the flat top during EDA H-mode with strong ITBs. So, these conditions would probably yield the largest TAE perturbations, but density control may be difficult for scanning through the TAE frequency.

Detection of RF tail loss: two possibilities are proposed, a ‘coarse’ method and a ‘fine’ method, depending on the magnitude of any loss. The first part of a run day would be devoted to the detection method suitable for large tail losses. If that fails to show any effect, then the second part of the run day would be devoted to the more sensitive detection method.

Coarse: If a substantial fraction (say of order 10%) of the ICRF tail ions is lost from the plasma core ($q \leq 1$), the heating efficiency would be reduced, and the neutron rate and the sawtooth reheat slope would be affected. Scanning the TAE frequency around the beat frequency by scanning the density in $\sim 10\%$ steps during a discharge would provide sets of neutron rates and sawteeth on and off resonance for comparison. The toroidal $B$-field would be kept constant so as not to change the ICRF deposition.

Fine: If the coarse method shows no gross effect, then the compact neutral particle analyzer (CNPA) would be employed to look for fast particle loss or redistribution. This is difficult, however, because very low densities ($n_l \simeq 3 \times 10^{19} \text{ m}^{-2}$) are desirable for the CNPA to work well. With 2+ MW from D and E, H-mode would normally preclude this low a density, so inboard limited equilibria would be run. (Upper null plasmas are incompatible with the CNPA views.) Finally, 10% controlled density steps might not be realistic at this low density, so the TAE frequency would be changed by stepping the toroidal $B$-field instead. (For this method, small changes in the ICRF deposition location don’t matter as much.)

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

**Toroidal Field:** 4.5 to 5.4 T (with ±10% steps for CNPA method)

**Plasma Current:** 0.8 MA

**Working gas species:** Deuterium
Density: Coarse method: \( n_l = 1 \times 10^{20} \text{ m}^{-2} \) with \( \pm 10\% \) steps during shot; Fine method: \( n_l = 3 \times 10^{19} \text{ m}^{-2} \)

Equilibrium configuration (if possible, refer to database equilibria): Coarse method: Begin with a standard RF fiducial (e.g., 1050705022) then may try an RF EDA ITB (e.g., 1040309031); Fine method: low density inboard limited current rise (e.g., 1040406027)

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

4.2 Auxiliary Systems

RF Power, pulse length, phasing: D (\( \geq 1 \text{ MW} \)) AND E (\( \geq 1 \text{ MW} \)) both have to be working well. If feasible, tune one or both systems so that the beat frequency is 400 kHz.

Pellet Injection (species): none

Impurity blow-off injection: none

Diagnostic Neutral Beam: If available, this would be useful for the CNPA measurements

Special gas puffing:

Non-axisymmetric Coils (Connections, Current): Standard configuration. CNPA method might require more attention to the locked mode issues.

Other:

4.3 Diagnostics

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

Fast magnetics, PCI, neutrons, core GPC’s and FRCECE, CNPA.

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.

1 run day. D and E antennas must both be running well.

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.

Begin with a standard RF fiducial such as 1050705022 but with D and E and no J port ICRF. The higher the power out of both antennas, the larger the TAE perturbation and the more likely to see an effect on the sawtooth reheat rate. Raise the power on D and E to high yet steady levels > 1 MW out of each antenna. The ICRF beat frequency must be
chosen to lie near the center of the TAE gap for q=1 for the given plasma conditions, which should be around 400 kHz. Vary the density or toroidal field by a few percent shot to shot to scan through the expected TAE gap to look for peaks in the magnetic perturbation and effects on the sawtooth reheat rate. If no effects are observed, a few shots might be tried lowering the field to 4.5 T to get long steady EDA H-modes with ITBs, which appear to increase the beat wave magnetic perturbations.

Next, try going to very low density to use the CNPA to measure fast particle losses. Since the largest beat wave magnetic perturbations have been observed with ICRF heating in the current rise, start with conditions such as 1040406027 and look for fast particle losses on the CNPA. Vary the toroidal field shot to shot by a few percent to scan the beat frequency across the expected TAE gap to look for resonant effects on the magnetic perturbation and the fast ion losses. Next, try flat top ICRF heating at very low density such as 1040415015 but inner wall limited to avoid the H-mode.

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.

This would be an interesting physics result, and may have implications for ICRF heating in machines that have large TAE’s driven by NBI or fusion α’s. It would complement similar studies with NBI on ASDEX Upgrade and JET. Fast particle losses due to TAEs are a high priority research area for the ITPA MHD group so these results may be important for ITER.

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