Program Overview

DoE Review
2003-2008 Co-Operative Agreement Renewal
May 13-14, 2003
presented by E. S. Marmar
on behalf of the C-Mod Group
Physics and Technology

Integrated Thrusts

Advanced Tokamak
High Bootstrap, High $\beta_N$
Quasi-Steady State

Burning Plasma Support
High Field, High Pressure

Next Step(s)

Transport
Edge/Divertor
RF
MHD
Unique Capabilities
⇒ Address Key Questions

- **Unique long pulse capability** (relative to skin and L/R times)
  - highly shaped, diverted, high pressure plasma
    - 5 second pulse length at B = 5 T
  → Quasi-steady lower hybrid driven AT scenarios
    - fully relaxed current profiles
- **High performance, compact, high field capability**
  → Next Step Burning Plasma issues
    - Tight e-i coupled regimes
    - H-mode threshold
    - Pedestal regulation
    - Reactor-like normalized neutral mean free path ($\lambda_0/a$)
    - Prototypical disruption forces
    - Reactor level pressure (disruption mitigation)
Unique Capabilities
⇒ Address Key Questions

- Exclusively RF driven
  - Heating decoupled from particle sources (most like $\alpha$-heating)
  - No external momentum sources; strong rotation in H-Mode
  → Reactor-relevant regimes for Transport, MHD, AT studies

- Unique dimensional parameters; comparable to larger tokamaks in dimensionless plasma parameters
  - Key points on scaling curves
  - Test sensitivities to non-similar processes (radiation, neutrals, etc.)

- Very high scrape-off layer power density (>0.5 GW/m²); Metal plasma-facing materials
  - Unique divertor regimes, ITER and reactor prototypical
  - Unique recycling properties
Program Contributes to all 4 IPPA MFE Goals
Emphasis on Goals 1 and 3

- Long Pulse AT
  - IPPA 3.1 steady state; 3.2 high performance
- Compact, High Field
  - 3.2 high performance; 3.3 burning plasma
- RF Driven
  - 1.3 wave-particle interactions; 4.1 plasma technologies; 1.1 turbulence and transport; 1.2 macroscopic stability; 3.3 burning plasma
- Unique Dimensional parameters
  - 1.1 turbulence and transport; 1.4 multiphase interfaces; 3.3 burning plasma; 1.2 macroscopic stability
- Very High Boundary Power Density, Long Pulse
  - 1.4 multiphase interfaces
- Advanced Materials
  - 4.1 plasma technologies; 1.4 multiphase interfaces
<table>
<thead>
<tr>
<th>Proposal Title</th>
<th>C-Mod FY03 Run Days Completed</th>
<th>C-Mod FY03 Additional Run Days planned</th>
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<tbody>
<tr>
<td>Effects of inside and vertical pellet launch</td>
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<td>$\beta$ scaling of confinement in ELMy H-modes</td>
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<td>Improving the condition of Global ELMy H-mode and Pedestal databases</td>
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<td>Development of hybrid scenario demonstration discharges</td>
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<td>Development of steady-state demonstration discharges</td>
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<td>High performance operation with $Te \sim Ti$</td>
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<td>ITB operation with no external momentum input</td>
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<tr>
<td>Improved physics understanding of QDB/QH-mode operation</td>
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<td>Improved understanding of $\beta$-limits with ITB operation</td>
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<td>Development of real-time profile control capabilities</td>
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<td>Dimensionally similar ITB scaling experiments</td>
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<td>Simulation and modelling support for T-10 turbulence studies</td>
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<td>Understanding of pedestal characteristics through dimensionless experiments</td>
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<td>JET/DIII-D pedestal similarity studies</td>
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<td>Comparative MHD analysis and predictive modelling of type I and type II ELMy H-mode</td>
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<td>Stability analysis with improved edge treatment</td>
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<td>Dimensionless identity experiments with JT-60U type II ELMy H-modes in DIII-D</td>
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<td>Impact of ELMs on the pedestal and SOL (effect of aspect ratio)</td>
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<td>Parameter similarity studies (L-H transition, EDA)</td>
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<td>Parameter similarity studies Quiescent H-mode regimes)</td>
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<tr>
<td>Scaling of type I ELM energy loss</td>
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<td>Tritium codeposition</td>
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<td>Scaling of radial transport</td>
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<td>Proposal Title</td>
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<td>C-Mod FY03 Additional Run Days planned</td>
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<td>Disruptions and effect on materials choices</td>
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<td>Role of Lyman absorption in the divertor</td>
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<td>Parallel transport in the SOL</td>
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<td>Pressure and size scaling of gas jet penetration for disruption mitigation</td>
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<td>Joint experiments on resistive wall mode physics</td>
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<td>Joint experiments on neoclassical tearing modes (including error field effects)</td>
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<td>Neoclassical tearing mode physics - aspect ratio comparison</td>
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<td>Comparison of sawtooth control methods for neoclassical tearing mode suppression</td>
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<td>Error field sideband effects for ITER</td>
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<td>Preparation of ITER steady-state scenario</td>
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<td>Preparation of ITER hybrid scenario</td>
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<td>Diagnostic First Mirrors</td>
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<tr>
<td>Measurement of q(r)</td>
<td>1.5</td>
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<td>Confined and escaping $\alpha$-particles and other fast ions</td>
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<td>Measurements needed to support advanced tokamak operation</td>
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<td>Development of radiation resistant components and ITER/reactor relevant measurement techniques</td>
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<tr>
<td>Total FY03 C-Mod Run Days for ITPA expts</td>
<td>11.5</td>
<td>16</td>
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<tr>
<td>Total FY03 C-Mod Run Days</td>
<td>24</td>
<td>28</td>
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<tr>
<td>Fraction of run days for ITPA expts</td>
<td>48%</td>
<td>57%</td>
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Collaborations are Significant in all Aspects of the Program

### Domestic Institutions
- Princeton Plasma Physics Lab
- U. Texas, Austin
- U. Alaska
- CompX
- UCSD
- Dartmouth U.
- GA
- U. Idaho
- LLNL
- Lehigh U.
- Lodestar
- LANL
- U. Maryland
- MIT Theory
- Notre Dame U.
- ORNL
- SNLA
- U. Washington
- U. Wisconsin

### International Institutions
- Budker Institute, Novosibirsk
- C.E.A. Cadarache
- Chalmers U., Sweden
- C.R.P.P. Lausanne
- Culham Lab
- Ecole Royale Militaire, Brussels
- IGI Padua
- IPP Greifswald
- IPP Garching
- ITPA
- JET/EFDA
- JT60-U/JAERI
- Keldysh Institute
- KFA Jülich
- Kyoto U.
- LHD/NIFS
- Politecnico di Torino
- U. Toronto
- Hebrew U.
Collaborators Integrated into Experiments; Students play a Big Role

- 31 Research runs in FY02
  - Collaborating session leaders: 5
  - Student session leaders: 7 (incl. 3 collab.)
- 26 research runs in FY03 (so far)
  - Collaborating session leaders: 2
  - Student session leaders: 5
- 12% of session leaders from collaborations
- 21% of session leaders are students
Majority of APS paper first authors not MIT Experimentalists

- **APS-DPP 2002 (Orlando)**
  - Total of 50 abstracts with direct connections to C-Mod research
  - 28 have collaborators as first author
  - corresponds to 56% of the abstracts
  - 25% of abstracts have student first authors

Jaeger, et al., Mode conversion at ion-ion hybrid resonance; Berry, et al., Analysis of mode conversion; D'Ippolito, et al., 2D ICRF wave solutions; Myra, et al., Nonlinear ICRF-driven flows; Ross, et al., Gyro simulations & experiments; Malkov, et al., Transport bifurcation; Coppi, Angular momentum; Ernst, et al., ITB modeling; Bernabei, et al., Lower Hybrid Current Drive; Wright, et al., ICRF modeling; Kopon, et al., (NUF), Fluctuations; Simakov, et al., Neutrals; Pigarov, et al., Far SOL recycling; Redi, et al., Gyrokinetic modeling; Mikkelsen, et al., Drift wave turbulence simulations; Nevins, et al., BOUT modeling; Hays, et al., (NUF) Li pellet imaging; May, et al., Rotation diagnostic development; Lynn, et al., Transient electron thermal transport; P. Phillips, et al., High resolution ECE; Oelker, et al. (NUF); Third harmonic ECE; Y. In, et al., ECE correlation radiometry; Rowan, et al., CXRS diagnostics; Sampsell, et al., BES diagnostics; Schilling, et al., ICRF results; X.Q. Xu, Turbulence & density limits; Perkins, et al., 100% bootstrap configurations; Snyder, et al., Theory and modeling of H-Mode pedestal.
MDSplus Collaborations

• MDSplus is the worldwide de-facto standard for data acquisition and remote data access in the magnetic fusion community
  – Greatly facilitates collaboration, sharing of data and modeling results
• C-Mod, NSTX, DIII-D, JET/EFDA, ASDEX-U, FTU, HIT, MST, LDX, MTF, FRX-L, PISCES, HBT-EP, CTX, RFX, TCV, KSTAR, HANBIT, CHS, H1, T-10, TH-7U, ITPA databases
• Proposing US/MIT lead development of data system software for ITER
C-Mod has Prominent Role in Education

• Typically have ~20 MIT graduate students doing their Ph.D. research on C-Mod
  – Nuclear Engineering, Physics and EECS
  – Collaborators also have students working at the facility
• MIT undergraduates participate through UROP program (~5 at any time)
• Host National Undergraduate Fusion Fellows every summer (4 in 2002)
• Students are integral to all aspects of the research
Transport Science

• Physics-based studies of H-mode threshold in terms of local quantities, critical $T_e(B)$; correlation with non-linear gyrofluid simulations
• Identification of role of QC mode in EDA H-mode; evolving theory/modeling to account for observations
• Non-dimensional identity Pedestal experiments in collaboration with DIII-D and JET, AUG (also threshold comparisons)
• Characterization of pedestal parameters and mapping of ELMfree/EDA boundary in terms of shaping and q
• Observations of strong core rotation with no external torque
  – Measurement of rotation profile time evolution:
    • Inward transport of $P$ following L-H transition
    • changes in rotation and $E_r$ in ITB discharges
• Nonlinear gyrokinetic analysis of critical gradients for ITG compared to C-Mod results
Highlights
Divertor and Plasma Boundary Science

- Importance of midplane recycling, cross field transport in SOL, and correlation with bursty transport events
  - Visualization of SOL turbulence and qualitative correlation with code simulations
- Dissipative/radiative divertor operation compatible with $Z_{\text{eff}} \leq 1.6$, H-mode, reducing divertor heat loads at $p_{||} \sim 0.5$ GW/m$^2$
- Measurements of volume recombination and ion loss to divertor plates in detached divertor plasmas
- Measurement of upper divertor pressures adequate for pumping in unbalanced DN equilibria with SSEP $\leq 5$ mm
- Relation of density limit to cross-field transport and turbulence
- New inner wall measurements show turbulence and transport suppressed on field lines not connected to outer SOL
- Demonstrated close coupling between divertor neutral compression and transport
- Divertor leakage is a minor contributor to main chamber neutrals
Highlights
RF (Wave-Particle) Science

• Demonstration of efficient heating in D-He\textsuperscript{3} at 8 T
• Successful modification of 4-strap antenna to eliminate \(E\parallel B\) arcing, increasing voltage stand-off to 25kV at 78MHz
• Development and exploitation of Modeling and Simulation codes for ICRF (TORIC) and Lower Hybrid (ACCOME)
  – Implementation of efficient serial and parallel computational techniques in TORIC
• Mode conversion experiments and analysis including observations of localized heating
  – Observation and identification of mode converted ICW
  – Computational modeling consistent with observations
### Highlights

**Global Stability Science**

- Observation and analysis of pedestal stability, including second-stable access to ballooning, observation of magnetic component of QC mode, and transition to grassy ELM regime
  - Observation and analysis (peeling-ballooning) of grassy ELM activity in high power H-mode pedestals
- Measurement and scaling of halo currents during VDEs, including toroidal asymmetry; demonstration of neutral point effect to inhibit VDE and killer pellet mitigation
  - Modification of disruption halo current behavior by new divertor geometry, and confirmation of finite element model of wall distortion
- Observation of β-limiting tearing mode activity
- Measurement of induced magnetic wall torque implicating static fields in mode braking
- Successful installation and initial operation of Active MHD Spectroscopy Antenna
- Observation of locked mode phenomena and successful first use of non-axisymmetric control coils
Highlights
Advanced Tokamak Research Thrust

- Discovery of ITB formation by off-axis (high- and low-field side) ICRF; spontaneous ITB generation in ohmic EDA H-mode discharges
  - Demonstration of control of ITB’s by on-axis ICRF heating, including those formed in ohmic H-modes
- Demonstration of long pulse operation, $t_{\text{pulse}} > 2L/R$ at 5 T
- Integrated modeling of AT scenarios, including time-dependent evolution
- Gyrokinetic simulation of particle fluxes in ITB's: Identified role of TEM in ITB control
- Expanded field and current range of ITB’s; scaling of barrier location
Highlights
Burning Plasma Support Thrust

- Extension of H-mode threshold database to high B, n, P/A
  - Significant modification of predicted power requirement for ITER
- Constraints on H-mode Confinement Database
  - Significant impact on ITER scaling, projections
- Demonstration of suitability of high-Z PFC’s, vertical plate divertor geometry for high power operation
- Identification of EDA H-Mode as benign edge relaxation mechanism
- Increase of operating current to 1.7 MA at 7.8 Tesla
- Extension of Edge Relaxation studies to higher (and lower) triangularity; cross-machine investigations of pedestals and EDA-like phenomena
- 50% of FY03 run time on experiments identified by ITPA Topical Physics Groups
Highlights
Facilities

- Successful implementation of DNB-based diagnostics
- Installation and successful operation of new inner divertor
- Modification to cryostat and cylinder to improve diagnostic access, maintainability, increase shot rate
- Improvements to diagnostic systems (TS, high-speed cameras, X-ray spectroscopy, high resolution ECE, ...)
- Completion of Lower Hybrid fabrication project
Advanced Tokamak Research Thrust

Integrated target: $\beta_N = 3$, $H_{89} \approx 2.5$, noninductive, $f_{bs} > 0.7$, $I = 0.85$ MA, $t = \tau_{L/R}$

- **Goals**
  - Current Profile Control via Lower Hybrid Current Drive, at reactor relevant densities
    - Extend pulse length to multiple current relaxation times, $\sim \tau_{L/R}$ with fully noninductive current drive (LHCD + Bootstrap)
  - Understanding, control and sustainment of Internal Transport Barriers, with $\tau^e_i \ll \tau_E$ and no momentum input
  - Attain and optimize no-wall $\beta$ limits ($\beta_N \geq 3$); explore means to achieve higher values

![Pulse-length (5 T) allows full current relaxation](chart.png)
Advanced Tokamak Research

- Requirements
  - Efficient off-axis current drive \((r/a \geq 0.7)\)
  - Confinement (control of edge + internal transport)
  - Impurity Control
    - L-mode or EDA/ELMy H-Mode edge
    - High heat-flux divertor
  - Efficient heating (ICRF + LH)
  - Density and density profile control
    - Active pumping, RF control

ACCOME scenario: Fully non-inductive, 70% bootstrap fraction, \(H_{89p} \approx 2.5\)
\(I_p = 0.86 \text{ MA} \quad I_{lh} = 0.24 \text{ MA} \quad f_{bs} = 0.7\)

\(P_{LH} = 3 \text{ MW}\)
Burning Plasma Support Thrust Objectives

Goals:

- Identify, characterize and understand optimized Edge Relaxation Mechanisms (ELMs, EDA)
- High power operation with acceptable divertor heat loads, steady-state density; understand extrapolations to BPX
- RF core heating in BPX relevant scenarios (D($^3$He), LH)
- Control of Neoclassical Tearing Modes with localized RF current drive (LHCD + MCCD)
- Develop, test, model High Performance scenarios
  - ITER shape and field
- Develop, model Disruption Mitigation technique(s)

Integrated Targets: $B=8T$, $I=2MA$, $P\geq6MW$, $H_{89}\geq2$, $Z_{eff}<1.5$

ITER Demo: $B=5.3T$, $I=1.4MA$, $P\geq6MW$, $H_{89}\geq2$, $Z_{eff}<1.5$
Science Goals: Transport

- Marginal stability & turbulence
  - Quantitative understanding of non-linear physics setting $\nabla T_i$ near marginal stability
  - Origin and role of Zonal/GAM flows
- Momentum transport
  - Self-generated flows
  - RF flow drive
- Particle transport
  - Characterize, detailed comparisons with theory
  - Correlation with fluctuations
- Electron transport ($\tau_e^i << \tau_E$)
  - Small scale turbulence and effects on electron channel
- Transport barriers (core & edge)
  - Understand threshold or trigger conditions
  - Understanding & predictive capability for H-mode pedestal (including relaxation)

BOUT Simulations may Identify EDA QC mode

Xu & Nevins, LLNL
Science/Technology Goals: Edge/Divertor

- **Edge Turbulence and Transport**
  - Expand turbulence measurements: locations, $\tilde{n}$, $\tilde{T}$ ('03-'07)
  - Improve poloidal characterization of radial ion fluxes ('03-06)
  - Understand relationship between turbulence and macroscopic profiles ('04-'08)

- **Neutral Dynamics & Fueling**
  - Wall recycling, Neutral flows, Co-deposition ('03-'06)

- **Impurity Sources & Transport**
  - Improved diagnosis of sources and ion fluxes
  - RF induced impurity effects (ICRF '03, +LH '03-06)

- **Power & Particle Control**
  - Expanded IR measurements ('04)
  - Tungsten brush (Tiles '03, Module '05, BPX prototype '07-'08)
  - Mitigation: detachment, strike point sweeping ('03-'08)
  - Active pumping ('04-'08)
Science/Technology Goals: RF

- **ICRF**
  - Predictive capability for near-field antenna-wave-plasma interactions
  - D(3He) absorption physics at 8T
  - Load-tolerant 4-strap antenna (10 MW/m², fast-matching)
  - Mode-Conversion poloidal flow drive
  - Mode-Conversion current drive
  - Fast wave e-heating & current drive $\omega<\omega_{ci}$

- **Lower Hybrid RF**
  - Coupling efficiency and power handling
  - Fast electron generation and impurity dynamics
  - LHCD current profile control; compare with theoretical predictions
  - Symbiotic effects with two couplers: compound spectrum

- **ICRF-LHRF synergies**
  - Interaction of mode converted waves with LH deposition location
Science Goals: MHD

• Disruption studies
  – Extend to 2 MA, 8 T; improved halo/eddy/strain diagnostics
  – High pressure gas-jet mitigation
  – Locked-modes; control coils

• MHD at high $\beta$, AT profiles
  – Study stability near no-wall limit
  – Stabilization of NTM: profile mod./sawtooth stab.
  – Active MHD feedback
  – Assess potential for “steady-state” high $f_b$ operation above no-wall limit using RWM feedback; Implement if feasible

• Pedestal stability
  – effects of higher $\delta$
  – Understanding ELM regimes: comparisons with theory/simulation
  – Compare single/double null
LHCD experiments begin in CY2003
- 3 MW source @ 4.6 GHZ + 8 MW source ICRF (03)
- 4 MW source @ 4.6 GHz + 8 MW source ICRF (05)
  • Add second LH launcher, new 4-strap ICRF antenna (05)

New facility and diagnostic upgrades (partial list)
- Asymmetric control coils; Cryopump (nₑ control); Divertor upgrades (advanced materials); Real-time antenna matching; Long-pulse DNB; New ports; High-P Gas Puff (disruption mitigation); Active wall (RWM)
- Thomson upgrades (SOL, spatial res.); Hard X-ray, non-thermal ECE (LHCD); Reflect. upgrades (higher nₑ); Polarimetry (j(r)); MSE & CXRS upgrades; PCI upgrades (spatial coverage, ρₑ scale); Scattering diag (long & short λ fluct.); Ultra-fast Imaging (ṅ, ¹); Erosion/deposition divertor diagnostics

Full utilization of the facility (25 weeks/year operation)
IPPA Goal 1: Advance fundamental understanding and enhance predictive capability through comparison of well-diagnosed experiments, theory and simulation.

Theory/Modeling accomplished mainly through collaborations

- Transport, Turbulence and MHD
  - Xu and Nevins: EDA H-mode QCM, Edge fluctuations
  - Ramos, Snyder and Wilson: Edge MHD phenomena
  - Carreras, Antar, : SOL turbulence analysis
  - Hallatschek and Rogers: Theory and modeling
  - Diamond: Theory
  - Mikkelsen and Dorland: Critical gradient – Non-linear stability
  - Redi and Ernst: GS2 microturbulence simulations
  - Bateman and Kritz: Baldur transport simulations
  - McCune, C.K. Phillips: TRANSP
  - Chang, Chan, Coppi, Eriksson, Perkins, Porcelli, Rogister, White: Transport, RF induced rotation

- Impurity and Particle Dynamics
  - Stangeby, Lisgo, Elder: OSM-Eirene neutral modeling
  - Stotler: DEGAS II neutral transport
  - Pigarov and Krasheninnikov: Edge atomic processes
  - Scott and Wan: Radiation transfer
Theory and Modeling (continued)

- **ICRF**
  - Jaeger, Myra and D’Ippolito: ICRF Flow Drive
  - Brambilla, D’Azevedo, Batchelor and J. Wright: Fast wave and Bernstein waves in toroidal geometry
  - McCune, C.K. Phillips, Brambilla and J. Wright: Full-wave/Fokker Planck minority heating simulations
  - R. Maggiora (Torino): TOPICA modeling of antenna-plasma system

- **Lower Hybrid**
  - Dumont, C.K. Phillips and J. Wright: 1D full wave simulations
  - Peysson, Bers: Fokker Planck LHCD efficiency and distribution functions
  - Harvey: 2D LHCD Fokker Planck simulations
  - Bernabei and Dumont: Scenario development
  - Bernabei: Launcher design and coupling simulations
  - McCune and C.K. Phillips: Integration of ACCOME into TRANSP
MIT Theory Strongly Coupled to Experiments

- Bers, Bonoli, Catto, Coppi, Ernst, Freidberg, Molvig, Ram, Ramos, Simakov, Sugiyama, Wright

- Areas of emphasis
  - ICRF and LHCD theory and modeling
  - Particle transport and ITB control
  - Neoclassical fluxes and rotation in ITBs
  - Neutral puffing effects on edge flows
  - Resistive ballooning effects on edge flows
  - Simulations of Li pellet striations and zonal flows

TEM Turbulence counters Ware pinch:
Establishes Steady-state ITB

PARTICLE FLUXES IN THE BARRIER vs. Time

- Calculated Inward Neoclassical Particle Flux
- Net Inward Particle Flux
- Outward Particle Flux from TEM Turbulence (GS2)

Measured Inverse Density Gradient Scale Length

D.Ernst, et al., Sherwood 2003
Key Core Diagnostics and Upgrades

- Long pulse DNB (ordered 4/03)
  - 1.5 s on time, 8 A (source), 55kV, 6cm FW@1/e
- MSE, CXRS upgrades
- Imaging X-ray crystal spectrometer
  - collaboration with PPPL/NSTX starting now
- PCI upgrade: increased coverage, k resolution, frequency response
- Active MHD upgrade: 2’nd antenna pair for toroidal phase control
- Core TS upgrade: additional spatial coverage
Key Edge/Divertor Diagnostics, Upgrades

- Divertor IR cameras: increased coverage
  - especially important for high power, long pulse
- SOL flow imaging
  - 2-d profiles, used with gas-puff imaging
- Ultra-fast edge fluctuation imaging
  - simultaneous imaging at multiple wavelengths to separate n and T fluctuations
- Material deposition monitors: erosion, redeposition
- Video system upgrades: improved coverage, especially for LHCD grills
- Li beam edge polarimeter
- Probe upgrades: higher bandwidth bias electronics and DAQ; 8 feed scanning probe head
Advanced Tokamak Diagnostics

- **current drive diagnostics needed to quantify performance:**
  - \( j(r) \)
    - initial MSE results encouraging; strong collaboration with PPPL
    - Polarimeter/interferometer in plan (initial feasibility tests in 2002 successful)
  - Rotation profiles
    - Added tangential views for soft x-ray doppler
    - Imaging crystal X-ray spectrometer
    - CXRS under evaluation; improved beam ordered
  - Fast electrons
    - Hard X-Ray imaging spectrograph under construction
    - Non-thermal ECE in plan

![q Profile using MSE](image-url)
Program Planning

• Program leaders identify areas around which proposals organized
• Ideas forum (~ annual)
  – Proposals encouraged from all team members (including collaborators) and broader community
• Task forces and topical groups discuss and prioritize ideas; roughly apportion run-time
• Miniproposals solicited for higher priority ideas
• Experimental Program Committee evaluates MP’s, prioritizes and schedules run-time
  – Includes representatives of major collaborations
• Program Advisory Committee meets annually to review the project and advise on priorities, research strategy and integration with national and world programs
Relationship between Funding and Research Run Time

C-Mod National Budget (2002 M$) vs. Physics Run Weeks
## Alcator C-Mod

**Overview Schedule (Program Planning Budgets)**

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<th>Calendar Year</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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### Operations: 25 Run Weeks/Year (04 - 08) **Full Facility Utilization**

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<th>Adv. Tok.</th>
<th>ITB Studies</th>
<th>Flow Drive</th>
<th>LHCD</th>
<th>Dimensionless Scaling</th>
<th>6MW, H89 ≥ 2, Zeff ≤ 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n-control, power, long pulse</td>
<td>Active n-control, j-control</td>
<td>fboot ≥ 0.7, βn=3, H89−2.5</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Burn Plasma Support</th>
<th>Double Null</th>
<th>2MA, 8T</th>
<th>Dimensionless Scaling</th>
<th>6MW, H89 ≥ 2, Zeff ≤ 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inner-Wall limited</td>
<td>I-rise opt</td>
<td>Power/Part Handling</td>
<td>Sawtooth/NTM stab</td>
</tr>
</tbody>
</table>

|-----------------------------|-------------------|-------------|-----------------|-----------------|

<table>
<thead>
<tr>
<th>Edge/Divertor</th>
<th>T_e, n_e Fluct.</th>
<th>Inner SOL Fluct.</th>
<th>Impurity Sources &amp; Transp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Neutral Physics</td>
<td>Pumping/Particle Control</td>
<td>Power Handling</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>RF</th>
<th>LH Propagation</th>
<th>LHCD</th>
<th>Compound Spect</th>
<th>LH/IC Synergies</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MCICW/MCIBW/MCCD</td>
<td>Load-Tol Ant.</td>
<td>ω &lt; ω_ci</td>
<td>ICCD</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>MHD</th>
<th>Ped. Stab.</th>
<th>Locked-Modes</th>
<th>2MA Disruptions</th>
<th>NTM</th>
<th>RWM</th>
</tr>
</thead>
</table>

### Facility

<table>
<thead>
<tr>
<th>3 MW LH</th>
<th>2nd Launcher, 4 MW LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 MW ICRF</td>
<td>3 Antennas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inner Div Up</th>
<th>IWS Probe</th>
<th>Cryopump/Up. Div.</th>
<th>Outer Divertor Up</th>
<th>Active Wall</th>
</tr>
</thead>
</table>

### Facility

<table>
<thead>
<tr>
<th>RFX Beam</th>
<th>CXRS, MSE, BES</th>
<th>Long Pulse Beam</th>
<th>RWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active MHD Ant.</td>
<td>Hard X-Ray Imaging</td>
<td>Ultra-fast CCD Camera</td>
<td></td>
</tr>
<tr>
<td>Edge Fluctuation Imaging</td>
<td>Reflectometry Up.</td>
<td>Polarimetry (30 ch)</td>
<td></td>
</tr>
<tr>
<td>Tang. HIREX</td>
<td>PCI Upgrade</td>
<td>Add Horiz Ports</td>
<td>PCI 2nd View</td>
</tr>
</tbody>
</table>

|-------------|--------|--------|
## Budget Profiles

<table>
<thead>
<tr>
<th>Institution</th>
<th>Guidance FY04</th>
<th>5 Year Proposal FY04</th>
<th>FY05</th>
<th>FY06</th>
<th>FY07</th>
<th>FY08</th>
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</thead>
<tbody>
<tr>
<td>MIT</td>
<td>20,112</td>
<td>22,100</td>
<td>24,330</td>
<td>25,300</td>
<td>25,900</td>
<td>26,200</td>
</tr>
<tr>
<td>PPPL</td>
<td>1,934</td>
<td>2,500</td>
<td>2,600</td>
<td>2,700</td>
<td>2,810</td>
<td>2,920</td>
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<tr>
<td>U Texas</td>
<td>427</td>
<td>540</td>
<td>560</td>
<td>585</td>
<td>610</td>
<td>630</td>
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<tr>
<td>LANL</td>
<td>96</td>
<td>110</td>
<td>120</td>
<td>125</td>
<td>130</td>
<td>137</td>
</tr>
<tr>
<td>National Project Total</td>
<td>22,569</td>
<td>25,250</td>
<td>27,610</td>
<td>28,710</td>
<td>29,450</td>
<td>29,887</td>
</tr>
</tbody>
</table>
C-Mod is Positioned to Make Major Contributions to the Fusion Sciences Program

- Broad and strong science program, focused technology developments
- Diagnostics & Facility upgrades being implemented
- Advanced Tokamak
  - Current profile control experiments begin in 2003
  - Integrated Goal: fully relaxed non-inductive current, with high $f_{boot}$, $\beta_N$, and confinement.
- Burning Plasma Support
  - Study phenomena and regimes prototypical of next steps