C-Mod 2006 Campaign Status
Presented by:
Stephen M. Wolfe

Alcator C-Mod Quarterly Review
MIT Plasma Science & Fusion Center
Cambridge, MA
Aug 2, 2006
C-Mod JOULE target 14 Weeks of Research Operation in FY2006

- Four weeks accomplished in Fall 2005
- Short up-to-air (pump-down 1/19/2006)
  - Replaced Faraday Screen on J-port ICRF Antenna
  - Re-installed LH Launcher with stainless steel couplers
- Plasma operation resumed in February, 2006
- Ten week (40 day) research campaign planned for Spring/Summer 2006

JOULE Target Accomplished (14.4 weeks) in Third Quarter
FY 2006 Experimental Campaign is now Complete

- 14 Research Weeks (56 days) budgeted
- Four week mini-campaign in 1-Nov through 6-Dec 2005
- Plasma operation resumed after vent Feb 8, 2006
  - Cooling problem on one TF leg (C-right vertical) reduced shot rate
  - Warm-up, repair, and recool took about 3 weeks
- Plasma operations resumed Mar 7, 2006
  - Research operations commenced immediately on re-start of the campaign (LH, ohmic experiments, wall-conditioning experiments)
  - First full boronization overnight April 6, 2006
  - J-port ICRF System operated at 78, 50, 70 MHz during the campaign
- Campaign completed July 28, 2006
  - 16.7 Research weeks
  - 1639 Plasmas
## Run Utilization (Days)

<table>
<thead>
<tr>
<th>Topic/Thrust</th>
<th>Through 3rd Quarter</th>
<th>thru July 28</th>
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<tbody>
<tr>
<td>Transport Physics</td>
<td>12.3</td>
<td>15.3</td>
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<td>Edge/Divertor</td>
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<td>Wall Conditioning</td>
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<td>ICRF Physics &amp; Tech</td>
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<td>MHD</td>
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<td>7.3</td>
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<td>Lower Hybrid</td>
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<tr>
<td>Integrated Scenario</td>
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<td>7.0</td>
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<tr>
<td>Operations/Diagnostics</td>
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<td>2.5</td>
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<tr>
<td><strong>Total Research Days</strong></td>
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<td><strong>66.9</strong></td>
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<td><strong>Startup &amp; Conditioning</strong></td>
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<td><strong>12.6</strong></td>
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<tr>
<td><strong>Total Operating Days</strong></td>
<td><strong>70.1</strong></td>
<td><strong>79.6</strong></td>
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Web Page enabled

An up-to-date online tabulation of cumulative run weeks (suitable for DoE auditor) is available at

http://www.psfc.mit.edu/research/alcator/facility/Operations/FY06_research_table.html
Lower Hybrid Experiment

Ron Parker
Randy Wilson (PPPL)

Quarterly Progress Report

2 August 2006
Numerous technical improvements made, coupled LH power increased to maximum of 900 kW.

Reflection coefficient ~ 20% for 60° phasing, $n_{||} = 1.6$.

Substantial current drive observed, $\sim 1$ MA @ 800 kW, $\bar{n} \sim 3-4 \times 10^{19}$ m$^{-3}$.

Current drive efficiency $\eta = \bar{n}_{20} I(MA) R(m) / P(MW) \sim 0.15-0.2$

Sawtooth stabilization and central electron heating observed.

Indications that $q_0 > 1$ and $l_i \sim 1$.

X-Ray profiles for $n_{||} = 1.6, 2.3$ and $3.1$ in qualitative agreement with expectations; Detailed modeling underway (A. Schmidt).

Parametric decay instability also observed in some discharges (G. Wallace).
The trophy shot – 7/20/06
LH Power can stabilize sawteeth and raise central $Te$

Shot 1060720029, LH Power $\approx$ 750 kW absorbed

Before LH pulse, $t = 0.57$ s

During LH pulse, $t = 1.2$ s
Loop Voltage ~ 0 V at 1 MA, 800 kW and $\bar{n} \sim 4 \times 10^{19}$ m$^{-3}$
Perspective

First experiments with LH have gone well, with a large fraction of current driven at low (for C-Mod) density (~5x10^{19} m^{-3}).

Power limit of the present launcher appears to be near 1 MW delivered to plasma. No indication that grill sets this limit.

Goal of fully non-inductive drive with LHCD and bootstrap current will require additional power, namely Phase II of LH system installation:

- Second launcher in D port (design underway)
- Repair of 4 additional klystrons from Alcator C

Achieving 3 MW delivered to plasma will require all 16 Alcator C klystrons operating at 250 kW, and reducing launcher/transmission system losses from ~50% to 25%.

At a minimum, 2 spares should be purchased. An additional cart with 4 new klystrons would significantly enhance possibility to reach 3 MW required for fully non-inductive, high-bootstrap goal – highly relevant for ITER.
Recent gas jet disruption mitigation runs

• Mitigation of VDEs using real-time detection and triggering by the digital plasma control system (DPCS)
  — Develop DPCS software that monitors error in Z-centroid
  — Will real-time, asynchronous operation be fast enough to mitigate, given C-Mod’s short disruption timescales?

• Can mixtures of inert gases work better than pure gases?
  — Helium is very fast, but doesn’t mitigate well (too low Z)
  — Ne, Ar, Kr mitigate well, but are significantly slower to reach plasma
Real-time detection and mitigation of VDEs

Halo current is reduced, but not as much as with pre-programmed mitigation of stable plasmas
90/10 He/Ar mix is just as fast as pure helium, but small Ar fraction precipitates faster thermal quench
Modeling of gas jet injection with (NIMROD+KPRAD=) NIMRAD

- Inclusion of models in NIMROD for injection of neutrals, atomic physics and radiation is complete
- Short simulations at actual C-Mod parameters show reasonable agreement in global parameters
- Profiles of jet penetration at edge match well with Thomson data.

- Simulations at $S=10^7$ (like C-mod) are time consuming, but not unreasonably so.
- Simulations past the end of the thermal quench will first be carried out at lower $S$. 
Near-term plans

- Develop DPCS detection of additional types of impending disruptions, particularly locked mode disruptions (neural network?)
- Possibly upgrade gas jet system for faster response, and/or more precise gas mixing
- Participate in DIII-D tests of ORNL large valve (postponed from 27 July)
- Carry out NIMRAD simulations for both Ar and He through the thermal quench
END OF PRESENTATION
Preliminary summary

• Real-time detection of impending VDEs by the DPCS is reliable, as is the firing of the gas jet valve by the DPCS.

• Overall response time is sufficient to achieve good mitigation, but not as good as pre-programmed, stable cases.

• Faster response will probably require hardware changes: large valve (ORNL/DIII-D); move system closer to plasma.

• Basic effect verified: ~ 90/10 He/Ar mixture gives a much faster quench than pure helium

• Present gas jet system is not ideal for mixing gases in-situ.

• RGA is useful diagnostic of He/Ar fractions
Real-time detection and mitigation of VDEs

DPCS trigger set at 11 mm (for these 1 MA plasmas)
Real-time detection and mitigation of VDEs

Radiated energy increased, but not quite as much as with pre-programmed mitigation of stable plasmas
Investigation of ELMs on Alcator C-Mod


- ELMs occur at relatively low $n^*$ ($0.2 < n^* < 1$)
  - discrete ELMs, variable size, type still uncertain, Type I or Type III
  - steady EDA, QC mode, no ELMs
  - small ELMs with EDA, at high power & pressure

Pedestal Relaxation for the High-triangularity Plasmas in which ELMs Occur

![Graph showing pedestal relaxation for high-triangularity plasmas with ELMs occurring.](image)

q$_{95}=3.5$, $\ell_{lower}>0.7$

$v^* = 0.2$

$v^* = 0.5$

$v^* = 1$

$v^* = 2$

$v^* = 5$

$T_{e,ped}$ (eV) vs. $n_{e,ped}$ ($10^{20}$ m$^{-3}$)

- discrete-ELMs
- Steady EDA
- EDA+ELMs
ELM Energetics

- Confinement is good in these H-modes (H_{ITER98y2} \sim 1), \( T_{eo} > 4 \text{ keV} \), \( n_{eo} = 2 \times 10^{20} \text{ m}^{-3} \)
- Energy loss per ELM typically 10-20% of \( W_{ped} \)
- Pedestal is not destroyed by ELM

![Graph showing Te vs. Rmid](image)

![Graph showing n_e vs. Rmid](image)

![Graph showing T_e vs. t-t_{crash}](image)
ELM Dynamics: Inboard vs Outboard Edge

- "primary" filament seen propagating radially outward into outboard SOL
- Inboard edge is perturbed earlier than outboard filament generation
- Inboard perturbation propagates into the SOL, i.e. radially inward

\[ V_{R_{\text{out}}} = 2.3 \text{ km/s} \]
Upper Divertor Cryopump

Quarterly Progress Report
Presented by B. LaBombard
Aug 2, 2006
Project Overview

Full toroidal cryogenic loop in upper divertor chamber
- one vertical port for feed lines

Upper divertor tiles/baffles arranged for optimal particle pumping
- system of 30 'pumping slots'

All-welded design
- in-vessel assembly using robotic 'orbital welder'

Liquid helium 'pot' design, capable of pumping hydrogen (4.6 K surfaces)

'Duplicate' of C-Mod pump to be fully instrumented and tested off-line in a dedicated vacuum chamber
All tiles & support components in-house, being prepared for installation

Full-scale test pump is assembled into a full loop; orbital welds are leak-tight

LHe transfer lines assembled; LHe dewars in-house and tested; Cryogenic 'dip-stick' parts ready

Procurement of parts for duplicate C-Mod pump is in progress

3-D Monte-Carlo modeling of cryopump and tile structure completed; optimum baffle geometry identified
**3D Monte Carlo Modeling**

=> Neutral Baffle Improves Pumping by 50%

- **Baffle Width (meters)**: 0.063
- **Profile Shot**: 1021002017:800
- **EFIT Shot**: 1031211007:0.660
- **SSEP**: -1.3 mm

- **Atoms Launched**: 10000
- **Trajectories Shown**: 300
- **Atoms Leaked**: 883
- **Atoms Pumped**: 431
- **Atoms Ionized**: 8686
- **Charge Exchange Events**: 8314
- **CX Reflected into Slot**: 2626
- **Pumped/Launched**: 0.043

- **Hits on Inner/Outer Connector**: 449
- **Source**: 2.64E+22 D atoms/s
- **373.1 torr-l/s D**

- **Neutral Baffle Modeling**:
  - **Pumping**: 1.14E+21 D atoms/s
  - **16.08 torr-l/s D**

- **Gas inventory**: 8.5 torr-l D$_2$

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**Alcator C-Mod**

**C-Mod Cryopump Simulation - Case CH1**
Remaining Tasks

Testing of full-scale pump (Aug/Sept)
- cool-down tests
- LHe level control
- assessment and benchmark of D₂ and H₂ pumping
- maximum inventory
- operational procedures

Assembly of duplicate pump for C-Mod

Installation of tile support structures and duplicate cryopump

Fabrication of C-Mod LHe transfer lines

In-vessel cool-down tests (~December)

Final installation of tiles and baffles

Cryopump operation during 2007 campaign
Up-to-Air Plans

DoE Quarterly Review
August 2\textsuperscript{nd}, 2006
Update

• Since the last quarterly review the primary engineering tasks have included
  – Improvements to the lower hybrid control system; delivered 1.8 MW of source power
  – Began fabrication of the new cryopump
  – Began fabrication of the new W-tiles
  – Continued development of real-time matching system for ICRF (FFT)
• In addition we have been working on
  – Diagnostic development: QMBs, fast scanning probes, X-Ray spectrometers, TS upgrades, PCI upgrades, bolometry upgrades, Penning gauges, polarimeter….
  – Brought DNB into long pulse operation
Plans

• Up-to-Air of approx 90 working days (5 day weeks)
• Major tasks planned for Up-to-Air period
  – Install cryopump
  – Install tungsten tile belt
  – Hi-pot and limited inspection of alternator
  – Install FFT prototype on E-Port Antenna
  – Inspect/refurbish ICRF antennas
  – New LH couplers
  – LH control system upgrade
  – Rotate DNB
  – Diagnostic upgrades
• FY2007 campaign to begin Jan 2007
Up-to-Air Task List

**General Ops:**
- Service Liquid Nitrogen System
- Service LN$_2$ vent duct
- Service Power Systems
- Sparker Development
- Service/Repair PFCs
- Replace HEAT TC Scanner
- Replace HV reed relays in TF Scanner
- Refurbish gas rack
- Ratiomatic upgrade
- Data system upgrades
- Network upgrades

**Diagnostics/Invessel:**
- NESOX move to k-hor 10" flange
- microbalance installation
- vacuum rabbit at k-hor
- bolometer upgrade
- mods to b-hor for hirex/new detector
- automate the MSE shutter
- MSE cals/checks/mods
- flapper removal/cover plate installation
- remove woven glass seal from divertor
- tungsten antenna protection tiles
- tungsten at other heat load areas?
- mods to reduce outer divertor radiation?
- outer divertor test tiles (B, CBN, W)
- shutter for polarimeter retros
- Mo/Ceramic polarimeter retros
- TCI feedback control
- install 7 limiter magnetic coils
- fix magnetics as possible (f11)
- mods to tiles at f-port (DNB location)
- mods to CXRS systems
- new upper divertor probe array
- new cryopump Penning gauges
- repair Penning gauge cables
- install two new inner-wall scanning probes
- install new F-top MKS gauge
- refurbish outer divertor probe array
- install 10 halo Rogowskis upper divertor
- change fiber bundle inner wall telescope
- Mo source diag coverage mods
- clean or replace fast camera telescope
- replace fiber bundle inner wall telescope
- new GPI telescope on A-B shelf
- Thomson Scattering Upgrades
- Upgrade to HiReX
- Improve LH camera reliability