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

The purpose of these experiments is to commission the newly installed upper-divertor cryopump. The goal is to develop a ‘turn-key’ system that can routinely support C-Mod physics experiments. This development requires effort in two areas: (1) characterize the behavior of the pumping system, including gas throughput benchmarks, and demonstrate a control scheme that interfaces the cool-down/regeneration cycle of the pump with the C-Mod shot cycle and (2) explore and develop operational scenarios (various magnetic equilibria, gas programming/feedback) for density control in discharges that are of interest for physics experiments. Completion of these goals would satisfy a C-Mod non-JOULE milestone for FY 2007: “Investigate particle and density control with the new upper divertor cryopump (September 30, 2007)”.

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

The upper divertor cryopump consists of a full toroidal loop (25.4 mm diameter inconel pipe with 0.25 mm wall) that contains helium liquid and vapor (see Fig. 1). The pipe acts as a vapor separator; it is divided internally into a series of compartments and is only partially filled with helium, allowing helium to boil at atmospheric pressure (4.6 K) with the resulting vapor existing via an exhaust tube. A superconducting level meter (‘dip-stick’) is inserted into the exhaust tube, indicating the height of helium liquid in the pipe. The helium pipe is surrounded by nitrogen-cooled and room-temperature surfaces, shielding the pipe from ambient radiation, which includes room-temperature blackbody radiation and plasma light. Molybdenum tiles protect the cryogenic structures from plasma contact. These tiles are arranged to provide an array of 30 ‘pumping slots’. A portion of the neutral particle flux that is generated at the molybdenum tiles surfaces undergoes charge-exchange collisions with the plasma and scatters into the ‘gas box’ that
surrounds the cryogenic tubes. By varying the mapping of the outer magnetic flux surfaces onto the tile surfaces, dynamic control of the gas-pumping throughput can be achieved – an effect that is to be explored in detail in this MP.

A full-scale prototype of the C-Mod pump has been tested in a dedicated vacuum vessel. Stainless steel baffles were used to simulate the tile/baffle geometry. This system demonstrated a pumping speed of 10,000 liters/s (D₂) and 12,000 liters/s (H₂) for room temperature gases. These gas-pumping benchmarks should be attainable for the installed C-Mod pump.

Figure 1 – Upper divertor cryopump system in C-Mod

Scenarios for cool-down, pumping and regeneration were also tested using the full-scale prototype. Results from these experiments provide guidance for the task of interfacing the actual C-Mod pump with the plasma shot cycle. Figure 2 shows an operational scenario that was developed, handling a series of 4 successive C-Mod ‘plasma shots’:

1. Cool down to LN₂ temperature before C-Mod run. This requires about 1 hour.
2. Start LHe flow (2 psi) just prior to a C-Mod shot (~7 minutes for first cool-down, ~2 minutes for subsequent).
3. The cryopump is ready for a plasma shot on indication of a LHe level on the 'dip stick'.
4. Take plasma shot while maintaining LHe flow.
5. Right after shot, stop LHe flow and begin flow of warm He gas at 10 cfh.
6. Regeneration is completed after about 4 minutes of He gas flow.

Proceed to step 2 for the next C-Mod shot.

Figure 2 – Simulation of 4 successive ‘C-Mod shots’ on the prototype test stand

A plan for the cryopump control system is shown in Fig. 3. (Note that this plan is subject to change as we develop experience with the system.) Initially, valves and sensors will be monitored and operated on an individual basis in order to control the state of the cryogenic system. Later, “state buttons” will be developed, allowing the cryopump operator to select the desired state such as “Cooldown to LN2” or “Regenerate”, for example. Finally, we plan to evolve the system towards a fully-integrated one, in which the C-Mod states of ‘INIT’, ‘CHECK’, ‘PULSE’, and ‘RECOOL’ will control the cryopump states semi-automatically.

In order to attain and/or transition to each of the cryopump states, a specific arrangement of valve settings and sensor readings must be attained. Table 1 shows more detailed information about the system settings and dependences that are associated with
attaining and maintaining each state. Again, this control system plan is subject to change and will undoubtedly evolve as we gain practical experience.

Figure 3 – Cryopump control system and operational states
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.

The tasks for cryopump commissioning break down naturally into five phases.

---

**Table 1 – Cryopump valve/sensor readings associated with each operational state**

<table>
<thead>
<tr>
<th>Operational State</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Helium Purge</strong></td>
<td>Rough-out Helium lines: Helium purge valve closed</td>
</tr>
<tr>
<td></td>
<td>Helium exhaust valve closed</td>
</tr>
<tr>
<td></td>
<td>Roughing pump valve open, roughing pump on</td>
</tr>
<tr>
<td></td>
<td>Wait until He exhaust pressure below threshold</td>
</tr>
<tr>
<td></td>
<td>Roughing pump valve closed</td>
</tr>
<tr>
<td></td>
<td>Helium purge valve open</td>
</tr>
<tr>
<td></td>
<td>Repeat 3 times</td>
</tr>
<tr>
<td></td>
<td>End with: Pressurizer off</td>
</tr>
<tr>
<td></td>
<td>LHe valve closed</td>
</tr>
<tr>
<td></td>
<td>Helium dewar vent valve open</td>
</tr>
<tr>
<td></td>
<td>Helium exhaust valve open</td>
</tr>
<tr>
<td></td>
<td>Roughing pump valve closed</td>
</tr>
<tr>
<td></td>
<td>Roughing pump off</td>
</tr>
<tr>
<td></td>
<td>N2 purge valve closed</td>
</tr>
<tr>
<td></td>
<td>LHe flow valve closed</td>
</tr>
<tr>
<td></td>
<td>If unsuccessful, go to &quot;Shutdown&quot;</td>
</tr>
</tbody>
</table>

| **Warm Standby**  | N2 purge valve open  |
|                   | Pressurizer off  |
|                   | Helium purge valve closed  |
|                   | LHe valve closed  |
|                   | Helium dewar vent valve open  |
|                   | Helium exhaust valve open  |
|                   | Roughing pump valve closed  |
|                   | Roughing pump off  |
|                   | LHe flow valve closed  |
|                   | If unsuccessful, go to "Warm Standby"  |

| **Cooldown to LHe** | LHe must be ready, otherwise go to "Cooldown to LHe"  |
|                     | Helium dewar vent valve closed  |
|                     | Pressurizer on  |
|                     | LHe valve open  |
|                     | Helium purge valve closed  |
|                     | Roughing pump valve closed  |
|                     | Roughing pump off  |
|                     | N2 purge valve closed  |
|                     | LHe flow valve open  |
|                     | If unsuccessful, go to "Cooldown to LHe"  |

| **LHe Ready** | LHe ready when LHe sensed at dip-stick (75-90% reading)  |
|               | and flow rate at helium exhaust is at some level (TBD)  |

| **C-Mod enters "INIT"**  |  |
| **Pulse** | Maintain "LHe Ready" state during pulse  |

| **C-Mod enters "RECOOL"**  |  |
| **Regeneration** | Pressurizer off  |
|                     | LHe valve closed  |
|                     | Helium dewar vent valve open  |
|                     | Helium exhaust valve open  |
|                     | Roughing pump valve closed  |
|                     | Roughing pump off  |
|                     | N2 purge valve closed  |
|                     | LHe flow valve open  |
|                     | Continue helium purge for ~5 min (time TBD)  |
|                     | Then go to "Cooldown to LHe"  |

| **Shutdown** | Pressurizer off  |
|              | Helium purge valve closed  |
|              | LHe valve closed  |
|              | Helium dewar vent valve open  |
|              | Helium exhaust valve closed  |
|              | Roughing pump valve closed  |
|              | Roughing pump off  |
|              | N2 purge valve closed  |
|              | LHe flow valve closed  |

| **LN2 Ready** | LN2 ready when LN2 sensor indicates liquid at outlet for a minimum time (TBD, something like 0.5 hour)  |

**System Ready Monitor**

- LHe dewar level ok
- LHe bottle pressure ok
- LN2 purge pressure ok
- LN2 pressure ok
- No valves faulted
- If not System Ready, then change present state to "Shutdown"
Phase I – System Assembly and Checkout
At the time of this writing, many components for the cryopump system (transfer lines and valves, pressure transducers, dewar carriage, PLC crate,...) are still being assembled. Thus, the first task is to get these components to work together as a system via remote control. This activity will be done ‘off-line’ and does not require C-Mod run time. The first cool-down of the cryogenic system to liquid nitrogen temperature will be performed manually, without PLC control. However, it is not practical (nor safe) to operate the cryogenic system for particle pumping in a manual mode. Remote control capability is required for both LN\(_2\) and LHe systems.

Phase II – Cool-down/Regeneration and Pumping Speed Benchmarks
Once remote PLC control of the system is established, we will begin controlled cool-down cycles (LN\(_2\) and LHe systems). Deuterium and hydrogen gas will be puffed into the torus via the NINJA capillary gas system. The system pumping speed will be determined by comparing the response of the torus pressures (using MKS baratron gauges) with the cryopump warm and with it at operating temperature. The gate valves for the C-Mod turbopumps will be closed to facilitate the comparison. These tests do not require C-Mod operation. We will also simulate a series of C-Mod shots consisting of cool-down, NINJA gas puff (“plasma shot”) and regeneration.

Phase III – Operation during C-Mod Discharge
From the experience gained above, we will be ready to operate the pump during a plasma shot. The first discharges should be plain-vanilla, ohmic, LSN shots with standard feedback control of the plasma density. Then we will try some standard USN discharges, which should exhibit strong pumping. We will operate with the turbopump gate-valves closed so that we can assess the amount of gas that was pumped during a subsequent regeneration cycle. This will become the standard operating scenario for all discharges that employ the cryopump.

Phase IV – Effect of secondary separatrix on pumping throughput
Ohmic discharges with different upper/lower X-point balance will be explored to determine the gas throughput and the degree of density control. Stepped changes in the EFIT SSEP parameter will also be programmed to facilitate the assessment.

Phase V – Density control in H-mode discharges
Finally, RF-heated H-mode discharges will be explored. Again, upper X-pt programming will be tested as a density-control knob before and after the L-H transition.

4. Resources
4.1 Machine and Plasma Parameters
Give values or range for:

Toroidal Field: 5.4 tesla (normal direction)
Plasma Current: 1.0 MA (normal direction)
Working Gas Species: Deuterium
Density: We will explore NL04 targets of $1.0 \times 10^{20} \text{ m}^{-2}$ and lower.

Equilibrium configuration (if possible, refer to database equilibria):
See detailed shot plan. We will run LSN, USN and near-DN equilibria.

4.2 Auxiliary Systems

RF Power, pulse length, phasing: 2 MW heating for 0.5 s during flat-top
Pellet Injection (species): none
Impurity blow-off injection: none
Diagnostic Neutral Beam: none
Upper Divertor Cryopump: Ready for operation
Special gas puffing: NINJA gas-puffing system
Non-axisymmetric Coils (Connections, Current): standard locked-mode compensation
Other: Gate valves closed during all shots
A well-conditioned, boronized machine is required for Run#3 (H-mode run).

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

In addition to the sensors associated with the cryopump control system, we will be paying close attention to a number of edge plasma diagnostics: in-situ Penning gauges, MKS baratron gauges and embedded divertor probes. We require only a minimal set of core diagnostics, most critically NL04 from TCI. On some shots we will want to get SOL profile information from the scanning probes (ASP, FSP, WASP).

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.

While Phase II experiments do not require plasma discharges, they will require coordination among engineers, technicians, and scientists. A ‘No Power Run’ plan is included below for these experiments, which could span a couple of days, depending on how things go.

Phases III, IV and V will require dedicated run days. Tentatively, 3 days should be allotted.

It would be advantageous to use the C-Mod startup phase to run a few of the LSN, USN and near-balanced DN equilibria that are called out in the Phase III and IV run plans. We can record neutral pressures in the upper chamber, fluxes to the upper divertor plate and fine-tune the flux surface shapes and SSEP control.
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.

No Power Run—Cool-down/Regeneration and Pumping Speed Benchmarks

Once we have remote control capability of the cryogenic system, we can plan on a
day for the following tests:

A. NINJA gas flow calibration.

Start with cryopump at room temperature. Based on previous shots (e.g.,
1021107002), the gas puff rate through a NINJA capillary can be up to 100 torr-liters/s
with a fill pressure of 35 psi. Try filling NINJA capillary system to 25 psi D_2. Close gate
valves, puff from inner wall capillary for about 2 seconds and record pressure rise in
vessel, then open gate valves. Adjust NINJA plenum pressure and increase puff duration
to attain a flow rate of approximately 50 torr-liters/s for 5 seconds. Repeat for H_2 gas to
determine the required plenum pressure.

B. Cool-down to LN_2

Flow LN_2 for approximately one hour. (Detailed information on the cryopump
controls for this state and others that are called out in this ‘shot plan’ is included in Table
1.)

C. Cool-down to LHe

Flow LHe until ‘dip-stick’ level sensor indicates 70% reading or greater.

D. H_2 Pumping speed benchmark shots

With gate-valves closed, take a C-Mod no-plasma test shot with NINJA gas puff
programmed as in step “A” above (H_2 gas). Record chamber pressure (G-side MKS
gauge) and cryopump pressure (F-cryo MKS gauge). System pumping speed will be
computed from NINJA flow rate divided by G-side MKS gauge reading.

E. Regeneration

While keeping the gate-valves closed, regenerate the pump. This is done by
stopping the LHe flow and flowing warm He gas at about 10 cfh. Monitor and record
chamber pressure with E-bottom MKS. (For times longer than 10 seconds, this reading
will need to be done manually. The digital readout is in the cell). Then open the gate-
valves to exhaust the regenerated material.

Repeat steps C, D and E a few times.

F. Repeat step D with cryopump at LN_2 temperature (i.e., not pumping).

This will give us a flow calibration for the NINJA puff rate.

G. D_2 Pumping speed benchmark shots
Repeat steps C, D, E and F for D$_2$ gas using the NINJA setup determined in step “A”.

H. C-Mod shot-cycle simulation

From the experience gained above, we will perform steps C, D, E in a rapid sequence that mimics a C-Mod shot cycle. The idea is to reproduce the prototype test results in Fig. 2. First, cool-down to LHe. With gate-valves closed, take a C-Mod no-plasma test shot with NINJA gas puff programmed as in step “A” for D$_2$ gas. Immediately after the shot, initiate a regeneration cycle. Chamber pressures from E-top, E-bottom and G-side MKS gauges are recorded by slow CAMAC units for 10 minutes after PULSE and can be used to study the regeneration event. Open gate-valves after this time. Repeat the shot-cycle simulation a number of times.

From these tests, we can address the following questions: If the LHe flow is initiated at INIT, is the pump ready at PULSE? Perhaps a check can be implemented during CHECK to see if the cryopump is indeed ready for pumping (i.e., LHe level detected, etc.). Can RECOOL be used to initiate a regeneration cycle? How long does it take to regenerate and pump-out the recovered gases?

C-Mod Run #1 – First operation of cryopump during C-Mod discharges

Having completed the C-Mod shot-cycle simulation, we will be ready to operate the pump in C-Mod discharges. The primary focus of these experiments should be on learning how the cryopump control systems behave in the environment of a C-Mod discharge and getting the pump to operate seamlessly within the standard C-Mod shot cycle. A secondary focus (albeit, a more exciting one) will be on how the cryopump affects the programmed plasma density and gas-valve feedback response. Nevertheless, we should be prepared to have multiple cell entries to fix problems as they might arise with the cryogenic systems/controls. Discharges during the start-up phase of C-Mod would therefore be ideal for this purpose. However, at the time of this writing, it has become clear that the cryogenic feed lines and control systems will not be ready in time.

A. LSN Discharges – Moderate density, minimal pumping

Start with a standard ohmic L-mode LSN discharge. This should be a 0.8 MA, 5.4 tesla discharge with nominal density of NL04 ~ 0.8x10$^{20}$ m$^{-2}$. Shot#1060324005 would be a good starting point (0.8 MA, 5.4 tesla, NL04 ~ 0.6 x10$^{20}$ m$^{-2}$, gaps optimized for scanning probes), reprogramming the density to NL04 ~ 0.8 x10$^{20}$ m$^{-2}$. These discharges tend to have about 20 mtorr of D$_2$ in the lower divertor but less than ~0.2 mtorr in the upper divertor. Thus, we should not expect much in the way of particle removal; the shot should proceed normally without any special gas programming. However, this will be the first time we will be attempting plasma breakdown with a 10,000 liter/s D$_2$ pump operating in the C-Mod vacuum chamber. We may need to fiddle a bit with the gas programming. We will operate with the gate-valves closed (time span of closure TBD) so that we can do full particle accounting on every shot. See Fig. 4 for how this LSN equilibrium fits with the new upper cryopump hardware.
Shot Sequence:
Prior to run, cooldown cryopump to LN$_2$
Reload 1060324005 and reprogram NL04 $\sim 0.8 \times 10^{20}$ m$^{-2}$.

**Shots 1-3** – reference discharges with cryopump not pumping. Optimize scanning probes.
Record neutral pressures in cryopump gas-box.

Begin particle pumping during discharge

**Shots 4-8** – get plasma with cryopump operating. Demonstrate cryopump cool-down to LHe, pumping and regeneration cycles.

**B. USN Discharges – Moderate density, maximal pumping**

Then switch to segment#3, which is an USN discharge (last run as shot#1060324002), and reprogram the density to NL04 $\sim 0.8 \times 10^{20}$ m$^{-2}$. As seen in Fig. 4, the upper strikepoint of this equilibrium is at an optimum location, i.e. on the toroidally continuous row of tiles just to the left of the pumping slot. Without pumping, this discharge would typically have $\sim 20$ mtorr of D$_2$ in the upper divertor. Thus, we should expect very strong particle removal with the cryopump on. Gas input flow rates on the order of 100 torr-liter/s might be required to achieve and maintain a target density of NL04 $\sim 0.8 \times 10^{20}$ m$^{-2}$. In preparation, the NINJA system should be ready with 35 PSI of D$_2$ in its plenum.

Shot Sequence:
Cryopump at LN$_2$ temperature (not pumping)

Turn on segment #3 (USN) and reprogram NL04 $\sim 0.8 \times 10^{20}$ m$^{-2}$.


**Shots 12-16** – cryopump cool-down to LHe, pumping/regeneration cycle each shot. Turn on NINJA puff as necessary to raise and possibly maintain the target plasma density.

**C. USN Discharges – Pumping efficiency at low density**

As the plasma density is lowered, the particle flux to the upper divertor plate falls, the pressure in the upper divertor also falls and the cryopump is less effective in removing particles (although there is also less particle inventory to remove). Here we want to examine the particle pumping rate as the discharge density is systematically lowered. We also want to determine how far down we can safely push NL04 with the cryopump. The idea is to create a low-density but non-slide-away discharge early in time and then reduce NL04 as much as possible with the cryopump.

Shot Sequence:
Cryopump operating in a pump/regeneration cycle for most shots. We will run a few shots with the cryopump at LN$_2$ temperature (not pumping) to assess the neutral pressures in the cryopump gas-box.

**Shots 17-25** – With a combination of reduced density programming, short early gas puffs and/or reduced or eliminated NINJA puffing, explore the pump-out behavior of successively lower density discharges.

![Figure 5 – LSN and USN equilibria for first operation of cryopump](image)

**C-Mod Run #2 – Effect of magnetic topology on pumping throughput**

Magnetic x-point topology is expected to be an important knob for dynamic control of the gas throughput to the cryopump. In Run #1 we will have explored the extremes: LSN and USN. Here we are interested in exploring finer variations in the balance between upper and lower x-points. Specifically, we are interested in using the EFIT parameter, SSEP, as a control knob, which is the distance between the primary and secondary separatrix mapped to the outer midplane. Feedback control of SSEP has been successfully used during previous “cryopump scoping” experiments, such as during the
1050303 run day (see Fig. 6). A good starting point for the investigation is shot #1050303023 (1.0 MA, 5.3 tesla, NL04 ~ 0.75 \times 10^{20} \text{ m}^{-2}), which had SSEP programming set at -5 mm. (The resulting SSEP was -3.5 mm.) Discharges with SSEP near zero are expected to exhibit strong pumping. Therefore, based on the experience gained during Run #1, we may need to set up the NINJA system for additional gas fuelling. Again, we will operate with the gate-valves closed so that we can do full particle accounting on every shot. We desire ohmic L-mode discharges for this run.

A. Unbalanced DN discharges with SSEP control

Reload from shot #1050303023. Set $B_T$ to 5.4 tesla, program SSEP to -10 mm, and NL04 ~ 0.8 \times 10^{20} \text{ m}^{-2}. Setup the NINJA system with up to 35 PSI of D$_2$ in its plenum (precise setup is TBD).

Shot Sequence:
- Cryopump operating in a pump/regeneration cycle for most shots. Again, we will run a few shots with the cryopump at LN$_2$ temperature (not pumping) to assess the neutral pressures in the cryopump gas-box.
- SSEP = -10 mm.

**Shots 1-5** – Tune up discharge, adjust gaps for scanning probes and add auxiliary fueling from NINJA as necessary to attain programmed density. Record particle pumping.

- SSEP = -5 mm.

**Shots 6-10** – Adjust gaps, add auxiliary fueling as necessary.

- SSEP = -2 mm.

**Shots 11-15** – Adjust gaps, add auxiliary fueling as necessary. Note: if it proves too difficult to maintain the programmed density, we can try programming step changes in SSEP, such as from -10 mm to -2 mm and back (~ 300 ms time scale).

- SSEP = 0 mm.

**Shots 16-20** – Adjust gaps, add auxiliary fueling as necessary. Again, step changes in SSEP may be required

B. Step change in SSEP control

If we have not already done so, we will begin running discharges with a step change in SSEP programming. The idea is to determine the maximum 'pump-out' rate that the cryopump can achieve for unbalance DN discharges (ohmic L-mode). Therefore, for the times when SSEP is changed to a small negative value, the density should also be programmed to be low.

Shot Sequence:
- Cryopump operating in a pump/regeneration cycle for each shot.
- SSEP = -10 mm, then step to 0 mm at 0.7 seconds.

**Shots 21-30** – Run discharges with different starting densities: NL04 = 1.0, 0.8, 0.6, 0.4 \times 10^{20} \text{ m}^{-2}.
Figure 6 – Unbalanced DN equilibria with SSEP variation. Equilibria with SSEP programming of -8 mm (left), -5 mm (center) and 0 mm (right) are shown.

C-Mod Run #3 – Density control in H-mode discharges

From the practical experience gained during Run #2, we should have the tools to explore density control in H-mode discharges. In particular, we are interested in using the cryopump in combination with SSEP control to ‘pump-out’ the discharge just after an H-L transition. We will start with a discharge from Run #2 and apply RF power (2 MW) for at least 0.5 seconds during flat-top. Good quality, long duration H-modes are required, allowing us to follow the pump-out behavior without interruption by back-transitions. Therefore, a well conditioned, boronized machine is required.

Shot Sequence:
- Cryopump operating in a pump/regeneration cycle for each shot (with the possible exception of a few no-pumping reference shots)
- SSEP = -10 mm, stepped to -2 mm at L-H transition

**Shots 1-5** – Tune up discharge, program NL04 = 0.8x10^{20} m^{-2} before L-H, 0.1x10^{20} m^{-2} after.
Shots 6-25 – Explore different L-mode target densities: 1.0, 0.8, 0.6, 0.4 x10\(^{20}\) m\(^{-2}\). Adjust RF power as necessary to achieve L-H transition.

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.

It is likely that a reliable, ‘turn-key’ upper divertor cryopump system for Alcator C-Mod will be an important research tool, facilitating: (1) controlled density target plasmas for advanced tokamak scenarios and lower hybrid current drive experiments, (2) extended physics investigations into low-collisionality regimes, (3) decoupling of H-mode densities from the L-mode target densities, (3) improved access to ELMy H-mode regimes, and (4) puff and pump experiments for impurity entrainment and edge flow modification. Through a combination of strong D\(_2\) fueling and pumping, the cryopump may also be an important tool for conditioning the walls and reducing the plasma’s H/D ratio during the start of a run campaign.

The non-axisymmetric ‘pumping slot’ design of the C-Mod divertor/cryopump is unique among the world’s tokamaks and may demonstrate an advantage with regard to strike point insensitivity. In addition, the idea of using separate, optimized divertors to handle the high SOL heat fluxes (lower vertical-plate divertor) and to provide particle exhaust (upper pumping-slot divertor) is novel; it is an outgrowth of C-Mod’s research on edge plasma transport. Therefore, experiments that explore and document the performance of the C-Mod divertor cryopump system are not just of practical importance to C-Mod. They will also elucidate plasma transport behaviors in the SOL and will be of broader interest to the boundary layer physics community.

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


March 22, 2007