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

We would like to understand whether variations in the boronization method can be more effective (localization, glow vs ECDC, wall temperature...)

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

Boronization of the machine has proven very effective in minimizing Mo levels in the core and achieving the best confinement plasmas. However, the effect can decay fairly quickly. Naturally, we would like to have a method of replenishing the boron layer in as short a time as possible. This will minimize the B put in the machine and the time between usable shots.

Efforts have been made to put B dust into discharges as a means of in-shot boronization. No obvious positive effects were recorded for B layers and reduction of Mo levels. We have also tried limiting the boronization to certain areas of the machine by setting the magnetic field sweep for our standard, multiple-hour boronization. The results of this are difficult to assess as a large fraction of a run day must be used to condition up the RF and evaluate how long the boron layers last.

Most recently we have tried between shot boronization (1050705). This has been the most successful as a method of quickly evaluating the effectiveness of the length of time used to boronized between shots. The results show, with an ECDC resonance scan from 0.5 to 1.03 m, that as the length of boronization increased the sustained neutron rate increased (Figure 1) and the rate of radiation increase during the initial H-Mode part of the discharge decreased (see Figure 2). 30 minutes of between-shot boronization was the most effective in enhancing plasma performance. There was some hint that the location
of the boronization was important as the one shot with a different boronization sweep before it (0.44 – 0.8m) resulted in a smaller enhancement of plasma performance.

2. 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.

The approach is to continue to use between-shot ECDC-based boronization (at 5 mTorr) to evaluate the effectiveness of the method but concentrate on the boronization locations and minimizing fizzles that occurred. So various scan ranges will be compared. The vacuum vessel is shown in figure 3 along with labels A-G identifying the locations of various components that will be covered by the various scan ranges. The inner wall (A) is located at 44 cm. The largest major radius edge of the inner divertor (B) is at 46.8 cm. The smallest major radius edge of the outer divertor, or outer divertor nose (C) is at 61.2 cm. The largest major radius location on the outer divertor (D) is at 75.6 cm. The smallest/largest major radius of the outer limiter tiles (E/F) are 81.8 (90.5) cm. Finally, the outer wall (G) is at 103.7 cm. A scan range of 10 cm would allow us to boronized the inner divertor independent of the outer divertor since those points are ~ 14 cm apart (only for the resonance – the plasma always drifts outward from the resonance). There is some structure to the ECDC plasma in the region of the resonance [1] (e.g. Ti rises 5 cm outside the resonance). This would argue for overlapping scans (shift every scan by 5 cm from the previous one).

To narrow the region of the 10 cm wide scans and make a connection with the results of 1050705 we will start with 2 wider scans than advocated above (25 cm range, one starting at 45 cm, the second starting at 65 cm). 10 cm wide scans will then be started over the 25 cm region identified as the best. We will work from the outer edge of the 25 cm region inward to minimize the possibility that the outward drifting ECDC plasma is boronizing outside our 10 cm range. If we followed this logic and the range needed (e.g. 65 – 90 cm for the inner edge of the scan), we would need 6 different 10 cm scan locations. We might be able to skip such locations as the middle of the outer divertor shelf.

After the between shot boronization we will take at least 1 shot to evaluate the boronization effect and whether any residual effects are there. The experience of 1050705 was that at most we needed to wait 2 shots. But we must be prepared for success, and waiting longer.

Once the optimal radial scan location is identified, it would be useful to vary other ECDC characteristics – pressure (lowering it in steps to 0.5 mT), and duration of the boronization (shortening to 10 minutes or less if the efficiency is good).

We also would like to evaluate the effectiveness of glow discharge for application of boronization. This carries the additional risk of coating windows and so will have to be approached more cautiously. We will need spectroscopic measurements through windows and off of mirrors of identical shots pre- and post- glow boronization. Ideally, we will also monitor the glow characteristics with cameras and Langmuir probes.

Since the glow effectively fills the chamber we will only scan glow characteristics such as pressure, voltage, and duration. We will evaluate the effectiveness in the same way as with ECDC – with tokamak discharges. Start with 5 mTorr pressure, 1A and 400 V. Raise the pressure in steps to 50 mTorr.
3. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field:** 5.3 Tesla (normal direction)
- **Plasma Current:** 1.05 MA (normal direction)
- **Working Gas Species:** D2
- **Density:** NL04 from $1.0 \times 10^{20}$ m$^{-2}$
- **Equilibrium configuration:** start from 10507050XX

4.2 Auxiliary Systems

- **RF Power, pulse length, phasing:** ~3 MW, use longer pulses than on 1050705, to wear off the boron faster in a single pulse; ~1 second RF pulse should be possible. We would prefer all sources in the 80 MHz range so that the highest power can be injected and connection to all other MP417 and 1050705 data can be made.

  - **Pellet Injection (species):** none
  - **Impurity blow-off injection:** none
  - **Diagnostic Neutral Beam:** none
  - **Special gas puffing:** Non-axisymmetric Coils (Connections, Current); compensation if needed to avoid locked-modes

  - **Other:** boronization between shots using ECDC and glow. NINJA filled to 12 PSI for measurement of boron density. ECDC and glow boronizations at 5 mT to begin with.

4.3 Diagnostics

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

Scanning probes (FSP, ASP, ISP) for analysis of changes in the SOL if any. Bolometric measurements of radiated power, spectroscopy measurements of core Mo (McPherson), core and pedestal diagnostics (ECE, Thomson, PCI,...). We need a measure of the boron density in the core (Chromex and GPI at inner wall).

For glow evaluation: Scanning probes if possible to monitor plasma characteristics. Some other measurements are needed to ascertain effects on mirrors and windows due to glow (as well as the general glow discharge characteristics). This will include the current drawn by the glow paddles, spectroscopic measurements (Chromex monitoring of the $D_\beta$ intensity of the GPI puff used for boron density measurements, diode measurements) of ‘identical’ discharges before and after, Langmuir probe measurements of the glow plasma characteristics...

4. Experimental Plan

*Both sections must be filled in.*

5.1 Run sequence Plan

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Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.

At least one run day to explore various boronization locations with ECDC resonance scans.
Minimum of another 1/2 day to evaluate glow boronization.

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.

ECDC between shot boronization:
Step a - Boronize twice with scan widths of 25 cm (inner edge 45 and 70 cm) to identify the best region to concentrate our 10 cm wide scans. Systematically vary the inner edge of the 10 cm ECDC scan width from the largest major radius edge of the better region in steps of 5 cm. We will need a minimum of 1 post-boronization shot to evaluate the effectiveness at each location. If the effect is not gone after one shot then more shots are run till it is gone before moving on to the next radial location. We will use 15 minutes/boronization as this should lead to a significant effect on the neutron levels based on 1050705.
Step b - Once done, return to the most effective location. Vary the pressure during the boronization below the usual value to 1 mTorr and 0.5 mTorr. If there is an effect explore it. When this is done reduce the length of boronizations.

Glow-discharge boronization:
Step a – vary pressure to optimize the boronization (length 20 minutes, pressure 5 mTorr to start). Again, we will need at least one shot to evaluate it. Monitor the plasma created (its extent and possibly plasma parameters with probes). Monitor the effect on windows and mirrors. Vary the pressure up from 5 mTorr to 50 mTorr in steps of 10 mTorr.

Step b – vary the boronization period to 10 and 30 minutes at optimal pressure.

5. 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.

We should have a better idea of how to localize the boronization for its most efficient application from ECDC. This will be useful for everyday operation and contribute to talks at the upcoming APS meeting (Invited, oral, posters). The evaluation of glow boronization will potentially give us a better boronization – lasting longer or some other unanticipated effect.

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

Figure 1:

![Graph showing the relationship between Total Neutrons/10^13 (0.7 < t < 1.2 s) and Length of boronization prior to shot (minutes).]
Figure 2:
Figure 3: Vessel cross-section with the edges of important surfaces labeled by the letters A-G. The inner wall (A) is located at 44 cm. The largest major radius edge of the inner divertor (B) is at 46.8 cm. The smallest major radius edge of the outer divertor, or outer divertor nose (C) is at 61.2 cm. The largest major radius location on the outer divertor (D) is at 75.6 cm. The smallest/largest major radius of the outer limiter tiles (E/F) are 81.8 (90.5) cm. Finally, the outer wall (G) is at 103.7 cm.