1. **Purpose of Experiments**

This MP proposes to measure the changes in penetration/screening of puffed nitrogen as the puff locations and ICRF-heating power levels are varied. It is expected that there will be differences in penetration depending on location of the puff relative to the energized antenna(s), and we desire to document those regions of good and poor impurity screening in the presence of ICRF heating. We also propose to document the changes to screening from inner-wall puffs when going from LSN to DN, an issue of importance for inner-wall ICRF and LH launch, i.e. ADX relevant.

2. **Background**

While ICRF-heating has been an efficient and reliable heating method on C-Mod, there are many areas in the complex interaction between the launched waves and the plasma that are not understood. Plasmas with strong ICRF heating and high-Z PFCs have often suffered from increased core impurity concentrations that result from the ICRF. Enhanced sputtering due to large ICRF-induced plasma potentials on open field-lines has long been thought of as the primary cause for the increased impurity concentrations. However, there is strong circumstantial evidence that this is not the entire story. Observations of 2D ICRF-induced electric fields [Cziegler 2010] and theoretical considerations of convective cells connected...
with such fields have raised the possibility that transport modifications that increase the penetration of impurities may also be playing an important, or even dominant, role.

Also at play in the impurity contamination problem is the hypothesis that inward impurity transport from interchange turbulence is a leading mechanism for molybdenum, released for the outboard limiters and RF limiter tiles, to penetrate into C-Mod discharges. If interchange turbulence is dominant in impurity penetration, then we have very strong justification for pursuing inner-wall ICRF launch on ADX. That is why it is important to do inner-wall vs. outer-wall N\textsubscript{2} screening tests in the presence of ICRF heating as part of this MP. Of particular interest in this regard is the change in screening from inner-wall impurities between LSN and DN configurations.

3. **Approach**

Our approach is to perform experiments analogous to those done by McCracken, et al. in 1997 [McCracken 1997], except that these will be done with the addition of ICRF and done in order to observe changes in penetration with and without RF. We must stay in L-mode in order that the core impurity confinement time is short and reproducible. The McCracken result for Ohmic L-modes is shown in Figure 1. Using the NINJA capillaries we will puff known and approximately equal amounts of N\textsubscript{2} from different locations, comparing the penetration at 0, 0.5, and 1.2MW of ICRF-power waveform. N\textsubscript{2} is chosen because it is non-recycling and we have extensive experience with it. We will puff from capillaries at inner-wall midplane, at two outboard midplane locations with different magnetic connections to the antennas, and at the top shelf of the outer divertor. The magnetic connection from these locations to the different antennas is indicated schematically in Fig. 2, and we wish to test whether or not magnetic connection matters in the screening. Certainly the ICRF-induced potentials (and, by extension, the induced convective cells) depend on this mapping, as was demonstrated by Cziegler, et al.
[Cziegler 2010], although Ochoukov, et al. [Ochoukov 2014] showed that RF-induced potentials exist even without magnetic connection to the antennas. The amount of nitrogen that penetrates the “core” will be monitored using the emission of the H-like and He-like N lines, as measured by the XEUS spectrometer. We will compare the “core” N level as a function of puff location and as a function of antenna (FA-J vs TA-D&E) at the same power level and single-pass absorption. We will use McCracken’s definition of the penetration factor $P_{NR} = N_{imp}/T_{imp}(s)$ to characterize the changes in the penetration of the puffed nitrogen, where $N_{imp}$ will be measured by core spectroscopy and $T_{imp}$ (the total impurity influx) is measured using calibrated NINJA puffs.

Because the NINJA is being used with $N_2$, the GPI is not able to measure the induced potentials at its viewing location. We will use the mirror Langmuir probe (MLP) scanning through the far-SOL for that. Indeed, the MLP has recently measured ICRF-induced potentials in the far-SOL. As seen in Fig. 2, it samples the middle part of the FA J-antenna (where the potentials are expected to be small [Garrett]) and the top part of the D-antenna (where the potentials are expected to be larger) at $q_{95}>5.1$, but misses the D and E antennas at smaller $q_{95}$. We will monitor the Molybdenum and Boron source rates at the antennas and at other locations where we have coverage with the Chromex. The core Mo will be monitored using LoWEUS. We will keep track of the core impurity confinement time using LBO of CaF$_2$.

Another part of this MP is to elucidate one aspect of the physics of the ICRF-induced potentials. A number of mechanisms have been proposed to explain the “anomalous” penetration depth of the ICRF-induced DC potential structures into the plasma. The most likely candidates depend on the connection length from the RF source to ends of the open field-line on which the potentials are induced. We propose to test the $L_{||}$ dependence by using outboard GPI (with a NINJA He puff!) to measure the RF potentials as the plasma is dynamically changed from diverted to inner-wall limited with a constant outer gap, i.e. the inner gap goes to 0 while the outer gap is held fixed.

4. Resources
As required to be similar to 1140808030, but at 0.8 MA and NL04=1.1x10$^{20}$ m$^{-2}$ to stay below the H-mode power threshold:

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field:** 5.4 T
- **Plasma Current:** 0.8 MA
- **Working Gas Species:** D$_2$
- **Density:** NL04=1.1x10$^{20}$
- **Boronization Requested:** no
- **Equilibrium configuration (if possible, refer to database equilibria):** LSN as in 1140808030, but 0.8 MA, for some shots go to DN
4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: 0.5 and 1.2 MW, constant for 0.6 s duration, dipole phasing, from J and separately from D+E
LHCD Power, pulse length, phasing: none
Pellet Injection (species): None
Impurity blow-off injection: yes
Diagnostic Neutral Beam: Special gas puffing: NINJA with varying amounts of N2 in the C-port plenum and 8 PSI D2 in the F-port plenum for CXRS No Ar minimal Ne, requested for some shots
Cryopump: no
Non-axisymmetric Coils (Connections, Current): Standard compensation
Other:

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

Critical diagnostics: XEUS, LoWEUS, Chromex, MLP, GPI
Desired diagnostics: TS, ETS, ECE, HiREX

5. Experimental Plan
5.1 Run sequence Plan
2 run days

5.2 Shot sequence plan

We plan to use the following NINJA capillaries:
“Cap 1” at AB limiter midplane (“ABLim”)
“Cap 2” at G port midplane (“02”)
“Cap 3” at divertor shelf at K port (“Kdiv”)
“Cap 4” at Innerwall B port midplane (“B16-001”)

Phase 0: perform NINJA calibrations into empty vessel on a maintenance day to find nitrogen plenum pressures that we anticipate will be needed (using the McCracken results as a guide). Take particular care to find the nitrogen plenum pressures at which equal flow rates are obtained from “Cap 1” at the AB limiter midplane and “Cap 2” at G port
midplane, since the penetration factor difference between those two locations will be the most sensitive test of the importance of the magnetic connection to the different antennas.

Three half days are requested in order to digest the results and not to foul the plasma with too much $N_2$ as the day progresses.

1\textsuperscript{st} half day
shots 1-4: Load 1140806030, but with $I_p=0.8\ \text{MA}$ and $NL04=1.1\times10^{20}$. Establish constant ICRF power at 0.5 MW for 0.5 s on J, followed by the same for D+E. Put the MLP into the far-SOL during each ICRF pulse.

shots 5-8: repeat above, but first with J antenna alone (0.9 to 1.5 s), puffing through “Cap 1” and on the subsequent shot with D+E only. Repeat, but puffing through “Cap 2”. (Note that both are midplane capillaries). LBO near the end of the RF pulse. Put the MLP into the SOL before and during the RF.

shots 9-12: repeat above, but first with 1.2 MW from J antenna alone (0.9 to 1.5 s), puffing through “Cap 1” and on the subsequent shot with 1.2 MW from D+E only. Repeat, but puffing through “Cap 2”. (Note that both are midplane capillaries). LBO near the end of the RF pulse. Put the MLP into the SOL before and during the RF.

shots 13-15: repeat above, first with J antenna alone, and then with D+E antennas only, puffing through “Cap 3” (on the divertor shelf at K port). LBO near the end of the RF pulse. Put the MLP into the SOL before and during the RF.

2\textsuperscript{nd} half day
shots 1-5: Load appropriate shot from the 1\textsuperscript{st} half day’s run. Repeat the 0.5 MW ICRF power pulse, first with J antenna alone, and then with D+E antennas only, puffing through “Cap 4” (inner-wall at B). LBO near the end of the RF pulse. Put the MLP into the SOL before and during the RF.

shots 6-9: repeat above, first with J antenna alone, and then with D+E antennas only, puffing through “Cap 4” (inner-wall at B) at the 1.2 MW power level. LBO near the end of the RF pulse. Put the MLP into the SOL before and during the RF.

shots 12-15: repeat above, i.e. puffing through “Cap 4” (inner-wall at B), but \textit{in DN configuration}

3\textsuperscript{rd} half day
shots 1-7: Load appropriate shot from previous half-day runs. Use He in the NINJA plenum so that GPI can monitor the RF-induced potentials along with the MLP. Use the 1.2 MW pulse 1\textsuperscript{st} from J antenna, then on different shots from D+E. Measure the RF potentials as the plasma is dynamically changed from diverted to inner-wall limited with a constant outer gap, i.e. the inner gap goes to 0 while the outer gap is held fixed at $\sim 2$ cm. Make sure that the LFS flux surface shape is up-down symmetric with respect to the J and D antenna cross-sections.
shots 8-15: Fill the NINJA plenum with N$_2$ and repeat penetration experiments with an outer midplane capillary puff, but add Ne-seeding (via B-side lower) to see if the Ne seeding changes the N$_2$ penetration. (This is of interest because Ne-seeding was seen to modify the induced potentials.) Also repeat the penetration experiments at any locations that were not completed on the earlier run days or require additional measurements.

6. **Anticipated Results**
This work will be the basis for a 2014 APS-DPP Invited talk (Y. Lin) and publication. It is extremely important that we understand the still-not-understood issues regarding impurities and ICRF heating.