1. Purpose of Experiments

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

The purpose of this experiment is to explore the possibility of achieving the enhanced reversed shear (ERS) mode of operation in Alcator C-Mod by early ICRF heating. Emphasis is placed on maximizing ion heating. This will follow pellet injection (Li or D₂) to produce the combined ERS-PEP mode with deeper shear reversal over a larger volume, and increased bootstrap current.

2. Background

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

Initial scoping experiments (MP125) were performed to obtain the enhanced reversed shear (ERS) mode in Alcator C-Mod using current ramp and early ICRF heating in the D(H) minority heating regime. Typical parameters at the end of a 0.23 sec sawtooth free period were $n_e = 1 \times 10^{20} \text{ m}^{-3}$, $B_T = 5.3 \text{T}$, $P_{rf} = 2 \text{ MW}$, $T_e = 5 \text{ keV}$, $T_i = 2.5 \text{ keV}$, and $I_p = 0.8 \text{ MA}$. The minority concentration was low, typically 2% and therefore we expect mostly electron heating. While good ICRF coupling and excellent heating were observed, there was no evidence of the ERS mode, presumably owing to insufficient power being coupled to ions. Recent results from DIII-D showed degradation of the ERS mode with fast wave electron heating, indicating the necessity of ion heating. In this proposal we focus on maximizing ion heating by using higher H minority concentration. Modeling with FPPRF indicate that further increase in ion heating can be expected by using $^3\text{He}$ minority ions. JET has reported that their best PEP mode is obtained when the pellet is injected before the sawtooth activity begins, pointing out the advantage of combining reversed shear and PEP mode. It would be of significant scientific achievement to demonstrate the minority heating induced ERS mode and combined ERS-PEP mode. Finally, our recent modelling work showed that C-Mod could achieve impressive results with the ERS mode once established.
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.

As stated in the previous section, we plan to maximize ion heating by using a higher H minority concentration. After optimization at 5.3 T, $^3$He will be used as the minority species to further increase the ion heating fraction. We will also attempt to slow down the current ramp rate to allow more time for the formation of the ERS mode, as suggested by several people. A lower final current (i.e., higher edge $q$) will also be tried. Finally, pellet injection (Li or D$_2$) and high power ICRF heating during the initial sawtooth free period will be attempted with the aim of producing the combined ERS-PEP mode.

The RF Power will be injected early on and at relatively low density $n_e 0.5 \times 10^{20} \text{m}^{-3}$ to pre-heat the plasma rapidly while the current is still ramping up. The final density at the end of current ramp should be at most $n_e \simeq 1 \times 10^{20}\text{m}^{-3}$. A fairly high minority concentration ($\simeq 10\%$) will be used to maximize ion heating. This has the added benefit of reducing fast ion losses during the low density, low current phase. We will need to scan the starting density, density ramp-up rate, and the final density.

The $q$ profile should be monitored using Li pellets and the cigar detector. This will also give an indication of PEP mode performance with reversed-shear start-up. Fluctuations will be monitored with reflectometer in the “core RS region” at sufficiently low densities.

Once a reasonable ICRF coupling is established at the desired power levels and pulse shape, and good discharges are established, we should see enhanced temperatures and confinement, followed by deterioration as the RS mode is lost during the evolution of the discharge. If the ERS mode is achieved, further optimization and high quality profile measurements should be performed, which will require a second day of operation.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field**: 5.3 and 8 T
- **Plasma Current**: 0.6–1 MA
- **Working gas species**: D (majority) and H or $^3$He (minority)
- **Density**: scan $n_e = (0.5–1.5) \times 10^{20} \text{m}^{-3}$
- **Equilibrium configuration** (if possible, refer to database equilibria): Lower single-null, outer gap of 1 cm.
- **Pulse length, typical current & density waveforms, etc.**: Variable current ramp-up and density ramp-up.
4.2 Auxiliary Systems

RF Power, pulse length, phasing: Full power

Pellet Injection (species): Li pellet and cigar detector; or D$_2$ pellet for ERS + PEP mode

Impurity blow-off injection: no

Special gas puffing: Separate H puff or mixed D/H puff

Other:

4.3 Diagnostics

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

All available diagnostics. In particular: CX for H energy distribution and H/D ratio; U. Md. spectrometer looking into main plasma for H/D ratio; Hirex for ion temperature profile; Thomson scattering (if operational) for density and temperature profiles, in addition to ECE and TCI. Reflectometer in the core region to monitor fluctuations.

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.)

Up to $10^{13}$ 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 (possibility of a second run depending on results).

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.

The initial current ramp-up rate should be slowed down from the plasma startup scenario developed under MP126 and MP125 (up to 10 shots). Two levels of the final current (0.6 and 1.0 MA) should be tried to see the effect of edge $q$. Main parameters to vary are density programming (starting density, density ramp-up rate, and final density), H minority concentration, and RF power programming, as discussed in Section 3. The $q$ profile should be monitored using Li pellets and the cigar detector. Injection of a pellet (Li or D$_2$) into a reversed shear plasma will be tried for a combined ERS-PEP mode. This should require approximately 3/4 of the run. In the remainder of the run, $^3$He minority heating at 8 T should be tried under steady conditions to identify the most promising
result, in order to further increase the ion heating fraction. The TF flat-top should be 0.2–0.6 sec (breakdown around 7.7 T).

If a successful high power reversed shear scenario with enhanced confinement is achieved, an additional run day will be requested for further optimization and documentation including high resolution (temporal and spatial) temperature, density, and current density profile measurements.

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.

Positive results from this mini-proposal will establish C-Mod as a serious contender in the Advanced Tokamak Physics studies even before the addition of LHCD. A successful outcome of this proposal would establish the foundations, and a strong incentive, for pushing for the addition of low frequency mode-conversion current drive equipment. Once the RS mode is established, it would take less off-axis current drive to maintain such a state. Positive results from this work could be reported in an APS invited talk, and would lead to several publications, including a PRL.

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