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

This is a revision to the approved MP443. It is updated at the request of the core transport group.

In these experiments, we will employ the $B_T$-jog technique to search for and identify the critical threshold value ($L_C$) for the electron temperature gradient scale length ($L_{Te}$) and then correlate it with input power level, density, and safety factor. It is the relation between heat flux ($Q_e$) and $R/L_{Te}$ that ultimately yields $L_C$. In this experiment, $L_{Te}$ follows from direct measurement, while profiles adequate for TRANSP analysis will be needed to extract the heat flux. Transport in the vicinity of a critical gradient is important to understand since the underlying physics is changing. The results of the experiment can be used to evaluate critical gradient models for their utility in these high field plasmas which may differ from those in which the models were developed. Gyro-kinetic simulations also predict critical values, and there may be some opportunity for comparison. We will attempt to extend the experiments to acquire turbulence data (e.g., CECE and PCI) so that turbulence behavior associated with the critical gradient can be identified. Possibly, the data set will be sufficiently complete to support gyro-kinetic studies of the critical value predictions. Our emphasis is to complete this well before the end of C-Mod operation.

2. Background
Discuss Physics Basis of the proposed research. Prior results at Alcator or elsewhere, and any related work being carried out separately.
Temperature gradients drive turbulence in hot, magnetically-confined plasmas. The scaling of the heat flux with the temperature gradient can reveal a break in slope so that at higher values of the temperature gradient $R/L_{Te}$ (where $L_{Te} = T_e/\nabla T_e$), the heat flux $(Q_e)$ increases more rapidly than at lower values. The critical threshold value for the gradient scale length is a defining feature in some anomalous transport models.\cite{1,2} For these types of models, the heat flux might be written as\cite{3}

$$Q_e \propto T_e^{3/2} L_{Te}^{-1} (L_{Te}^{-1} L_C^{-1})$$

The critical gradient is observed\cite{4} and there are many examples. Confirmation that theory and experiment can agree on its existence is that it is actually predicted by the recent multi-scale gyrokinetic simulations.\cite{5} The results of this simulation is being incorporated into models to improve prediction. Models based on critical gradients have even had some success in identifying turbulent processes (for example, electromagnetic ETG turbulence model in Tore Supra) through trial of various critical gradient predictions.\cite{6}

Our goal is to measure this physically relevant parameter for a power scan in L-mode and explore the degree to which it is consistent with critical gradient models and the degree to which it can describe the C-Mod plasma.

Recently, we have established a precise technique (called B$_T$-jog) to directly measure the electron temperature gradient scale length ($L_{Te}$), via the high spatial resolution (~7mm) radiometer-based ECE (FRCECE) at Alcator C-Mod. The technique is based on small (~1.5%) variation of the toroidal magnetic field; consequently, the viewing volume of each ECE channel shifts, and the ratio of the average of the signal to the change in the signal during the jog yields $L_{Te}$; this technique is entirely independent of any calibration.\cite{7} Figure 1 shows an example of the application of the technique in a piggy-back experiment. Figure 2 compares the electron temperature profile (averaged over the ramp-up period) and the scale length measured through the B$_T$-jog technique. The jog is not known to induce plasma changes however, that is invariably checked. From the opposite point of view, it requires that the plasma not be evolving during the time of one ramp up or ramp down.

**Figure 1.** The time evolution of the toroidal magnetic field is shown in the top panel. B$_T$ is increased by ~1.5% over a 150ms ramp-up. As a result, each ECE channel’s view shifts to larger radii with lower temperature as the channel is on the LFS. The bottom panel shows uncalibrated ECE signal from channels 5 (black) and 6 (red) of the FRCECE diagnostic (C-Mod shot 1140402019)
Figure 2. $T_e$ profile (top) averaged over the ramp-up period and the scale length profile (bottom), measured through the B$_T$-jog technique (C-Mod 1140402019)

In Figure 3 there is a summary of the B$_T$-jog technique.

Figure 3. a) Ratio of the toroidal field to its mean value ($\langle B \rangle = 5.45$T, shown with dots) and its smoothed value (blue curve) used in analysis. As an example, the largest $\Delta t$ along the ramp-up corresponding to the last pair of times is selected (shown in •). Note that all of the time-pairs are used to yield multiple $L_{Te}$ measurements. b) Raw ECE signal of channel 5 during the ramp-up of the jog. $\Delta ECE = ECE_2 - ECE_1$ and the average ECE are defined.

Thus, the scale length can be found as

$$L_{Te}(r_i) = -\frac{T_e(r_i)}{\nabla T_e(r_i)} = -\Delta r_i \frac{ECE(r_i,t)}{\Delta ECE(r_i,t)} \text{ during ramp}$$

and

$$\Delta r_i = \frac{r_i}{B_0} \Delta B.$$
where \( r_i \) is the location of the \( i^{th} \) ECE channel, \( \overline{ECE} \) is the average of the ECE raw signal for a given channel before the jog and \( \Delta ECE \) is the change in the signal during the ramp-up (or ramp-down) of the jog.

This experiment was first attempted some time ago (run 1060419). See Figure 4. The experiment was largely successful so far as jog measurement was concerned (see Figure 5), however, the variation in RF power level was not sufficiently fine scale and the L-mode experiment was plagued by H-mode. Some signatures of \( L_C \) can be observed, and we would like to repeat the experiments with 100 kW increments (up to 1.2 MW) to confirm the presence of \( L_C \) in these measurements.

![Figure 4. Toroidal field and RF power during ramp-up (0.7s < t < 0.9s) and ramp-down (1.1s < t < 1.3s).](image)

![Figure 5. \( T_e \) and \( R_0/|L_{Te}| \) Profiles for ramp-up and ramp-down periods, shot 1060419005.](image)

For the experiments proposed here, the plasma will be heated by ICRF in L-mode plasmas with varying power levels. The scale lengths will be measured through the \( B_T \)-jog technique. Measured profiles will be processed via TRANSF to determine the heat fluxes. This will be sufficient to meet our goal to search for and find the critical gradient and compare it to a range of predictions. Our preference would be to actually use it to describe C-Mod plasmas but that would depend on the quality of the results. If turbulence diagnostics are available, then we will correlate fluctuation levels with critical values.
If time permits, the experiments will be extended (part 2) for different plasma current and densities by which the parametric dependence of $L_C$ on safety factor and density will be investigated.

Finally, the data will be available for Gyro-kinetic studies for $L_C$ observations.

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.

Compare $L_{Te}$ measurements in L mode shots with an RF scan limited by the L-H transition at $B_T = 5.25T$. The $B_T$ jog is represented by the toroidal field demand (red curve) in Figure 8. As also shown in the figure, it will be applied during the flat top region of RF deposition. Ideally, this is two measurements of the identical plasma. In practice, the two ramps are in plasmas of slightly differing parameters. That is not a disadvantage as it just means more diverse data. The relative orientation of this MP, another MP, and the transient is shown for a 1 s ICRF pulse. Part 1 of this MP is an RF power scan and has the priority. It is desirable to have a joint run day for these experiments and those in MP802. Part 2 encompasses scans in density and current.

![Figure 6](image-url) Figure 6. The sequence of events in a joint run of MP443a and MP802.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: **5.25T**
- Plasma Current: **0.8 MA for part 1; shot by shot scan from 0.6 to 1.2 MA for part 2**
- Working Gas Species: **D$_2$**
- Density: **$n_{i04} = 0.55 \times 10^{20}$ m$^{-2}$ for part 1; shot by shot scan from $n_{i04} = 0.3 \times 10^{20}$ to $1.0 \times 10^{20}$ m$^{-2}$ for part 2**
Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.): No
Equilibrium configuration (if possible, refer to database equilibria): In reversed field use 1160831027 and in forward field use 1120221012.

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: Step up central RF in 100kW steps
LHCD Power, pulse length, phasing: No
Pellet Injection (species): --
Impurity blow-off injection: No
Diagnostic Neutral Beam: desirable but not necessary
Special gas puffing: --
Cryopump: Yes
Non-axisymmetric Coils (Connections, Current);
Other:

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

FRCECE, GPC’s, HirexSR, TS (necessary)
PCI and CECE (desirable)

5. Experimental Plan
Both sections must be filled in.

B_T-jog on top of the RF flat top, as described in Figure 8.

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.

Part 1 is the top priority and requires 0.5 day. Since most of the following shots are common with MP802, it is highly desirable to have a joint run day with MP802.

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.

Part 1: RF power scan, n_l04/10^{20} = 0.55, (I_p = 0.8 MA if forward field, I_p = 0.6 MA if reversed field)
First 10 shots, P_{RF} = 0.0 - 1.0 MW, steps of 100kW

One shot with locked mode for HirexSr calibration. Shots are available from late August (e.g., 1160831024) but choose the one nearest in time to the run.

Next 4 shot., P_{RF} = above 1.0 MW, steps TBD contingent upon L_{Te} outcome

Part 2: Density and I_p scan
Next 6 shots., n_l04/10^{20} = 0.55, P_{RF} = 0.0 and 0.5 MW, I_p = 0.6, 1.0, and 1.2 MA
Next 10 shots, P_{RF} = 0.0, 0.25 and 0.50 MW, n_l04/10^{20} = 0.3, 0.8, and 1.0
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, an ITER request, or an external database.

A threshold for the critical scale length will be found via precise $L_{Te}$ measurements (BT-jog technique). It will be used to evaluate critical gradient models. As available, turbulence measurements can be added and correlated with the critical gradient. Multiscale gyro-kinetic simulations would enhance the value of these results but are not absolutely necessary. The results will be documented as publication in peer reviewed journals, as well as presentations in APS-DPP 2016 and TTF 2016.

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