Alcator C-MOD
Mini-Proposal

Subject: Perturbation test of non-local transport **MP No.** ________
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Approved by: ______________________________ **Date Approved:** ______________

1. Purpose of Experiments

These experiments will determine the nature of the electron temperature response in C-MOD to rapid perturbations, specifically from laser-ablated impurities. Similar experiments on other tokamaks have produced surprising results, at least under some discharge conditions. These experiments are intended to determine whether related effects occur in C-MOD, and if so, the conditions for which they occur and the relation to predictions of marginal stability and critical gradient theories. Explaining these phenomena provides a critical test of theory.

2. Background

Enigmatic, nonlocal responses of the electron temperature to a variety of perturbations and transitions have now been reported in JET [1], TEXT [2,3,4], TFTR [5,6], and RTP [7]. These include the L-H transition in JET, response to impurity ablation in TEXT and TFTR, and shallow pellet injection in RTP. Specifically, rapid strong edge cooling in TEXT, TFTR, and RTP has been found to cause a prompt increase in central temperatures. In JET, prompt core responses of both signs are found [8]. In all experiments, an intermediate region can be found in which no significant change occurs. In the context of a diffusion equation, no signal should propagate past such a region, and a sign inversion cannot occur.

Beyond their phenomenological curiosity, these effects suggest long-range communication and a transport criterion that is not part of any conventional turbulent transport model, for which transport and fluxes are fully determined by the local thermodynamic variables. The nonlocal effects suggest that the electron channel, in particular, includes considerably more physics than now envisioned. Since the few theoretical ideas so far proposed have not been supported by experiment [4], we have no alternative to further experiments as a source of ideas.

The disappearance of the effect at higher densities [6,7] has suggested a role for collisionality, although decreases in collisions by auxiliary heating actually decrease the effect. An obvious contrast is that between circular cross-sections with limiters (TEXT, TFTR, and RTP) and JET.

These sorts of perturbation experiments also have the potential of providing sensitive tests of theories -- critical gradients, marginal stability, self-organized criticality -- but since most of the calculations are more applicable to the ion channel than the electron channel, the immediate experiments may not be decisive. Nevertheless, the theories do make testable predictions for this sort of experiment.

3. Approach

The approach for C-MOD is simply to observe the electron temperature response with ECE to impurity ablation. Light impurity injection permits the more complete analysis because the direct radiative cooling is confined to a narrow layer at the edge, allowing an uncomplicated transport analysis over almost all of the minor radius. Carbon was used in previous experiments. Because edge conditions in C-Mod are quite different, another somewhat heavier element might be preferable. Consequently, piggy back experiments in which the injected impurity can be varied to search for the optimum impurity and injection level would be invaluable. We would therefore propose to proceed in stages.

First, we would like to conduct piggy back experiments to determine appropriate impurity, injection level, and discharge condition. These could be experiments in which impurities are already being injected. In this case, it would be useful to be able to increase the amount of injected impurity and and move to lower plasma currents and densities. If nonlocal effects are found with a commonly injected impurity such as scandium, we would like to switch to a lighter injection element for optimum data in those discharges. If impurities are not being injected for the purposes of the main experiment, but piggy back injections are allowed, then we would like to vary the impurity and injection level. Once again, as allowed, we would want to move to lower plasma currents and densities. Finally, we would like to conduct dedicated runs with our best choice of impurity and discharge regime.

4. Resources

4.1 Machine and Plasma Parameters

Toroidal Field: 5.3 T (As required for ECE)

Plasma Current: 0.6 MA (low enough to minimize sawteeth); extending to higher currents after effects found.

Working gas species: H or D

Density: 8×10^{19} (as low as possible), followed by density scan to find limit of effect.

Equilibrium Configuration: Any

Pulse length, typical current & density waveforms, etc.: Quasi-equilibrium

4.2 Auxiliary Systems

RF power, pulse length, phasing: None for initial runs; later runs in L and H mode

Pellet Injection (species): None

Impurity blow-off injection: Any (for tests); carbon for best data

Special gas puffing: None

Other:

4.3 Diagnostics

The ECE system with maximum time resolution is essential. Fast bolometers are also useful. Edge diagnostics would be interesting, but not necessary. Any fast fluctuation diagnostic (e.g. reflectometry) would also be valuable.

4.4 Neutron Budget

Negligible

5. Experimental Plan

5.1 Run sequence plan

The initial work will be piggy-back. We shall routinely examine shots with injection for impurity confinement that have full ECE data for signs of the effect. Second, on runs with interesting conditions (low current, low density) and ECE but with no scheduled impurity injection, we would plan to inject impurity in the late OH phase whenever possible. This would permit some exploration of the amount of injected impurity.

From the piggy-back data, we shall probably find little nonlocal response under most conditions. Therefore we would request some run time to explore low-density, low plasma current conditions. These explorations could be interpolated in the run schedule as convenient.

If suitable regimes for observing nonlocal phenomena are found, we would request roughly one day with carbon injection to develop the density, current, and shape boundaries of the effect.

5.2 Shot sequence plan

The three principal control parameters to be investigated are plasma density, plasma current, and shape (limited vs. diverted, etc.) with a later extension to power scans for L and H modes. The amount and type of ablated material may also be interesting, but seems less informative as long as it is sufficient to produce an effect.

For the initial (exploratory) sequence, we would begin with low current and low density ohmic conditions. The shape and magnetic configuration (diverted vs. limited) would be varied (via selective piggy backing) to include the circular, limited plasmas most similar to those in which the effect has been found to the more standard C-MOD configurations. (~ 4 shots injection set-up and ~2 shots/ configuration)

The subsequent major experimental runs depend upon the results of this exploration. A run would probably be needed for each configuration exhibiting nonlocal effects. For each configuration, a complete run sequence would be:

Set up at low current and density (~3 shots)
Density scan (2-4 shots)
Increase current in 3-4 steps with 3-4 shot density scan at each current (~16 shots)
From a suitable ohmic starting condition, a power scan (~4 shots)

If possible, a run sequence for a configuration in which H-mode occurred would be valuable.

6. Anticipated Results

Since TEXT/TFTR and JET have both seen nonlocal responses to impurity injection, but of different sorts, we expect a nonlocal response in C-MOD, at least under some conditions. The difference between TFTR and JET remains puzzling. A result from a different machine would give a clue; additional experiments, perhaps with various shapes, may be needed. If the effect can be found in C-MOD, the range of parameters for which it appears could determine the role of electron collisionality and decoupling of the electron channel in the phenomena.

At worst, no nonlocal response will be found under any conditions in C-MOD. Although such a negative result would be disappointing for the prospects of doing further experiments on the phenomena, it would tell us something very definitive about the plasma conditions required for nonlocal effects. A negative result would be especially significant if found under conditions for which a theory, e.g. the IFS/PPPL model, predicted fast, nonlocal-type response.

7. References

[1] J.G. Cordey, D.G. Muir, S.V. Neudachin, V.V. Parail, E. Springmann, and A. Taroni, Nucl. Fusion **35**, 101 (1995).

[2] K.W. Gentle, W.L. Rowan, R.V. Bravenec, G. Cima, T.P. Crowley, H. Gasquet, G.A. Hallock, J. Heard, A. Ouroua, P.E. Phillips, D.W. Ross, P.M. Schoch, and C. Watts, "Strong Nonlocal Effects in a Tokamak Perturbative Transport Experiment," Phys. Rev. Lett. **74**, 3620-3623 (1995).

[3] K.W. Gentle, R.V. Bravenec, G. Cima, H. Gasquet, G.A. Hallock, P.E. Phillips, D.W. Ross, W.L. Rowan, A.J. Wootton, T.P. Crowley, J. Heard, A. Ouroua, P.M. Schoch, and C. Watts, "An Experimental Counter-example to the Local Transport Paradigm", Phys. Plasmas **2**, 2292-2298 (1995).

[4] K.W. Gentle, R.V. Bravenec, G. Cima, G.A. Hallock, P.E. Phillips, D.W. Ross, W.L. Rowan, A.J. Wootton, T.P. Crowley, A. Ouroua, P.M. Schoch, C. Watts, "The Evidence for Non-Local Transport in the Texas Experimental Tokamak," Phys. Plasmas (to be published).

[5] M.W. Kissick, E.D. Fredrikson, J.D. Callen, C.E. Bush, Z. Chang, P.C. Efthimion, R.A. Hulse, D.K. Mansfield, H.K. Park, J.F. Schivell, S.D. Scott, E.J. Synakowski, G. Taylor, M.C. Zarnstorff, Nucl. Fusion **34**, 349 (1994).

[6] M.W. Kissick, J.D. Callen, E.D. Fredrikson, A.C. Janos, G. Taylor, "Non-local component of electron heat transport in TFTR," Nucl. Fusion **36**, 1691 (1996).

[7] G.M.D. Hogeweij, "Confinement Bifurcations in RTP", TTF May, 1997, Madison.

[8] R. Giannella et al., "Studies of Energy and Particle Transport in JET," IAEA-CN-60/A2-III-1, Seville, Spain (1994).