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

This experiment aims to extend the upper ranges of density (both absolute and normalized) for I-mode operation. It follows up on the very successful initial experiments at in MP 712, in the last few discharges of 1120907. IO has indicated that the ability to increase density is key to the interest in this scenario for ITER.

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

The I-mode regime has been developed on C-Mod into a robust, high confinement regime with pedestals and normalized confinement reaching or exceeding that of H-mode. The best access and performance has been found to be with reversed field, lower null discharges; in many cases I-mode has then been sustained up to the maximum available power, with no H-mode transitions. [Hubbard IAEA 2012].

There is an optimal density window for accessing I-mode, typically between about 1.1 and 1.8e20 m⁻³ (nebar). Below this density, L-I threshold rise, as do impurities. At some point plasmas just stay in L-mode. At higher density, plasmas transition directly from L-mode to H-mode, with at most a short, transient, I-mode phase.

However, once the I-mode is formed, one can increase the density by simultaneously heating and fuelling. This was tried on a few shots on 1120907, and worked immediately. Fig. 2 shows an example – only the second attempt (1120907032) where gas puffing was added (pre-programmed) at 0.9 secs. A 30% increase of density was
achieved, to nebar 2.0e20 m\(^{-3}\). There were a few other good examples later in the run, but we did not, in just a few discharges, have time to fully explore or optimize. This proposal aims to do that.

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.

We plan to start with LSN configuration and shape for which robust I-modes have been reliably seen. We will start with the conditions of MP 712, 5.8 T, 1.1 MA. Maximum ICRF power from all antennas will be used. PFC heating is likely to be an issue as on other high power I-mode runs. We will use Neon seeding, and also try small sweeps of the inner strike point to reduce peak temperature.

We will start by repeating the fueling of the original run, with NINJA. We will assess the maximum density before an I-H transition. We will then try different means of fueling, using density programmed to rise during the I-mode phase at different rates, and different gas valves, to see if this makes a difference in the limits. Keeping RF on will be important, and perhaps challenging. Will keep cryopump in reserve to reduce neutral pressure if needed.
Once the 1.1 MA operating space has been thoroughly documented, we will repeat at a lower current, 0.8 or 0.9 MA. This is likely to reduce the absolute operational density window, but may result in a higher normalized density \((n/n_G)\) which is of interest to ITER. The L-I and I-H power thresholds should be proportionally lower, which would be less demanding of ICRF, and may provide a better means of assessing I-H threshold conditions (often no H-mode is seen at higher current and max power). For this step we will use whichever fueling recipe works best at 1.1 MA. If we find that we are limited to low Greenwald fraction, we will try ramping the current down during an I-mode.

An important secondary goal of this MP is to provide high quality I-mode examples for good diagnosis using pedestal profile and fluctuation diagnostics. Several forum ideas are counting on this MP to provide ‘piggyback’ data in high performance I-modes. Thus we will repeat key discharges with suitable puffing for CXRS and GPI as needed. At least one full run day is needed; the option of an additional half day would be valuable.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: \(5.6-5.8\ T\), REVERSED
- Plasma Current: \(0.9-1.1\ MA\)
- Working Gas Species: D2
- Density: Target \(n_e 0.5-0.9\times10^{20}\ m^{-2}\).
- Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.): Recent boronization is not essential but would be beneficial. Not the night before, though.
- Equilibrium configuration (if possible, refer to database equilibria): Discharge 1120907028 or recent equivalent

4.2 Auxiliary Systems

- ICRF Power, pulse length, phasing: Heating phasing, 80 MHz, variable power. Need D, E, J all operational, minimum 4 MW, 5 MW desired. Most shots will request up to max available.
- LHCD Power, pulse length, phasing: No
- Pellet Injection (species): No
- Impurity blow-off injection: Not needed. LBO may be permitted in some shots.
- Diagnostic Neutral Beam: Desirable, not essential.
- Special gas puffing: 8PSI D2 in the F-Port plenum for GP-CXRS. 8 PSI He in C-Port NINJA for GPI. Neon should be available, will likely be needed for seeding, divertor cooling.
- Cryopump: Desirable for ne control, and neutral pressure control. Not first shot; suggest N2 precool, He in reserve.
- Non-axisymmetric Coils (Connections, Current): Standard reversed B configuration (for error field correction).
- Other:
4.3 Diagnostics
List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

Essential: Edge and core TS, ECE, reflectometry to monitor fluctuation changes which signal L-I transitions, divertor and limiter thermocouples to check safe PFC temperatures. Highly desirable: Edge CXRS, PCI, GPI, HIREX, inner divertor

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 initial run day. Possible extension to second half-day if results warrant (ie if operational limits do not seem to have been reached, or full diagnostic set for key conditions not yet obtained).

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.

1. Unfuelled reference I-mode discharge. Load 1120907028, or recent equivalent. (5.8 T, 1.1 MA, stepped ICRF to max available). Target nel ~ 8x10^19 m^-2. 2-3 discharges, to get one good case.

2. Fueling scan. Start with preprogrammed puff from NINJA, 15 psi D2 from inner valve to start (between 1120907032 and 033 levels). If I-mode is maintained, increase puff. If we get transitions to L-mode or H-mode, likely at some point, then we will try different preprogrammed density ramps, perhaps with RF ramps; our sense is that power and density should increase in tandem. If neutral pressure is causing ICRF trips, turn on cryopump. 6-8 discharges.

3. Once upper limit to density/power/pressure is reached, and assuming transitions to H-mode are limiting us, repeat 1-2 discharges with He puff for GPI. Would like to document what is changing in local conditions, flows and turbulence that triggers the I-H transition. 2 discharges.

4. Reduce I_p to 800 kA. Establish I-mode, with target nel about 6e19 m^-2. If clear L-I signatures are not seen, increase I_p to 900 kA. At this lower current we should have enough ICRF to also reach I-H threshold. 3-4 discharges.

5. Repeat fueling and power scans as in step 2. Use our experience there to decide most effective valves and feedback methods, so it should take fewer shots. 4-6 discharges.
6. For comparison, and to try to increase Greenwald fraction, try establishing an I-mode at ~ 900 kA, then ramping current down, to ~ 600 kA, during the ICRF. 2-3 discharges.

7. Repeat discharges as needed to obtain full set of pedestal and fluctuation profiles (GPI, CXRS…) at this current, both in moderate density, maximum density I-modes, and at I-H transitions. We want to be able to assess physical variables, and ideally the mechanism, of the limit in density for I-mode. 
As many as it takes, or until we run out of time.

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.

This experiment will, most importantly, contribute to understanding the extrapolation of I-mode to ITER. Results will contribute to Hubbard’s IAEA presentation on multi-device I-mode studies. Both joint and C-Mod publications are expected.

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