(Draft)
ALCATOR C-MOD
FY03-FY04 WORK PROPOSAL

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1. Introduction

Alcator C-Mod is the high-field, high-density divertor tokamak in the world fusion program. The overall theme of the Alcator program is

Compact high-performance divertor tokamak research to establish the plasma physics and plasma engineering necessary for a burning plasma tokamak experiment and for attractive fusion reactors

The Alcator C-Mod research program explores two parallel, complementary paths: **Advanced Tokamak** quasi-steady state configurations with high bootstrap current fraction and RF current and flow profile control; **High field** high pressure regimes providing the physics basis for the high field approach to ignition.

Unique aspects of the Alcator C-Mod facility provide the logical foundations for the scientific areas of emphasis in our research endeavors to answer key outstanding questions in the development of practical fusion energy:

- **Long pulse capability**—C-Mod has the unique ability among highly-shaped, diverted tokamaks, to run high pressure plasmas with pulse length equal to the L/R relaxation time, at $B_T > 4$ Tesla. This provides an outstanding opportunity to investigate the extent to which enhanced confinement and stability of Advanced Tokamak configurations can be maintained in steady-state, using active profile control.

- **High magnetic field**—With capability to operate at very high absolute plasma densities and pressures, and with magnetic field up to 9 Tesla, C-Mod offers a unique test-bed for exploring the physics and engineering which is prototypical of possible compact ignition experiments.

- **Exclusively RF driven**—C-Mod does not use beams for heating, fueling or momentum drive. As a result, the heating is decoupled from particle sources and there are no external momentum sources to drive plasma rotation. It is likely that the same constraints will obtain in a fusion power plant; the studies of transport, MHD and AT physics in C-Mod are highly relevant to reactor regimes.

- **Unique dimensional parameters**—C-Mod is dimensionlessly comparable to larger tokamaks, but dimensionally unique, which allows us to provide key points on scaling curves for confinement, H-Mode threshold, pressure limits, etc. At the same time, coordinated experiments with other facilities allow for important tests of the influence of non-similar processes, including radiation and neutral dynamics.

- **Very high power density scrape-off layer plasma**—With parallel power flows approaching 1 GW/m^2, C-Mod accesses unique divertor regimes which are prototypical of reactor conditions. The issues of edge transport and power handling which are explored go beyond those specific to the tokamak, being relevant to essentially all magnetic confinement configurations.

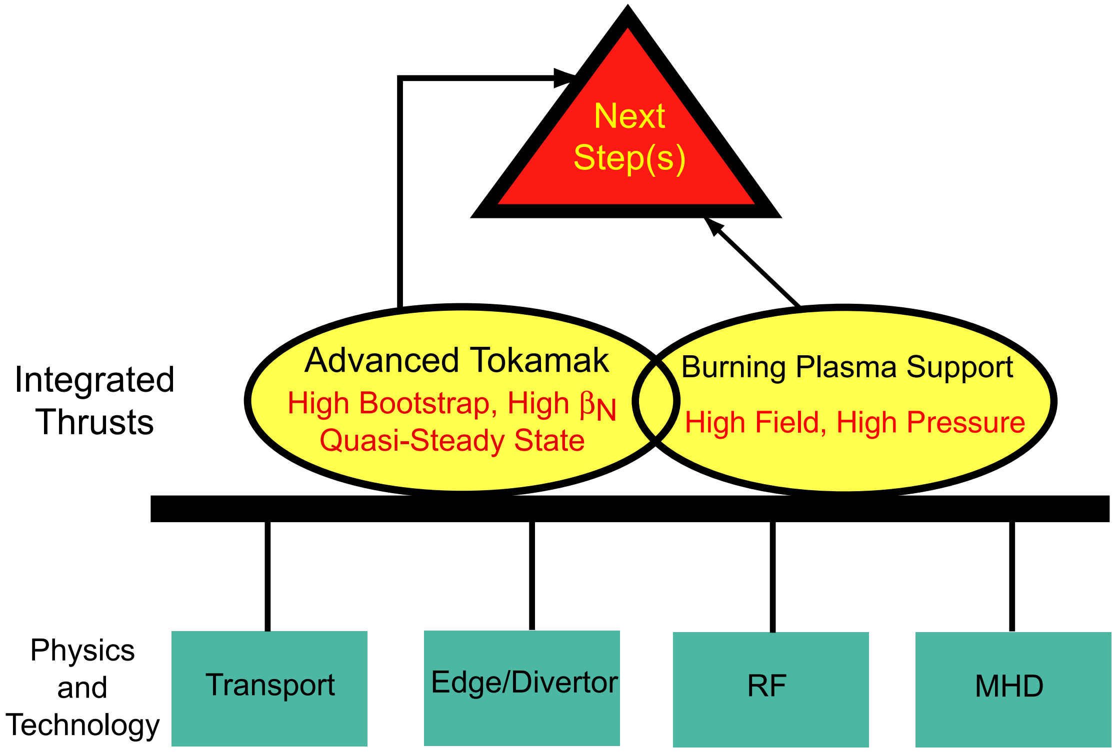
- **High Z metal walls**—The molybdenum plasma facing components on C-Mod are unique among the world's major facilities. The use of high Z PFC's is also reactor prototypical, and leads to unique recycling properties, and density and impurity control challenges.

Education is an integral part of the Alcator project mission, and the project has a large contingent of graduate students working toward their PhD degrees. They are drawn from multiple departments at MIT, as well as from collaborating Universities.

Organization of the program is through a combination of topical science areas and programmatic thrusts. The topics relate to the generic plasma science, while the thrusts focus this science on integrated fusion objectives crucial to the international program. The two thrusts are **Advanced Tokamak** and **Burning Plasma Support**. The Burning Plasma Support takes advantage of the high-field high-pressure capability of the facility and also includes some critical research aimed at resolving performance questions related to next-step fusion experiments.

The connections among the topical science areas and the programmatic thrusts are illustrated in Figure 1.

Fig 1. Programmatic thrusts and topical science.



Links to the IPPA MFE Goals

The Integrated Program Planning Activity has developed four high level goals, endorsed by FESAC, for the Magnetic Fusion program in the US:

1) Advance fundamental understanding of plasma, and enhance predictive capabilities, through comparison of well-diagnosed experiments, theory and simulation;

2) Resolve outstanding scientific issues and establish reduced-cost paths to more attractive fusion energy systems, by investigating a broad range of innovative magnetic confinement configurations;

3) Advance understanding and innovation in high-performance plasmas, optimizing for projected power-plant requirements, and participate in a burning plasma experiment;

4) Develop enabling technologies to advance fusion science, pursue innovative technologies and materials to improve the vision for fusion energy, and apply systems analysis tools to optimize fusion development.

The Alcator program contributes to all four of the goals, with our strongest efforts concentrated on goals 1 and 3. For goal 1, Figure 2 gives a graphical representation of the mapping between specific C-Mod program components and the 5-year objectives identified by the IPPA for this science goal. Note that our program targets specific scientific contributions, and many of our initiatives address overlapping topics.

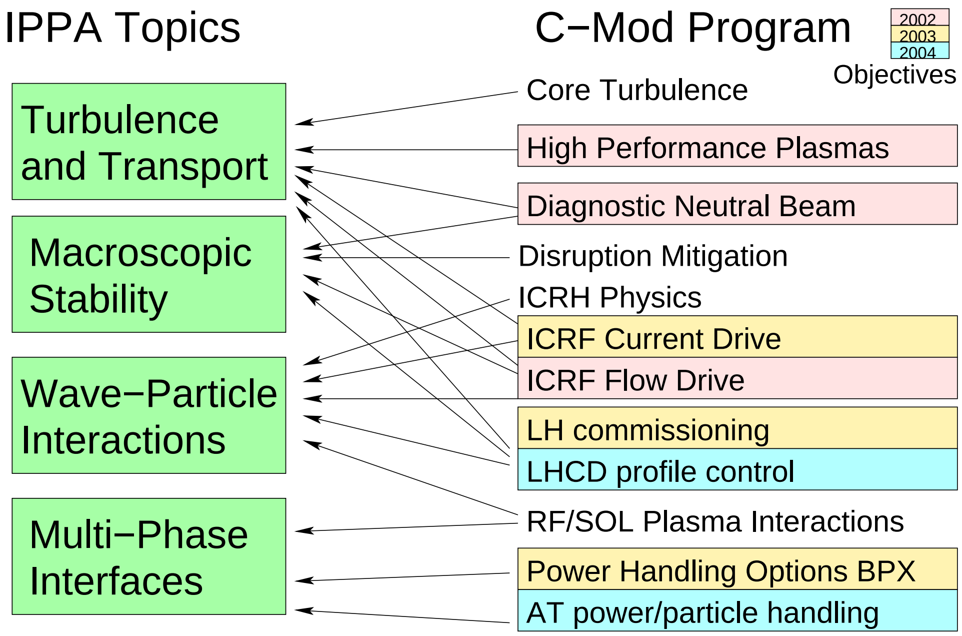


Figure 2. Mapping between Alcator program and IPPA Goal 1 objectives

Regarding IPPA goal 3, the two main thrusts of the C-Mod program are quasi-steady state Advanced Tokamak research and Burning Plasma Support investigations. These are focussed on addressing the 5-year objectives related to Steady State, High Performance and Burning Plasma, as illustrated in Figure 3. Both thrusts will help to resolve outstanding questions about the optimal integrated design of next-step devices and future reactors, as well as addressing the fundamental science underlying their challenges.

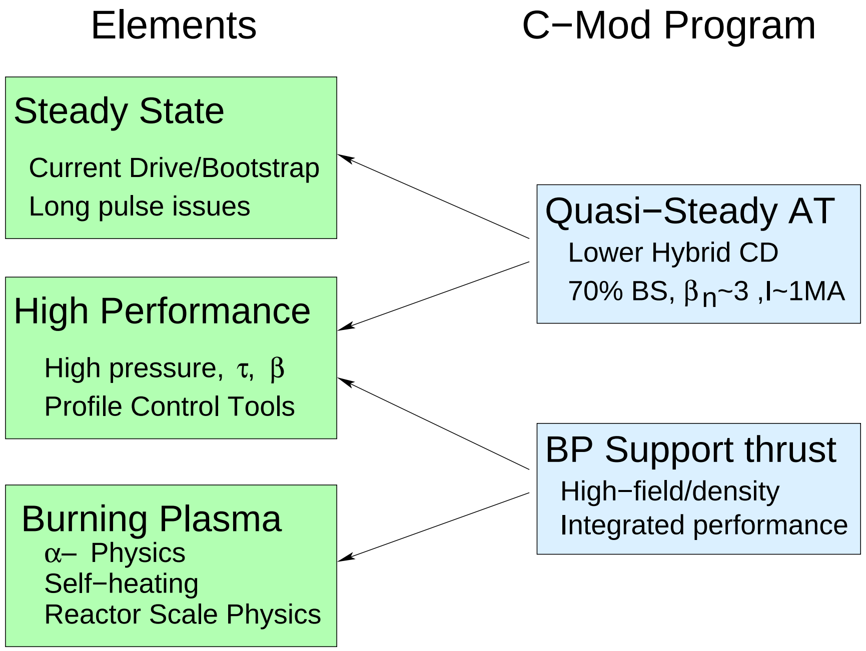


Figure 3. Mapping between Alcator program and IPPA Goal 3 objectives

Concerning goal 4, the C-Mod program focuses attention in selected areas: ICRF and Lower Hybrid technologies, and high Z metal walls/divertors with reactor level heat flux. The Advanced Tokamak is an innovative concept that is a critical part of the broad range emphasized in goal 2.

Detailed discussion of how Alcator's specific topical science plans address the key programmatic objectives are given in the respective sections.

Budget and Schedule

The baseline (A) budget for the C-Mod project has been determined by guidance from the Office of Fusion Energy Sciences, assuming flat funding in FY2004 relative to the presidential-request funding in FY2003, having total project funding of \$22.2M, including \$18.3M at MIT, and major collaborations totalling \$3.9M. These increases relative to the FY2002 level, coming from the facilities operations initiative within DOE, enable the run time to be more than doubled in 2003 and to remain at that higher level in 2004. For this purpose, modest increases in staff are necessary, and consist in the addition of one technician, two engineers and two physics staff, as well as a major increase in overtime. In addition, the major items that these budgets permit us to fund through MIT are shown in the following table.

Table 1. Items included in guidance budgets

Item	**Cost**	**Notes**
Fiscal Year 2003	($k)	
LH Phase 1	420	Completion of MIE
Alternator Inspection	1030	Required earlier for additional ops
ICRF Instrumentation etc	255	Needed for more reliable operation
Data Acquisition	135	Replacing obsolete, failing units
Control/Computing	165	Replacing obsolete, failing units
Cryopump	240	First installment
Fiscal Year 2004	($k)	
RF Instrumentation etc	160	Needed for more reliable operation
Launcher Upgrades	400	Start needed items for LH phase 2
4 Strap ICRF antenna	200	First installment
Diagnostic Neutral Beam	635	Replace borrowed RFX beam
Control/Computing	200	Replacing obsolete, failing units
Cryopump	200	Completion

Within these guidance budgets a number of important initiatives cannot be funded. We therefore also propose a higher, B budget, totalling approximately \$21.6M at MIT in FY2003 and FY2004, which would permit the following additions.

Table 2. Items funded only in incremental budget

Item	**Cost**	**Notes**
Fiscal Year 2003	($k)	
Fast Ferrite Tuners	750	ICRF matching and operation
LH Phase 2	350	More aggressive schedule
Diagnostic Upgrades	540	MSE j and E_r profile
Data-Acquistion/Control	420	mostly replacements
EFC PS upgrade	180	for high plasma current operation
ICRF PS upgrade	255	part 1
Fiscal Year 2004	($k)	
EF2 PS upgrade	120	for long-pulse operation
ICRF PS upgrade	265	part 2
LH Phase 2	300	More aggressive schedule
Outer Divertor Upgrade	940	High current/energy operation
Diagnostic Upgrades	465	
Control and Data-Acquistion	480	

These incremental levels of activity would require additional personnel costing approximately \$700k. The FY04 increment would also permit additional experimental run time of about 4 weeks. Naturally, the FY04 increment would be dependent upon whether the FY03 increment were available. Therefore Table 2 should be interpreted as approximately a prioritized list of desirable items to be funded in either year.

Of particular operational importance are the ICRF and PS upgrades. If the prototype fast ferrite tuner proves to be of substantial advantage, they may be very important for improving ICRF reliability. The diagnostic, data-acquisition, and control upgrades are predominantly focussed on supporting the control of Advanced Tokamak operations and science. Phase 2 of the Lower Hybrid project really should be begun soon, but is begun at only a modest level in FY04 without increments.

Table 3. Items cut under a 10% FY04 Decrement

Item	**Cost**	**Notes**
Fiscal Year 2004	(\$k)	
Diagnostics	150	turbulence & flow measurements
New ICRF antenna	200	needed for LH phase 2
LH Phase 2	400	postpone start
DNB	300	delay in replacement
Consumables	100	3 week run time cut
Personnel cut	650	3 tech, 1 eng, 1 phys

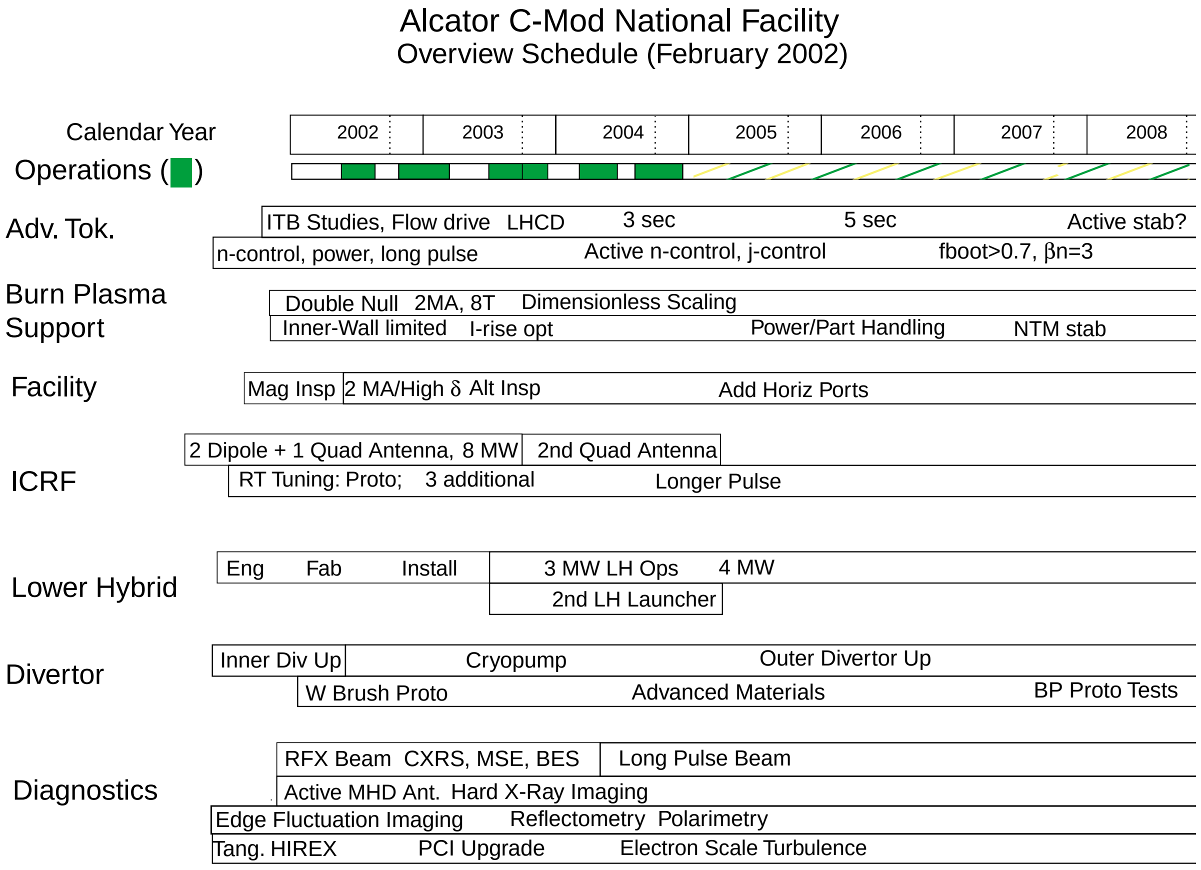
Proposed tokamak run-time is given in the following table. In addition to the guidance case we show the incremental (04I) and decremental (04D) cases for fiscal year FY04.

Fiscal Year	02	03	04	04I	04D
Budget (\$M)	14.3	18.3	18.3	21.6	16.5
Operating Weeks	8	21	21	25	18
Operating Hours	270	700	700	830	600

The Alcator C-Mod program consists of work performed by the MIT Alcator group who originally proposed, designed, built and commissioned the tokamak, plus significant collaborations from different institutions. The present Work Proposal covers in detail the MIT responsibilities in the program, but assumes an integrated effort involving all the major contributors plus a large number of smaller national and international collaborations.

A summary of the planned facility schedule, assuming the guidance budget levels, is shown in Figure 4.

Fig 4. Schedule of Major installations



Research Goals in Plain English

In order to communicate the excitement of plasma fusion science to a wider audience, each year we develop research goals, expressed in non-technical language, which reflect some highlights of our program plans. These goals do not represent the full scope of our program; the detailed technical research plans are described by topical science area in the succeeding sections of this proposal.

Plasma Probing with Energetic Neutral Particles: Critical Measurements [May 03]

By injecting energetic neutrals into the plasma, a wealth of new information will be gathered on (a) the profiles of ion temperature and ion flow which are important for plasma confinement, (b) the plasma current profile which determines the macroscopic stability of the plasma, particularly at high pressure, and (c) plasma density fluctuations, which are responsible for the turbulent transport that ultimately determines the quality of confinement.

Exploiting Divertor Upgrades [Sep 02]

Significant modifications and upgrades to the inner divertor structures in Alcator C-Mod are being implemented in Fiscal Year 2002. The hardware is being strengthened to permit full plasma current operation and the previous highly shaped inner wall structure is being replaced with a flatter, more open design, which will allow for the investigation of a broader range of plasma shapes, especially those with increased plasma triangularity. These upgrades expand the range of current and shape that can be studied and are expected to open up new plasma regimes on Alcator C-Mod.

Plasma Flow Control with Radio Waves [May 03]

A crucial part of control of transport is the control of the flow that helps to stabilize the responsible turbulence. Theoretical studies suggest that radio waves of the type used for heating Alcator C-Mod can control the plasma flow. We will complete the first experiments to verify, using our new diagnostics and the high power RF, what degree of control is possible, and how this can be used to optimize the plasma confinement.

Higher Performance Plasmas [Sep 03]

Produce high temperature plasmas with 5 Megawatts of radio frequency heating for pulse lengths of half a second. These plasmas should achieve conditions where the relative importance of plasma particle collisions is similar to what is expected for the burning plasma regime. The studies of the susceptibility of the plasma to instabilities and the losses of plasma across the confining field under these conditions should therefore be applicable to predicting the performance of next-step experiments.

Test the merits of Power Handling options for Next Step Designs [Sep 02]

Burning plasma experiment designs incorporate different options for the challenging task of taking away safely the heat escaping from the confined plasma. One choice is whether to use an edge magnetic configuration that is up-down mirror symmetric or an asymmetric configuration where the bottom divertor handles all the heat. Another choice is between using magnetic topology or a material surface to define the confined plasma boundary. Since Alcator is able to operate under all these conditions and has edge power densities comparable to future burning plasma experiments, we will study how the different options affect the plasma performance.

Commissioning of the Microwave Current Drive System [03]

Theory and past experiments show that microwaves launched as so-called Lower Hybrid waves can be used to drive toroidal plasma currents with high efficiency, and that these currents can be localized radially. Importantly, hollow current profiles can be formed which lead to improved stability, higher plasma pressures, and nearly steady state ”Advanced Tokamak” operation. To pursue this research on Alcator requires the installation of a microwave transmitter system and an appropriate launcher. We plan to complete this engineering and commence Advanced Tokamak experiments before the end of FY 2003.

Driving Electric Current with Radio Waves [Sep 03]

For steady-state operation, which is attractive for a reactor, it is necessary to drive current in the plasma with waves, not just with DC electric fields. A new method of driving the current involves launching waves in such a way that they are converted by interaction with ion resonances inside the plasma from long wave-length to short wave-length. They then drive the electrons of the plasma, creating a current. The first round of C-Mod experiments on this scheme will be completed, establishing its efficiency and suitability for the future.

Power and Particle Handling for Advanced Tokamak Plasmas [04]

Techniques for safely radiating away the extremely large parallel heat flow encountered in magnetic confinement plasma exhaust have been demonstrated at relatively high density. Quasi-steady state Advanced Tokamak plasmas may require lower density and involve techniques that are constrained by the needs of optimizing confinement. We will establish the limits of the divertor techniques and their performance in regimes appropriate for these plasmas.

Current Profile Control with Microwaves [04]

These experiments are aimed at developing efficient steady-state tokamak operation by launching microwaves into Alcator C-Mod plasmas. The location of current driven by the "Lower Hybrid" waves we will use depends on their wavelength as measured parallel to the magnetic field. We will vary this wavelength and measure the location and amplitude of the driven current, with the intention of demonstrating an improvement of the plasma confinement through current-profile control. By adding independent plasma heating, the plasma pressure will be raised, and by varying the location of the RF-driven current, we can begin to investigate the stability limit of the plasma, i.e. the maximum pressure the plasma can sustain without developing global instabilities.

Sensing approach to instability using active coils [04]

Plasma performance can be limited by large scale instabilities, which cause loss of confinement and in severe cases lead to termination of the plasma. These oscillations are normally stable but may be driven unstable by unfavorable combinations of pressure and current profiles which may develop as the plasma evolves. By using external currents in specially designed antennas to excite the oscillations at small amplitudes, it may be possible to assess their damping in stable plasmas, and thereby determine when the plasma is close to becoming unstable. If this technique is successful, it opens the possibility of avoiding the onset of these instabilities, using a feedback scheme to control the profiles.

Goals Accomplished in FY2001

Goal: *Active formation and Control of Internal Transport Barriers*

Plasmas with Internal Transport Barriers show promise as the goal for future advanced tokamak steady state reactor operation. Plasmas with simultaneous edge and core energy and particle transport barriers have been formed in Alcator C-Mod with auxilliary radio wave heating. This is accomplished without the need for neutral beam particle and mo-

mentum sources, which have been required to achieve these core barriers on other tokamak experiments, and which are likely to be unavailable in tokamak reactors as they are presently envisioned. The prescription for achieving the core barrier is to lower the magnetic field, which causes the radio waves (at 80 MHz) to be concentrated in the inner portion of the plasma, a significant distance away from the hottest reacting core of the plasma. Further heating power at 70 MHz will be concentrated at the core of the plasma to increase the temperature of the plasma center, inside the barrier region, to hold the density profile steady and to arrest impurity accumulation. The fundamental role of plasma rotation in the internal barrier formation will also be investigated.

Report:

A highly successful series of experiments was carried out in the 2001 campaign using the two different heating frequencies. It was established that the transport barrier can be created by heating either on the inboard or the outboard side of the plasma: an important indicator for the formation mechanism. Analysis has shown that the barrier does indeed lower the thermal transport as well as the particle transport. Associated analysis of transient heat pulses has produced evidence for the localization of the region of reduced thermal conductivity. Most importantly, heating in the plasma center has shown the ability to control the degree of peaking of the density profile, by affecting the transport. Control of transport barriers is a very important long-term objective and so the present demonstration of transport barrier control is an important step forward in magnetic confinement research. Further development and exploitation of this topic remains an important objective of our program.

Goal: *Visualization of Turbulence*

The plasmas in our experiments exhibit strong turbulence, chaotic behavior which can spoil confinement by transporting energy and particles. The understanding of turbulence, which defies straightforward analysis, is perhaps the greatest challenge left in classical physics. Our goal is to attempt to study this process by imaging fluctuations in the edge and core of our plasmas. The measurements will be compared to results of simulations run on powerful supercomputers and should provide insight into the origins and effects of turbulence in fusion plasmas.

Report:

During the 2001 campaign excellent initial results were obtained from the visible turbulence imaging diagnostic. These show graphically the intermittent “blobs” of plasma that had been inferred from other measurements as being responsible for the very rapid transport in the edge plasma. Comparisons with computer simulations show encouraging similarities, and the promise of a more fundamental understanding of these phenomena. Intermittency is one of the principal scientific themes of turbulence research across a whole range of disciplines. Therefore this ongoing research promises to contribute even more widely than the fusion plasma physics area.

2. Alcator C-Mod Research

2.1 Advanced Tokamak Thrust

Connection to Integrated Program Planning Activity

As one of two major integrated research thrusts in the C-Mod program, the Advanced Tokamak Program incorporates elements of all four plasma science areas; transport, MHD stability, RF wave and divertor physics. It is thus relevant to a large number of IPPA objectives, as outlined in Table 2.1-I. A number of these, particularly those relating to *MFE Goal 1, Advance understanding of plasma* will be covered in more detail in the corresponding topical physics sections. In this section we focus on those activities which involve integration of physics across the topical boundaries, and which lead directly to advancing *MFE Goal 3, Advance understanding and innovation in high-performance plasmas.* Our research program particularly addresses the goals, and closely parallels the implementation approaches, of *IPPA 3.3.1 Profile Control.* As an introduction to the scope of, and plans for, this work, the present and expected contributions are identified below.

IPPA 3.3.1.1 Plasma Current Profile

The C-Mod program emphasizes inherently long-pulse techniques of current drive, primarily Lower Hybrid wave-driven current and self-driven (bootstrap) plasma current, as opposed to transient techniques such as current ramping. The Lower Hybrid MIE, discussed in detail in Section 3.2, is on schedule for installation and commissioning in FY2003. It will be used for off-axis current drive, and current profile control, in FY2004. In parallel with this effort, we will continue optimization of the bootstrap current generated by internal transport barriers. Exploratory experiments to establish the efficiency of Mode Conversion Current Drive will begin in FY2003. This could be a useful new tool for driving current near the axis. Diagnostic measurements of current profile (by MSE) and non-thermal electron distributions (by an imaging hard x-ray spectrometer) are under development and will be important tools for all of this work. The LHCD and MCCD investigations, which are discussed more fully in Section 2.6 and include state-of-the-art model development, are also highly relevant to *IPPA 3.1.3.1 Plasma Heating and Current Drive.*

A *10 year IPPA objective* in this area is Advanced Tokamak operation for pulse lengths much greater than current penetration times. C-Mod is *uniquely* positioned to address this goal in a much shorter time frame, since it has already demonstrated pulses of 3 seconds and, with current drive, will be capable of extending this to five seconds. For comparison, typical current rearrangement time (τ_{CR}), for C-Mod is 0.8 secs at 5 keV.

IPPA 3.3.1.2 Plasma Pressure Profile

C-Mod currently employs high power, highly localized ICRF heating, with deposition radius controllable by varying magnetic field and heating frequency. Two frequencies (locations) can be used simultaneously. A unique operating regime has been found in which heating location not only affects the heat source but the plasma transport, allowing *active control of both temperature and density profiles.* Double transport barriers have been maintained for many energy confinement times. Such techniques hold the promise of true profile control to avoid the MHD instabilities and impurity accumulation which often plague AT regimes.

IPPA 3.3.1.3 Plasma Flow Profile

We will be investigating in the near term (FY2002-03) a novel means of externally controlled flow drive using mode-converted ion Bernstein waves driven by our present ICRH system. This work is discussed in detail in Section 2.6. Poloidal rotation will be measured via high resolution x-ray spectroscopy, and we will investigate the effect on core turbulence and transport. If successful, this would be a useful tool in our Advanced Tokamak scenario development.

IPPA 3.3.1.4 Plasma Transport Profile

As mentioned above, varying the deposition profile of ICRH has proven to be effective in controlling core particle and energy transport. Improved profile and fluctuation diagnostics and continued comparison to theoretical models will be used to develop a fuller understanding of these phenomena. Current profile control control capability will be used to explore the effect of magnetic shear on transport. This work is also directly relevant to *IPPA 3.1.1.2 Understanding transport barriers.*

IPPA 3.3.1.5 Low density divertor operation

Since lower hybrid current drive is most effective at lower densities, we will be operating in a density regime which is relatively low for C-Mod ($\sim 1-3\times 10^{20} m^{-3}$), although still higher than on most other tokamaks and in the same range as might be expected on future burning plasma experiments. Divertor power densities on C-Mod are already in a range typical of reactors, and will increase with additions of ICRH and LHCD power. Techniques for power dissipation, which are described in Section 2.4, will thus be directly applicable to optimized tokamak scenarios on future experiments.

The C-Mod Advanced Tokamak Program is also highly relevant to *IPPA 3.3.2, High Beta Stability and Disruption Mitigation.* We expect MHD studies, including active control techniques such as CD stabilization, to increase in importance over the course of the next five years. In FY2003 and FY2004, the primary emphasis will be on *IPPA 3.3.2.3 Active Profile Control to Avoid Unstable Boundaries.* Using the current and pressure profile measurement and control techniques described above, we will attempt to maintain profiles near operational boundaries. Modeling shows that operation near $\beta_n = 3$ is possible. This work is also directly relevant to *IPPA 3.1.2.1, Understanding Observed Macroscopic*

Stability Limits.

Finally, it should be emphasized that the results obtained in the C-Mod Advanced tokamak thrust will be directly relevant to *MFE Goal 3.3: Burning Plasmas.* Specifically, IPPA 3.3.3.1 aims to *"Exploit the capability of existing and upgraded tokamaks to explore and establish operation regimes suitable for burning plasma experiments, and to better develop the scientific basis for next step burning plasma experiments."* The burning plasma experiments currently under consideration by the US and world fusion communities, specifically FIRE and ITER, have as an important part of their mission the exploration of advanced tokamak techniques. The C-Mod regime will be prototypical of such experiments in several important respects, eg.

- RF current drive, without direct momentum input or core particle sources.
- High density, leading to strongly coupled electron and ion temperatures.
- Pulse lengths exceeding τ_{CR}.
- Large (60-80%) bootstrap fraction.
- $B_T \sim 4 - 6T$.

We therefore expect C-Mod experiments to play an important part in establishing the physics basis necessary to decide on, and plan operational regimes for, next step devices. Because of this relevance to burning plasma experiments, there is in fact considerable interconnection between the "Advanced Tokamak" and "Burning Plasma" thrusts, as well as with each of the science topical areas.

Recent Accomplishments

A substantial fraction of the 2001 campaign was devoted to investigation of internal transport barriers. A novel means of triggering ITBs was discovered on C-Mod in 2000.[1] Density profiles spontaneously peaked, with central values approaching $10^{21} m^{-3}$, when the ICRH minority resonance location was well to the high field side, at r/a ~ -0.45. At the same time the central toroidal rotation, typically strongly co-current in H-mode discharges, decreased and even changed direction. This regime was further explored and extended in 2001, using ICRH at 70 MHz as well as 80 MHz.[2,3] An important result was that the regime could be triggered by ICRH on the low field as well as high field side. This is illustrated by Fig. 2.1-1, which shows a toroidal field scan from 3.7 T to 5.4 T, with 70 MHz heating. The red points, with $\mid r_{res} \mid /a > 0.45$, exhibit barrier formation, while the green points do not. This condition was thus independent of frequency. By using two frequencies simultaneously, with one resonant near the axis, it was possible to stabilize the density peaking, arresting impurity buildup, and to extend the duration of the steady-state, double-barrier discharge for up to 15 τ_E, limited only by the RF pulse length. An example of a discharge with two frequencies is shown in Fig. 2.1-2.

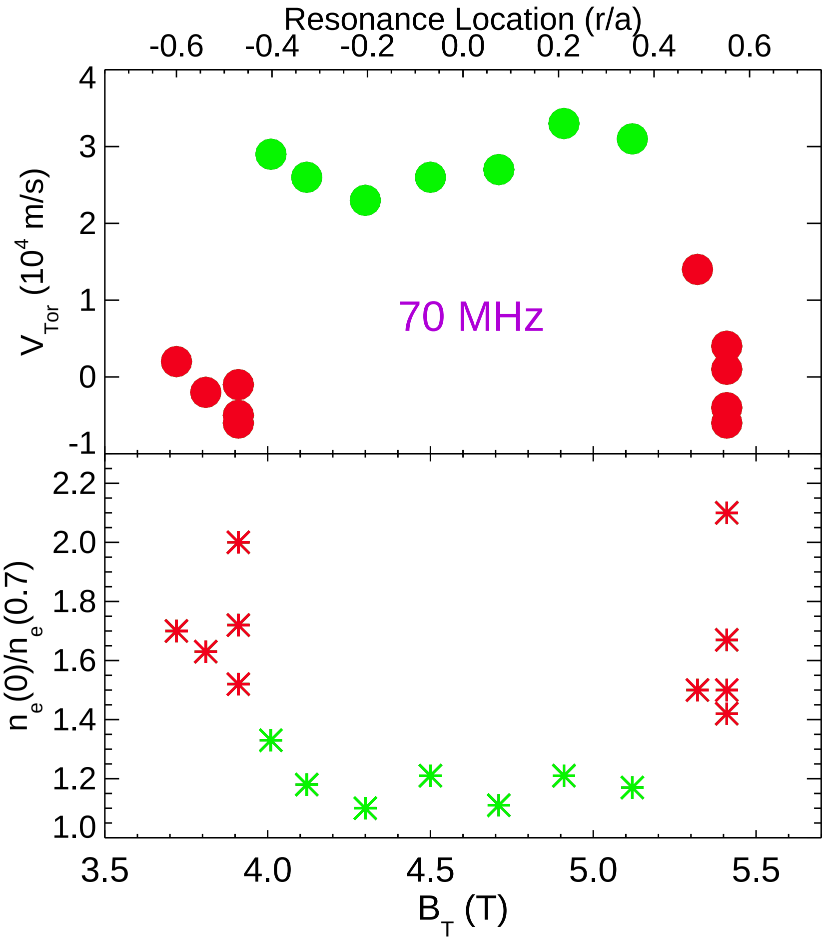


Figure 2.1-1. Toroidal field scan showing the central toroidal rotation velocity (top frame) and core-to-edge electron density ratio (density peaking, bottom frame) as a function of toroidal magnetic field/ICRF resonance location, evaluated at 450 ms after the initiation of the ICRF pulse, for a series of similar 0.8 MA discharges with 70 MHz waves at 1.5 MW. The ITB discharges (red points) are characterized by high peaking and low rotation velocities.

In all cases, these internal transport barriers arise in discharges which have a steady H-mode, usually in the EDA regime; ELM-free H-modes do not develop ITBs. They thus have a *double* transport barrier. A threshold in target (L-mode) density has been found to initiate this regime, which may be related to the previously observed threshold for EDA. Interestingly, ohmic EDA H-modes also often develop peaked density profiles, suggesting that the barrier is not purely due to RF wave effects.

To confirm and study in more detail the apparent changes in core transport via the application of off-axis ICRH, discharges have been analyzed using the transport analysis code TRANSP. The deduced radial profiles of $\chi_{\rm eff}(r)$ from TRANSP, at three times during an ITB evolution in Fig. 2.1-2 are shown in Fig. 2.1-3. Before off-axis ICRH is turned on,

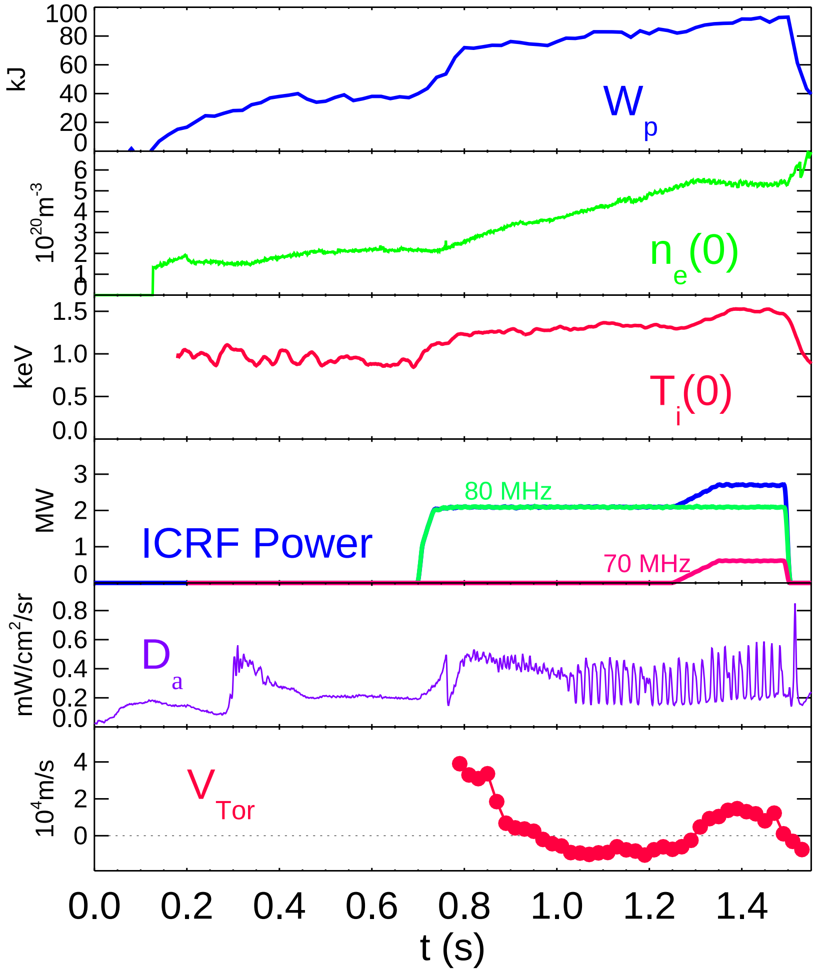


Figure 2.1-2. Parameter time histories for a double barrier plasma at 4.5 T, showing strongly increasing central density (second panel) with 80 MHz off-axis heating only, and stabilization of the peaking with the addition of 70 MHz heating.

the effective thermal diffusivity is anomalous with $\chi_{\text{eff}}(r) \simeq 1\ \text{m}^2/\text{s}$ for $0 \lesssim r/a \lesssim 0.8$. However, after the ICRH is turned on and with off-axis ICRH only, there is a clear reduction by factors of 5-10 in $\chi_{\text{eff}}(r)$ inside $r/a \simeq 0.5$, signifying the formation of a thermal energy barrier. At the later time, when the on-axis ICRH is also applied, the profile of $\chi_{\text{eff}}(r)$ still retains its barrier feature and the value of χ_{eff} approximately doubles, still staying well below the ohmic discharge levels. By adjusting the balance of on and off-axis heating, it is thus possible to control actively the thermal conductivity, a very important accomplishment which potentially can be used, for example, to avoid violating MHD pressure limits.

TRANSP analysis also indicates the density peaking observed in the ITB mode formation is consistent with a reduction in particle diffusivity within the barrier region combined with an inward neoclassical pinch velocity. This result is based on a simple model for the

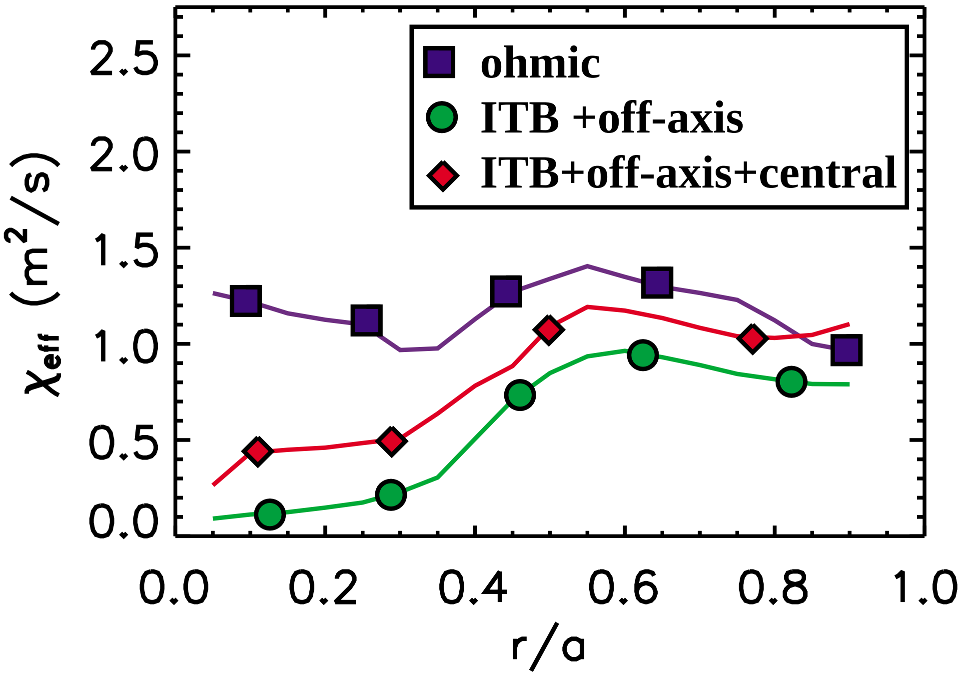


Figure 2.1-3. Radial profiles of thermal enegy diffusivity (χ_{eff}) from TRANSP at three different times in the ohmic, (blue squares), ITB with off axis heating phase (green circles) and 2-frequency stabilized ITB (red diamonds)

particle flux of the form $\Gamma_\mathrm{e} = -D\nabla n + \Gamma_\mathrm{e}^\mathrm{W}$, where Γ_e is deduced by TRANSP, $\Gamma_\mathrm{e}^\mathrm{W}$ is the neoclassical Ware pinch, and D is the particle diffusivity. The particle diffusivity from this type of analysis is plotted for three different times in Fig. 2.1-4. During ITB barrier formation, and even during the on-axis heating phase where the density peaking is arrested, the particle diffusivity is reduced by factors of 5 or more relative to the ohmic phase of the discharge. Particle and thermal diffusivity thus appear to be strongly linked, as has been found in other ITB regimes.

We have also carried out transient thermal transport analysis of the ITB discharges using sawtooth heat pulses, which reveal a narrow region of strongly reduced conductivity, and are beginning gyrokinetic stability analysis of the ITG and TEM modes.[2] These results are described in Section 2.3.

Another important experimental accomplishment during the 2001 campaign was demonstration of long plasma discharges, with the end of flat top increased to 3.0 s. Discharges had $B_T = 5$ T and Ip= 800 kA, typical of AT scenarios, and were run with 1 MW ICRH. Both L and H-mode plasmas were studied. At the typical temperatures of 2 keV, the achieved pulse length was $\sim 15\tau_{CR}$, and two L/R times. No difficulties with any magnets or power supplies were encountered, giving confidence that 5 sec pulses are technically achievable. Engineering details are given in Section 3.1. Steady and relatively low densities, $0.3 \times 10^{20} < \bar{\mathrm{n}}_\mathrm{e} < 1.2 \times 10^{20}/m^3$, were maintained, and no wall saturation was observed with the gas fluxes used. Other experiments relevant to density control were

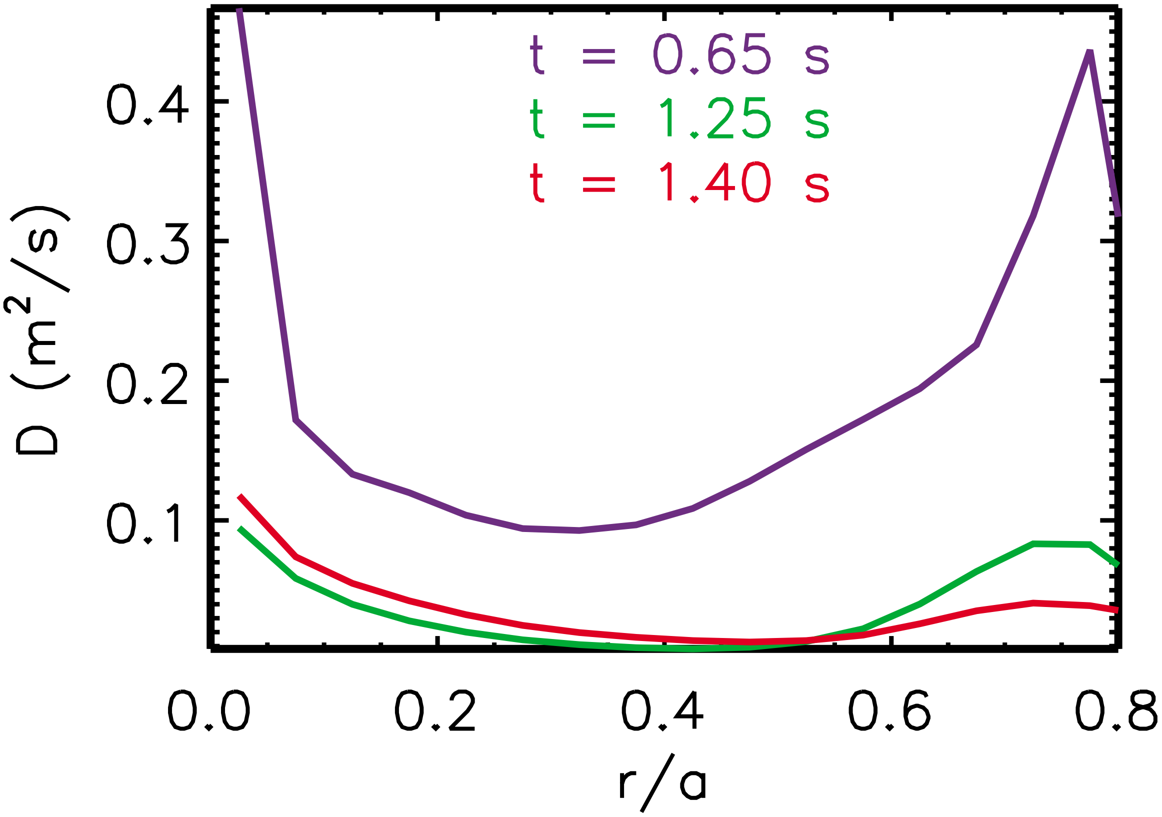


Figure 2.1-4: Radial profiles of particle diffusivity (D) from TRANSP at three different times corresponding to the regimes in the previous figure.

carried out during the campaign, which are described in Section 2.4. These have led to identification of a cryopump in the upper vacuum vessel as the most promising technique for active density control.

During the past year we have investigated the feasibility of driving lower hybrid (LH) current in target plasmas with a density barrier characteristic of the ITB mode produced with off-axis ICRH. The ACCOME current drive and MHD equilibrium solver was used in these studies and the code was run in a constant current mode in much the same way as a tokamak is operated. In this mode the total current $I_\mathrm{p} = I_\mathrm{oh} + I_\mathrm{bs} + I_\mathrm{lh}$ is held constant by adjusting the loop voltage (ohmic drive). Preliminary studies indicate that it is possible to drive about 0.11 MA of off-axis current with 3.0 MW of LHRF power. In these simulations a density profile typical of these ITB modes was used with $n_\mathrm{e}(0) = 6 \times 10^{20}$ m^{-3} and $n_\mathrm{e}(ped) = 2 \times 10^{20}$ m^{-3}. The magnetic field was 4.5 T and $T_\mathrm{e}(0) = T_\mathrm{i}(0) = 3.0$ keV, assuming 3.5 MW of central ICRF heating power. The current density and q-profiles for the resulting MHD equilibrium are shown in Fig. 2.1-5. The total current is $I_\mathrm{p} = 0.79$ MA, with $f_{\mathrm{bs}} = 0.6$, $I_{\mathrm{oh}} = 0.2$ MA, $q(0) = 2.7$, $q_{\min} = 1.9$, $\beta_{\mathrm{t}} = 1.96$ %, and $\beta_{\mathrm{N}} = 2.55$. The importance of off-axis LHCD in achieving high bootstrap fraction is especially evident under the assumption of constant current operation. If the simulation in Fig. 2.1-5 is carried out with no LHCD then the resulting equilibrium has $I_{\mathrm{p}} = 0.80$ MA, $f_{\mathrm{bs}} = 0.46$, $I_{\mathrm{oh}} = 0.43$ MA, and $q(r)$ is monotonic with $q(0) = 1.19$.

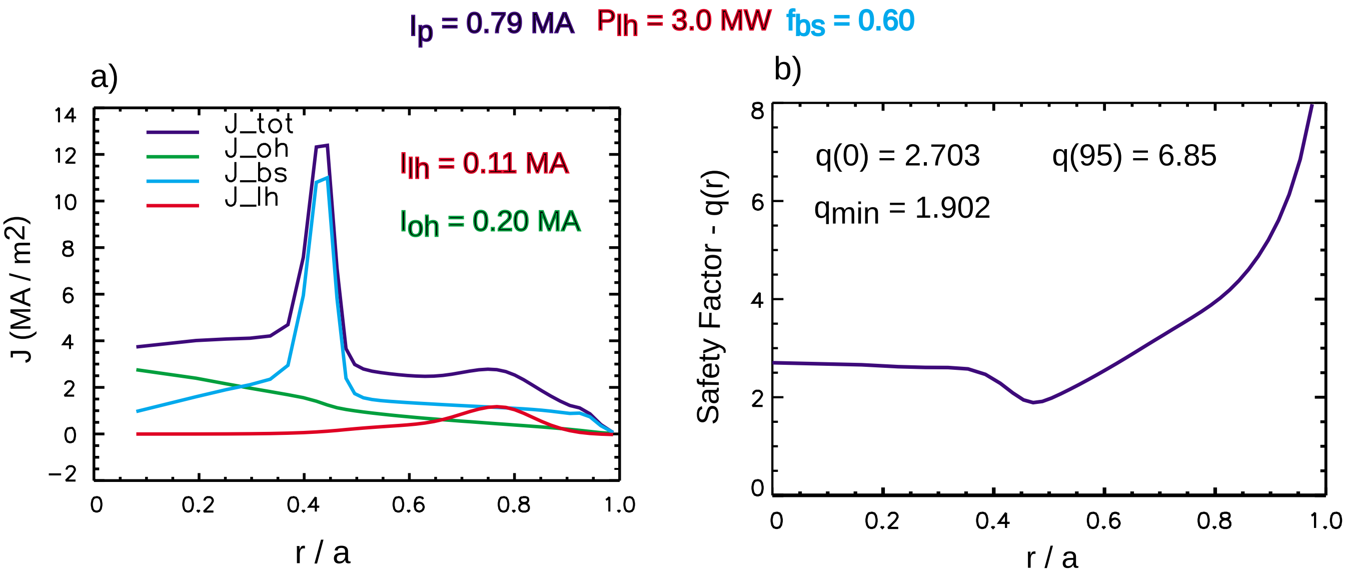


Figure 2.1-5: ACCOME results for off-axis LHCD using an ITB mode type density profile [$P_{\mathrm{lh}} = 3$ MW, $I_{\mathrm{p}} = 0.79$ MA, $I_{\mathrm{lh}} = 0.11$ MA, $f_{\mathrm{bs}} = 0.6$, $I_{\mathrm{oh}} = 0.2$ MA]**. Radial profiles of: (a) parallel current density components; (b) safety factor -** q**.**

During the past year we also started to use the ACCOME code to assess the LHCD that can be expected for EDA-like H-mode target plasmas at 5.4 T. The initial focus of this work was to study LH wave propagation and accessibility for density profiles characteristic of this mode with $n_{\mathrm{e}}(0) \simeq 3 \times 10^{20}$ m^{-3} and $n_{\mathrm{e}}(ped) \simeq 2 \times 10^{20}$ m^{-3}. Toroidal ray calculations indicate that wave accessibility to a wide range of plasma locations (core to periphery) can be achieved under a variety of launch conditions, i.e. different launch positions and waveguide phasings. This work will continue during FY02 - FY04 and is an integral part of the AT scenario and target plasma development effort. In parallel with this scenario modeling, we have been collaborating on the development of more accurate LHCD simulation codes, as described in Section 2.6.

Research Plans

The period of FY2003-2004 promises to be an exciting one for the Advanced Tokamak program, in that it includes the preparation for, commissioning of, and first experiments with, Phase I of the new LHCD system. Preparation activities will be carried out both in the short 2002 summer campaign and the early FY2003 campaign. Two experimental activities will be emphasized: Investigation and control of internal transport barriers, and target development for LHCD scenarios.

Important questions remain in understanding the new ITB regime with off-axis ICRH. While density peaking can be reliably triggered, we do not fully understand the physical mechanism behind this effect. Several experiments are planned to test hypotheses, including systematic B_T ramps and variations of R/L_T. Density peaking in ohmic H-modes will also be studied. Improved diagnostics with the DNB will also be very important, and will couple to transport modeling, described in Section 2.3. A related question with practical importance to the use of double-barrier plasmas in an advanced tokamak scenario is: *What determines the barrier location?* The steep pressure gradient at the barrier is an important source of bootstrap current. Ideally, we would prefer to expand the radius at which this occurs. We will systematically vary the plasma current and RF deposition location over a wider range. Upcoming experiments also aim to maximize the global confinement, and amount of bootstrap current, taking advantage of the higher ICRH power and the recently discovered capability of triggering ITBs at higher field (5.4 or 6.2 T). Other tokamaks have shown an influence of magnetic shear on barrier formation. In the near term, we will explore such effects by means of fast current ramps. Later, once LHCD is available, current profile modification will used to study the role of j(r) more systematically.

Experimental scenario development is being carried out in close connection with the modeling effort, as illustrated in Fig. 2.1-6. Profiles from non-optimized experimental plasmas have been taken as a starting point; some examples were shown above. These are then used as inputs to the ACCOME code to predict the LHCD, and bootstrap, current which would result from application of LH and/or increased ICRH power. Sensitivity studies are carried out to determine which parameters will have the greatest impact on driven current. For example, modeling has highlighted the strong influence of plasma density; there is a more than $1/n_e$ increase of I_{LH} as density is lowered. Accordingly, reduction of target plasma density, while still maintaining the good confinement necessary for high temperatures and bootstrap current, will be a key part of our near-term experimental program. Target plasmas will be developed in L-mode, H-mode and double-barrier regimes, giving us wide flexibility for initial LHCD experiments.

Because of the strong interaction between profiles and transport, we will be improving the coupling between transport and RF modeling. The TRANSP code, coupled with the FPPRF (ICRH) and LSC (LH) modules, will be used in a predictive mode, so that we can predict in a dynamic and more self-consistent manner the response of temperature profiles to various RF scenarios. Promising scenarios will be examined for low n and ballooning stability using the PEST-2, MARS and Keldysh codes. In the longer term, we will work with PPPL on the predictive code TRANSP-P to develop more theory-based predictions of transport coefficients, and to improve prediction of particle transport. A number of advances in RF modeling, described in Section 2.6, are also planned.

Near term experimental activities in early FY2003 will include long pulse experiments at higher ICRF power. This will enable us to test the divertor at higher heat loads. It

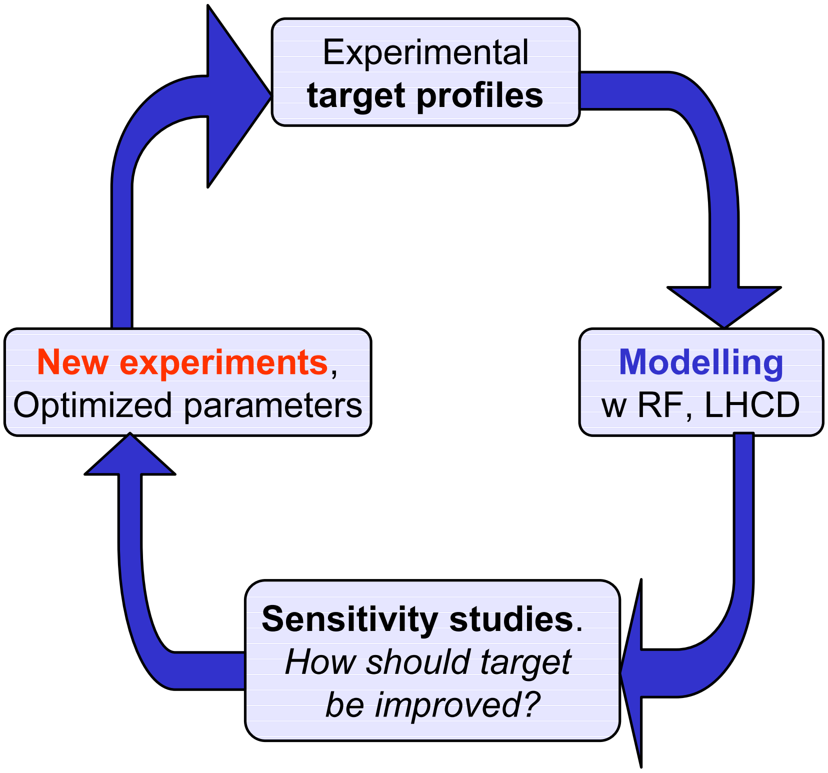


Figure 2.1-6. Schematic showing the iterative process of modeling and discharge development. Experimental profiles are used as inputs to LHCD modeling to predict the driven current profiles and other parameters. Sensitivity studies are then used to guide the next series of experiments so as to optimize the target plasma.

will also allow operation at higher densities and integrated gas influx, which would reveal whether any wall saturation or degassing occurs. A related activity involves experiments required to finalize the design of the cryopump. This will involve running unbalanced double-null discharges to increase neutral pressure in the upper chamber.

Once the lower hybrid system is installed in spring 2003, it will become the most important tool for our advanced tokamak thrust. It is expected that the summer 2003 campaign will be devoted largely to commissioning and performing required coupling and LHCD efficiency studies, described in detail in Section 2.6. These will use one or more of the previously developed target plasmas. Exploitation of the LHCD system for current drive and profile control will be a major emphasis of the FY2004 campaigns. The launcher has been designed for a wide range of $N_{||}$. Because we typically operate close to the accessibility limit, it should be possible to vary the deposition radius of the waves, and thus the driven current, by varying $N_{||}$ and toroidal field. Modifying the local shear profile will enable us to study directly the effect on transport, in particular on the creation and control of ITBs. Systematic variation of the density will be used to determine the optimum balance between bootstrap current and LHCD. A goal in FY2004 is to produce plasmas which have a total of 50% non-inductive current drive.

Another RF control tool which will be investigated is Mode Conversion Current Drive (MCCD), in which mode converted ion Bernstein waves (IBW) drive current. Our existing ICRH antennas can be used. Current drive efficiency is predicted to be highest on axis, complementing the off-axis CD from LH. If successful, this technique would be a valuable addition to our current profile control capabilities, and could enable investigation of high ℓ_i regimes.

By 2004, we expect to be coupling a total of 6-7 MW in additional heating, for up to 3 seconds. This will create large heat loads on the divertor. Development of techniques to deal with such loads will be a crucial part of the program, as discussed in Section 2.4. The high input powers will also allow us to begin exploration of β limits. An active MHD spectroscopy diagnostic, described in Section 2.5, is being developed which will sense proximity to stability limits. We will use pressure and current profile control techniques to maximize these limits and avoid deleterious instabilities; calculations show that $\beta_N \sim 3$ is achievable. In the longer term (beyond FY2004) we will explore active stabilization techniques, including LHCD suppression of NTMs, to further increase β_N.

Upgrades

The most significant upgrades planned in support of the Advanced Tokamak thrust are the Lower Hybrid project and cryopump, which are discussed in detail in Section 3. Fabrication for LHCD Phase II is planned to begin in FY2004. Diagnostics of the current profile and non-thermal electron distribution and profile will also be critical to the experimental program.

Table 2.1-I:
Advanced Tokamak Thrust, Including Areas of Contribution of the Lower Hybrid Experiments, to the IPPA Goals

IPPA Top Level Goals	General areas of Contribution	In-depth areas of Contributions
3.1 MFE Goal 1: Advance understanding of plasma, the fourth state of matter, through well-diagnosed experiments, theory and simulation	**3.1.1 Turbulence and Transport**	**3.1.1.2 Understanding transport barriers** - explore roles of magnetic and velocity shear as well as ICRH heating location
	3.1.2 Macroscopic Stability	**3.1.2.1 Understanding Observed Macroscopic Stability Limits** - use current profile control to understand limits to operation near the β_{N} limit
		3.1.2.2 Understanding Physics Underlying External Stability Control - Use pressure profile control and active MHD diagnostic to explore effects on macroscopic stability
	3.1.3 Wave - Particle Interactions	**3.1.3.1 Plasma Heating and Current Drive** - Check theory of current drive by lower hybrid waves, e.g. $f(\mathbf{v})$. Investigate off-axis current drive and sustainment for long (L/R) time scales. Investigate physics of current drive by mode converted IBW.
		3.1.3.2 Energetic Particle Effects on Radial Profiles and Confinement - Investigate role energetic particles generated by ICRH in formation of internal transport barrier
3.3 MFE Goal 3: Advance understanding and innovation in high-performance plasmas,	**3.3.1 Profile Control**	**3.3.1.1 Plasma Current Profile** -Develop consistent models of self (bootstrap) and LH driven

optimizing for projected power-plant requirements; and participate in a burning plasma experiment		current. Seek to demonstrate states of higher plasma stability.
		3.3.1.2 Plasma Pressure Control -Explore use of variable frequency ICRF heating in conjunction with current profile to improve plasma confinement and stability.
		3.3.1.3 Plasma Flow Profiles- Investigate flow drive using mode converted ion Bernstein waves, and measure with rotation profile diagnostics.
		3.3.1.4 Plasma Transport Profiles -Control core transport using ICRH deposition profile and current profile control, and compare to theoretical models.
		3.3.1.5 Low Density Divertor Operation - Develop techniques for handling over 6 MW ICRH and LH input to the divertor, at densities consistent with good current drive.
	3.3.2 High β Stability and Disruption Mitigation	**3.3.2.3 Active Profile Control to Avoid Unstable Boundaries-** Use combination of external and internal current drive, and variable heating profiles to explore and extend stability boundaries.
	3.3.3 Burning Plasma	**3.3.3.1 Coordinated & Joint Experiments** - Conduct experiments prototypical of AT regimes on burning plasma experiments.

<u>Reeferences</u>

[1] J.E. Rice, et al., Nucl. Fusion **41** (2001) 277.

[2] S.J. Wukitch, et al., accepted for publication Phys. Plasmas **9** (2002).

[3] J.E. Rice, et al., accepted for publication Nucl. Fusion **42** (2002).

2.2 Burning Plasma Experiment Support

The Burning Plasma Support Program on Alcator C-Mod emphasizes two complementary themes:

> *Development and validation of the Physics Basis underlying the key issues (transport, stability, heating, ...) in the relevant parameter ranges for a tokamak Burning Plasma Experiment (moderate beta, collisionality);*
>
> *Development and demonstration of Operational Scenarios and Techniques for optimization of burning plasma experiments*

The Research Program entails an integrated approach to developing the supporting Physics called for in IPPA Goal#3, "Advance understanding and innovation in high performance plasmas, optimizing for projected power-plant requirements; and participate in a burning plasma experiment." The intent is to address all three of the five-year objectives elucidated in the IPPA document

3.1 Profile Control

3.2 High β stability and disruption mitigation

3.3 Burning Plasma scenario assessment

in the context of the evolving Next Step program. In addition, Alcator C-Mod will participate in targeted development and testing of Enabling Technology in support of a burning plasma experiment, as called for in IPPA Goal #4. In planning and carrying out the Burning Plasma research program, we draw on results from all of the topical science areas (see sections 2.3–2.6 below) as well as from the Advance Tokamak thrust (section 2.1).

At this time, several proposals for a Next-Step Burning Plasma Experiment are under consideration by the World Fusion Program. While these differ in scope and capabilities, they share a number of common features. In all cases, the primary mission is the study of self-heating (burning) phenomena, which FESAC has called "the next scientific frontier in the quest for magnetic fusion energy." The mainline approach taken by each of the proposed facilities is "standard" tokamak operation, although to some degree all have incorporated the ability to exploit the developing understanding of "advanced" tokamak regimes. The primary scenarios envision operation at moderate, though substantial β, β_N, β_p, and $\mathrm{f_{bs}}$, and moderately low $\mathrm{q}^* \sim 3$ and $\mathrm{q_0} \sim 1$, with a monotonic q profile. Typically the collisionalities ν^*, ν/ω_*, are somewhat higher than in AT scenarios, and the edge density somewhat higher, though generally less than the empirical "Greenwald" limit. Typical pulse lengths are comparable to the current penetration time, $t_p \sim 2\tau_{CR}$, so the approach to ignition may occur with non-equilibrated j profiles. Additional common features include $\mathrm{T_e} \sim \mathrm{T_i}$, lack of significant external torques to drive rotation, and high SOL power density.

The experimental program on a burning plasma facility should be devoted to the unique features and problems of self-heated plasmas, not to exploration of "enabling physics" and component testing that can be modeled in non-burning devices. Experiments on present-day, non-burning tokamaks can contribute to successful, efficient operation of a next-step device: by increasing the physics understanding of relevant issues through dedicated experiments and model validation; by development and demonstration of extrapolable solutions in terms of feasible techniques in relevant regimes; and by carrying out technology development, from concept validation through scaled prototype tests.

Alcator C-Mod offers unique capabilities for such research and development activities in support of a next-step burning plasma experiment. The high field $\leq$ 8T, plasma density $n_e \lesssim 10^{21} m^{-3}$ and power density of Alcator C-Mod are all highly relevant to a BPX. C-Mod is an RF driven device, with respect to both heating and current drive, which is also characteristic of the planned Burning Plasma Experiments. The use of metallic walls and plasma facing components in C-Mod is also prototypical of next-step proposals. The demonstrated C-Mod capability of operation for multiple current relaxation times at 5 T, and $\sim 1 \times \tau_{CR}$ at 8 T, permits exploration of current penetration issues of direct relevance to the compact high-field BPX proposals.

Recent Accomplishments

In addition to the long-pulse experiments, high-field operation of Alcator C-Mod was resumed for the first time in several years. Plasma shots were produced at toroidal fields up to 8.1 T, and all systems performed nominally. D-He^3 ICRF heating experiments at were carried out at 80MHz in conjunction with the 8 T operations. A full inspection of the TF magnet was carried out following the 2001 campaign, with satisfactory results. Operation of Alcator C-Mod at high field is a key element of the planned burning plasma support program in future campaigns.

Research Plans

Near-term Research in this area exploits new C-Mod capabilities, and responds to needs of the Next Step Proposals in advance of the Snowmass Study scheduled for the summer of 2002. Specific experiments include: characterization of high performance H-mode discharges at $P_{RF} \gtrsim 5MW$, $I_p \leq 2MA$ in Single Null geometry; an initial assessment of the potential of double null, high triangularity configuration for Next Step Burning Plasma Experiments (FIRE); and current rise optimization studies in support of ignition scenarios for Ignitor. A study of the dependence of the H-mode threshold in equilibria with small inner gaps and inner-wall limited equilibria will also be of interest with respect to Ignitor. Total time for dedicated burning plasma experiments during the eight week 2002 Campaign is severely limited (5 days). Additional relevant data will be obtained as piggyback on scheduled Topical Science experiments addressing pedestal transport and stability, ICRF heating in D-He^3 plasmas, and density limit physics.

Increased operating time in FY 2003 will benefit the burning plasma support effort substantially. We anticipate that the initial FY03 experimental campaign could include demonstration (ρ^* scaling) experiments matching β, ν^* of each of the three proposed BPX candidates (FIRE, Ignitor, ITER-FEAT). ICRF Physics Studies, including D-He^3 heating and mode conversion current drive studies at 60 MHz would be carried out. Initial tests of Tungsten Brush tiles could also be undertaken in collaboration with Sandia. The summer 2003 Campaign would begin to address Lower Hybrid coupling and current drive issues at moderate to high edge density.

Burning Plasma Issues will remain a significant focus of the C-Mod Program in 2004, and into the future. Specific directions of the BP supporting research effort will depend to some extent on NSO decisions in the world fusion program, but many of the basic issues will remain relevant regardless of which configuration(s) are selected. Three principal topics have been identified as foci of the C-Mod contributions in this area: pedestal physics; power and particle handling at high plasma and power density; and the use of RF (ICRF and Lower Hybrid) for heating, current drive, and plasma control. Operational scenario development and specific component testing may be expected to become increasingly important as the program proceeds.

Prediction and control of the *pedestal* is potentially the highest leverage issue for an H-mode Burning Plasma Experiment. The height and width of the pedestal strongly influence core performance through profile stiffness, while edge relaxation phenomena can dominate power and particle exhaust, as well as impacting RF coupling. At this time, no applicable first-principles transport model capable of predicting the relevant parameters is available. MHD stability theory, including non-ideal, non-linear effects which dominate the edge relaxation, is also lacking. The C-Mod research program in this area will extend the database of observations to higher power and ∇P, in the relevant configuration and parameter range, and provide direct tests and benchmarking of models of transport and stability in the pedestal as they develop. The long-term goal of this research is to develop and demonstrate control of the edge pedestal suitable for application to a burning plasma configuration.

In the RF physics and technology area, burning plasma support research will address outstanding issues of heating and plasma control in the context of a next-step experiment. Models of ICRF absorption and heating physics, particularly in D-He^3, require validation. Of particular interest is the issue of parasitic edge absorption mechanisms that limit the overall efficiency. We will also be testing and developing techniques for real-time impedance matching, load-tolerant antenna coupling, and arc detection. Other BPX-relevant investigations include mode conversion current drive (MCCD) physics and technology issues, which may be useful for NTM stabilization in a burning plasma, fast wave current drive (FWCD) below all cyclotron resonances, which is relevant for avoiding parasitic absorption on α particles, and Lower Hybrid coupling and current drive efficiency at moderate to high edge density.

Other issues and potential contributions include: continuation of our program in disruption effects, mitigation, and avoidance; studies of density limit physics; fueling and density profile control; and study of rotation effects with low/no external torque.

Finally, the Burning Plasma support program on C-Mod is closely coupled to the other major integrated activity in the C-Mod program, Advanced Tokamak Research. In several areas, the results and techniques developed in one effort will translate directly into the other. For example, internal barrier control techniques developed in the AT program could be applied to production of peaked density profiles in high-performance H-modes, with corresponding increases in reactivity for the burning plasma scenarios. The understanding and control mechanisms arising from the pedestal physics studies in the BP program will be applicable to control of AT plasma scenarios with H-mode edge. Solutions for divertor power handling materials should benefit both programs.

2.3 Transport

Connection to Integrated Program Planning Activity

Transport research on C-Mod is well aligned with the fusion sciences mission and goals as outlined in the IPPA report of November, 2000, namely 1.1 "Advance scientific understanding of turbulent transport forming the basis for a reliable predictive capability in externally controlled systems." Most of the transport related scientific issues outlined in section 3.1.1 and appendix III are addressed directly by the C-Mod program.

> *What determines the amplitude and width of edge pedestals in plasma pressure and temperature?* Experiments in this area have been enabled by the array of high-resolution edge profile diagnostics and have included scaling studies with plasma current, density, input power, and plasma shape.[1] Studies of the EDA and small-ELM H-modes emphasize the role of micro- and macro-stability in determining pedestal transport and profiles.
>
> *How does neutral hydrogen recycling affect stability and transport?* Utilizing its array of high resolution edge profile diagnostics, including the ability to measure Ly_α with mm resolution, experiments have been conducted to quantify the role of neutrals in energy, momentum and particle transport. At the same time, dimensionless identity experiments conducted in collaboration with DIII-D and ASDEX-Upgrade provide valuable data on the relative role of plasma physics and atomic physics in determining the pedestal profile shape.
>
> *What is the influence of the plasma edge on the plasma core and on the global properties of confined plasma?* Past work has clearly shown evidence of critical temperature gradient lengths. The manifestation of this behavior is self-similarity of the profiles, where an increase in the edge temperature leads to a proportional (rather than additive) increase in the temperature profile everywhere. Current work emphasizes the quantitative comparison between the measured gradients and those predicted from non-linear theories of ITG turbulence.
>
> *What are the effects of finite-beta and confinement geometry on transport?* Measurements of the very strong magnetic component to the quasi-coherent oscillation seen in EDA H-modes along with a significant magnetic component observed in the L-mode plasmas indicate an important role for finite β and β' in edge transport.[2] With available increases in heating power, we are also beginning to see some β related effects in the core plasma. As the RF power is raised, these effects will grow in importance. The modification of the inner divertor will enable the study of a wider range of plasma shapes. Experiments have shown, for example, a strong triangularity dependence on the EDA/ELMfree boundary.
>
> *What are the mechanisms responsible for anomalous electron thermal transport?* We will begin by documenting regimes in which the electron channel dominates trans-

port, looking for evidence of critical gradients and comparing these with theoretical calculations. Experimental profiles will be used to calculate the expected spectrum of short wavelength fluctuations and optimize a CO_2 scattering experiment currently under design.

How does the power threshold for internal transport barriers scale with gyroradius in the absence of externally driven rotation? With its ability to create transport barriers without the use of neutral beams, C-Mod is in a unique position to explore this issue.

What is the fundamental origin of the observed density limit on tokamak operation? Recent experiments on C-Mod, described below, suggest that the density limit is due to changes in edge fluctuations and anomalous perpendicular transport which occur as the density is raised.[3] Further studies will attempt to uncover the physical mechanism responsible for this change in transport.

Recent Accomplishments

Work in edge transport has focussed on two areas: studies into the physics basis and scaling of the H-mode pedestal and investigations of the micro and macro-stability of the plasma edge. The motivation for these studies is clear. With "stiff" temperature profiles, which are predicted theoretically and observed experimentally, the performance of the core plasma is strongly dependent on the boundary conditions at the edge.[4] Figure 2.3-1 shows a set of data from C-Mod experiments where the total stored energy is seen to scale linearly with the pedestal pressure over a wide range of operating conditions. In H-mode, it is necessary to have excellent energy confinement accompanied by only moderate particle confinement in order to avoid impurity build-up. This has led to the adoption of the ELMy H-mode regime as the baseline operational mode for proposed burning plasma experiments. At the same time, it will be critical to mitigate the effects that large ELMs have on the first wall. An important part of the C-Mod program is aimed toward creating and understanding discharges with just this combination of characteristics.

Utilizing an array of high resolution edge profile diagnostics, systematic studies of H-mode pedestal profile scaling have been carried out. In general, the profile widths are of the same order of magnitude as the poloidal ion gyro-radius; however, it is clear that the scaling does not match this parameter. The widths of both the electron temperature and density profiles show no dependence on either the toroidal field (B_T) or the plasma current (I_P). The height of the density pedestal does show dependences on these variables, $n_{pedestal} \propto {I_P}^{0.9} {B_T}^{-0.5}$. The height of the temperature pedestal (though not the density pedestal), depends mainly on the input power. Another difference between the behavior of the two profiles is the effect of shaping. Higher triangularity can lead to wider density profiles, but has no such effect on the temperature. Data from these experiments are being provided to the appropriate ITPA databases and working groups.

To shed further light on the physics which determines the pedestal profiles, a set of dimensionless identity experiments was carried out in collaboration with the DIII-D

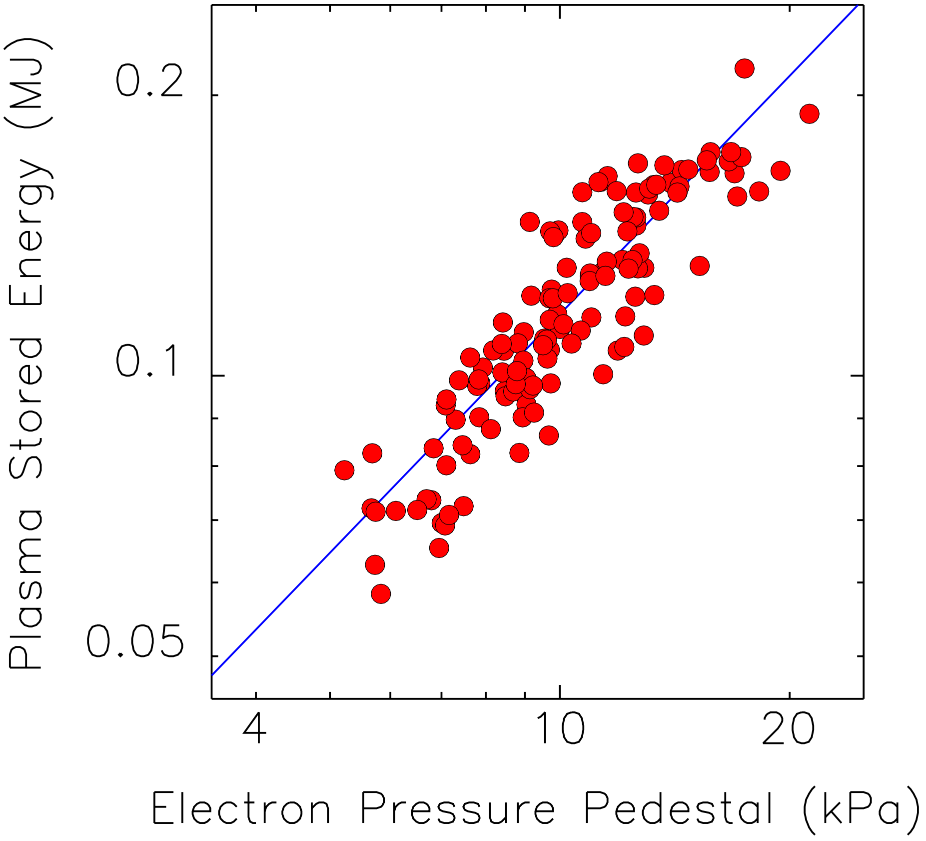


Figure 2.3-1. Plasma stored energy is plotted vs the height of the electron pressure pedestal for a wide variety of discharges. The strong correlation is believed to be connected to the proximity of the core plasma to the marginal stability of ITG modes which imposes self-similarity on the temperature profiles.

group. In these experiments, discharges were run in the two machines with identical dimensionless geometric parameters (q, ϵ, κ, δ) and with identical dimensionless plasma parameters at the top of the pedestals (ρ_*, β, ν_*). Since the sizes of the two machines are very different, the dimensioned quantities were quite different as well. The result was that the pedestal showed dimensionless similarity over the entire profile. An example of this match can be seen in Figure 2.3-2. At the same time, the dimensionless power conducted through the edges also matched, a result, not a requirement of the experiment. The most straightforward explanation of these results is that the pedestal profiles are set by plasma physics alone. For example, if atomic physics were important, the similarity should not be observed since the quantity na is the appropriate similarity scaling for atomic physics while na^2 applies for plasma physics. In our experiments, only the latter was held fixed. The DIII-D team has offered an alternate explanation based on a difference in fueling location on the two machines.[5] This will be further investigated in future work, as described in

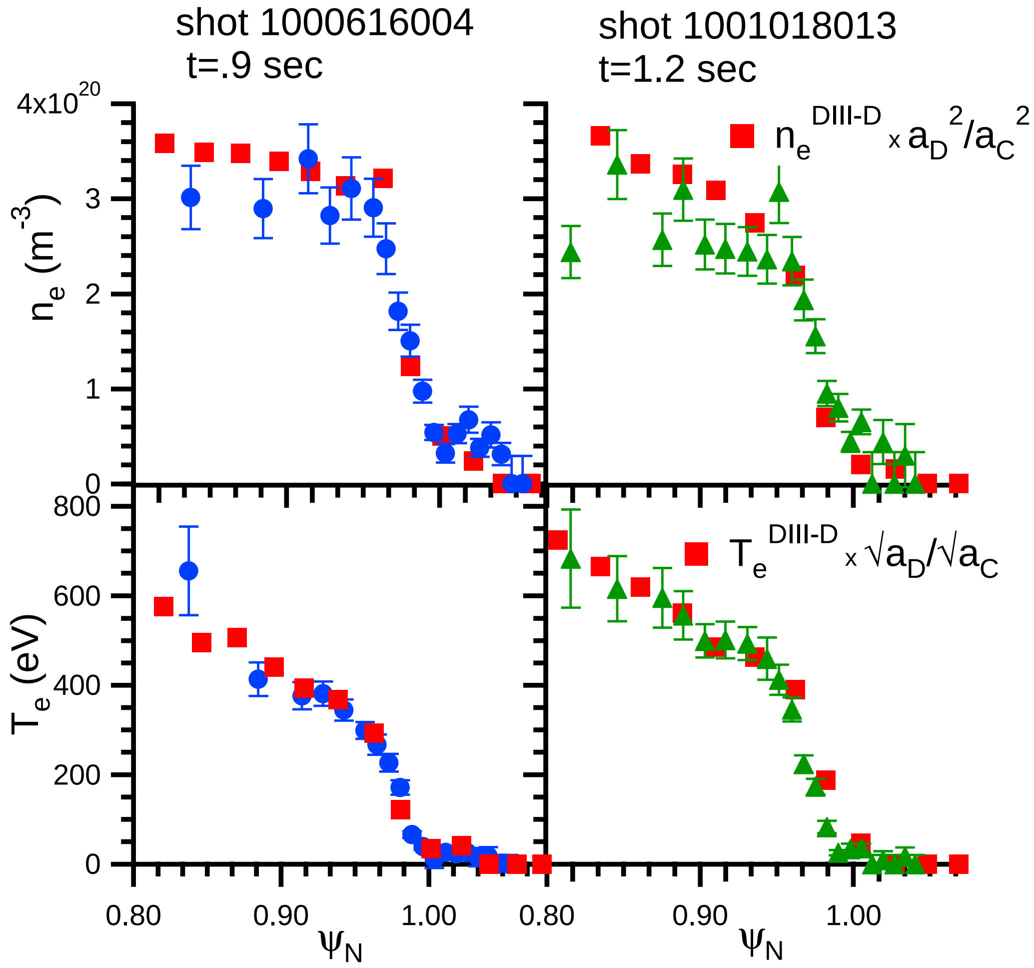


Figure 2.3-2: Edge density and temperature profiles from dimensionless identity experiments performed in collaboration with DIII-D are plotted against normalized radius. The DIII-D points (squares) have been normalized appropriately for comparison with the C-Mod profiles (circles and diamonds). The match of profiles when the plasma physics dimensionless quantities are matched at a single point, strongly suggests the dominance of plasma physics in determining the pedestal shape and height.

the research plans section.

Studies of edge stability have concentrated on H-mode regimes with either small ELMs or no ELMs at all. We have continued our investigations into the EDA H-mode, a regime that has the desirable mix of traits outlined above. The principal signatures of EDA are quasi-coherent (QC) fluctuations in the edge density, potential and magnetic field.[6] Earlier work suggested a link between these fluctuations and gyro-fluid simulations of edge turbulence by the U.Md group in which similar fluctuations were identified as resistive ballooning modes. Recent experiments found that the plasmas in the EDA regime developed small ELMs and then lost the QC mode entirely as the collisionality was lowered - a result consistent with the predicted stability of resistive ballooning.[7] The dependence of the mode stability on ion mass also matched experimental observations of the EDA regime boundaries. In collaboration with LLNL, three-dimensional, non-linear fluid simulations have been carried out using the real tokamak geometry, including the separatrix and open field lines (BOUT code). These simulations support the notion that the QC mode is a manifestation of resistive ballooning and adds important new physics due to the geometry resulting in so-called "resistive X-point" modes.[8] The simulations match the observed wavelength of the mode, but predict a somewhat broader radial extent than that observed in experiments. Analysis of PCI (phase contrast imaging) data suggests that the mode is no more than 1-2 mm in width.

Work has continued on the relationship of micro-stability and the core temperature profiles. In C-Mod, even more than in other devices, strong transport from ITG turbulence is predicted to keep the ion temperature profiles very close to marginal stability. (This prediction is supported by early observations that the temperature profiles in C-Mod show "self-similarity": the local temperature gradient is proportional to the local temperature, consistent with critical gradient-length mechanisms like ITG.) If true, this model allows the prediction of the temperature profile from a stability calculation, since the profile will be forced to be very close to the critical gradient. Earlier work with physics-based transport models found a substantial discrepancy with C-Mod profiles, the difference being traced to the linear calculation of the critical gradients used in these models. Results from a non-linear gyro-kinetic code (gs2) have been compared in detail to experimental profiles. These show reasonably good agreement, certainly within experimental error, and point out some important physics in the dynamics of the ITG mode. They support the notion that non-linear processes, in particular the generation of zonal flows, can lead to an upshift in the critical gradient by a substantial factor. However, unlike earlier studies, these did not find that the zonal flows were principally damped by collisions. Instead, by properly treating electron dynamics, the simulations found that a tertiary mode was responsible, leading to the opposite scaling with collisionality than that which had been expected. The results can be seen in Figure 2.3-3, which compares the linear calculation with two non-linear simulations, one with the actual C-Mod collisionality and the second with that collisionality artificially reduced. These results explain why the non-linear calculations were necessary for C-Mod, with its higher collisionality, but were not as important for lower collisionality experiments, which were reasonably matched by the linear theory. Note that this analysis suggests that future machines, with lower collisionality, should also run closer to the linear threshold and thus have lower temperature gradients and somewhat poorer confinement than would be predicted from more optimistic estimates of the non-linear upshift.

Significant experimental time has recently been devoted to studies of discharges with internal transport barriers. These studies are particularly noteworthy as they are achieved with ICRF and ohmic heating alone and thus do not include the external momentum and particle sources which accompany standard ITB experiments performed with neutral beam heating. Because of the high densities in C-Mod, $T_i \approx T_e$, which is prototypical of the reactor regime. The ITB regimes in C-Mod are characterized by peaked density

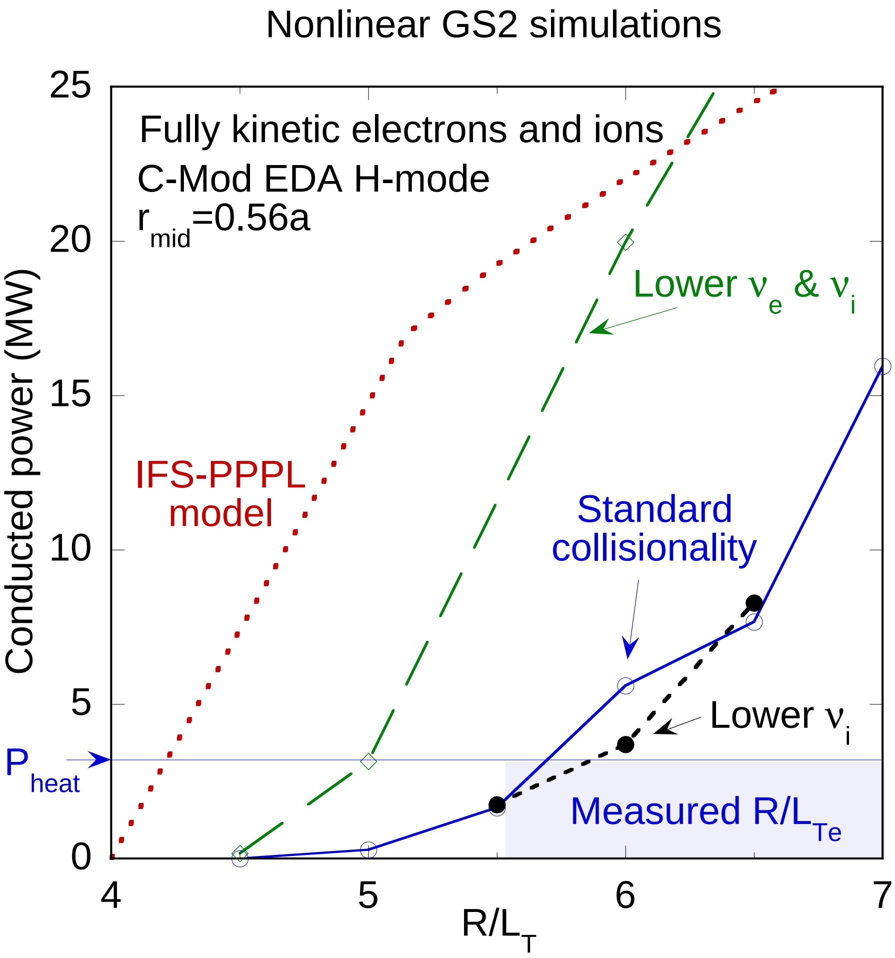


Figure 2.3-3. Results of non-linear, gyro-kinetic simulations are compared at various values of ion and electron collisionality and to the linear calculations. The non-linear runs at the measured collisionality are in reasonable agreement with experimental values, $Q_{NORM} \equiv 15$ and $R/L_T \equiv 5.5$-7, while the linear runs predict significantly lower temperature gradients. The work also points up the importance of correctly treating electron dynamics in the simulations.

profiles and sharply reduced thermal diffusivity inside the barrier. Studies of the gyrokinetic stability of the ITB regimes have found that the ITG modes are stabilized within the barrier by the peaked density profile, that is where $L_n \leq L_T$. The trapped electron mode (TEM) is also found to be stabilized inside the barrier foot ($0 \leq r/a \leq 0.3$) by the high densities (increased collisionality reducing the importance of trapped particles) but is destabilized by the steep density gradient within the barrier foot region ($0.3 \leq r/a \leq 0.5$). The TEM growth rate is found to increase with the application of central ICRF heating power which is consistent with increased T_e and decreased collisionality (destabilizing). The role of ExB shear in the stability of these modes is being investigated.

Because the C-Mod ITB modes are achieved in normal shear - that is sawtoothing

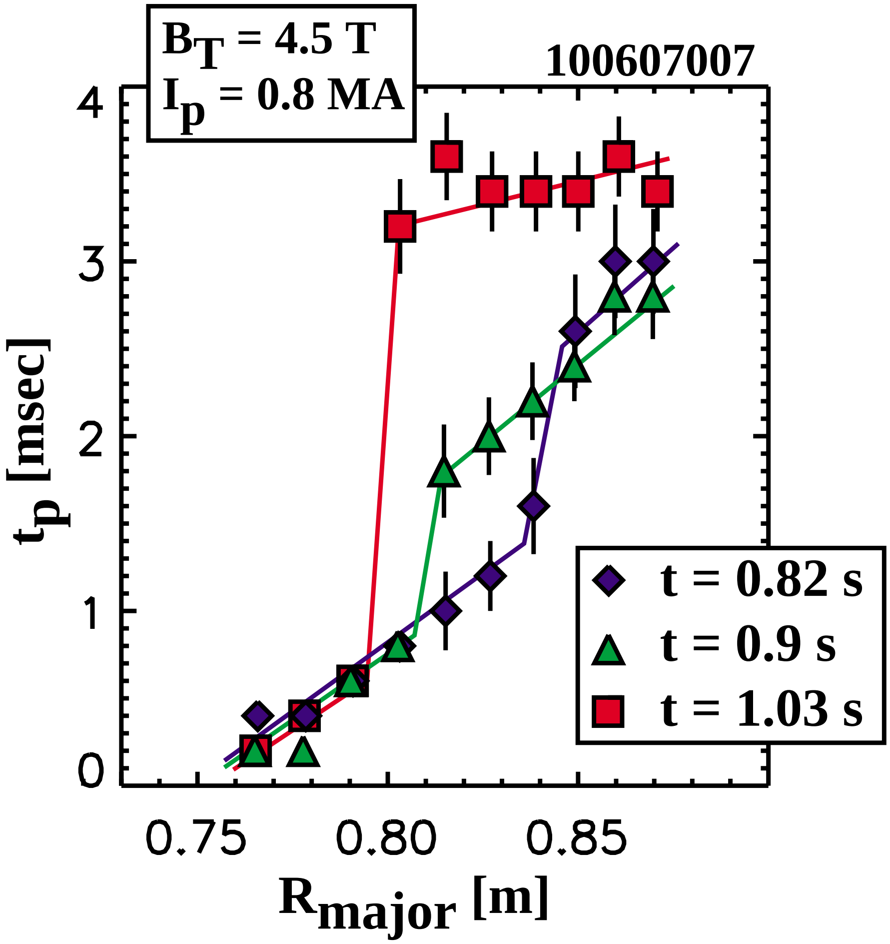


Figure 2.3-4: Data from heat pulse propagation experiments in RF produced ITBs are shown for three different times during the formation of the barrier. The time-to-peak is plotted against radius and implies a narrow region of sharply reduced transport which propagates as the barrier forms.

- discharges, there is the unique capability to probe the transport barrier via heat pulse propagation from the sawtooth collapse. Results of such analysis can be seen in Figure 2.3-4, where the time-to-peak is plotted for heat pulse propagation from several sawteeth which occurred during the development of the barrier.[9] The steep jumps in the curves implies a very narrow barrier region and some propagation of the barrier is seen after its formation. Numerical solutions of the diffusion equation for the electron temperature perturbation induced by the sawtooth pulse show that the time-to-peak data are consistent with a χ^{hp} profile that has a narrow region of reduced transport. This conclusion is somewhat different from the transport analysis results from TRANSP, where it was found that the χ_{eff} profile showed a reduction throughout the region inside the barrier foot.

Research Plans

Reliable extrapolation of favorable operating regimes can only be achieved through a more complete understanding of the underlying phenomena. To that end, a significant effort will be devoted to mapping out the 'phase space' of the observed edge regimes. These regimes include L-mode, H-modes with type I, II, and III ELMs, as well as ELMfree and EDA H-modes. In these experiments, we will exploit the higher input power and increased shaping capabilities that are now available. In order to make closer contact to the underlying physics, the emphasis in these studies will be on local variables and profiles rather than global parameters. The operating space to be examined will include scans of input power, plasma current, triangularity, and density - with the aim of independently varying the plasma gradients and collisionality as well as those variables that affect micro- and macro-stability. The results of these studies can be compared directly to the output of microstability codes like gs2 and macrostability codes like ELITE. These studies will include further work on the L/H threshold. A principal goal will be to elucidate the role of the edge temperature, which has been shown to be a key parameter in the L/H transition. Improved pedestal diagnostics should enable us to determine whether the temperature or its gradient is more important and whether the pressure or pressure profile plays a critical role. The effects of triangularity on the threshold will be explored and studies of the transition in double null discharges will be included. Working with the edge/divertor group, we will attempt to understand the origin of the ∇B effect on the threshold by careful studies of SOL profiles, fluctuations and flows. Finally, an attempt will be made to trigger an L/H transition by directly manipulating the radial electric field. In these experiments, the ICRF resonance will be set at the plasma edge on the high-field side, which should create a population of energetic ions on lost orbits. The preferential loss of ions should create an E_r well and may drive the transition.

Studies of the EDA H-mode regime will include further comparisons with simulation codes. These codes make a number of concrete predictions that are testable with our current set of diagnostics. In addition to the low frequency QC mode, the simulations find higher frequency fluctuations due to drift-Alfven and geodesic curvature modes (Figure 2.3-5). These are in the MHz range - which can be accessed with some modest modification of the PCI system. Experimentally, the EDA/ELMfree boundary is found to depend strongly on q and δ. The database for these observations will be widened with the improved capability for shaping and compared to systematic numerical studies. Improvements in the high-resolution x-ray diagnostics along with charge exchange spectroscopy from the new diagnostic beam should allow better measurements of the rotation profile. These in turn will allow more quantitative comparison between the predictions of the code and the measured mode frequency. At the same time, joint experiments carried out in collaboration with the JET and ASDEX-Upgrade teams will search for the EDA on these devices. Similarly, we will work with the W7-AS stellarator group in comparing their newly reported IC mode to the EDA in C-Mod.

Pedestal scaling experiments will be continued, including the similarity experiments carried out with DIII-D, and will exploit the new shaping capabilities and increased RF power available. The focus of these latter experiments will be on resolving the debate over the relative importance of plasma physics compared to atomic physics in determining the

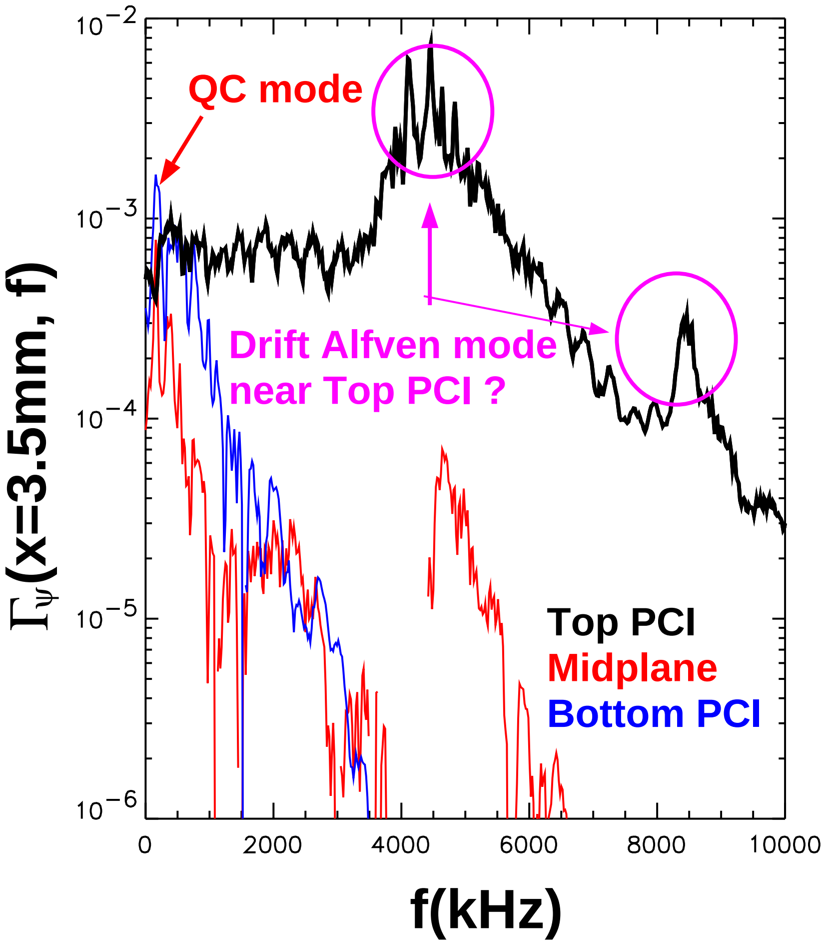


Figure 2.3-5. The amplitude of fluctuations from a non-linear fluid simulation shows a low frequency feature with similar wave number to the QC mode observed in EDA H-modes. The simulation also predicts higher frequency fluctuations which should be measurable with a modified PCI system. Observation of these high-frequency modes would tend to confirm the validity of the simulations and their identification of the QC mode.

pedestal profiles. The approach of these studies will be to alter the neutral interactions independently of the bulk plasma parameters. Techniques which will be used include: inner and outer gap scans, which can localize the plasma wall interactions and the fueling source; density scans, which change both the magnitude and the location of the neutral source; and comparison of helium and deuterium discharges. This last case relies on the difference in neutral penetration and recycling for the two species. Experiments are also in progress for dimensionless identity studies with the ASDEX Upgrade device. These include both threshold and pedestal scaling experiments and should provide useful information on the role of neutrals as well.

Magnetic shear is an important parameter in determination of the critical gradient for

ITG modes and so far has been estimated only from EFIT reconstructions. With the employment of the MSE diagnostic to measure current profiles, studies of core micro-stability can be carried out with greater precision. The anticipated accuracy of the measurement will make a quantitative difference on the comparison between theory and experiment. The calculations will be extended to a wider variety of discharge conditions with an attempt to verify specific predictions, (for example the dependence of the non-linear upshift on collisionality.) At the same time, HIREX and CXR measurements of the rotation profile will allow the assessment of the role of ExB shear in non-ITB discharges. Measurements of core turbulence with BES and the upgraded PCI system should allow localized measurements of core density fluctuations. These can be compared in detail to the predictions of the non-linear codes. Overall, the aim of these studies is to understand the nature of turbulence and transport close to the marginal stability point.

While gyro-kinetic stability studies have provided a rudimentary understanding of the fully developed ITB discharges, the origins or "trigger" for the mode remains a mystery. The peaked density profile, which suppresses the ITG modes in the developed ITBs, is entirely absent at the onset of barrier formation. The current profiles are peaked and the magnetic shear is normal in these plasmas, unlike the typical recipe for ITB formation where reversed shear from current ramping is used to lower the growth rate of dominant instabilities. Further, two other stabilizing effects, the Shafranov shift and plasma rotation are unexceptional in these discharges. Experiments and modeling will examine the role that off-axis heating may be playing. One hypothesis is that the off-axis heating leads to reduced core temperature gradients. For discharges near marginal stability, this could correspond to greatly reduced levels of turbulence. If this turbulence were responsible for particle as well as energy transport (a reasonable assumption for ion modes), the reduction in turbulence levels could lead to density peaking and self-sustainment through η_i stabilization. This hypothesis will be tested by varying the ratio of on vs off-axis heating and analyzing the onset and hysteresis of the ITB regimes, while monitoring flows, profiles and fluctuations. These can be compared to stability calculations for the resultant profiles. Fluctuation measurements should allow assessment of the magnitude of core turbulence throughout this process. Heat pulse analysis will be expanded by use of an upgraded, soft x-ray imaging array.

The new and upgraded rotation diagnostics will also be employed to investigate the origins of the strong rotation which is commonly observed in C-Mod.[10,11,12] This rotation, which occurs in both ohmic and ICRF discharges, is not due to an external momentum source, as would be the case with neutral beam injection. So far, observations have not been consistent with theories based on production of radial ion currents by ICRF interaction with the hydrogen minority. The increased range and sensitivity of the new systems will allow measurement across the entire profile and should help in the understanding of this phenomenon.

In addition to the heat pulse experiments described above, a number of studies using analysis of transient phenomena to explore transport are planned. The provision of thicker carbon laser blow-off targets should enable us to carry out cold pulse experiments, where the plasma edge is rapidly cooled by injection of a finite quantity of impurities. Previous experiments on the TEXT device found anomalous core heating following the injection, results which are difficult to understand in the standard framework of diffusive transport.[13] Energy transport will also be explored via localized modulated heating using mode converted IBW waves. These will allow us to map out the incremental diffusivity and compare it to models based on marginal stability. To explore particle transport, injection of trace quantities of non-recycling, non-intrinsic impurities will be used to obtain improved measurements of impurity transport coefficients. Similarly, modulated gas puff experiments will attempt to measure the transport of the working gas. Using the improved rotation measurements, the transient response of the flow profiles will be analyzed to get an estimate of momentum transport in source free discharges. If MCIBW flow drive experiments are successful, this method could also be used to drive transients which could be analyzed to recover momentum transport coefficients.

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2.4 Edge and Divertor Physics

Connection to Integrated Program Planning Activity

Edge and divertor research on Alcator C-Mod is well aligned with the FESAC goals contained in the IPPA report.

A number of diagnostics are being utilized to provide characteristics of the SOL and across the separatrix. The information, provided in the form of profiles and turbulence measurements, are all important for determining the accuracy of transport models (*predictive capability* - IPPA 1.1.1) and more specifically to the region of the separatrix (*integrated models of core and edge physics* -IPPA 1.1.3; *coupling between edge and core plasmas* - IPPA 1.4.2).

The analysis of perpendicular transport in the SOL is aimed at a general understanding of *plasma edge physics* (IPPA 1.4.1). The focus is not only on characterizing the perpendicular transport, but in determining the underlying physics (*pursue fundamental research in plasmas* - IPPA 1.5.1). This has lead to a new understanding of the relative role of divertor and main chamber walls. In particular, it has been found that there is much more interaction with the walls (*plasma wall interaction* - IPPA 1.4.3) than previously thought. There are significant levels of particle and heat flows to the wall. The latter may be very important in understanding the density limit which reflects back on the goals - *coupling between the edge and core* - IPPA 1.4.2, and *disruption control/amelioration* - IPPA 3.2.4.

The strong cross-field transport of particles and heat appears to lead to wall impurity sources. The mechanisms for such impurity sources (e.g. sheath rectification and sputtering) and resultant transport to the core can be characterized as contributing to *plasma edge physics* - IPPA 1.4, and *general plasma science* - IPPA 1.5.1. We have varied the antenna limiter material from molybdenum to boron in an effort to evaluate the relative merits of these two materials. This is part of a general emphasis on improving the core plasma through improving materials used for the first-wall (*materials* - IPPA 4.4).

All of the above work is useful for development of so-called ‘advanced tokamak’ plasmas as well as ‘burning plasma’ scenarios. In addition we have spent time addressing the control of plasma density in an all-metal machine (*profile control; low-density divertor operation* - IPPA 3.1.1).

We have made a number of important advances in understanding divertor physics and more specifically detachment physics (*plasma-wall interactions* - IPPA 1.4.3), and this work will continue.

Recent Accomplishments

C-Mod experiments have outlined the roles that cross-field particle transport in the edge plasma can play in a tokamak discharge [1,2]. Cross-field particle transport can be so rapid as to compete with flows along field lines toward the divertor. This in turn affects the level of recycling in the main-chamber and the degree to which neutral baffling can be used to affect main-chamber neutral densities. The underlying transport mechanism appears to involve 'bursty' transport events, rendering the often assumed 'diffusive' paradigm of transport inadequate. Moreover, the 'bursty' transport behavior begins to invade closed flux surface regions at high density, hinting that the empirically observed discharge density limit may directly involve edge transport physics. A number of experiments and diagnostics developed during the past year have been focussed on the topic of edge plasma turbulence and resultant transport and its effect on the tokamak discharge.

The scrape-off layer (SOL) in C-Mod exhibits a two-zone structure, a 'near SOL' ($\sim$ 5 mm zone near separatrix) with steep density and temperature gradients and a far SOL with flatter profiles. Recent measurements and analysis of the fluctuations in the far SOL of visible light emission [3], and density, potential, and particle fluxes [4] clearly exhibit non-Gaussian statistics with long-time correlations [5], characteristic of a self-organized criticality system. The cross-field particle fluxes driven by these transport events are large, consistent with previous observations (based solely on global particle balance) of a large level of main-chamber recycling.

During the past year, a new gas-puff imaging (GPI) diagnostic has been developed in order to study the physics of the 'bursty', intermittent transport in the plasma edge and SOL. The diagnostic employs high resolution ($\sim$0.2 cm) spatial measurements ($>$ 1000 pixels within a 6 cm x 6 cm poloidal cross-section) [6]. This is accomplished by viewing emission from a localized gas puff with gated and/or fast framing (up to 1 MHz) cameras. We observe the 2D structure and dynamics of the emission and often find localized, intermittent features (also sometimes called "blobs"). See Fig. 2.4-1a.

In addition to this improvement in imaging edge turbulence, recent advances in the numerical modeling of edge turbulence now allow detailed comparison with the experimental observations. In particular, we have compared directly the patterns of the 2D radial vs. poloidal turbulence calculated from 3D non-linear drift-ballooning codes [7,8] with those of the experimental images [3,6]. Fig. 2.4-1(b) shows the result from one of the simulations. We find that the average size-scales, fluctuation amplitudes, and diffusion coefficients of a local simulation (using measured n_e, T_e, and their local gradients) agree to within about a factor of two with the measurements. However, there appear to be significant differences in the turbulence autocorrelation times and the k_{pol} spectrum.

A cross-check of fluctuation-induced particle fluxes as recorded by the fast-scanning Langmuir probe with particle fluxes inferred from global particle balance yielded a surprising but very important result: the fluxes recorded by the electrostatic probe are not indicative of the fluxes in the unperturbed plasma. Rather, the fluxes recorded by the probe appear to correspond to the perturbed flux that must 'fill-in' the probe-induced presheath zone [9]. This result has potentially broad consequences; fluctuation-induced fluxes recorded by electrostatic probes have been used for many years to draw conclusions

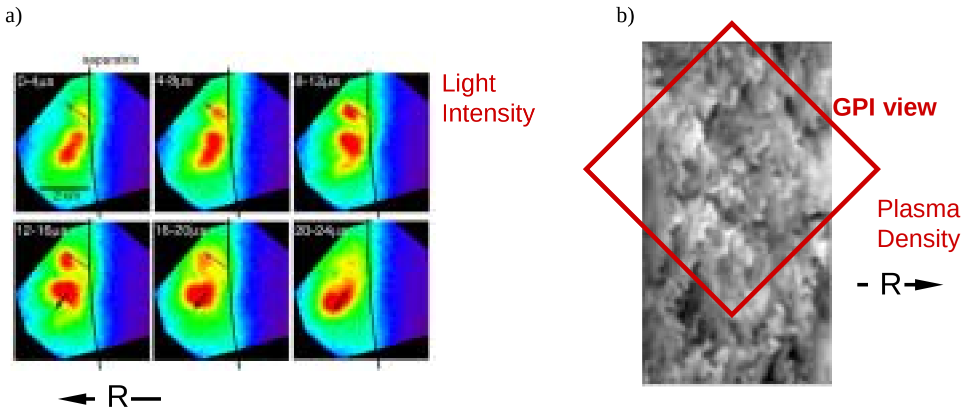

Figure 2.4-1(a). Six consectutive experimental images of D_α emission showing the space and time evolution of the edge turbulence in the R,Z plane. The black line is the separatrix location. The top arrow indicates the outward (toward the vessel wall) and upward movement of one "blob". The black arrow indicates the movement of another. Both arrows remain in the same position frame-to-frame. Figure 2.4-1(b) Snapshot of the density fluctuations in the R,Z plane (in grey scale) from a 3D non-linear simulation of the C-Mod edge. The simulation uses the time-averaged densities, temperatures, and respective gradients that were measured in the discharge whose turbulent emission is shown in (a).

about transport in the unperturbed plasma. The particle fluxes measured this way are quantitatively inaccurate. It remains to be determined if other features of the plasma turbulence are affected by the presence of the probe (k-spectrum, coherency, etc.).

During the past year, we have explored in more detail edge plasma profiles in discharges near the density limit. Owing to the reduced temperatures near the separatrix in these discharges, the scanning probe could be used to record profiles more than 1 cm inside the separatrix. The 'flattened' density and temperature profiles near the separatrix (observed previously) were found to persist even 1 cm inside the separatrix. A transition in the profile to a 'bursty' fluctuation character was also found to exist inside the separatrix.

Previous results have shown that there are significant radial fluxes in the SOL, competing with parallel flow of plasma into the divertor. In the past year we have performed a series of experiments to determine the relative contributions of wall recycling and divertor leakage to the midplane pressure. For the limited data set available we have found the contribution of wall- recycling is large: it appears to be larger than the divertor leakage [10].

An experimental effort has also been started to see if the C-Mod results are unique. D. Whyte has been working (with B. Lipschultz) to measure SOL parameters in DIII-D and see if the radial fluxes scale similarly to those in C-Mod. For a set of 3 different densities (L-mode plasmas) we have found that the density and density profile shapes scale from C-Mod to DIII-D and appear essentially the same - a sharp falloff near the separatrix with a broad density profile further out [11]. In addition, applying the same ionization radial ion flux analysis to C-Mod and DIII-D SOL plasmas shows similar trends. The radial fluxes are roughly constant across the SOL (are not drained to the divertor) and become stronger as the core density is raised. Both experiments show similar SOL characteristics in H-mode.

The wall recycling studies had another benefit. We now have a better understanding of the potential of putting a cryopump in the upper divertor. We have found that when the second separatrix (lower x-point dominant) is within ~ 5 mm of the first separatrix at the midplane, the upper divertor pressure can be significant (several mT). Such pressures indicate that we could locate the cryopump in the upper divertor while still operating with the lower divertor receiving most of the heat load. Even higher pressures can be obtained as the equilibrium becomes closer to double-null. This is demonstrated in Figure 2.4-2.

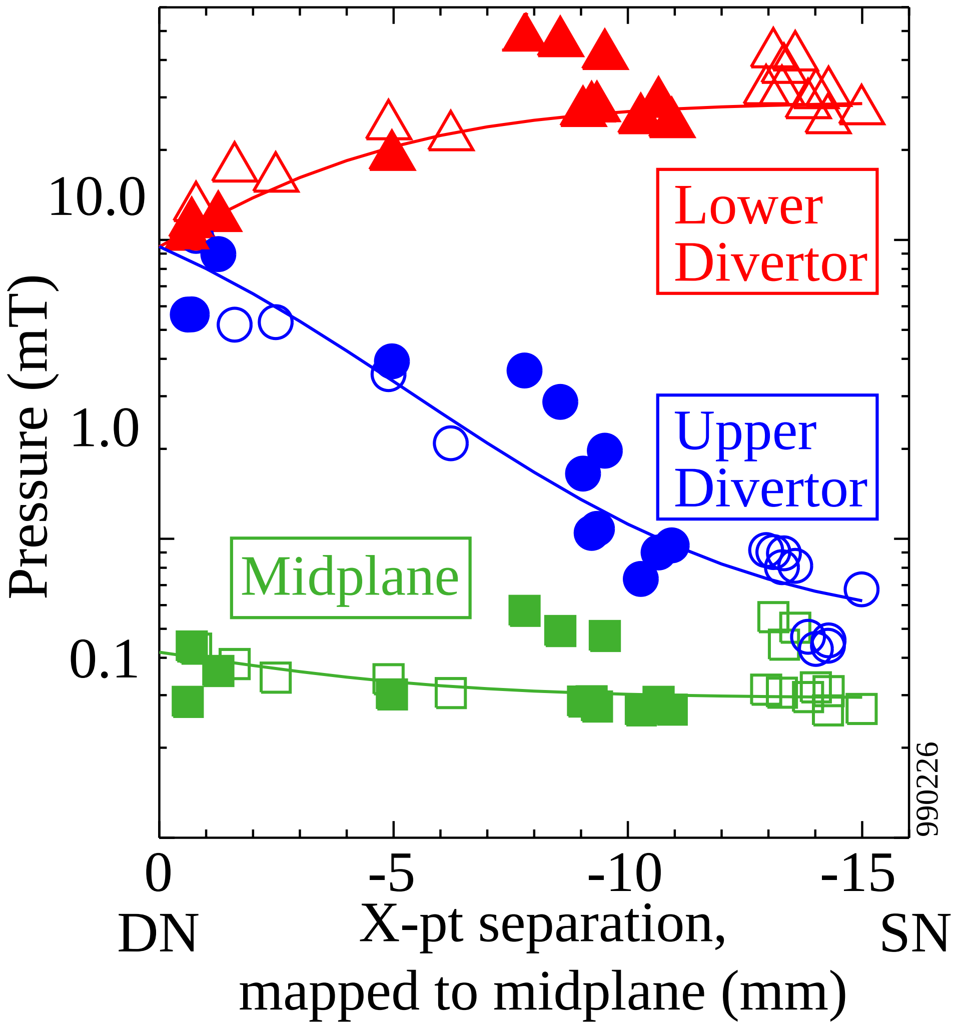

Figure 2.4-2. Changes in measured pressures as the magnetic configuration is changed from double-null to strongly lower-single null. When in a double-null configuration, the pressures in the upper, open divertor and in the lower, closed divertor are essentially equal. The pressure in the upper divertor is significant even for lower single-null configurations.

At the high level of neutral pressures in the divertor of C-Mod, neutral-neutral collisions become an important player in the neutral transport dynamics. C-Mod experimental data therefore provide an important test for divertor physics models. The University of Toronto group has started modeling the flow of neutrals in the divertor region and the resultant neutral pressures using an onion-skin plasma model (OSM) coupled to a Monte Carlo neutral transport code (EIRENE). Although the OSM-EIRENE code contains one of the most complete descriptions of neutral transport physics to date, the code yields pressures that are too low, suggesting incomplete or incorrect physics models. In addition, they have found that toroidal asymmetries in the divertor structure may lead to variations in the divertor pressure. As a results of this work, experiments are being planned with improved neutral pressure and flow measurements to provide a better bench-mark test of the code.

The Monte Carlo code, DIVIMP, originally developed at the University of Toronto has been useful this year in explaining previous impurity compression results [12,13]. These simulations have reproduced a number of experimental findings regarding the compression ratio (the ratio of impurity neutral density in the divertor to impurity ion density in the core plasma) for recycling impurities (helium, neon, argon and krypton). At a given plasma density, this ratio increases with atomic number and this is reproduced in the DIVIMP simulations, with respect to both the relative trend and the absolute values (within a factor ~ 2). The code indicates that two processes dominantly determine impurity compression: the friction of the hydrogenic plasma on impurity ions as the plasma flows towards the divertor plates and the leakage of impurity neutrals through various gaps in the divertor plate structure [14].

We have expanded our study of impurity sources from different locations to include B and F in order to understand how these impurities affect plasma performance. We have found that B and Mo divertor sources scale similarly while B and Mo source rates at the inner wall differ. We are now in the process of modeling these data as well as comparing such behavior to that observed with another low-Z impurity, carbon, in other tokamaks such as JET, DIII-D and JT-60U.

Research Plans

The understanding of transport in the separatrix/SOL region and its relationship to the core will continue to be a strong area of emphasis of the C-Mod program. Work in FY03 and FY04 will focus on physics experiments, new and improved fluctuation measurements, and detailed comparisons of experiments with numerical simulations of edge plasma turbulence.

Experiments in the area of edge transport and turbulence during FY03 and FY04 will be aimed at exploring the radial/poloidal dependence of turbulence and its statistics, the scaling of turbulence/transport with discharge conditions (EDA H-modes, RF power scans, discharges near the density limit), and separate measurements of density and temperature fluctuation fields. As the lower hybrid power is ramped up in FY03/04, we will also be looking at the response of the SOL plasma and fluctuations.

A number of new and improved diagnostics will be developed and operated in the FY03/04 experimental campaigns. A new inner-wall fast scanning probe, being developed during the FY02 run campaign, will be fully operational in FY03/04. Its location is shown in Figure 2.4-3. In addition, measurements of D-alpha fluctuations near the inner wall will be performed. These new diagnostics combined with those presently operating will allow us to examine the poloidal variation in plasma turbulence and flow characteristics. The recently developed gas-puff imaging system (GPI) [3,6] has proven valuable in allowing us to visualize edge turbulence.

Improvements/upgrades to this system during FY03/04 include "two-color" imaging (i.e. imaging the same view with two different emission lines) in order to separate density and temperature fluctuations, and the use of more advanced fast-framing digital cameras (128x128 resolution, 250,000 frames/second) being developed by Princeton Scientific Instruments. A two-color upgrade to the fast visible-diode diagnostic will also be performed, enabling time evolution measurements of density and temperature fluctuations.

With these new/improved diagnostics, in combination with a series of dedicated experiments, we will continue to explore the evolution of the transport and turbulence in the edge plasma as discharges approach the density limit. Areas of focus in these experiments will include: plasma profiles and fluctuation characteristics inside the last closed flux surfaces, evolution of SOL flows, and the poloidal/radial variation in turbulence.

During FY03/04 we are planning experiments to compare probe-measured fluctuations with those from infrared visible imaging. This will allow the turbulence field in the vicinity of the probe head to be imaged with a GPI system. Also, by inserting the probe deep inside the plasma, this system will be used to study fluctuations inside the separatrix. With the injection of gaseous impurities from the probe, the cross-field dispersal of resultant impurity ion 'plumes' will be studied, and the pattern of local ExB flows can be inferred.

The connection to modeling is crucial to the interpretation of the turbulence measurements. We have a working relationships in place with theorists (Klaus Hallatschek, presently at MIT, Barrett Rogers at Dartmouth U. and Bill Nevins and X. Xu at LLNL) running two of the most sophisticated turbulence codes in the world [7,8]. Both codes do 3D non-local electromagnetic turbulence simulations using non-linear plasma fluid equations. One of them, the BOUT code, does this using a realistic divertor geometry. These relationships foster not only direct comparison with the C-Mod experimental results, but also benchmark the codes against each other. Our goals in this comparison of experiment and theory are nothing less than understanding the first-principles physics of the SOL turbulence. We will attempt: 1) to simulate the dynamics and evolution of the observed intermittent structures ("blobs") from their birth near the separatrix; 2) to match the observed radial and poloidal k-spectra; 3) to simulate the apparent two-zone (near-SOL and far-SOL) structure in the SOL profiles; 4) to reproduce the scalings (or lack thereof) in measured transport levels with plasma parameters; and 5) to reproduce the observed

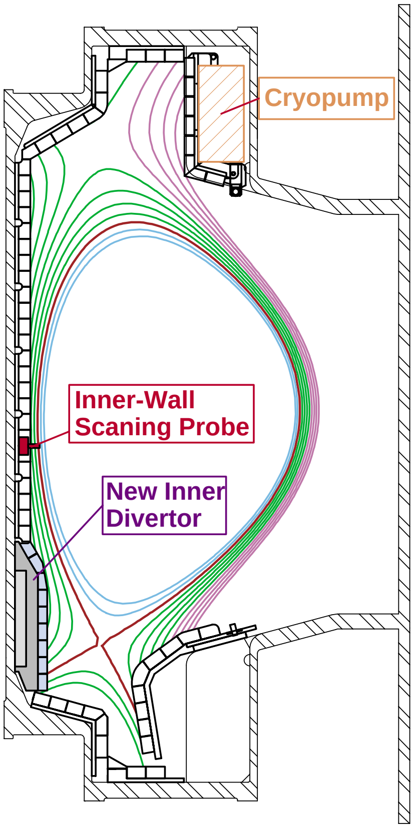

Figure 2.4-3. A cross-section of the machine showing 1) the location of the inner-wall scanning probe, 2) the shape of the new inner divertor, and 3) the schematic location of an upper divertor cryopump.

statistics in the fluctuating quantities. The codes will be tested especially in the regime that approaches the density limit, since we believe that the density limit and the SOL turbulence are intimately related (see above). One of the methods we will apply is the use of "synthetic diagnostics" in the simulations. This means post-processing the simulation results so that an experimental measurement is mimicked, e.g. when comparing to the ion saturation current measured by a probe, construct the I_{SAT} signal from the simulation's density and temperature.

We have made a commitment to develop better density control on C-Mod. This capability may prove crucial to the success of the AT program to keep the density low enough to achieve efficient current drive in different parts of the plasma. Past experiments have demonstrated that we can achieve reasonable pressures in the upper divertor even when the lower X-point is dominant. (See Figure 2.4-2.) Experiments are planned for FY02 to better characterize the dependence of such pressures on the degree of single-null vs double-null, triangularity and other plasma conditions. Based on this work we will start a design for a cryopump in the upper divertor in FY02-FY03, with installation in FY04. The location of such an upper divertor cryopump is shown schematically in Figure 2.4-4. Such an installation will mandate modification of the upper divertor as well.

We also have plans to understand the role of the walls in pumping and gas release in C-Mod. In FY02-03 we have experiments planned in collaboration with Dennis Whyte of UCSD/DIII-D to determine the amount of pumping done by the wall and furthermore, how much of that pumping is due to codeposition vs. wall absorption. This will be part of an ongoing effort to extend our knowledge of long-pulse plasmas and the role of the wall. During FY04 this work will include the effect of the cryopump.

Another area of development that we believe will be crucial for the success of both the AT and burning plasma support programs is the upgrading of the lower divertor and accompanying diagnostic set. The description of the future upgrade of the outer divertor described in the facilities section (3.1) of this proposal. The design work will likely start in FY04. In the meantime our efforts will be primarily on developing divertor components that can withstand higher heat fluxes. This work will be in collaboration with Sandia Laboratory Albuquerque (M. Ulrickson) and include in FY02-03 the testing of several W brush tiles in the outer divertor. In FY03-04 we plan to incorporate the results of that work into the design of the new outer divertor and perhaps replace a section of the current outer divertor with W brush tiles. In parallel, we will be working with Sandia to ascertain the viability of the liquid metal divertor concept.

In order to understand what the performance limits of the divertor are as we prepare for LHCD and long pulse, we need to improve our divertor surface diagnostics. In particular, we plan to develop infrared and visible imaging systems for monitoring both the inner and outer divertor in FY03-04. A new thermocouple set has been installed in the inner divertor. The same will be installed in the outer divertor.

As part of the effort to maximize our pulse length and core cleanliness we will continue our work on measuring impurity sources and screening. We have some amount of impurity source rate monitoring through spectroscopic views. This will be enhanced in FY04-05. The present work utilizing DIVIMP to understand impurity compression will continue at least into FY03. Collaborative work with JT-60U (T. Nakano) and DIII-D (D. Whyte) on comparing low- and high-Z first wall impurity source rates is planned to be continued through FY04.

Further development of our understanding of wall recycling - when it occurs and its relative role in determining the midplane pressure - is dependent on better diagnostics and modeling. During FY02-03 we will continue to develop Penning gauge measurements of divertor pressure that can be placed anywhere and have fast response time. More views of the regions above the divertor bypass valves are required to measure leakage rates. New camera views of the structures around the tokamak will help us identify the locations of wall recycling. On the modeling side we will continue to rely on our collaboration with U.

Toronto to push the modeling to understand the data.

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2.5 MHD

The Alcator C-Mod MHD research program addresses issues of macroscopic stability encountered in the context of the overall C-Mod Program. Major topics of past and current interest inlude Disruption Physics, energetic particle modes associated with ICRF tail ions, instabilities associated with the H-mode pedestal, and beta-limiting core instabilities. In addition to IPPA Goal 1.2 (Macroscopic Stability), the pedestal stability research, particularly with respect to the Quasi-coherent Mode, also relates to IPPA Goal 1.1 (turbulence and transport), while the disruption physics and mitigation work contributes to IPPA Goal 3.2 (disruption mitigation).

Recent Accomplishments

Previous work established that the quasi-coherent (QC) mode, which is a signature of the EDA H-mode, has a strong magnetic component. More recent measurements, and analysis by several of our theoretical collaborators, have led to a tentative identification of this mode as having a resistive ballooning character. The QC mode is observed in a region of parameter space characterized by moderate edge q, typically $q_{95} > 3.5$, and pedestal temperature, $\mathrm{T_e} \leq 450\mathrm{eV}$. Measurements using magnetic loops mounted on a scanning probe confirm that the mode has $k_\theta \sim 1.5cm^{-1}$.

At higher ∇P and higher $\mathrm{T_e^{ped}} > 450\mathrm{eV}$, grassy ELM activity appears. Analysis of ideal ballooning stability of the C-Mod edge shows that the edge pressure gradient is not limited by infinite n ideal ballooning mode if edge bootstrap current, even strongly reduced by high edge collisionality, is taken into account. Linear stability analysis, using the ELITE code, of coupled ideal peeling/ballooning medium n modes driven by the combination of edge pressure and current gradients, shows that the modes become marginally unstable at the C-Mod edge in the range of pressure gradients where the grassy ELMs are observed. This result is consistent with a model of the ELMs as intermediate n peeling/ballooning modes. On the other hand, demonstrated stability of the ideal modes in the EDA regime, together with the fact that low $\mathrm{T_e^{ped}}$ is required for its existence, supports theoretical models showing the resistive character of the QC mode.

Recent operation at increased ICRF power ($\mathrm{P_{rf}} \geq 4\mathrm{MW}$) has resulted in observations of β-limiting core MHD activity. At low collisionality ($\nu_i/(\epsilon\omega_{*e}) < 0.5$) large amplitude ($5 \times 10^{-5} < [\tilde{B}_\theta/B_\theta]_{wall} \leq 5 \times 10^{-3}$) low frequency modes appear. Modes with m/n=5/4, 4/3, 3/2, and 2/1 are sometimes destabilized for $\beta_p > 0.5$ and increase in amplitude with increasing β_p until a rollover or collapse in β occurs. The largest amplitude 2/1 modes locked, strongly degrading momentum and energy confinement, bringing the central (impurity) ion toroidal rotation close to zero. While many features of this behavior are consistent with neoclassical tearing modes, detailed analysis has been unable to rule out unambiguously the possibility that the observed mode is a classical tearing mode, since the inferred Δ' is near zero within the uncertainties of the equilibrium reconstruction.

Research Plans

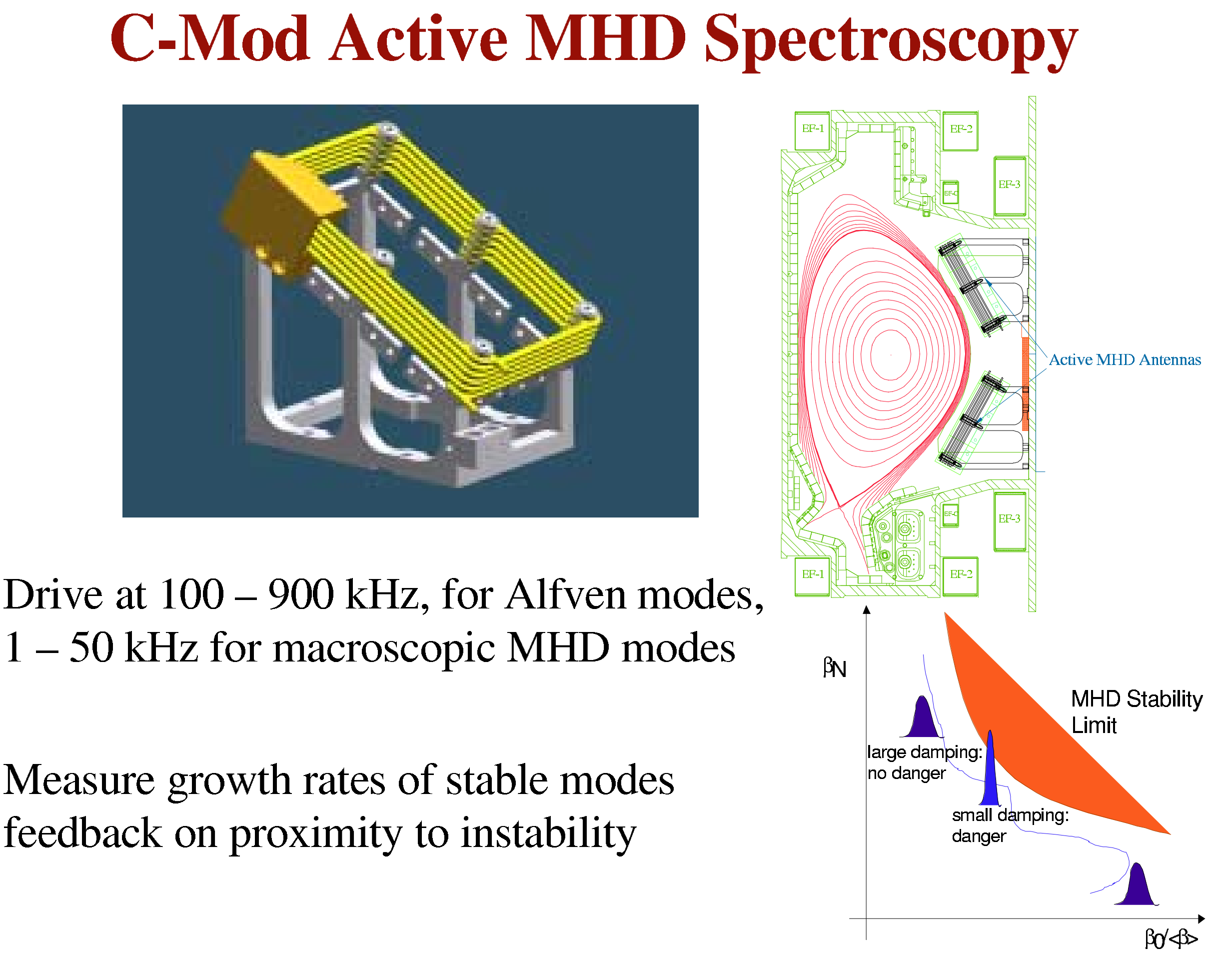
During the FY 2002 Run Campaign, the MHD Research program will take advantage of the new C-Mod capabilities for increased RF power and higher triangularity equilibria. Dedicated experiments addressing stability of the H-mode pedestal will explore the effect of shaping on access to the grassy ELM regime, and compare with intermediate-n stability calculations. We will also look for a predicted three-wave coupling of the QC mode to a higher frequency Alfvén mode and an electron geodesic acoustic mode, as observed in the BOUT code simulations. We will also be extending our investigation of low m/n tearing mode activity to higher β and lower ν_* regimes. These studies will be continued in the initial FY03 campaign, when additional run-time will allow more in-depth investigations, including coordinated experiments with DIII-D on NTM's as well as pedestal stability.

As demonstrated on JET, active MHD spectroscopy can be a useful tool for understanding macroscopic stability and for developing predictive capabilities. The system being installed in C-Mod for the 2002 campaign consists of a pair of antennas above and below the midplane on the outboard vessel wall (see Fig. 2.5-1); a second pair is planned for installation in 2003. Power supplies for this experiment will operate in both a low frequency band (1-50 kHz) to study global MHD modes, and a high frequency band ($\sim 100 - 900$ kHz) to study Alfvén eigenmodes; in each case antenna currents in the range of 10-20 A will be available. The principal objective is to search for stable modes and measure their damping rates by sweeping the antenna $\tilde{B}$ fields to identify resonant frequencies and to measure the frequency widths of the resonances (which directly give the mode damping rates). In this way, it may be possible to determine in real time whether a particular mode is getting close to marginal stability, and ultimately to take evasive action if necessary, such as reducing heating power or modifying pressure and/or current profiles before a problem occurs.

The disruption diagnostics in Alcator C-Mod have been enhanced as part of the installation of the new girdle/inner divertor project. In the design of the girdle, accommodation for arrays of Rogowski coils has been incorporated. This instrumentation will allow us to measure all of the halo current entering the wall from the inner divertor, with 36° toroidal resolution. In addition, for the first time, measurements of toroidal eddy currents will also be possible, again with 36° toroidal resolution. This will allow us to compare disruption forces produced by halo and eddy currents respectively. The toroidal symmetry of disruption eddy currents can also be studied, as can currents generated during startup and other non-disruption transients. The rangefinder laser interferometry measurements of disruption-induced flexing of the inboard vessel wall will be very useful in verifying the strengthening effected by the new girdle, and the girdle design accommodates the present in-vessel components of this diagnostic. The rangefinder capability, combined with the new halo/eddy current instrumentation, will be an enormously useful tool for studying and understanding disruption forces and vessel stresses.

For the second FY03 experimental campaign we will have installed a second pair of Active MHD Spectroscopy antennas, at a second toroidal location 72° from the first, allowing better control of the n-spectrum of the probing perturbations. During this campaign and the one that follows in FY04, we expect to make an assessment of the potential of this system to detect the approach to instability of low m/n modes, and determine whether the results are sufficiently predictive to serve as the basis for a control algorithm.

Also during the second FY03 experimental campaign, we will begin exploitation of the newly-installed Lower Hybrid Current Drive system. MHD research activities will continue to support the main C-Mod research goals during this period, as the program increases its emphasis on advanced tokamak operation. Key issues related to reversed shear, profile control, and very high β_N, such as resistive wall modes, rotation stabilization, double tearing modes, and bootstrap alignment will be addressed.



C-Mod Active MHD Spectroscopy

Drive at 100 – 900 kHz, for Alfven modes,
1 – 50 kHz for macroscopic MHD modes

Measure growth rates of stable modes
feedback on proximity to instability

Figure 2.5-1 – Active MHD Spectroscopy Antennas being installed in C-Mod to measure damping (growth) of modes in C-Mod. The first pair will be installed in FY02, and a second (at a different toroidal location) in FY03.

2.6 RF Heating and Current Drive

The two programmatic goals for the Alcator C-Mod RF group are to provide flexible and reliable ion cyclotron range frequency (ICRF) heating and off-axis lower hybrid (LH) current drive (installation in '03). The compact size, high power density, and large disruption forces present significant challenges to ICRF and LH antenna design. C-Mod provides a unique opportunity to explore RF wave propagation, heating, current drive, flow drive, and mode conversion physics in reactor relevant discharges. These investigations are facilitated by: flexible ICRF and LH systems; access to sophisticated ICRF and LH simulation codes; and the availability of advanced diagnostics for RF wave measurements.

With respect to IPPA goals, the C-Mod RF group is well situated to make significant contributions. Supporting IPPA goal 1.3, wave-particle interactions, we have available sophisticated codes (through the Scientific Discovery Through Advanced Computing Initiative (Sci-DAC Initiative)) to simulate and predict wave propagation, absorption, and mode conversion in 2-D and 3-D, and sophisticated RF diagnostics to measure wave propagation and power absorption in the presence of RF. From the IPPA Appendix III, an important question to address is *can RF waves maintain and control desirable confinement in long-pulse or reactor-scale plasmas?* Profile control using ion cyclotron and mode conversion heating, current drive, and flow drive are under investigation (IPPA 3.3.1 and 3.3.1.3). With the installation of the LHCD system, a more efficient current profile control capability will be added. This is critical to advanced tokamak operation with broad current profiles, because this is possibly the only approach capable of providing sufficient off-axis current enabling operation with fully relaxed current profiles ($t_{pulse}/\tau_{L/R} \lesssim 2$).

a. Recent Accomplishments

(i) Antenna issues

The 4-strap (J-port) antenna design modifications made before the 2001 experimental campaign have proved to be successful. The strip line modification allowed the peak RF voltage to reach 25 kV (compared to 17 kV previously) for 78 MHz operation. The postulated empirical limit allowed the successful prediction of the maximum voltage limit for the modified antenna. The tile and septum modifications resulted in reduced RF-plasma edge interactions.

Compared to the original two 2-strap antennas (D and E-port), the limited access dictates using a folded strap design and vacuum strip line for the antenna feeds for the J-port antenna. In addition, the Faraday screen and antenna box are more open than on E and D-port antennas to allow for a better current drive spectrum. The J-port heating efficiency, absorbed power to injected power, and impurity generation have been shown to be nearly identical to the other antennas, indicating the design features do not adversely affect the heating efficiency. The more open antenna box and Faraday screen design has resulted in higher antenna loading (2.5 times D and E-port antenna loading) for the same plasma conditions. For typical H-mode discharges, the J-port loading is 10-12 Ω while D and E-port are 4-5 Ω. The similar heating efficiency suggests the higher loading is the result of better coupling rather than increased parasitic loading.

Although the heating efficiency is similar, the J-port antenna voltage and power handling have been different from the other antennas. Presently, D and E-port have achieved maximum voltages of 40 kV in plasma operation. The J-port antenna has been successfully modified in order to raise the maximum voltage to 25 kV and maximum injected power of 3 MW at 78 MHz. The low maximum (antenna conditioned to 40 kV into vacuum) operating voltage appears to be related to breakdown in regions where the RF E-field is parallel to the tokamak B-field (E||B). The empirically determined average E-field (V/spacing) limit is 15 kV/cm for E||B. This appears to agree with the voltage breakdown found by the Joint European Torus RF group reported at a recent workshop.[1] The breakdown voltage for the RF E-field perpendicular to the static B-field ($E \perp B$) appears to be at least 30 kV/cm. The breakdown voltage in vacuum is greater than 40 kV/cm. Reduced breakdown voltage was first observed in the strip line power feeds. The original strip line feeds had a long strip line section where E||B in a region that reached the maximum voltage corresponding to 15 kV/cm for 78 MHz. Arc damage found during an inspection confirmed the location of the arcing. By redesigning the power feeds so $E \perp B$, the maximum voltage was increased to 25 kV at 78 MHz and 30 kV for 70 MHz. The 25 kV limit and the variation with frequency suggested the voltage limiting arcing location moved to the grounding bridge of the antenna strap itself. At this location, the RF E-field was again parallel to the static field and modeling indicates that E $\sim$ 15 kV/cm at this location when antenna maximum voltage reached 25 kV at 78 MHz and 30 kV at 70 MHz. Upon inspection, arc damage was found localized to this region.

(ii) Wave propagation physics

Analysis of the heterodyned Phase Contrast Imaging (hPCI) data from mode conversion experiments show good agreement between the measured and predicted wave numbers and the backward phase velocity of the ion Bernstein wave (IBW). Interestingly, the hPCI data also has a structure indicative of a wave with 1.5 cm wavelength (longer than an IBW and shorter than a fast wave). Since the hPCI observations are vertical chord averages, the full-wave ICRF code TORIC has been used to simulate the wave fields in these plasmas, thus aiding the interpretation. Using large poloidal mode number simulations, the IBW can be successfully resolved and the expected hPCI signals have been simulated. These simulations suggest the observed structure is density fluctuations on the low field side of the nominal mode conversion surface. If the interpretation is correct, these are the first direct experimental measurements of a rather complex wave pattern (somewhat unanticipated) in the vicinity of the mode conversion region. These results have important implications regarding the location (and localization) of IBW assisted flow drive and current drive in future experiments.

In addition to TORIC, a combined 2-D ($v_\perp, v_\parallel$) Fokker Planck and toroidal ray tracing model (CQL3-D and GENRAY) was developed to simulate the proposed C-Mod LHCD experiments. This work was done in close collaboration with R.W. Harvey at CompX. This model is more accurate than the ACCOME-LHCD module in that the exact 2-D velocity space distribution function is used to compute the wave damping and quasilinear diffusion coefficient. This is in contrast to the ACCOME-LHCD module which uses an adjoint solution of the 2-D Fokker Planck equation and does not explicitly solve for $f_\mathrm{e}(v_\perp, v_\|)$. In the adjoint method the quasilinear diffusion coefficient which is needed to evaluate the wave absorption is obtained from a $1\frac{1}{2}$-D electron distribution function. Initial calculations with CQL3-D and GENRAY indicate an enhancement of up to 30% in the driven LH current over the ACCOME-LHCD prediction. Although this result is extremely encouraging, more complete comparisons will be required during FY02-04 to increase confidence in this result.

b. Research Plans

Based on the results of the 2001 experience and subsequent analysis, the J-port antenna will be modified further to reduce the RF electric field below $\sim$ 15 kV/cm at all locations where $\mathrm{E}\|\mathrm{B}$. To reduce the RF-plasma interaction at boron nitride metal interfaces, all antenna tiles, including those on D and E-port, will be modified to shield all fasteners and metal interfaces.

The immediate FY02 run campaign objective is to evaluate the power and voltage handling characteristics of the modified J-port antenna. The impurity production of all three antennas will be compared as well, with particular attention paid to the BN-metal interface regions. Another important test for the J-port antenna is operation with current drive phasing. The coming campaign will be the first test of the power, voltage and impurity characteristics of the antenna with current drive phase. These tests can be done for both strong and weak central absorption scenarios and compared directly to D and E-port antenna performance. It is expected that the local RF-plasma edge interaction will be stronger for current drive antenna phasing. Developing a means to minimize these interactions and their impact will be an important issue to address. If the antenna proves successful, a new 4-strap design based upon that of J-port will begin, with installation planned for FY05.

Realizing high heating efficiencies in D(^{3}He) discharges is important for planned 2 MA, 8T operation. The additional heating power will allow investigation of heating efficiency with higher power and bulk plasma temperature. These are expected to strengthen the single pass absorption and improve the heating efficiency.

Another important research theme, perhaps relevant to triggering and controlling transport barrier formation, involves RF driven flows. A promising scenario for poloidal flow drive is using mode converted ion Bernstein waves (MCIBW). With present diagnostics, the poloidal rotation, RF power deposition, and RF density fluctuation profiles can be simultaneously measured. These data will allow an assessment of the amount of poloidal flow, its profile, and its relation to RF wave propagation and absorption to be made. Depending on its success, RF flow shear could be used to trigger or maintain internal transport barriers.

Localized RF current drive via mode converted IBW is another candidate for ITB sustainment. Experiments investigating the current drive efficiency will begin once antenna operation in current drive phase has been demonstrated. The driven current will be deduced from analysis of the surface loop voltage. For the off-axis case, the RF current density is expected to be a significant fraction of the ohmic current density. For centralized current drive, the predicted driven current exceeds the local ohmic current density. However, overall IBW current profile control is expected to be limited. The installation of the 4.6 GHz LHRF (lower hybrid range of frequencies) system in FY03 will provide a more efficient current profile control capability.

In the ICRF technology area, ferrite matching prototype elements will be tested under plasma conditions. If successful, the installation of such a matching technology will be sought for the ICRF system. Furthermore, tests of load tolerant antenna matching using stubs will be investigated using one of the two-strap antennas. This could result in a relaxation of the specifications of the ferrite matching elements and greatly reduce their cost.

The Lower Hybrid Project is scheduled to be completed in mid-FY2003 and physics experiments will then begin. This project will be a major tool for the Advanced Tokamak thrust, described in Section 2.1. Its long-term goal is to achieve efficient steady-state tokamak operation at moderately high $\beta_N \sim 3$, good confinement, $H_H \sim 1-2$, and high bootstrap fraction, $f_{\mathrm{BS}} \sim 70\%$.

Initial investigations of lower hybrid current drive will focus on optimizing the coupling of the lower hybrid waves to the plasma, and on evaluating possible interactions between ICRF antennas and the LH launcher. Full coupling of the LH power (3 MW at the source) to the plasma corresponds to a rather high power density, comparable to that achieved in PBX-M for relatively short pulse (0.5 s vs. up to 5 s planned in the C-Mod experiments). However, substantial current drive can be achieved even with 2 MW delivered to the plasma, and this should be considered a realistic goal for the first phase of these experiments. The double-barrier mode, produced in Alcator C-Mod with off-axis ICRF heating, presents an attractive target for initial investigations. Ideally, the density should be somewhat lower than in the present experiments in order to achieve higher driven currents. This has motivated the installation of a cryopump in FY 04 and achieving barrier formation at somewhat lower density will be a continuing subject of near-term investigations.

The primary goal of initial lower hybrid experiments in the summer, 2003 run campaign will be to evaluate the coupling efficiency of the antenna and to bring the coupled power up to the goal of 2 MW. A key issue is the extent to which a satisfactory match can be simultaneously obtained for each of the 96 waveguides that make up the grill. Sensitivity to launcher and limiter positions, and to the density and the density gradient at the antenna mouth will be investigated. Assuming satisfactory performance of the antenna, the location and spatial distribution of the LH driven current will be investigated as a function of the plasma parameters. An interesting aspect will be to determine the extent to which the profile of the driven current can be controlled by varying the parallel index of refraction at the launcher, which is determined by the phase shift between adjacent waveguides. Assuming significant current drive can be produced in this initial LH run period, the effect of replacing ohmic current by off-axis LH-driven current on the internal barrier can be investigated.

Experience with AT regimes in other tokamaks has shown that current profile measurements are indispensable to understanding the physics of barrier formation and confinement improvement, in particular the effect of magnetic shear and $q_{\min}$. As indicated elsewhere, a high priority is being placed on the development of the diagnostic neutral beam and MSE measurements in C-Mod. An additional diagnostic under development is an imaging x-ray spectrometer. Such an instrument has proven invaluable to investigating the location of the current driven by LH waves and correlating the results with theoretical predictions. We have initiated a collaboration with the Tore Supra group on the design of an imaging x-ray spectrometer and will fabricate such an instrument in FY 03, in time for the first lower hybrid experiments.

A major effort to modify the current profile with lower hybrid waves and use this tool to produce and sustain AT modes in Alcator C-Mod will take place in the FY 04 run campaigns. During these campaigns, 3 MW of LH source power and 8 MW of ICRF source power will be available. In addition, a cryopump will be installed and will be used to control the edge density, an important parameter determining off-axis current drive efficiency. The goal here will be to achieve regimes with at least 50% non-inductive current drive, with more than half due to the bootstrap effect. This will require successful coupling of ∼2 MW of LH power. Using these tools, we will investigate the production and sustainment of internal barrier modes and, with the availability of current profile control, we will seek to clarify the roles of magnetic and velocity shear. Achieving a high bootstrap fraction will require operation near the β limit and the MHD stability of these regimes will be investigated with the aid of the active MHD spectroscopy diagnostic. The potential for active stabilization of MHD modes near the β limit will be assessed. In particular we may have the opportunity to use LHCD to stabilize NTM's.

With the potential for coupling up to 8 MW to the plasma, we expect heating of the divertor plates to become an issue, particularly for pulse lengths of 3 s or more. This issue will be assessed during FY04 and, if required, a divertor upgrade will be designed and fabricated for installation prior to initiation of the second phase of lower hybrid experiments beginning in FY 05.

To explore the underlying RF wave physics, a detailed investigation comparing simulation results and experiments will be pursued. The primary areas of emphasis are wave propagation, absorption, mode conversion, and antenna coupling for both ICRF and LH. With the installation of the LH coupler in FY03, the first experiments investigating the power handling of the coupler and coupler-plasma edge will be undertaken. The LH wave propagation near the parametric decay instability density limit will be investigated. Beginning in FY04, the interaction of MCIBW and LH waves will be investigated. The testing of advanced RF computational tools developed in conjunction with the Sci-Dac Initiative (a collaborative effort including R.W. Harvey (CompX), Y. Peysson (TORE SUPRA), R. Dumont and C.K. Phillips (PPPL), M. Brambilla (Garching), and E. D'Azevedo and E.F. Jaeger (ORNL)) will be an important aspect for understanding the physics of wave propagation.

During FY03 we plan to implement a combined 2-D velocity space Fokker Planck and ray tracing module in the ACCOME current drive and MHD equilibrium code. Several important physical effects arise from self-consistent 2-D velocity space Fokker Planck simulations. As an example, it has been shown that pitch angle scattering of electrons from the negative to positive velocity direction, caused by coupled LH power at low negative phase speeds, can play a crucial role in closing the so-called spectral gap in LH current drive.[2] The main consequence of this physical effect is an enhancement in the predicted LH current. During FY03 we will also complete upgrades to a full-wave ICRF field solver (TORIC) that will allow the code to resolve routinely mode converted ion Bernstein waves and compute mode conversion current drive using 250 - 500 poloidal modes. These upgrades involve the use of highly efficient out-of-core matrix inversion methods and the use of massively parallel computing platforms. In the longer term (FY03 - FY04) we plan to carry out 1-D and 2-D full wave field solutions of LH waves in toroidal geometry. This major advancement will be accomplished by using a 1-D integral wave code (METS 1D) and by rewriting the dielectric tensor elements in the TORIC field solver to be valid in the LH frequency regime. Full-wave LH field solutions in 2-D will greatly increase our insight into the physical processes which cause large poloidal mode number variations in propagating LH waves, thus modifying LH wave accessibility and absorption in toroidal geometry.

Relationship to IPPA Goals

As shown in Table 2.1-I, there is a strong overlap of the goals of the Alcator C-Mod lower hybrid current drive experiments and the FESAC goals as articulated and expanded in the IPPA document. Once underway in FY 2003, these experiments are expected to contribute heavily to achievement of the 5-year FESAC-IPPA objectives.

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3. Operations

3.1 Facilities

Recent Accomplishments

During the last year, 953 plasma discharges have been produced in support of C-Mod physics goals. They have been produced with a 76% startup reliability and an engineering systems availability of greater than 97%. The engineering and physics groups have worked to make improvements to the ICRF transmitters and antennas, and DNB diagnostics. We have also completed the installation of the new inner divertor and associated diagnostics, and the Lower Hybrid MIE Project has gone from a design and fabrication effort to a major hardware installation activity in the cell.

In support of our heating, and flow and current drive goals, a major activity over the last year has involved improvements to the J-Port ICRF 4-strap antenna. This antenna over the last year has gone from reliable operation at power levels of less than 2 MW to greater than 3 MW with good heating efficiency. Damage to the striplines found in earlier up-to-air periods has been completely eliminated. Power levels above 3 MW were limited by a discharge developing between the antenna straps and a grounding bridge. During the Fall-Winter up-to-air we have made the changes required to fix this problem and bring the power levels up to the 3.5 MW design level. We also continue to make changes to the plasma facing components of the antenna to reduce impurity generation.

A great deal of work has also been done to the ICRF diagnostic, control, and fault protection systems. A new phase demodulator with very good resolution and a very fast response time has been developed both to improve fault protection and to allow better analysis of the ICRF system performance. Light, pressure, and RF magnetic field measurements have been added to the J-Port antenna to both protect it and help understand its operation.

In FY2003 experiments will be aimed at developing efficient steady-state tokamak operation by launching lower hybrid waves into Alcator C-Mod plasmas. Up to 3 MW of RF power will be available at a frequency of 4.6 GHz. Over the last year we have reconditioned the carts used on Alcator C to house four klystrons, tested them, and installed them in the C-Mod cell. A photograph of this installation is shown in Fig. 3.1-1. In addition, as seen in Fig. 3.1-2, a great deal of the fault protection and transmitter control electronics is also now installed in the cell and is being cabled together with the carts, PLCs, and data acquisition system.

PPPL has lead responsibility for design and construction of the lower hybrid launcher. The launcher consists of the windows, tiles, couplers, tapers, and other high power microwave components needed to feed the output from the 12 klystrons into the 96 waveguides at the coupler. Four modules, each with 24 waveguides, make up the launcher front end. Alumina windows brazed into the waveguide provide the vacuum interface. The

Figure 3.1-1. Installation of Lower Hybrid klystrons and carts on the new mezzanine. The water cooling system for the klystrons is also shown that will provide up to 1200 gallons/minute of cooling water to the tubes and other LH components.

launcher position can be moved between shots radially from 0.5 cm outside the separatrix to well behind the limiter. Successful tests of the windows have been made over the last year, and a prototype coupler is being fabricated that will eventually be tested at MIT at high power.

A major component of the Lower Hybrid Project is the 50 kV, 208 A, high voltage supply that powers the klystrons. This unit was installed at MIT in Oct, 2001, and commissioned successfully to full voltage and current with 5 second long pulses in Feb 2002. The supply uses an array of IGBT switches that both regulate the applied voltage during normal operation and shut down the supply very rapidly during a fault condition. Individual crowbar circuits are therefore not required for each klystron.

In support of the Lower Hybrid Project, as part of the MIT infrastructure improve-


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Figure 3.1-2. Installation of the Lower Hybrid transmitter protection and control racks. These racks are installed below the klystron mezzanine and the installation of cabling between the racks and the klystron carts is underway.

ment program, MIT has provided approximately 1.5 million dollars in site improvements over the last year. They have provided the pumps, water lines, valving, and instrumentation needed to supply 1200 gallons/min of cooling water to the klystron carts, and associated equipment at up to 200 psi. MIT has made improvements to the lab space needed for lower hybrid system development and support. They have installed the new mezzanine in the experimental cell needed to support the klystrons, and also upgraded the air conditioning needed to support the added heat load from the Lower Hybrid Experiment. Finally, they provided the slab in our Hi-Yard that now supports the new lower hybrid high voltage supply.

In support of high performance plasmas, significant upgrades to the inner divertor structure in Alcator C-Mod have been implemented since our last work proposal. Besides allowing high field, high current operation at the 8 T, 2 MA level, the new design accommodates a larger range of plasma shapes especially higher triangularity. It consists of twenty interlocking inconel 625 plates forming a girdle surrounding the inner wall. The number of studs on the inner wall will be tripled to provide the strength needed to hold the girdle in place during worst case disruption events. A picture of the new divertor is shown in Fig. 3.1-3. Extensive structural and thermal modeling of the new components indicates a very strong structure that can easily handle the forces and heat loads expected during disruptions and long pulse AT operation. A great deal of work also went into the installation of new halo, eddy, rangefinder, thermocouple, and probe diagnostics installed on or behind the divertor structure. Some of these new diagnostics can be seen in Fig. 3.1-4.

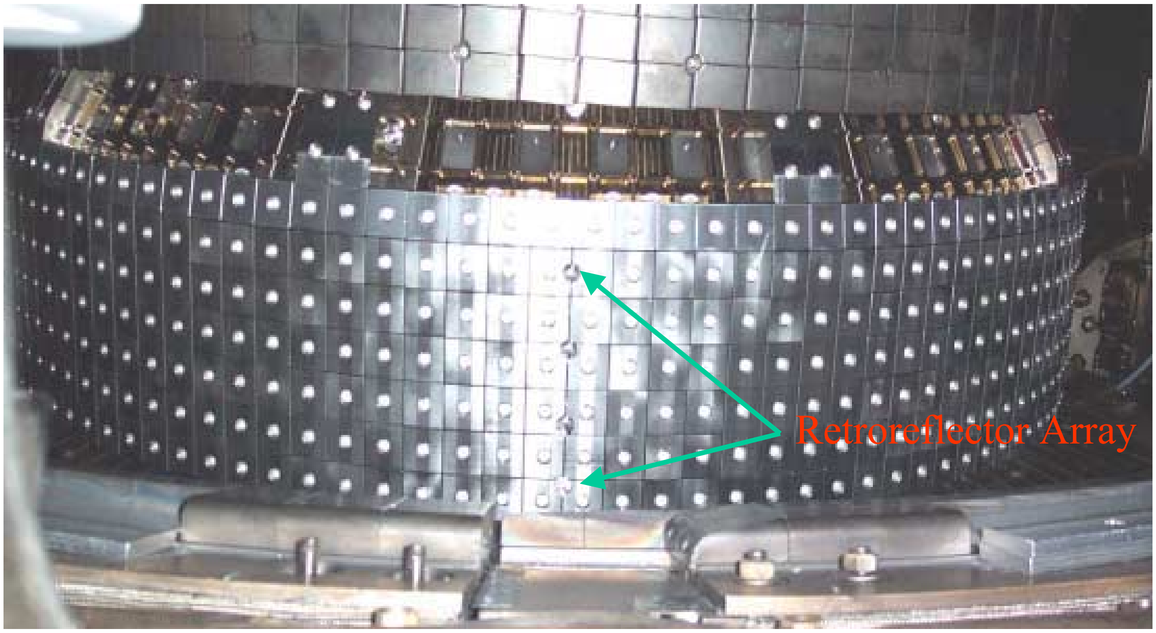

Figure 3.1-3. Status of the new inner divertor. Only a few nose tiles remain to be installed. This project has gone from procurement to installation over the last year.

Crucial measurements of plasma current, ion temperature, and rotation profiles, as well as fluctuation levels will be provided by a new DNB and its associated diagnostics. University of Texas, PPPL, and MIT scientists and engineers are bringing the new DNB, together with several very important beam related diagnostics, into operation this year.

Near the end FY2001, plasma discharge lengths long enough for our advanced tokamak experiments were performed. Plasma discharge lengths as long as 3.4 seconds were produced. Mechanical and thermal stresses on the coils, power supplies, breakers, fuses, bus, and alternator were found in excellent agreement with those calculated through extensive simulation work performed before long pulse operation began. An extensive set of new instrumentation was added to our power systems to monitor component and bus temperatures. A great deal of new software to display these data and also that from other machine instrumentation was developed and brought into routine operation during the last

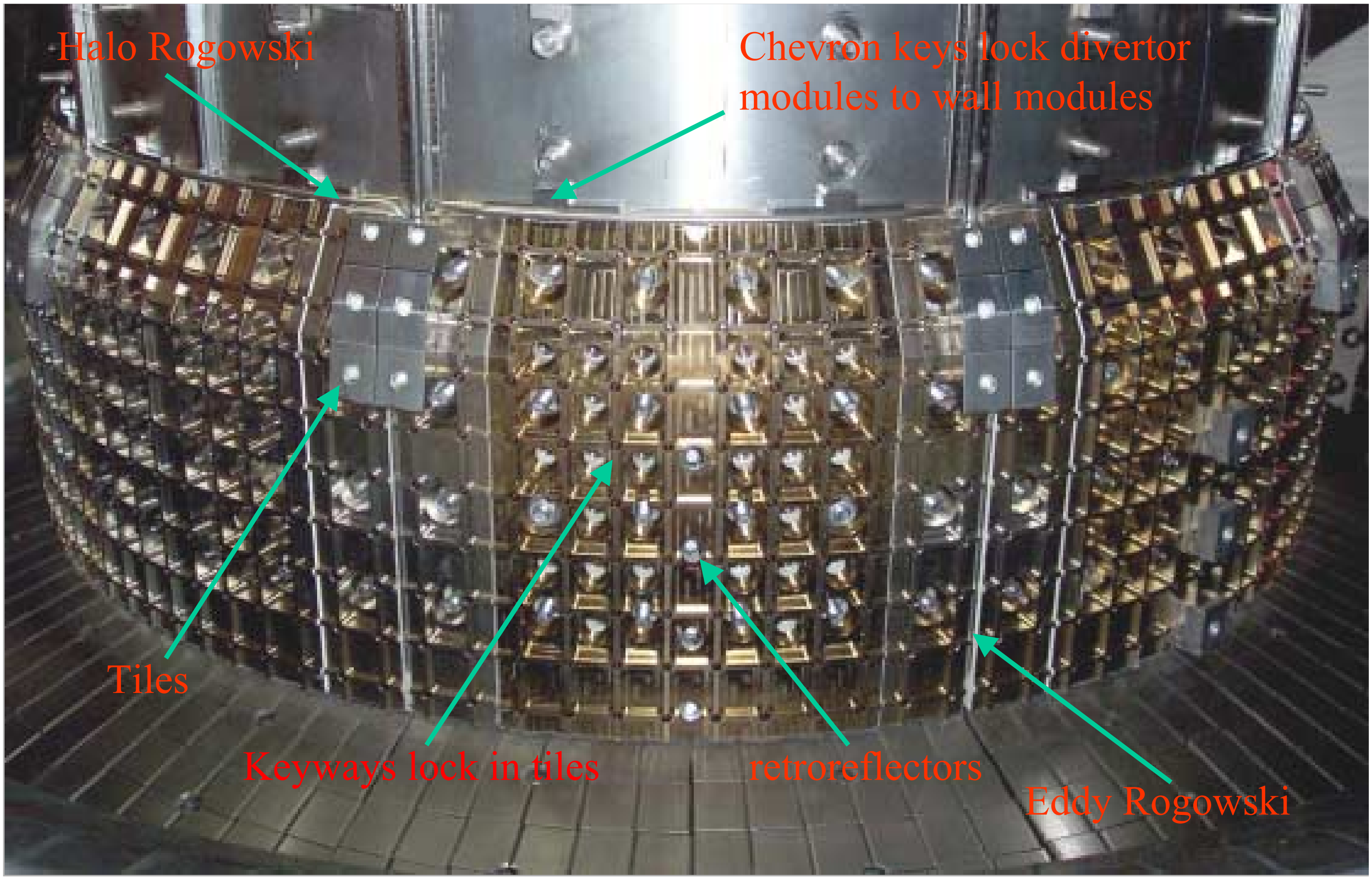

Figure 3.1-4. Some important diagnostic and design features of the new inner divertor are shown during installation. Halo and eddy current Rogowskis will measure essentially all current flowing in the divertor structure. Retroreflectors will allow movement of the inner wall to be monitored. Keyways lock tiles into position, and chevron keys lock inner divertor components to wall components.

year. This first period of long pulse operation has determined that only minor changes to the air cooling system for some TF transformers are required before Lower Hybrid experiments can begin. In addition, experiments to study wall conditioning, plasma fueling, divertor heat loads, and density control benefitted from this early long pulse operation.

A careful inspection of the Alcator C-Mod TF magnet, OH coax, and most other machine components was carried out between Aug 2001 and Jan 2002. The TF magnet horizontal arms and vertical legs were found to be in excellent condition. After the TF fault in 1998, changes to the springplates and springplate pressure, plating of the sliding joint surfaces, and the addition of a graphite coating to the feltmetal, have resulted in very much improved performance of the TF magnet. Several feltmetal pad locations indicated that more graphite would be useful, and we are therefore increasing the coating thickness at all joint locations during reassembly. These locations showed a somewhat frosted appearance indicating more interaction with the opposing TF finger than expected.

Inspection of the OH coax connections indicated a reduction in the preload on several of the bolts; by in one case as much as 33%. Damage to the bolt threads was also found as well as to the helicoil inserts into which they engage. After reanalysis and simulation of the coax foot behaviour, and extensive testing and measurements of the coax components, several changes were made to the coax connection. High strength bolts are now being used and the engagement of the bolts with the inserts was increased up to a factor of two. The Belleville stacks that maintain the preload have been changed to provide more compliance, and wedges have been added to restrain movement of the top of the coax foot. These changes will improve the reliability of these crucial components.

More generally, heater and thermocouple leads, TF instrumentation cabling, LN2 cooling lines, and bus components are all being refurbished as part of the the inspection/reassembly effort.

Research Plans

The engineering group will work to provide the new RF, power, and diagnostic systems needed to pursue the major physics goals of Alcator C-Mod.

Upgrades

C-Mod will provide at least 21 weeks of physics operation each year starting in FY03. The incremental cost for this operation includes additional liquid nitrogen, electricity, technical, engineering, and physics manpower, and increased maintenance cost of all our systems. Additional physics, engineering, and technical staff will also be required between run periods, since new fabrications and installations will need to be completed in less time. New instrumentation and data acquisition equipment will be needed to increase both the reliability and the capabilities of our engineering and diagnostic systems.

We consider it essential to our program goals to be able to reliably supply 5 to 6 MW of ICRF power to the plasma. We will begin development in FY04, in collaboration with PPPL, and possibly Oak Ridge, of a new 4-strap antenna to replace the D and E-Port antennas. The new antenna will be installed at E-Port while allowing diagnostic access to D-Port. We also will continue taking whatever steps are required to reduce the interaction of all the antennas with the edge plasma, and improve high voltage handling capability of the transmission lines, striplines, straps, phaseshifters, and stub tuners. We will also continue to improve transmitter control systems, fault detectors, and diagnostics directly related to antenna performance.

During the Spring/Summer 2002 run campaign more experiments will be run to determine the best location for the new cryopump. Using these results, and past experience, we will begin design of the cryopump in late FY02 with design work probably continuing well into FY03. Installation of the cryopump is planned for mid FY04. This new system will very likely be similar to the pump found on DIII-D, with pumping speeds of 20,000 to 30,000 l/s. It is very likely that the pump will be in the upper part of the C-Mod vacuum vessel. If this is the case, this upgrade will also involve modifications to the upper divertor to both protect the cryopump and possibly improve the strength and heat load capability of the upper vessel components.

A fast ferrite tuning system is being considered for FY03 and FY04. This system will eliminate the shot-to-shot tuning process that now makes inefficient use of run time and the scientific staff. This system will be able to automatically maintain a good match between antennas and transmitters with shot-to-shot variations in plasma conditions and changes in confinement mode. In late FY02 we will install a prototype system, and we will develop and test the fast control system electronics using this prototype in FY03. Depending on the prototype results, in FY03 to FY04, we will consider installing three conditioned devices, so that all transmitters would have the advantage of automatic tuning.

Both to improve spectrum control and reduce the power density at the plasma to antenna interface, we plan to add a second lower hybrid launcher, provided by PPPL, by FY05. Design and fabrication for this launcher will begin mid to late FY03. An upgrade of the source power from 3 to 4 MW will begin on the same timescale at MIT. Since the second launcher will displace important diagnostics on one of our horizontal ports, a large effort will also be required to reposition and replace diagnostic systems now using this port.

The Faraday screens on the three ICRF antennas will require modifications to tolerate the heat loads of full power, long pulse, operation. We plan to make these upgrades beginning late FY03 to early FY04, with MIT taking responsibility for the D- & E-port antennas, and PPPL for the J-port antenna.

During our next up-to-air period we plan to install, in collaboration with Sandia National Lab (Albuquerque, NM), a set of tungsten brush tiles in our outer divertor. This new type of PFC has been tested at heat loads approaching 25 MW/m^2 and is currently the prospective solution for FIRE. The tiles would be ready for operation during our first FY03 run campaign. These components have never been tested in a tokamak before, so we should gain new information important to the BPX.

Results from the tungsten brush experiments will naturally feed into our plans to upgrade the outer divertor. We expect the heat load capability of the outer divertor to be less than required to handle high power, long pulse operation. We are therefore planning to upgrade the outer divertor in early to mid FY05, with the design effort to begin mid to late FY03. More experiments on advanced divertor concepts are planned both before and during the design phase. More extensive use of the tungsten brush concept, or possibly very limited tests of liquid divertor materials such as gallium are planned during this time.

Both the flywheel and the alternator will require inspection during FY03. They each have required inspection periods that are determined by both the number of C-Mod shots and the number of start-stop cycles. During the inspection, the alternator will be hi-potted and numerous ultrasonic and dye penetrant tests will be performed on both the flywheel and the alternator. An extensive inspection regime will be performed on all systems bearings.

3.2 Lower Hybrid Project

FY 02

Progress in fabricating the equipment required for the first phase of lower hybrid experiments during FY 02 has been excellent. Among the highlights:

- A new mezzanine has been installed in the Alcator C-Mod cell to support the klystron carts; (See Figure 3.1-1)
- Three carts and equipment racks supporting 4 klystrons each (a total of 3 MW source power) have been refurbished and installed on the mezzanine in the Alcator C-Mod cell; (See Figure 3.1-2)
- A new power supply (50 kV, 208 A, 5 s) has been installed in the Alcator C-Mod power yard and is in the final stages of commissioning;
- The high power control system has been fabricated and is being used in the power supply commissioning;
- The low-level RF control system has been designed and the verifying R&D completed;
- The water cooling system for the klystrons (two loops, 1200 gpm @180 psi and 600 gpm @ 150 psi) has been installed. (See Figure 3.1-1)
- The FDR has been successfully completed for the antenna design and all critical path procurements have been placed (PPPL will report separately)

MIT has contributed strong support to the project, underwriting the costs of the mezzanine and water cooling system, and providing a pad and cabling for the new power supply.

FY 03

The Lower Hybrid MIE will be completed in FY 03. The RF transmitter is scheduled to be completed by the end of FY 02 with the demonstration of 250 kW of RF power delivered into dummy loads by each of the 12 klystrons. The schedule then calls for the coupler to be delivered by PPPL to MIT in March 2003, and this will be followed by installation into Alcator C-Mod. After installation of the coupler into C-Mod, waveguide runs will be connected between the transmitter and the coupler and a number of integration tasks will be performed. These include calibration of detectors, measurement and trimming of fixed phase shifts, in-situ measurement of the phase progression along the array, testing the operation of coupler arc protection circuits and integration of the coupler detection circuitry into the control system. Proper operation of the system will require monitoring of some 400 channels of data and for this purpose a new CPCI data system has been purchased and is being integrated into the C-Mod data acquisition system.

FY 04

During FY 04 we intend to prepare for the second phase of the lower hybrid experiments by fabricating a second antenna and installing an additional cart containing 4 klystrons, thereby bringing the total available source power to 4 MW. This second phase is essential for achieving our long range goal of using lower hybrid current drive to produce sustained ($> 3 - 5\tau_{\rm skin}$), high bootstrap ($f_{BS} \geq 70$ %) good confinement (H_H = 1-2) discharges in Alcator C-Mod. In order to drive sufficient current for achieving steady-state scenarios in high density C-Mod regimes, a full 3 MW of coupled power will be required. As mentioned above, based on empirical scaling from other LH experiments we expect the coupled power in the first phase to be limited to about 2 MW. The addition of a second antenna and the installation of an additional MW will lower the required coupled power per antenna to about 1.5 MW, corresponding to a power density that should be achievable according to long-pulse experience in other LH experiments, e.g., in JET. In addition to maximizing the use of the installed source power, the second antenna will provide flexibility in varying the deposition profile of the LH driven current since its $N_{||}$ spectrum will be independently controllable. This would also provide the possibility for heating the edge plasma by setting the progressive phase shift to 180° in adjacent waveguides or driving negative current by setting the phase shift so that its $N_{||}$ spectrum corresponds to waves launched in the counter current direction. In this way it may be possible to locally control the shear and evaluate the effect on the production of transport barriers.

The second lower hybrid antenna will be fabricated at PPPL. Some design work will begin in FY03, but will be limited to taking note of assembly issues and performance of the first antenna and incorporating design modifications as necessary. Otherwise the second antenna is expected to be identical to its predecessor, although the splitters will need to be modified since each antenna will be fed by 8 rather than 12 klystrons.

The RF system will also be modified by the PSFC, with installation of a fourth cart containing the remaining 4 klystrons from the Alcator C experiment. The hardware modifications for the fourth cart will be minimal since all Phase I support systems (power supply, plumbing, etc.) have been designed and fabricated for the full complement of 16 klystrons. Since two of the remaining klystrons have filament problems, we intend to have these tubes rebuilt with new filaments in FY 03. Should the rebuild be unsuccessful in recovering full power capability, the purchase of 2-3 new klystrons is foreseen. In any case, it would be prudent to purchase 1-2 new klystrons to be used as spares.

4. Alcator C-Mod Collaborations

- active as of FY 2002 -

Collaborative efforts, with both domestic and international participation, form a vital and integral part of the Alcator C-Mod program. Contributions of collaborators cover the entire spectrum of activities, with particular emphasis on theory, modeling, plasma heating and current drive, and diagnostic development. Ongoing collaborations are summarized in the following bulleted lists. Continuation of these collaborations is contingent upon each collaborator's separate funding situation.

4.1 Major Collaborations

PPPL

– ICRF physics and modeling, antenna upgrades, operations

– Lower Hybrid Current Drive Project

– Lower Hybrid physics and modeling

– Comparisons with physics based transport models

– Motional Stark Effect diagnostic implementation, measurements and upgrades

– Reflectometry upgrades

– Fluctuation studies

– Advanced Tokamak Physics

– Burning Plasma Physics

– Divertor modeling

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– DNB diagnostics (CXRS, BES)

– Fluctuation physics and diagnostics

– ECE diagnostics, temperature profiles and fluctuations

– DNB operation

4.2 Other Collaborations

- C.E.A. Cadarache – X-ray imaging diagnostics, Lower Hybrid modeling (Y. Peyson)

- Chalmers University, Sweden – Resistive MHD modeling (Bondesson, Fulop)
- C.R.P.P. Lausanne – MDSplus
- Culham Lab – MHD, rotation theory (J. Hastie, H. Wilson, P. Helander)
- Dartmouth U. – Transport modeling (B. Rogers)
- DIII-D – Coordinated SOL/divertor studies, ICRF physics, dimensionless similarity studies, confinement physics, density limit studies, pedestals, MDSplus (D. Whyte, P. Stangeby, R. Pinsker, J. Deboo, C. Petty, R. Groebner, R. Moyer, P. Snyder, F. Perkins)
- Ecole Royale Militaire, Brussels – ICRF modeling (Evrard, Ongena)
- Griefswald – Divertor modeling (X. Bonnin)
- International Database Groups – Databases (Cordey, Conner, Kamada)
- IGI Padua – X-ray tomography, MDSplus, Diagnostic Neutral Beam (P. Franz, P. Martin, M. Valisa)
- JET – Similarity studies, modeling, edge physics, Coordinated EDA studies, Coordinated wall recycling and SOL radial transport studies, MDSplus (G. Cordey, J. Christensen, Huysmans, G. Matthews, G. Maddison, G. Saibene)
- JT60-U – Lower Hybrid current drive modeling (S. Ide), Edge probe studies (N. Asakura), Disruptions studies, Impurity sources and penetration, SOL radial transport and wall recycling (Yoshino, Nakamura, Neyatani, Nakano, Asakura)
- Keldysh Institute – Atomic physics and radiation transport (Novikov, Barob'ev)
- KFA Jülich – Rotation modeling, Plasma-neutral interactions (A. Rogister, D. Reiter)
- Kyoto U – Impurity spectroscopy (K. Kondo)
- Lehigh U – Transport modeling, Pedestal scaling (G. Bateman, A. Kritz, T. Onjun)
- LLNL – high-Z atomic physics and radiation transfer (K. Fournier, A. Wan, H. Scott), Transport and divertor studies (R. Cohen, M. May, W. Nevins, X.Q. Xu)
- Lodestar – Transport and divertor modeling (Myer)
- Los Alamos National Lab – Visible/IR imaging diagnostics, disruption studies (G. Wurden, R. Maqueda).
- Max-Planck Institut, Garching – ICRF heating, ICRF modeling, High Z first wall

studies, Dimensionless similarity studies, Coordinated SOL transport studies, Transport modeling (R. Neu, A. Kellman, D. Hartmann, J.-M. Noterdaeme, M. Brambilla, W. Suttrop, Mertens, K. Hallatschek)

- MIT-PSFC Theory and Modeling Group – Transport, divertor, MHD, RF (P. Catto, J. Ramos, P. Bonoli, A. Bers, A. Ram, J. Decker)
- MIT-Physics – Transport theory and modeling (B. Coppi, L. Sugiyama)
- NET –B2/EIRENNE edge modeling (A. Loarte)
- NIFS/LHD – Impurity studies, diagnostics, atomic physics, MDSplus (N. Noda, Y. Yamauchi, B. Peterson, H. Funaba, T. Kato)
- Notre Dame U – Atomic physics modeling (U. Safranova)
- ORNL – Neutrals and H-mode threshold theory and modeling, self-organized criticality, RF modeling (B. Carreras, L. Owens, E. D'Azevedo, E.F. Jaeger); ICRF technology (R. Goulding, P. Ryan)
- Sandia National Labs. - Albuquerque – Advanced divertors (M. Ulrickson)
- TEXTOR – Atomic physics modeling for He beam edge diagnostic (Schweer)
- U of Alaska – Internal transport barrier dynamics (D. Newman)
- U.C.S.D. – Divertor/edge theory, modeling, Coordinated SOL transport studies (S. Krasheninnikov, G. Antar, D. Whyte)
- U of Maryland – High resolution spectroscopic diagnostics, plasma flows, H/D ratios (H. Griem, R. Elton)
- U of Maryland – Transport, H-mode thresholds, and density limits (J. Drake, W. Dorland, P. Guzdar)
- U of Idaho – ECE diagnostics, temperature fluctuations (R. Gandy, Y. In)
- U of Texas, IFS – TAE theory (H. Berk), linear gyrokinetic analysis (M. Kotschenreuther), transport (D. Ross)
- U of Toronto – Edge modeling (P. Stangeby, S. Lisgo, Elder)
- U of Washington – MDSplus
- U of Wisconsin – BES hardware and analysis techniques, MDSplus (R. Fonck, G. McKee)

4.3 RFX (DNB) Collaboration

Knowledge of the current profile is required in order to fully understand the physics involved in the AT program planned for Alcator C-Mod. As part of a collaboration with Consortium RFX in Italy, C-Mod has borrowed a diagnostic neutral beam (DNB) injector that will enable the MSE diagnostic to make q-profile measurements all the way in to the core of plasmas with densities up to $\sim 3 \times 10^{20} m^{-3}$, and in to the mid-radius of even higher density plasmas. The DNB will also enable CXRS measurements of T_i and plasma flow velocity, as well as BES measurements of density fluctuations. This collaboration also provides for the full time assignment of an RFX physicist to C-Mod, primarily to test out different detectors for making fluctuation measurements, study impurity transport, and document beam performance.

4.4 JET Collaboration

4.4.1 Cross-field transport in the SOL and its relationship to main chamber recycling and the density limit

Purpose

The purpose of this collaboration with JET is to further the understanding of cross-field transport in the SOL. Closely related as part of this goal is to understand how cross-field transport affects wall-recycling, main chamber impurity sources, the density limit, and to overall usefulness of a divertor.

Scientific Objectives

A number of tokamaks are finding that cross-field transport in the SOL can be much higher than expected, possibly leading to radial fluxes competing with flow into the divertor. The result is high main-chamber recycling. Such effects have very important implications for the tokamak as a reactor, for control of particle and heat flows, for control of main wall impurity sources (which are more poorly screened than those originating from the divertor), and also potentially for controlling core energy transport. In addition results from Alcator C-Mod show that cross-field heat transport can become so strong near the density limit that it could lead to core cooling and be an important factor leading to core thermal collapse.

In the past year the collaboration has involved several efforts: 1) B. Lipschultz visited JET for a short period (3 days) and worked with G. Matthews, W. Fundamenski, P. Coad, J. Strachan, M. Stamp to understand JET data, and plan for an experimental run in October of 2002 (FY03). It was found that there were working probes on the poloidal limiters that could be used. We also determined that the vessel viewing camera could be used to monitor the D_α profiles in the SOL, and thus we could calculate the radial fluxes as has been done for C-Mod and DIII-D. The vessel viewing camera was moved by P. Coad in order to obtain a better view of the SOL. Dennis Whyte, who is the DIII-D collaborator on this work, also visited JET at this time and participated in the planning. The development of the miniproposal is still ongoing.

Proposed Collaboration

The proposal of collaborative work on JET centers around the accepted miniproposal planned to be run in early FY03. We will be working during FY02 to further develop the run plan and associated diagnostics. During FY03 Bruce Lipschultz will travel to JET for the run and some amount of data analysis. The remainder of FY03 will be spent with comparisons of JET and the other tokamaks in the study - C-Mod, DIII-D, and JT-60U.

We hope to also obtain related data on impurity sources in this study. Part of the run plan is to change the wall-separatrix gap both at the inner and outer midplane. We will attempt to include impurity diagnostics to isolate out the contribution of main chamber impurities to the core impurity levels.

Benefits to the US Program

An important part of the process to evaluate the usefulness of the tokamak configuration is the efficacy of the divertor in removing the plasma-wall interaction to the divertor from the main chamber. The new results from C-Mod and elsewhere indicate that our understanding of perpendicular transport is flawed. Understanding how such main chamber recycling characteristics scale from C-Mod to JET will be crucial in assessing the importance of this issue for the future of tokamaks. The universality (or lack thereof) of such recycling will be better understood if we have information about the physics underlying such macroscopic processes. We believe that determining the local diffusion coefficient and turbulence measurements will give us that needed information. An added benefit of determining the diffusion coefficient will be that scaling studies for this parameter can be done as well. This has important implications for the heat flux profiles in the divertor. We plan to work with members of the US theory/modeling community to test our understanding of the processes that lead to the measured diffusion coefficients.

It has generally been assumed that impurity sources from the main chamber are small and so are not typically included in modeling. If the results from this study show otherwise this will be important information and will affect that modeling.

4.4.2 Enhanced D-alpha H-Modes in JET

Purpose

The purpose of this collaboration is to better understand the nature of the Enhanced D-alpha (EDA) H-mode observed on C-Mod and its similarity to the Low Particle Confinement H-mode (LPCH) on JET. Reproducing LPCH-mode on JET or an EDA equivalent regime with steady-state good confinement and no large ELMs is particularly desirable to demonstrate such a reactor relevant regime on a large device with lower collisionality. Differences between C-Mod and JET will help us to understand the role that collisionality may play in this kind of regime and further the understanding of H-modes in general. This proposal has been developed in collaboration with the S1 Task Force and the UKAEA-Association Euratom.

Scientific Objectives

Understanding the physics of the EDA H-mode regime on C-Mod or equivalent regimes such as the LPCH-mode regime on JET may allow such steady-state good confinement regimes to be developed in a next step burning plasma experiment. These regimes are particularly relevant to a next step experiment because they provide good confinement without the large intermittent first wall heat loads of giant ELM's found in other H-mode regimes. The impurity source from the edge to the plasma core is reduced in these regimes apparently due to enhanced impurity transport in the edge by a short wavelength quasi-coherent mode. We would like to determine if such a mode can be driven in a large size, low collisionality device like JET. The Edge Harmonic Oscillation (EHO) on DIII-D and Type II ELMs on JT-60U appear to be similar regimes.

The Low Particle Confinement H-mode (LPCH), was the first such regime discovered in JET in 1989 when the plasma volume was larger and higher triangularity was possible because no divertor was present. Only a few discharges were produced with ICRF heating. Since the divertor was installed, they could no longer reproduce this regime, possibly because high triangularity could no longer be obtained. In the limited run time available for these experiments, we found a small ELMy regime, but no clear EDA/LPCH-like regime, though there was a 30 - 50 kHz mode present on reflectometer and magnetic pick-up coil signals during the ELM-free phases that could be similar to the C-Mod QC mode. Further run time is required to use impurity injection and gas puffing to attempt to recreate the LPCH regime. Since collisionality is believed to play a role in driving the quasi-coherent mode in C-Mod, a similarity experiment at the same beta and collisionality in the edge pedestal may also lead to this kind of regime.

The results of our collaboration were presented at the 28th EPS Conference on Controlled Fusion and Plasma Physics in Madeira, Portugal in June 2001 by G. Maddison. Figure 4.4-1 shows the magnetic and density fluctuations found in one of the EDA attempts on JET showing clear modes in the range of 30 - 50 kHz in the ELM-free phase. Figure 4.4-2 shows the collisionality from the discharge in Figure 4.4-1, an old LPCH-mode discharge on JET, and a standard EDA H-mode on C-Mod. The collisionality is about an order of magnitude higher in C-Mod than in JET across the profile. Using the inboard temperature profile, the edge collisionality in the old LPCH-mode discharge begins to approach the edge collisionality in C-Mod EDA H-modes. If H-modes can be obtained at higher density and lower edge temperature in JET, then similar edge conditions to those in C-Mod may be obtainable.

Proposed Collaboration

Another run day has been approved on JET for the edge similarity experiments with C-Mod. It should be run at the end of FY02 or beginning of FY03. Two C-Mod staff scientists intend to participate in this experiment on site at JET as well as to perform further analysis on JET data remotely. D. Mossessian has performed H-mode edge similarity experiments on DIII-D and so his experience with such experiments is essential for this experiment on JET. J. Snipes will continue to provide operational experience in EDA H-mode on C-Mod for the collaboration on these experiments. The experiment has already been approved and scheduled but further help is needed from C-Mod staff to specify the operational parameters and provide insight as the experiment unfolds on the day. A joint paper describing the results of the experiment may be written.

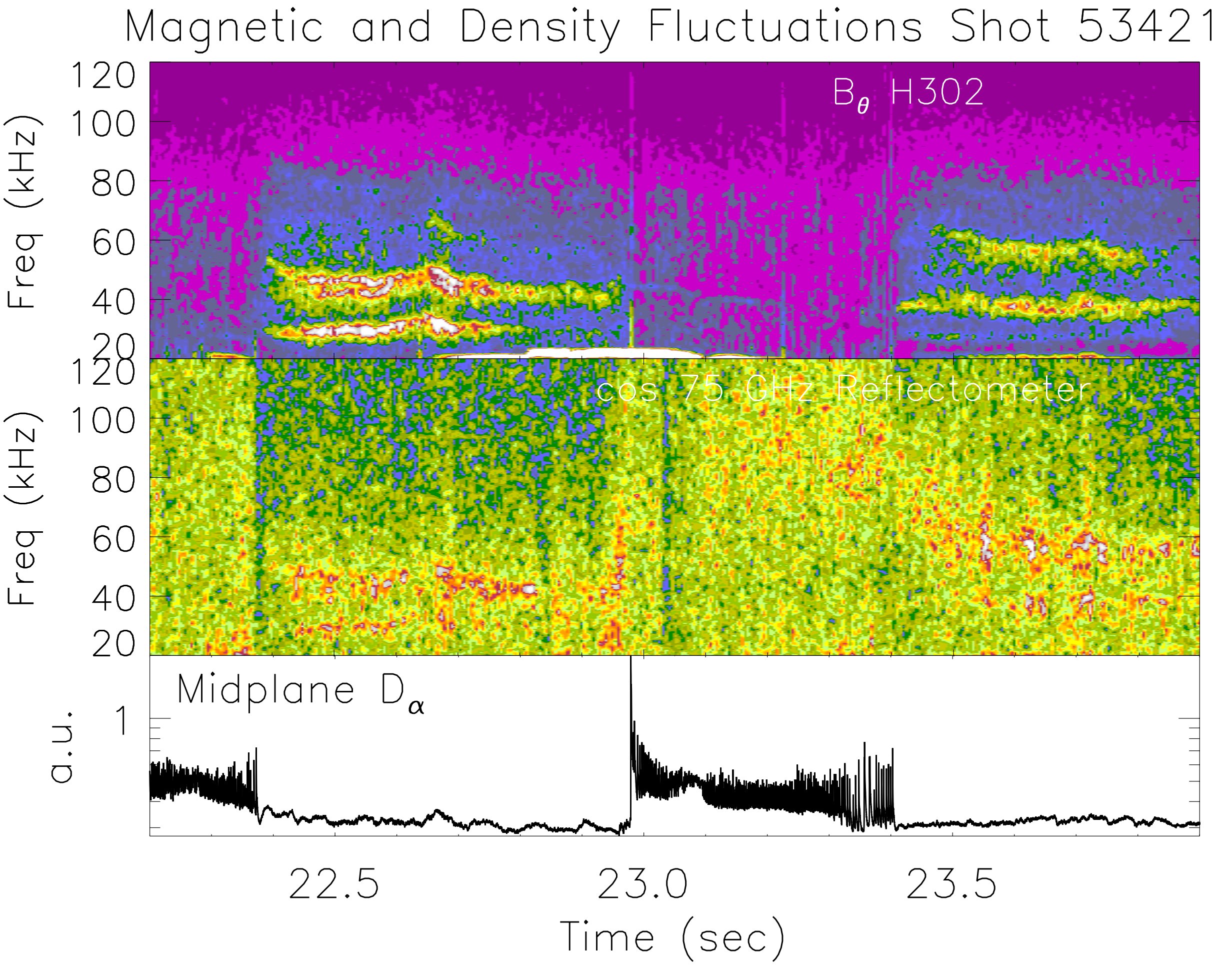

Figure 4.4-1. Coherent magnetic and density fluctuations in the 30-50 kHz range in a JET ELM-free H-mode attempt to achieve EDA/LPCH-mode.

Benefits to the U.S. Program

If the EDA mode can be regularly obtained in JET it may be understood well enough to transfer it to a future burning plasma experiment in accordance with IPPA MFE program goals 1 and 3. Specifically, this collaboration supports IPPA goals to advance the understanding of plasma science in the areas of 1.1 turbulence and transport and 1.2 macroscopic stability. It also supports IPPA goal 3.3 to advance the understanding of high performance plasmas toward developing and assessing burning plasma scenarios. The US Fusion Energy Sciences program will gain further expertise in this reactor relevant operating regime that has important advantages over ELM-free and ELMy discharges including good energy confinement, reduced impurity confinement, and little or no ELMs affecting antenna coupling and divertor heat loads.

4.4.3 Enhanced Confinement Regimes with Combined LHCD and ICRF in JET

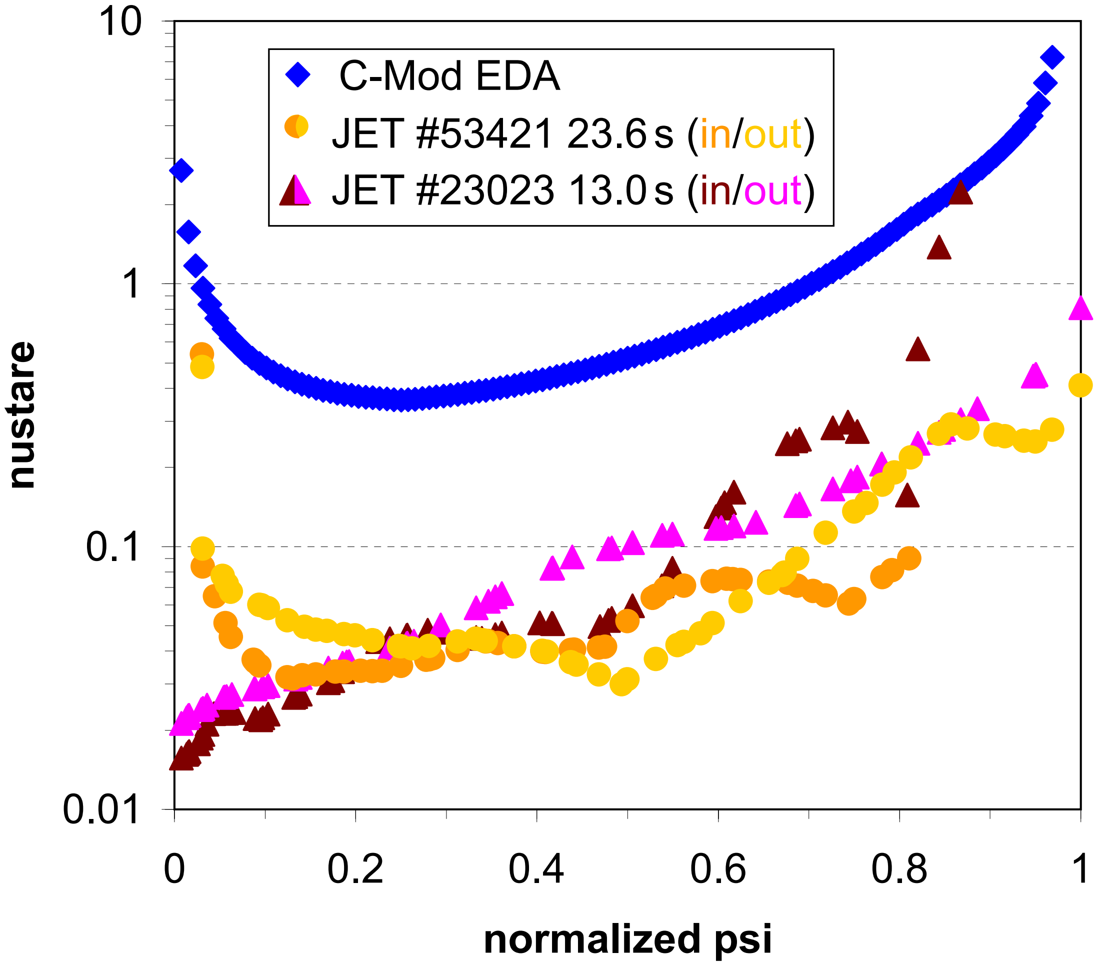

Figure 4.4-2. Comparison of the collisionality profiles in a typical C-Mod EDA H-mode and in JET LPCH-mode and recent EDA/LPCH-mode attempts showing that the collisionality is much lower in JET than in C-Mod. The apparent high edge collisionality on the inboard side of LPCH-mode is believed to be due to errors in the temperature measurement there.

Purpose

The purpose of this collaboration with JET is to exchange knowledge and expertise in the analysis and understanding of the physics of enhanced confinement regimes with combined Lower Hybrid Current Drive (LHCD) and ICRF.

Understanding RF driven internal transport barriers (ITB's), without external momentum sources, is important for the future C-Mod AT program as well as for steady-state operational regimes in future tokamak experiments. This proposal has been developed in collaboration with the S2 Task Force the CEA-Association Euratom.

Scientific Objectives

Enhanced confinement regimes with internal transport barriers (ITB's) and peaked density and temperature profiles are found on many tokamaks that could lead to improved steady-state tokamak performance if they can be maintained. On C-Mod, spontaneous peaking of the density profile has been observed under some conditions in EDA H-mode. The C-Mod 'Advanced Tokamak' program has a goal to demonstrate full non-inductive driven ITB discharges with $70\beta_N = 3$.

JET also has a strong experimental program with LHCD and ICRF heating with a goal to demonstrate the feasibility of steady-state 'Advanced Tokamak' operation. This collaboration will concentrate on the analysis of the improved confinement regimes and accompanying MHD activity that are associated with the observed ITB's. Techniques learned on JET to avoid disruptions and or stabilize beta limiting MHD modes may be applicable to future C-Mod AT regimes.

Proposed Collaboration

Task Force S2 has experiments on combined LHCD + ICRF heating scheduled for the third week of May 2002. These experiments will emphasize high performance steady-state scenarios with high density ITB's. They are preceded by a series of similar ITB experiments in April and early May that will prepare for the high performance experiments. One C-Mod staff scientist (J. Snipes) will participate on site at JET in the high performance LHCD experiments to gain operational experience with LHCD and provide expertise in the analysis of confinement properties and MHD activity associated with the high confinement modes of operation. It will be valuable to compare results between a large, low collisionality experiment like JET where $T_i >> T_e$ with ion heating or with $T_e >> T_i$ with electron heating and smaller size, high collisionality regimes on C-Mod. The visit to JET in FY02 will be for a period of 1 week in May followed by future one to two week visits to maintain the collaboration in future years and compare directly with C-Mod LHCD results.

Benefits to the U.S. Program

This collaboration will benefit the U.S. fusion program by exchanging expertise in obtaining and understanding enhanced confinement regimes in C-Mod and JET. Since C-Mod will soon be adding LHCD to its program, the expertise obtained will be quite valuable to the future C-Mod program. This collaboration is in support of IPPA goals to advance the understanding of plasma science in the areas of 1.1 turbulence and transport, 1.2 macroscopic stability, and 1.3 wave particle interactions. It also supports IPPA goals to advance the understanding and innovation of high performance plasmas in the areas of 3.1 profile control and 3.2 high beta stability. The comparison of low collisionality operational regimes in JET with higher collisionality ITB regimes in C-Mod may provide improved understanding of these enhanced confinement modes of operation for use in a future burning plasma experiment. Since similar combined RF heating schemes will be employed on both JET and C-Mod, the techniques learned on JET may be easily transferred to C-Mod. This collaboration also helps to integrate scientists of the U.S. fusion program within the world fusion program by exchanging expertise between the U.S. and the European fusion program.

4.4.4 Comparison of 'Small ELM' regimes on JET and Alcator C-Mod

Purpose

This activity is closely related to the proposal 4.4.2, "Enhanced D-alpha H-modes on JET". It aims to examine in detail the pedestal profiles, in particular of dimensionless parameters, in EDA and "Small ELM" regimes on C-Mod and JET. We aim to understand the similarities and differences of these regimes, in order to guide JET experiments.

Scientific Objectives

While JET has not yet achieved the EDA regime, they have found some operating conditions in which Type I ELMs become smaller and less frequent, while still maintaining good confinement. Reducing ELM heat pulses to the divertor is critical for burning plasma experiments. Several techniques have been proposed to extend and explore such regimes. These include strong shaping, dominant ICRF heating and high density, which are all typical of C-Mod conditions. On C-Mod, at high power, we also see a regime of fairly small ELMs, which evolves from EDA It is proposed to carefully compare edge pedestal parameters on C-Mod and in JET 'smaller ELM' regimes, to understand better the similarities and differences in their physics. This will include analysis of dimensionless parameters and edge stability. Such comparisons should increase understanding and guide JET experiments to access and improve Type II ELM regimes.

Proposed Collaboration

We will participate in the planning of, and data analysis from, experiments planned on JET by the S1 Task Force. The principle JET contact is Gabriella Saibene (EFDA-CSU), and the main C-Mod participant will be Amanda Hubbard, who is also serving as coordinator for all US-JET bilateral activities regarding "Performance Limiting Edge Phenomena". If experimental schedules are compatible with those of C-Mod, she will participate directly in the JET experiments. Following experiments, high resolution pedestal profiles will be used to compute profiles of dimensionless parameters ρ^*, ν^* and β. Fluctuation characteristics will also be compared. We will determine similarities and differences in terms of operating space and ELMs. Hubbard will then help to plan the next campaigns of JET H-mode experiments and assure good coordination with those on C-Mod and DIII-D.

4.4.5 ICRF Driven ITB and Plasma Rotation Studies

Purpose

It is proposed to study ITB formation and induced plasma rotation with off-axis ICRF minority heating in JET.

Background

In Alcator C-Mod it is observed that as the minority resonance layer is moved sufficiently far off-axis (r/a = 0.45) to the high field side (for example by scanning the magnetic field) a strong ITB is formed. Simultaneously, plasma rotation is reversed from co- to counter-current direction. Although there have been several theoretical predictions with regard to plasma rotation during ICRF heating in C-Mod, the experiments do not seem to support these predictions. In addition, the observed ITB formation is not predicted. It is not clear if these phenomena occur because of ICRF induced particle orbit effects, or some other change in plasma equilibrium associated with local heating which would induce strong ExB shearing.

Proposed Collaboration

A comparison with similar ICRF experiments in JET might shed light on the physics of these observations. Local Er measurements, if available in JET, would be highly beneficial to interpret the physics. In addition, recently power from a second ICRF system has been added with a lower frequency which heats on-axis. A combination of these two frequencies simultaneously has been used to control the strength of the ITB formation. Alternatively, in JET, NB heating could be used simultaneously with off-axis ICRF for transport control. The collaboration would include plasma rotation studies and TRANSP. Participants for C-Mod are J. Rice, P. Bonoli, M. Porkolab, S. Wukitch, and G. Schilling. JET contacts are R. Wolfe and J.-C. Notredaeme.

4.5 ASDEX-Upgrade

4.5.1 Dimensionless Comparison of H-mode Thresholds and Pedestals on C-Mod and ASDEX-Upgrade.

Purpose

This collaboration aims to extend the physics understanding of the H-mode threshold, pedestal parameters and edge fluctuations, through carefully controlled and matched experiments.

Scientific Objectives

Both C-Mod and ASDEX-Upgrade have a strong interest in, and good diagnostics of, local plasma conditions at the L-H mode threshold and in the H-Mode pedestal. Questions of importance are: to what degree these are governed by dimensionless plasma physics ρ^*, ν^* and β, and what influence may be exerted by other variables such as neutral and atomic physics. Such variables are hard to separate in a single experiment. By matching dimensionless parameters, at very different dimensional parameters, more insight can be gained. These experiments have been of interest for some time, but increased in priority during the last year, when increased shaping flexibility made it possible to closely match the shapes on the two tokamaks. ASDEX-Upgrade also obtained for the first time a regime of small ELMs at high density, and under some conditions sees broadband density fluctuations similar in some respects to the EDA regime.

Proposed Collaboration

This collaboration has already been active in 2001 and 2002. Key personnel are Amanda Hubbard at MIT and Lorne Horton and Wolfgang Suttrop at IPP Garching. In the C-Mod summer 2001 campaign a series of discharges was carried out at a shape matching that of existing AUG discharges, with up to 3.8 MW ICRH. Interestingly, at this shape the H-Modes produced were all ELM-free, rather than EDA. Power scans were also carried out to document parameters at the L-H threshold. Experiments are currently underway on AUG, as part of their 2002 campaign. Results to date are that, matching our dedicated discharges, they also see ELM-free H-modes. Other AUG plasmas have matched the shape, and attempted to match the dimensionless parameters, of more typical C-Mod EDA discharges. To date all discharges have either been ELM-free or have had Type I or II ELMs. High resolution edge profiles are being compared. Further iterations are required, on both tokamaks, to more closely match dimensionless parameters both in the H-mode and at the threshold. It is planned to present results at the October 2002 IAEA meeting. Data will then be submitted to the ITPA pedestal database, along with those from other inter-machine comparisons. Depending on what is concluded, we expect to plan and conduct further experiments in FY 2003 and FY 2004.

4.6 Proposed FTU Collaboration

Advanced Tokamak Physics with Lower Hybrid Current Drive in FTU

Purpose

The purpose of this collaboration with FTU is to exchange knowledge and expertise in the analysis and understanding of enhanced confinement regimes and MHD activity associated with internal transport barriers (ITB's) produced with Lower Hybrid Current Drive (LHCD) in 'Advanced Tokamak' operation. Understanding ITB's in a regime with equilibrated electron and ion temperatures and without external momentum sources is important to attempt to demonstrate the feasibility of steady-state tokamak operation at moderately high densities.

Scientific Objectives

Internal transport barriers (ITB's) are found on many tokamaks to yield peaked density profiles with improved confinement that could lead to improved steady-state tokamak performance if they can be maintained. C-Mod has demonstrated spontaneous ITB's with Ohmic as well as with ICRF heating in EDA H-mode in a regime with $T_i = T_e$ and with no external momentum source. LHCD will soon be installed on C-Mod to reach high β with ITB's and with high bootstrap fraction at toroidal fields of 4 - 5 T for long pulse operation.

FTU has demonstrated good current drive efficiency with LHCD at toroidal fields between 4 and 7 T and densities up to 1×10^{20} m^{-3} (Pericoli-Ridolfini, *PRL* **82** (1999) 93). In FY2002 and 2003, FTU will operate with up to 5 MW source LH power, 1.6 MW Electron Cyclotron Heating (ECH) power, and 1.5 MW Ion Bernstein Wave (IBW) power. A major thrust of the FTU program is to attempt to obtain and control Internal Transport Barriers (ITB's) to demonstrate the feasibility of steady-state 'Advanced Tokamak' operation. LHCD in the plasma startup will be used with multiple pellet injection and a combination of ECH and IBW heating. This collaboration will concentrate on the analysis of the improved confinement regimes and accompanying MHD activity that are associated with the observed ITB's. The different heating schemes on the two machines will provide interesting comparisons to be made in the synergistic effects of different heating schemes combined with LHCD. Practical expertise on how to obtain and maintain ITB's with LHCD will be obtained that may then be applied to C-Mod when the LH system becomes operational.

Proposed Collaboration

One C-Mod staff scientist (J. Snipes) will participate on site at FTU in the LHCD experiments to gain operational experience with LHCD and provide expertise in the analysis of confinement properties and MHD activity associated with the high confinement modes of operation. Earlier experience on JET LHCD experiments will be valuable to compare results between large low collisionality experiments where $T_i >> T_e$ and smaller high collisionality regimes on FTU and C-Mod. With additional ECH, FTU can also operate in a regime with $T_e > T_i$ for comparison. The visits to ENEA-Frascati will be for a period of 2 weeks in each fiscal year during FTU operation with LHCD. The exact schedule will depend on coordinating FTU and C-Mod operation plans.

Benefits to the U.S. Program

This collaboration will benefit the U.S. fusion program by exchanging expertise in obtaining enhanced confinement regimes in C-Mod and FTU. Since C-Mod will soon be adding LHCD to its program, the expertise obtained will be quite valuable to the future C-Mod program. This collaboration is in support of IPPA goals to advance the understanding of plasma science in the areas of 1.1 turbulence and transport, 1.2 macroscopic stability, and 1.3 wave particle interactions. It also supports IPPA goals to advance the understanding and innovation of high performance plasmas in the areas of 3.1 profile control and 3.2 high beta stability. The similarities between the tokamaks and their operational regimes may allow experimental techniques for obtaining and maintaining ITB's learned on FTU to be directly applied to C-Mod. The differences in the heating schemes will also provide some contrast to determine how important are the synergistic effects of combined heating with LHCD. This collaboration also helps to integrate scientists of the U.S. fusion program within the world fusion program by exchanging expertise between the U.S. and Italy.

4.7 MDSplus

Recent Accomplishments

MDSplus use has continued to grow in the worldwide fusion community. There have been new installations in the US, and at the Culham Laboratory in the UK and the IPP in Germany. Currently there are more than 30 client sites. Ongoing support for these installations continues to be a major activity for the MDSplus development group. A workshop for MDSplus users was organized in Padova Italy with attendance from more than a dozen countries.

MDSplus is a key element of the National Fusion Collaboratory, a project whose main goals are improved access to digital resources through application of a set of standard software technologies. As part of this work, a security implementation has been added to MDSplus, using the GLOBUS security infrastructure with authentication based on X.509 certificates. MDSplus connections can now be encrypted and secured by any user with a valid certificate from the DOE Science Grid. A similar approach will be used to secure connections to remote databases. As a first step toward this goal, database access through the MDSplus API has been implemented.

A number of activities are underway at MIT as part of an overall migration away from OpenVMS computing. A LINUX cluster consisting of a disk server and user workstations has been deployed for use in data analysis and display. An aggressive effort to port analysis codes onto these platforms has begun. A mid-scaled beowulf cluster has been assembled and will be used for between shot analysis and to run larger physics codes. Finally, a SCSI CAMAC driver for LINUX has been completed, which will allow us to migrate existing data acquisition equipment onto the new platforms. At the same time, we are deploying compact PCI based data acquisition hardware using integral LINUX hosts.

Future Plans

Support for remote MDSplus sites will be increasing as the number of sites and the number of users increases. An effort will be made to improve online documentation and to train local support staff at each of the major sites where the code is used. The plan is to hold the MDSplus users meetings on an annual basis.

The MDSplus architecture will be extended to allow transparent distribution of data archives across multiple servers. (Currently users must connect separately to each server from which they wish to retrieve data.) We will investigate the feasibility of storing and retrieving very large files - such as those generated by large simulations which can be 10s or 100s of GBytes and exceed the addressable space on 32 bit architectures. Secure access to relational databases using the MDSIP API will be completed with the port of the GLOBUS toolkit to the PC platform.

We expect to complete the migration of users and applications from OpenVMS to

LINUX over the next two years. We will begin migration of data acquisition applications to the new platforms as well as migrating away from CAMAC as a standard for data acquisition hardware. Software to support new CPCI based timing systems will be written, enabling us to support data systems completely free of CAMAC modules. The combination should allow a faster and more reliable data acquisition cycle. Data should also become available to applications sooner in the between-shot cycle. The data storage systems, based on large disk arrays, will be expanded as needed to meet the expanded run schedule - we anticipate adding approximately 1 TByte of rotating storage per year. Tape systems will be updated to safely backup all data.

Finally, we plan on replacing the hybrid digital/analog plasma control computer with an all digital system. The system would allow more flexible control algorithms to be implemented and should reduce the programming uncertainties which arise in gain and offset errors in the analog electronics. These should speed up the discharge development process and allow more productive use of run time.

5. Run-Planning

Standard operation on C-Mod consists of single shift (8.5 hours) run-days, typically four days per week, with Mondays normally reserved for maintenance activities. Between 20 and 30 plasma shots are normally produced during a run-day. During the past three years physics run-time has been 24 weeks (FY1999), 18 weeks (FY2000), and 12 weeks (FY2001). Eight physics run-weeks (32 run-days) are budgeted for FY2002. For the last few years, operational time has been funding-limited, with direct costs being dominated by liquid nitrogen, electricity, and labor. This is also the case for FY2002.

Detailed planning of the operational time is performed in order to maximize the scientific and programmatic return from the facility. The run planning process begins with the C-Mod Experimental Program Committee (EPC) setting the overall goals and strategy. (The EPC consists of the Group Leaders, the Project Head, and representatives from the major collaborating institutions.) This strategic planning is also done with input and guidance from C-Mod's Program Advisory Committee, which is typically assembled once per year. The program's priorities are facilitated by elucidation of "task-force thrust areas". Ideas and experiments are solicited within those thrust areas and within four "topical science areas". The ideas and experiments are presented at an "Ideas Forum". The Forum is open to all interested parties, including current and potential future collaborators. The Ideas Forum for the FY2002 run campaign was held on December 12-13, 2001. The two thrust areas were the "Advanced Tokamak Thrust" and "Burning Plasma Experiment Support". The four topical science areas were:

Transport Physics
RF Physics
Divertor/Edge Physics
MHD Physics

Of course, none of these areas is distinct, and all overlap in various degrees.

At the 2002 Ideas Forum, a total seventy ideas were presented, coming from nine different institutions. All presentations were available electronically, with full audio and video feeds to and from General Atomics, PPPL, and the University of Texas. This accommodated a number of remote, video presentations from those institutions. All presentations are available online at www.psfc.mit.edu/people/terry/forum_agenda.html. Approximately the same number of ideas/proposals are still active from previous campaigns. After the Forum, all new and still-active ideas are then organized, consolidated, and prioritized for development within each of the areas by working groups. The resulting prioritized lists are reported to the EPC, and run-time is allocated among the areas, based on the program goals and the ideas themselves. Because of the limited run time available during FY2002, many of the ideas will also be considered for the FY2003 campaigns. The allocation of run-time among the areas for the FY2002 campaign is:

Advanced Tokamak Thrust-31%

Burning Plasma Experiment Support-17%
RF Physics-21%
Transport Physics-14%
Divertor/Edge Physics-10%
MHD Physics-7%
Approximately 10% is designated as contingency.

Thus a list of high-priority ideas is developed, and a tentative schedule for at least the first part of the campaign is prepared.

Detailed miniproposals are then written, implementing the high-priority experimental ideas. A miniproposal describes the purpose of the experiment, approach, required resources, an outline of the planned shot sequence, and a statement of the goals and anticipated impact of the experiment. It typically covers from one to a few run-days. Miniproposals are reviewed by the EPC and, when approved, are available for scheduling. The tentative schedule is updated continuously during the campaign, based on the tokamak's operational situation and consistent with the overall topical and thrust allocations.

This run-planning activity, minus an Ideas Forum, will be repeated for the first campaign of FY2003. Because of the addition of the first Lower Hybrid launcher in mid-2003, another Ideas Forum is planned for 2003, preceding that installation and the second campaign of that year. The planning activity will again be repeated.

Overall, the emphasis in the planning for the next two run campaigns (FY2002 and the first campaign of FY 2003) is on the "Advance Tokamak Thrust", the "Burning Plasma Experiment Support" and the RF physics needed to support those thrusts. The second campaign scheduled for FY2003 will have primary emphasis on Advanced Tokamak issues, coinciding with the commissioning of the first Lower Hybrid launcher.

6. Explanation of Milestones

Milestones Completed since March 2001

75. Evaluate density control

> *Evaluate potential methods to control wall-gas inventory and target plasma density in anticipation of long pulse operation. Wall reservoirs for particles will be characterized and potential conditioning techniques and fueling options will be evaluated.*

Both active and passive density control options have been evaluated in detail. In passive density control, the wall is conditioned such that it acts as a 'pump' during a discharge. Thus, it is important to establish the capacity for the wall to pump and methods to condition the wall between discharges. In active density control, a cryopump or other activated surface (e.g., getter) is employed. In order for these systems to work they must have both sufficient pumping speed and capacity to handle the gas-load during a discharge. The gas load is set by the plasma/neutral inventory in the chamber and the capacity of the wall to hold neutral gas (since it may evolve from the wall during a discharge).

A) Wall Condition and Wall Pumping Capacity Experiments:

Wall condition and wall pumping capacity experiments were performed to assess helium glow discharge cleaning as a technique to condition the walls for passive density control (MP273, "Effects of Glow Discharge Cleaning on Boronization and Wall Conditions"). Helium glow discharge cleaning was performed over a weekend and between discharges for 1/2 hour intervals. If was found that even with the most extensive use of helium glow, the wall could only be depleted by about 30 torr-liters of deuterium gas. A single shot following helium glow was sufficient to reload the wall. Thus, the idea of conditioning the wall for pumping in C-Mod is not a viable option. Similar conclusions were drawn from experiments that assessed the rate of change-over from deuterium → hydrogen → deuterium (MP274,"D/H Changeover").

B) Active Pumping Options:

We have found that the only pumping techniques that have sufficient pumping speed and capacity for C-Mod are cryo-panels and liquid lithium surfaces.

B.1) Liquid Lithium Surfaces:

On Tuesday April 3, 2001, a 1-day meeting was held to discuss ideas for using liquid surfaces for pumping hydrogen in Alcator C-Mod. The participants included: Mike Ulrickson (SNLA), Dennis Whyte (UCSD), Dick Majeski (PPPL), Jeff Brooks (ANL). It was concluded that liquid lithium surfaces may provide a large pumping speed and capacity. However, the technology is in the development stage. The risks associated with the use of liquid lithium in C-Mod were found to be unacceptable at the present time.

B.2) Cryopump:

A prototype cryopump has been successfully operated in C-Mod, yielding ∼1000 liters/ second pumping speed for a 1/10 size test unit. This technology is well established and utilized in many tokamak experiments. It is desirable to increase the surface area of the cryopump and to simplify its design. Towards this end, we have investigated the possibility of locating a full toroidal loop cryopump in the upper divertor region. Recent analysis of unbalanced double-null experiments shows that the pressures in the upper divertor can be sufficiently high to enable a pump to be operated there. Follow-up experiments are planned during the 2002 run campaign to scope the neutral pressures in the upper divertor for a range of upper x-point locations.

B.3) Long Pulse Experiments:

We have operated C-Mod with pulse lengths extended to 3 seconds, in part to assess gas evolution from the walls (results presented at APS, Long Beach, 2001, www.psfc.mit.edu/cmod/sciprogram/Aps/Aps2001/Wolfe_poster.pdf). It was found that the wall maintained a moderate level of pumping throughout the 3 second pulse. Target densities did not exceed the programmed densities. However, owing to volt-second limitations, these long-pulse discharges were performed at low to medium densities. Wall saturation & degassing effects, if they are to be seen at all, might occur in higher density and higher power discharges. In any case, from the wall capacity experiments as described above, we have a good estimate on the maximum wall inventory that could be degassed during a discharge, ∼ 30 torr-liters. On this basis, we have the information we need to start a conceptual design for a full-scale cryopump in C-Mod.

76. Investigation of ITB control with multiple frequency ICRF

> *Plasmas with Internal Transport Barriers (ITBs) show promise as the goal for future advanced tokamak steady state reactor operation. Plasmas with dual edge and internal, energy and particle barriers have been formed in Alcator C-Mod with auxiliary radio wave heating, in the absence of the usual neutral beam particle and momentum sources (which will be unavailable in future reactors). The prescription for achieving these ITBs is to lower the magnetic field, which causes the radio waves (at 80 MHz) to be concentrated in the inner portion of the plasma, off-axis. Further heating power at 70 MHz will be concentrated at the core of the plasma to increase the temperature of plasma center, inside of the ITB, to hold the density profile steady and to arrest impurity accumulation. The fundamental role of plasma rotation in the ITB formation will also be investigated.*

The ITBs, formed in conjunction with a reversal of the co-current central toroidal rotation velocity, are apparent for both particles and energy, confirmed by a dramatic reduction in the inferred core thermal diffusivity from TRANSP modeling. Among the unique features of the C-Mod ITBs are the presence of sawtooth oscillations, the monotonic q profile (with the ITB foot location near q=1.5) and that they form in the absence of external momentum input. For ITBs formed with single frequency ICRF waves, the particle and impurity densities continue to increase at the plasma axis until the central radiation exceeds the central input power (which is lower with the off-axis heating used to create the ITB) and the barrier collapses. Additional central heating power from a second frequency ICRF antenna has been found to arrest the particle and impurity build-up at the same time as increasing the core temperature, and double transport barrier plasmas have been held in steady state for as long as six energy confinement times. Simultaneously with the arrest of the core density and impurity buildup, the toroidal rotation reappears in the co-current direction. Steady state double barrier plasmas have been achieved both at 4.5 T (with 80 MHz ICRF on the high field side to form the ITB and 70 MHz ICRF for the core heating) and 5.4 T (with 70 MHz ICRF on the low field side to form the barrier and 80 MHz ICRF for the core heating). This final result shows that the triggering of the barrier formation is not explicitly related to high-field side ICRF heating, but rather the transition can be triggered by strong off-axis heating on either the high- or low-field side. This, in turn, rules out the primacy of ICRF-induced ion orbit effects which formed the basis of some of the theories proposed to explain the phenomenon. Further details of these results are elucidated by Steve Wukitch in an invited talk from the Long Beach APS-DPP meeting (www.psfc.mit.edu/cmod/sciprogram/Aps/Aps2001/Wukitch_Invited.pdf) and in its accompanying manuscript (www.psfc.mit.edu/library/01ja/01JA034/01JA034_full.pdf).

77. Evaluate operation of modified J-Port 4-strap antenna

> *Operate the modified 4-strap antenna at 78 MHz with improved arc detection and additional diagnostics up to the maximum power that can reasonably be achieved. Using heating phase, evaluate the heating efficiency, power handling, reliability, and impurity generation of the 4-strap antenna.*

The operation of the modified J-port antenna (see description below) was quite successful in the past campaign, concluded at the beginning of August, 2001. The modified strip lines were in excellent condition (no indication of arcing on the strip lines or vacuum vessel) after the campaign. Furthermore, arc damage was predicted to be located at the ground bridge between the bridge and the strap where E‖B exceeds ∼15 kV/cm when the maximum voltage on the transmission line was 25 kV @78 MHz (∼50% higher than during the winter 2000 campaign) and 30 kV @70 MHz (consistent with expected frequency scaling). Arc damage was found at this location particularly on straps #2 and #3. The modified J-port antenna was operated at 70 and 78 MHz and at power levels up to 3.0 MW without significant RF-plasma edge interaction at the antenna corners in H-mode plasmas. From camera data, damage was expected on the BN tile fasteners and this damage was found to be generic to all antennas where a BN-metal interface was exposed to the plasma. This suggests further modifications to be implemented before the FY2002 run campaign, based upon the empirical observations of limiting the E‖B field to <15 kV/cm and removing the plasma facing BN-metal interfaces.

Compared to the D and E antennas, the overall heating efficiency was similar. A phase scan showed that the nominal $[0,p_i,0,p_i]$ was the most effective heating phase and had little or no negative edge interaction. An outer gap scan was also completed and suggested a gap of 1-1.5 cm was better than larger outer gaps. Antenna performance was insensitive to toroidal field from 5-5.6T.

The modified J-Port antenna differed from the previous version in the design of the strip line components, front tiles, and back plate. Due to arc damage found after the previous (winter 2000) campaign, the radial strip lines elements were aligned with magnetic field to prevent E parallel to B. In addition, the electrode spacing was increased from 1 cm to 1.5 cm. S-parameter measurements of this new configuration indicated that the antenna was not significantly modified with respect to RF electrical characteristics. These measurements confirm our attempt to maintain a 50 Ohm transmission line while eliminating E parallel to B-field arc paths.

During the winter 2000 campaign, a strong RF plasma edge interaction limited the injected power to ∼2.5 MW into H-mode and the interaction appeared to follow field lines. The BN tiles were aligned and all metal surfaces except the Faraday screen were covered or removed. Measurement of the antenna tile position on all antennas confirmed that the J-port antenna is at the same radial location as the D and E-port antennas. In order to interrupt long field lines across the antenna, an insulating septum was installed. The back plane feedthrus were also modified to reduce the E-field parallel to the B-field. In addition, four optical arc monitors, six B-dot probes, and an MKS pressure gauge were installed. These modifications have all contributed to the successful operation and understanding of this antenna.

The optical arc monitor signals had recorded large transient signals that correlated with reflected-to-forward power arc detection during some vacuum conditioning shots. In plasmas operation, the optical arc monitor signals did not correlate with most arc detection faults. This suggested that most faults were occurring outside their view. In addition, the optical monitors detected signal when the D and E-Port antennas were active. Comparisons with the voltage data indicate the induced voltage from D and E-Port antennas are low when the light signal is detected and high when no light is observed. This result suggests that the low induced voltage is sufficient to initiate multipactoring. This low power multipactoring does not impact plasma operation, nor does it affect the subsequent operation of the J-port antenna.

The new B-dot probes indicated that the current in strap 4 was equal in both the top and bottom half of the antenna strap. They also proved to be the most sensitive to arcs in the antenna.

The new 200 kHz and 1 MHz digitizers allowed direct monitoring of the arc protection system. During a particular experimental day, the fast data indicated that some arcs survived for 30-80 micro-sec. Up to 100 J could be available to dissipate in these arcs; therefore, we reduced the reflected-to-forward power ratio necessary to generate a trip by 25% for all future experiments. This successfully limited the arcs to ∼15 micro-sec or ∼15 J per MW injected.

78.0 Complete inner wall modifications

> *All components of the inner wall modifications will be installed and ready for operation. These modifications will strengthen the inner divertor and wall, allowing for operation at higher plasma currents, while simultaneously increasing plasma shaping flexibility for our standard lower single-null divertor configurations.*

All twenty interlocking inner wall girdle plates have been installed along with the approximately 1000 molybdenum tiles, tile support plates, and tile keeper hardware. The number of inner wall studs was tripled to better hold these new components. New eddy and halo rogowski coils, thermocouples, retro-reflectors, and probes have also been installed behind the divertor. Simulations indicate that not only will the new divertor easily survive high current, high field disruptions, but it will also add strength to the inner wall and provide a substantial increase in the heat load capacaity of the inner divertor during long pulse AT discharges.

Outstanding Milestones

62.0 Operate with plasma current of 2 MA

Operation with $I_p \geq 2$ MA for a flat-top time ≥ 0.5 seconds will have been achieved in our standard single null divertor configuration.

67.0 Evaluate integrated H-mode performance with 6 MW ICRF, $I_p \geq 1.2$ MA

With a total of 8 MW ICRF source power, full performance in H-Mode plasmas, with currents in the range above 1.2 MA, will be evaluated.

68.0 Evaluate mode conversion current drive

The four strap PPPL antenna will allow for experiments to evaluate mode conversion current drive with regard to efficiency and prospects for current profile modification. MCCD will be documented and the results reported in one or more publications.

70.0 Measure edge rotation profile with CXRS

CXRS systems are being added to look at toroidal and poloidal rotation, in conjunction with the diagnostic neutral beam. The edge poloidal rotation system should yield high spatial resolution measurements, which will be particularly important for H-mode pedestal studies.

71.0 Measure current density profile with MSE

An MSE system, also operated in conjunction with the DNB, is being installed and the system will undergo evaluation.

73.0 Evaluate mode conversion flow drive

Mode conversion electron heating experiments will be performed with our ICRF systems. During these experiments poloidal flow will be monitored using some combination of our charge exchange recombination and high resolution X-ray spectroscopy diagnostics. Flow drive efficiency will be quantified, and evidence for influence on internal transport barriers will be assessed.

74.0 Evaluate performance at high triangularity

Operate with increased triangularity, up to the range 0.8-0.9, as permitted by the modification of the inner divertor, and evaluate resulting performance. In H-mode discharges, the higher triangularity should provide improved MHD stability in the steep gradient pedestal, and is expected to modify the ELM behavior and the ELM-free/EDA boundary. High triangularity will also provide enhanced stability for AT optimized core shear equilibria and may impact internal transport barrier formation. The more open divertor configuration may also modify particle control properties.

79.0 Completion of Lower Hybrid fabrication project

The Lower Hybrid fabrication project, a collaboration between MIT and PPPL, will be completed. This project entails implementation of 3 MW of klystron source power at 4.6 GHz, with one waveguide array launcher, designed for current drive as a critical tool in the C-Mod long pulse Advanced Tokamak program.

Proposed New Milestones

80.0 Compare single-null, double-null and inner-wall-limited discharges

Plasma operation with balanced and unbalanced double null will be compared with our more standard single-null configurations, as well as with inner wall limited discharges. Particular attention will be paid to global energy confinement properties, as well as H-mode thresholds and overall access to H-mode. Edge and divertor particle dynamics will also be compared, including implications for the design of an active pumping system.

81.0 Establish limits of divertor power handling for Advanced Tokamak plasma regime

The power handling limits of divertor target surfaces will be evaluated in discharges optimized for Lower-Hybrid Current Drive. Operational thresholds for damage to divertor surfaces and/or increased divertor-source impurity levels in the core plasma will be assessed. This information will aid in the design of an advanced outer divertor target.

82.0 Initial assessment of Lower Hybrid Current Drive

The results of current drive experiments conducted during the FY03 and FY04 run campaigns with the Phase I Lower Hybrid system (source power from up to 12 klystrons coupled through a single antenna) will be assessed. Specific points of interest include: 1) power handling capability of the antenna; 2) impurity dynamics; 3) effects of changing the $N_{||}$ *spectrum through antenna phasing.*

83.0 Assess active MHD technique for sensing instability damping rates

Standard approaches to feedback stabilization of MHD instabilities require an unstable mode to be present at some amplitude in order to provide a signal (observer) which can be used in the control scheme. It would be preferable to use an observer which is present even when the mode is absent, allowing continuous feedback to maintain a stable range of operation, avoiding the instability altogether. Using the Active MHD Spectroscopy antennas, we will measure the plasma response to driven, low m/n, small amplitude perturbations in moderate to high beta discharges as a function of driving frequency. The width of the resonant response is expected to be proportional to the damping of stable MHD modes, and should decrease as the plasma approaches instability. By observing the evolution of this feature in plasmas in which such instabilities appear, we will test this prediction. If the results are well-correlated with the observed mode onset, then we will assess whether the technique provides a sufficiently quantitative measure of the proximity to instability to be used as an observer in a control algorithm to avoid these instabilities.

Milestones Completed since MAR 2001	Baseline	MAR 2001 Target	Completed
75.0 Evaluate density control	APR 2002	AUG 2001	FEB 2002
76.0 Investigation of ITB control with multiple frequency ICRF	AUG 2001	AUG 2001	SEP 2001
77.0 Evaluate operation of modified J-port 4-strap antenna	AUG 2001	AUG 2001	SEP 2001
78.0 Complete inner wall modifications	APR 2001	APR 2002	MAR2002

Outstanding Milestones	Baseline	MAR 2001 Target	Current Target	
62.0 Operate with plasma current of 2 MA	JUN 1997	SEP 2002	SEP 2003	limited FY02 run time
67.0 Evaluate integrated H-mode performance with 6 MW ICRF, $I_p \geq 1.2$ MA	JUN 1999	AUG 2001	SEP 2003	
68.0 Evaluate mode conversion current drive	JUN 1999	SEP 2002	SEP 2003	limited FY02 run time
70.0 Measure edge rotation profile with CXRS	JAN 2000	JUL 2001	MAY 2003	new DNB and optics
71.0 Measure current density profile with MSE	JAN 2000	SEP 2002	MAY 2003	new DNB
73.0 Evaluate mode conversion flow drive	SEP 2001	SEP 2001	MAY 2003	
74.0 Evaluate performance at high triangularity	SEP 2001	SEP 2002	SEP 2002	
79.0 Completion of Lower Hybrid Fabrication Project	MAR 2003	MAR 2003	MAR 2003	operation of klystrons in cell SEP 2002

Proposed New Milestones	Baseline	Comments
80.0 Compare single-null, double-null and inner-wall limited discharges	SEP 2002	
81.0 Establish limits of divertor power handling for Advanced Tokamak plasma regime	SEP 2004	
82.0 Initial assessment of Lower Hybrid Current Drive	SEP 2004	
83.0 Assess active MHD technique for sensing instability damping rates	SEP 2004	

7. ALCATOR C-Mod Cost Summary & Budgets

MIT Budget Summary

October 1, 2001 - September 30, 2004
Dollaris in Thousands

	Research	Facilities Operations	Lower Hybrid	JET	MDSplus	FTU	Total
FY2002	5,139	8,201	710	55	149		14,254
FY2003 A	5,790	11,972	419		147		18,328
FY2003 B	5,952	14,762	419	60	147	17	21,357
FY2004 A	5,790	12,391			147		18,328
FY2004 B	5,995	15,373		63	152	18	21,601
Plan A Total	16,719	32,564	1,129	55	443	0	50,910
Plan B Total	17,086	38,336	1,129	178	448	35	57,212

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Summary of Total Budget

	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 1,414,018	$ -	$ -	$ 11,987	$ 20,418	$ -	$ 1,446,423
ENGINEERS	-	1,194,579	-	-	-	-	1,194,579
COMPUTER STAFF	51,128	244,303	-	8,957	45,651	-	350,039
TECHNICIANS	-	1,266,145	-	-	-	-	1,266,145
DRAFTERS	-	93,164	-	-	-	-	93,164
ADMINISTRATIVE STAFF	53,460	14,373	-	-	-	-	67,833
ADMINISTRATIVE ALLOCATION	231,493	355,786	-	2,703	7,069	-	597,051
RESEARCH ASSISTANTS	372,862	-	-	-	-	-	372,862
SUBTOTAL SALARIES & WAGES	$ 2,122,961	$ 3,168,350	$ -	$ 23,647	$ 73,138	$ -	$ 5,388,096
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	474,232	871,296	-	6,502	20,113	-	1,372,143
TRAVEL	144,510	-	-	4,314	-	-	148,824
RA TUITION	165,565	-	-	-	-	-	165,565
MATERIALS & SERVICES	447,481	1,477,964	-	227	595	-	1,926,267
TOTAL DIRECT COSTS	$ 3,354,749	$ 5,517,610	$ -	$ 34,690	$ 93,846	$ -	$ 9,000,895
BASE FOR F & A (SEE BELOW)	2,572,902	4,096,778	-	31,007	84,204	-	6,784,891
FACILITIES & ADMINISTRATION COSTS	1,685,251	2,683,390	-	20,310	55,154	-	4,444,105
TOTAL EST. OPERATIONS	$ 5,040,000	$ 8,201,000	$ -	$ 55,000	$ 149,000	$ -	$ 13,445,000
CAPITAL EQUIPMENT (See Attached)	99,000	-	710,000	-	-	-	809,000
TOTAL ESTIMATED COSTS	$ 5,139,000	$ 8,201,000	$ 710,000	$ 55,000	$ 149,000	$ -	$ 14,254,000
EXCLUSIONS FROM PRIMARY F&A BASE		-					
Administrative Allocation*	$ 231,493	$ 355,786	$ -	$ 2,703	$ 7,069	$ -	$ 597,051
E.B. on Administrative Support*	64,818	99,620	-	757	1,979	-	167,174
Allocated Expense*	19,471	29,926	-	227	595	-	50,219
RA Tuition	165,565	-	-	-	-	-	165,565
Equipment Rental	7,500	7,500	-	-	-	-	15,000
Subcontracts >$25K	180,000	60,000	-	-	-	-	240,000
Cambridge Electric, Boc Gasses	-	387,000	-	-	-	-	387,000
Fabrications/Upgrades	113,000	481,000	-	-	-	-	594,000
TOTAL EXCL. FROM MTDC BASE :	$ 781,847	$ 1,420,832	$ -	$ 3,687	$ 9,643	$ -	$ 2,216,009

Summary of Person-Years

	FY02 Research	FY02 Facility Operations	FY02 Lower Hybrid	FY02 JET Collaboration	FY02 MDS+	FY02 FTU Collaboration	FY02 TOTAL
SCIENTIFIC							
FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	0.44
OTHER ACADEMIC STAFF	3.66	0.00	0.00	0.05	0.20	0.00	3.91
SCIENTIFIC RESEARCH STAFF	12.98	0.00	0.00	0.10	0.00	0.00	13.08
RESEARCH ASSISTANTS	17.45	0.00	0.00	0.00	0.00	0.00	17.45
SUBTOTAL SCIENTIFIC	34.53	0.00	0.00	0.15	0.20	0.00	34.88
TECHNICAL & ENGINEERING							
ENGINEERING RESEARCH STAFF	0.00	17.69	0.00	0.00	0.00	0.00	17.69
COMPUTER STAFF	0.74	0.00	0.00	0.10	0.56	0.00	1.40
TECHNICIANS	0.00	25.05	0.00	0.00	0.00	0.00	25.05
DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
SUBTOTAL ENGINEERING & TECH.	0.74	44.74	0.00	0.10	0.56	0.00	46.14
OTHER SUPPORT							
ADMINISTRATIVE STAFF	1.30	0.50	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE SUPPORT	4.62	7.10	0.00	0.05	0.14	0.00	11.91
SUBTOTAL OTHER	5.92	7.60	0.00	0.05	0.14	0.00	13.71
TOTAL MAN-YEARS	41.19	52.34	0.00	0.30	0.90	0.00	94.73

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Detail of Person Years			FY02				FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
FACULTY							
Fasoli, Ambrogio F.	0%	0%	0%	0%	0%	0%	0%
Hutchinson, Ian	27%	0%	0%	0%	0%	0%	27%
Parker, Ronald	17%	0%	0%	0%	0%	0%	17%
Porkolab, Miklos*	0%	0%	0%	0%	0%	0%	0%
TOTAL FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	44%
RESEARCH STAFF - OTHER ACADEMIC							
Marmar, Earl S.	100%	0%	0%	0%	0%	0%	100%
Greenwald, Martin	71%	0%	0%	0%	20%	0%	91%
Lipschultz, Bruce	95%	0%	0%	5%	0%	0%	100%
Lin,Yijun -Post-Doc	100%	0%	0%	0%	0%	0%	100%
TBD-Post-Doc	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH STAFF	3.66	0.00	0.00	0.05	0.20	0.00	3.91
SCIENTIFIC RESEARCH STAFF							
Bonoli, Paul T.	35%	0%	0%	0%	0%	0%	35%
Egedal-Pedersen, Jan	80%	0%	0%	0%	0%	0%	80%
Fiore, Catherine L.	50%	0%	0%	0%	0%	0%	50%
Granetz, Robert S.	100%	0%	0%	0%	0%	0%	100%
Hubbard, Amanda	98%	0%	0%	0%	0%	0%	98%
Irby, James	100%	0%	0%	0%	0%	0%	100%
LaBombard, Brian	100%	0%	0%	0%	0%	0%	100%
Mossessian, Dmitri	100%	0%	0%	0%	0%	0%	100%
Ramos, Jesus	45%	0%	0%	0%	0%	0%	45%
Rice, John E.	100%	0%	0%	0%	0%	0%	100%
Snipes, Joseph	90%	0%	0%	10%	0%	0%	100%
Terry, James	100%	0%	0%	0%	0%	0%	100%
Testa, Duccio	100%	0%	0%	0%	0%	0%	100%
Wolfe, Stephen	100%	0%	0%	0%	0%	0%	100%
Wukitch, Stephen	100%	0%	0%	0%	0%	0%	100%
Layoff Scientist	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL SCIENTIFIC RES. STAFF	12.98	0.00	0.00	0.10	0.00	0.00	13.08

* MIT fully supports the salary of Miklos Porkolab as Director of the Plasma Science and Fusion Center, but makes no specific commitment of time or salary to any individual research project.

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Detail of Person Years

	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
ENGINEERS							
Andreyev, Sergey	0%	25%	0%	0%	0%	0%	25%
Beck, William	0%	100%	0%	0%	0%	0%	100%
Burke, William	0%	100%	0%	0%	0%	0%	100%
Byford, William G.	0%	100%	0%	0%	0%	0%	100%
Childs, Robert	0%	100%	0%	0%	0%	0%	100%
Cochran, William	0%	100%	0%	0%	0%	0%	100%
Dekow, Gary	0%	100%	0%	0%	0%	0%	100%
DiMaria, Michael	0%	77%	0%	0%	0%	0%	77%
Fitzgerald, Edward	0%	100%	0%	0%	0%	0%	100%
Grimes, Montgomery	0%	0%	0%	0%	0%	0%	0%
Gwinn, David	0%	17%	0%	0%	0%	0%	17%
Koert, Peter	0%	100%	0%	0%	0%	0%	100%
Murray, Richard	0%	100%	0%	0%	0%	0%	100%
Parkin, William	0%	100%	0%	0%	0%	0%	100%
Rokhman,Yuriy	0%	100%	0%	0%	0%	0%	100%
Rosati, James	0%	100%	0%	0%	0%	0%	100%
Terry, David R.	0%	100%	0%	0%	0%	0%	100%
Thomas, Paul	0%	40%	0%	0%	0%	0%	40%
Titus, Peter	0%	10%	0%	0%	0%	0%	10%
Vieira, Rui	0%	100%	0%	0%	0%	0%	100%
Woskov, Paul P.	0%	0%	0%	0%	0%	0%	0%
Zaks, James	0%	100%	0%	0%	0%	0%	100%
Zhong,Xiwen	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL ENGINEERS	0.00	17.69	0.00	0.00	0.00	0.00	17.69
COMPUTER STAFF							
Bergler, Henry	5%	45%	0%	0%	0%	0%	50%
Fredian, Thomas	0%	44%	0%	5%	30%	0%	79%
Kreisel, Felix	30%	70%	0%	0%	0%	0%	100%
London, Mark	0%	10%	0%	0%	0%	0%	10%
Nelson, Donald	0%	50%	0%	0%	0%	0%	50%
Sherman, Stuart	15%	38%	0%	0%	26%	0%	79%
Stillerman, Joshua	24%	50%	0%	5%	0%	0%	79%
TOTAL COMPUTER STAFF	0.74	3.07	0.00	0.10	0.56	0.00	4.47

Detail of Person Years	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
TECHNICIANS							
Anderson, Eric	0%	100%	0%	0%	0%	0%	100%
Arsenault, David	0%	100%	0%	0%	0%	0%	100%
Bellofatto, David	0%	100%	0%	0%	0%	0%	100%
Cauley, Charles	0%	100%	0%	0%	0%	0%	100%
Chicarello, James	0%	75%	0%	0%	0%	0%	75%
Danforth, Richard	0%	100%	0%	0%	0%	0%	100%
Gerolamo, Jerry	0%	80%	0%	0%	0%	0%	80%
Iverson, Mark	0%	100%	0%	0%	0%	0%	100%
Keating, William	0%	20%	0%	0%	0%	0%	20%
Mackay, George T.	0%	0%	0%	0%	0%	0%	0%
Muttart, Douglas B.	0%	100%	0%	0%	0%	0%	100%
Nickerson, John	0%	100%	0%	0%	0%	0%	100%
Pfeiffer, Andrew T.	0%	100%	0%	0%	0%	0%	100%
Pierson, Samuel	0%	100%	0%	0%	0%	0%	100%
Pina, Wanda	0%	100%	0%	0%	0%	0%	100%
Rettman, Kenneth	0%	100%	0%	0%	0%	0%	100%
Rollins, Edgar	0%	100%	0%	0%	0%	0%	100%
Rosati, Ronald	0%	100%	0%	0%	0%	0%	100%
Rowell, Michael	0%	100%	0%	0%	0%	0%	100%
Shefton, Frank	0%	100%	0%	0%	0%	0%	100%
Silveira, Maria	0%	80%	0%	0%	0%	0%	80%
Sylvia, Robert	0%	100%	0%	0%	0%	0%	100%
Szczepanowski, Wanda	0%	100%	0%	0%	0%	0%	100%
Tambini, Steven	0%	100%	0%	0%	0%	0%	100%
Telesmanick, Paul	0%	50%	0%	0%	0%	0%	50%
Toland, Thomas	0%	100%	0%	0%	0%	0%	100%
Vestal, David	0%	50%	0%	0%	0%	0%	50%
New Tech TBN	0%	0%	0%	0%	0%	0%	0%
New Tech TBN	0%	0%	0%	0%	0%	0%	0%
New Tech TBN	0%	0%	0%	0%	0%	0%	0%
Overtime	0%	150%	0%	0%	0%	0%	150%
TOTAL TECHNICIANS	0.00	25.05	0.00	0.00	0.00	0.00	25.05

Detail of Person Years	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
DRAFTERS							
Lienard,Paul	0%	100%	0%	0%	0%	0%	100%
Savelli, Henry	0%	100%	0%	0%	0%	0%	100%
TOTAL DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
ADMINISTRATIVE STAFF							
Censabella, Valerie	80%	0%	0%	0%	0%	0%	80%
Zibcevoc, Dragana	50%	50%	0%	0%	0%	0%	100%
TOTAL ADMINISTRATIVE STAFF	1.30	0.50	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE LAB SUPPORT							
Various	4.62	7.10	0.00	0.05	0.14	0.00	11.91
Detail of Research Assistant Effort							
RESEARCH ASSISTANTS							
Bai, Bo	100%	0%	0%	0%	0%	0%	100%
Boswell, Christopher	100%	0%	0%	0%	0%	0%	100%
Chung, Taekyun	100%	0%	0%	0%	0%	0%	100%
Decker, Joan	100%	0%	0%	0%	0%	0%	100%
Gangadhara, Sanjay	100%	0%	0%	0%	0%	0%	100%
Graves, Timothy	0%	0%	0%	0%	0%	0%	0%
Hughes, Jerry	100%	0%	0%	0%	0%	0%	100%
Jennings, Thomas M.	100%	0%	0%	0%	0%	0%	100%
Lee, William D.	100%	0%	0%	0%	0%	0%	100%
Liptac, John Edward, Jr.	100%	0%	0%	0%	0%	0%	100%
Marr, Kenneth David	100%	0%	0%	0%	0%	0%	100%
Nelson-Melby, Eric	25%	0%	0%	0%	0%	0%	25%
Sarlese, Justin A.	71%	0%	0%	0%	0%	0%	71%
Schmittdiel, David Anthony	100%	0%	0%	0%	0%	0%	100%
Tang, Vincent	100%	0%	0%	0%	0%	0%	100%
Thomas, Michael J.	100%	0%	0%	0%	0%	0%	100%
Thoms, Jon G.	100%	0%	0%	0%	0%	0%	100%
Youngblood, Brian J.	49%	0%	0%	0%	0%	0%	49%
Yuh, Howard Y.	100%	0%	0%	0%	0%	0%	100%
Zhurovich, Kirill	100%	0%	0%	0%	0%	0%	100%
New Student-TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH ASSISTANTS	17.45	0.00	0.00	0.00	0.00	0.00	17.45
Total Man-Years	41.19	55.41	0.00	0.30	0.90	0.00	97.80

Detail of Research Assistant Tuition

	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
RESEARCH ASSISTANTS TUITION							
Bai, Bo	9,488	-	-	-	-	-	9,488
Boswell, Christopher	9,488	-	-	-	-	-	9,488
Chung, Taekyun	9,488	-	-	-	-	-	9,488
Decker, Joan	9,488	-	-	-	-	-	9,488
Gangadhara, Sanjay	9,488	-	-	-	-	-	9,488
Graves, Timothy	-	-	-	-	-	-	-
Hughes, Jerry	9,488	-	-	-	-	-	9,488
Jennings, Thomas M.	9,488	-	-	-	-	-	9,488
Lee, William D.	9,488	-	-	-	-	-	9,488
Liptac, John Edward, Jr.	9,488	-	-	-	-	-	9,488
Marr, Kenneth David	9,488	-	-	-	-	-	9,488
Nelson-Melby, Eric	2,372	-	-	-	-	-	2,372
Sarlese, Justin A.	6,736	-	-	-	-	-	6,736
Schmittdiel, David Anthony	9,488	-	-	-	-	-	9,488
Tang, Vincent	9,488	-	-	-	-	-	9,488
Thomas, Michael J.	9,488	-	-	-	-	-	9,488
Thoms, Jon G.	9,488	-	-	-	-	-	9,488
Youngblood, Brian J.	4,649	-	-	-	-	-	4,649
Yuh, Howard Y.	9,488	-	-	-	-	-	9,488
Zhurovich, Kirill	9,488	-	-	-	-	-	9,488
New Student-TBD	-	-	-	-	-	-	-
RA TUITION TOTAL	165,565	-	-	-	-	-	165,565

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Detail of Materials and Services

	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
OFFICE MATERIALS AND SERVICES	40,010	40,010	-	-	-	-	80,020
Xeroxing	7,000	7,000	-	-	-	-	14,000
Telecommunications	9,000	9,000	-	-	-	-	18,000
Office Supplies	8,000	8,000	-	-	-	-	16,000
Postage/Shipping	4,000	4,000	-	-	-	-	8,000
Journals & Books	4,110	4,110	-	-	-	-	8,220
Equipment Rental (No O/H)	7,500	7,500	-	-	-	-	15,000
Graphic Arts	400	400	-	-	-	-	800
Computing Materials & Services	40,000	92,000	-	-	-	-	132,000
PSFC Computer Contribution	-	6,000	-	-	-	-	6,000
Computer Maintenance	30,000	50,000	-	-	-	-	80,000
Computer Software & Supplies	10,000	25,000	-	-	-	-	35,000
MIT Networking Charges	-	11,000	-	-	-	-	11,000
Operations Material & Services	-	760,028	-	-	-	-	760,028
Materials & Services	-	363,028	-	-	-	-	363,028
Safety	-	10,000	-	-	-	-	10,000
DNB Shipping	-	-	-	-	-	-	-
Boc Gases (Nitrogen)	-	310,000	-	-	-	-	310,000
N/Star (Cambridge Electric)	-	77,000	-	-	-	-	77,000
RF Materials & Services	15,000	15,000	-	-	-	-	30,000
Diagnostic Materials & Services	40,000	-	-	-	-	-	40,000
Lower Hybrid Materials & Services	-	-	-	-	-	-	-
Subcontracts (No O/H)	180,000	60,000	-	-	-	-	240,000
Plasma Surface Engineering	130,000	-	-	-	-	-	130,000
M Technology	30,000	60,000	-	-	-	-	90,000
University of Toronto	20,000	-	-	-	-	-	20,000
Flywheel Inspection	-	-	-	-	-	-	-
Alternator Inspection	-	-	-	-	-	-	-
SUBTOTAL MATERIALS & SERVICES	315,010	967,038	-	-	-	-	1,282,048
ALLOCATED EXPENSE	19,471	29,926	-	227	595	-	50,219

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Detail of Travel Costs

			FY02				FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
A. DOMESTIC:							
APS - FY2002, Long Beach, CA	49,184	0	0	0	0	0	49,184
APS - FY2003, Orlando,FL	0	0	0	0	0	0	0
APS - FY2004, Albuquerque, NM	0	0	0	0	0	0	0
Berkley, CA	3,074	0	0	0	0	0	3,074
Livermore, CA	0	0	0	0	0	0	0
San Diego, CA	13,833	0	0	0	0	0	13,833
Snowmass, CO	0	0	0	0	0	0	0
RF/Diag Conference	2,120	0	0	0	0	0	2,120
Princeton, NJ	8,752	0	0	0	0	0	8,752
Sherwood Theory - FY2002	0	0	0	0	0	0	0
Sherwood Theory - FY2003	0	0	0	0	0	0	0
Sherwood Theory - FY2004	0	0	0	0	0	0	0
Texas	0	0	0	0	0	0	0
Washington DC	14,840	0	0	0	0	0	14,840
Madison, WI	0	0	0	0	0	0	0
High Temp Plasma Conf	0	0	0	0	0	0	0
(TTF) FY02, Annapolis, MD	8,904	0	0	0	0	0	8,904
(TTF) FY03	0	0	0	0	0	0	0
(TTF) FY04	0	0	0	0	0	0	0
B. FOREIGN:							
England (JET)	0	0	0	4,314	0	0	4,314
EPS FY2002 - Switzerland	0	0	0	0	0	0	0
EPS FY2003	11,024	0	0	0	0	0	11,024
EPS FY2004	0	0	0	0	0	0	0
Germany	6,804	0	0	0	0	0	6,804
Italy (Frascati)	2,120	0	0	0	0	0	2,120
(IAEA) Lyon, France (FY03)	0	0	0	0	0	0	0
(IAEA) Tech Mtg (Arles, France)	0	0	0	0	0	0	0
Japan	15,900	0	0	0	0	0	15,900
Japan (PSI) - Fy2002	7,955	0	0	0	0	0	7,955
China (PSI) - Fy2004	0	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0	0
TOTAL ESTIMATED TRAVEL COSTS	144,510	0	0	4,314	0	0	148,824

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Detail of Fabrications and Upgrades	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Operations Fabs/Upgrades	0	226,000	0	0	0	0	226,000
Machine Upgrade	0	100,000	0	0	0	0	100,000
Cylinder Upgrade	0	66,000	0	0	0	0	66,000
EFC Upgrade	0	0	0	0	0	0	0
Cryostat Fab	0	30,000	0	0	0	0	30,000
EF2 Upgrade	0	0	0	0	0	0	0
Igloo	0	10,000	0	0	0	0	10,000
Control (paragon replacements)	0	0	0	0	0	0	0
Digital Control (Hybrid replace)	0	20,000	0	0	0	0	20,000
ICRF Fabs/Upgrades	0	230,000	0	0	0	0	230,000
Transmitter Upgrade Fab	0	5,000	0	0	0	0	5,000
Matching Fab	0	25,000	0	0	0	0	25,000
Instrumentation/Control Fab	0	30,000	0	0	0	0	30,000
RF Diagnostics Fab	0	5,000	0	0	0	0	5,000
Data Acquisition Fab	0	50,000	0	0	0	0	50,000
Access Grid (Display Technology)	0	0	0	0	0	0	0
ICRF Transmission Line Upgrade	0	15,000	0	0	0	0	15,000
ICRF Dummy Loads Fab	0	25,000	0	0	0	0	25,000
ICRF Antenna Fab	0	75,000	0	0	0	0	75,000
Antenna Upgrade (D&E)	0	0	0	0	0	0	0
New 4-Strap Antenna (1/2)	0	0	0	0	0	0	0
ICRF Power Supply Upgrade	0	0	0	0	0	0	0
Fast Ferrite Tuners	0	0	0	0	0	0	0
Divertor Fabs/Upgrades	0	25,000	0	0	0	0	25,000
Cryopump Fab	0	0	0	0	0	0	0
Divertor Upgrade	0	25,000	0	0	0	0	25,000
Outer Divertor Upgrade	0	0	0	0	0	0	0
OPS/EQUIPMENT	73,000	0	0	0	0	0	73,000
Miscellaneous	20,000	0	0	0	0	0	20,000
Workstations/Servers/PCs	50,000	0	0	0	0	0	50,000
Data Communications	0	0	0	0	0	0	0
Vacuum and Pumping	0	0	0	0	0	0	0
Test Equipment	3,000	0	0	0	0	0	3,000
Machine Tools	0	0	0	0	0	0	0
Safety Equipment	0	0	0	0	0	0	0
Switch Gear	0	0	0	0	0	0	0
ICRF Transmitter Tube	0	0	0	0	0	0	0
Lower Hybrid Fabs/Upgrades	0	0	0	0	0	0	0
Instrumentation/control	0	0	0	0	0	0	0
Lower Hybrid Upgrade	0	0	0	0	0	0	0

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Detail of Fabrications and Upgrades (Continued)	FY02 Research	 Facility Operations	 Lower Hybrid	 JET Collaboration	 MDS+	 FTU Collaboration	FY02 TOTAL
Diagnostic Fabs/Upgrades	40,000	0	0	0	0	0	40,000
Diagnostic Neutral Beam	0	0	0	0	0	0	0
Fast Thermocouples	5,000	0	0	0	0	0	5,000
MSE Fab	0	0	0	0	0	0	0
Fast Scanning Probe Fab	5,000	0	0	0	0	0	5,000
Active MHD Fab	30,000	0	0	0	0	0	30,000
EUV Spectrograph Upgrade	0	0	0	0	0	0	0
PCI Upgrade	0	0	0	0	0	0	0
Imaging X-Ray Spectrometer Fab	0	0	0	0	0	0	0
Core TS	0	0	0	0	0	0	0
Polarimetry Fab	0	0	0	0	0	0	0
2nd MHD antenna	0	0	0	0	0	0	0
Divertor IR camera	0	0	0	0	0	0	0
SOL Thomson upgrade	0	0	0	0	0	0	0
SOL Flow Diagnostic	0	0	0	0	0	0	0
Two -color Ne/Te Twiddle	0	0	0	0	0	0	0
Penning Gauges	0	0	0	0	0	0	0
D-Alpha imaging	0	0	0	0	0	0	0
CXRS telescope	0	0	0	0	0	0	0
CXRS Spectrometer (Kaiser)	0	0	0	0	0	0	0
Thomson digitizers	0	0	0	0	0	0	0
DNB upgrade (cap bank)	0	0	0	0	0	0	0
Long Pulse DNB	0	0	0	0	0	0	0
HIREX electronics	0	0	0	0	0	0	0
TOTAL FABS/UPGRADES	113,000	481,000	0	0	0	0	594,000

Detail of Capital Equipment

	FY02						FY02
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Data Acquisition Equipment							
Misc.	0	0	0	0	0	0	0
Crates & Controllers	5,000	0	0	0	0	0	5,000
Digitizers	5,000	0	0	0	0	0	5,000
Plasma Control Equipment							
Computer Equipment							
Computers, Workstations/Servers	30,000	0	0	0	0	0	30,000
Mass Storage	0	0	0	0	0	0	0
Other Equipment							
Video & Optical Equip. and Instr.	4,000	0	0	0	0	0	4,000
Electronic Equipment	10,000	0	0	0	0	0	10,000
CMOD TV System Fab	5,000	0	0	0	0	0	5,000
Flush Mount Array Upgrade Fab	5,000	0	0	0	0	0	5,000
Lower Hybrid							
Capital Equipment	0	0	710,000	0	0	0	710,000
Operations							
Safety Equipment	5,000	0	0	0	0	0	5,000
Switch Gear	30,000	0	0	0	0	0	30,000
TOTAL CAPITAL EQUIPMENT	99,000	0	710,000	0	0	0	809,000

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Summary of Total Budget

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 1,425,616	$ 175,454	$ -	$ -	$ 21,133	$ -	$ 1,622,203
ENGINEERS	-	1,472,438	-	-	-	-	1,472,438
COMPUTER STAFF	52,901	265,231	-	-	44,050	-	362,182
TECHNICIANS	-	1,581,712	-	-	-	-	1,581,712
DRAFTERS	-	96,424	-	-	-	-	96,424
ADMINISTRATIVE STAFF	58,306	11,901	-	-	-	-	70,207
ADMINISTRATIVE ALLOCATION	243,529	442,463	-	-	6,975	-	692,967
RESEARCH ASSISTANTS	384,650	-	-	-	-	-	384,650
SUBTOTAL SALARIES & WAGES	$ 2,165,002	$ 4,045,623	$ -	$ -	$ 72,158	$ -	$ 6,282,783
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	482,305	1,112,546	-	-	19,843	-	1,614,694
TRAVEL	172,000	-	-	-	-	-	172,000
RA TUITION	174,200	-	-	-	-	-	174,200
MATERIALS & SERVICES	935,484	3,457,727	-	-	587	-	4,393,798
TOTAL DIRECT COSTS	$ 3,928,991	$ 8,615,896	$ -	$ -	$ 92,588	$ -	$ 12,637,475
BASE FOR F & A (SEE BELOW)	2,690,090	5,123,823	-	-	83,072	-	7,896,985
FACILITIES & ADMINISTRATION COSTS	1,762,009	3,356,104	-	-	54,412	-	5,172,525
TOTAL EST. OPERATIONS	$ 5,691,000	$ 11,972,000	$ -	$ -	$ 147,000	$ -	$ 17,810,000
CAPITAL EQUIPMENT (See Attached)	99,000	-	419,000	-	-	-	518,000
TOTAL ESTIMATED COSTS	$ 5,790,000	$ 11,972,000	$ 419,000	$ -	$ 147,000	$ -	$ 18,328,000
EXCLUSIONS FROM PRIMARY F&A BASE							
Administrative Allocation*	$ 243,529	$ 442,463	$ -	$ -	$ 6,975	$ -	$ 692,967
E.B. on Administrative Support*	68,188	123,890	-	-	1,953	-	194,031
Allocated Expense*	20,484	37,217	-	-	587	-	58,288
RA Tuition	174,200	-	-	-	-	-	174,200
Equipment Rental	7,500	7,500	-	-	-	-	15,000
Subcontracts >$25K	300,000	1,050,000	-	-	-	-	1,350,000
Cambridge Electric, Boc Gasses	-	700,000	-	-	-	-	700,000
Fabrications/Upgrades	425,000	1,131,000	-	-	-	-	1,556,000
TOTAL EXCL. FROM MTDC BASE :	$ 1,238,901	$ 3,492,070	$ -	$ -	$ 9,515	$ -	$ 4,740,486

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Summary of Person-Years

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SCIENTIFIC							
FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	0.44
OTHER ACADEMIC STAFF	3.63	0.10	0.00	0.00	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF	13.60	1.70	0.00	0.00	0.00	0.00	15.30
RESEARCH ASSISTANTS	17.49	0.00	0.00	0.00	0.00	0.00	17.49
SUBTOTAL SCIENTIFIC	35.16	1.80	0.00	0.00	0.20	0.00	37.16
TECHNICAL & ENGINEERING							
ENGINEERING RESEARCH STAFF	0.00	20.84	0.00	0.00	0.00	0.00	20.84
COMPUTER STAFF	0.74	3.22	0.00	0.00	0.51	0.00	4.47
TECHNICIANS	0.00	29.55	0.00	0.00	0.00	0.00	29.55
DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
SUBTOTAL ENGINEERING & TECH.	0.74	55.61	0.00	0.00	0.51	0.00	56.86
OTHER SUPPORT							
ADMINISTRATIVE STAFF	1.40	0.40	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE SUPPORT	4.86	8.53	0.00	0.00	0.13	0.00	13.52
SUBTOTAL OTHER	6.26	8.93	0.00	0.00	0.13	0.00	15.32
TOTAL MAN-YEARS	42.16	66.34	0.00	0.00	0.84	0.00	109.34

Detail of Person Years	FY03A Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	FY03A TOTAL
FACULTY							
Fasoli, Ambrogio F.	0%	0%	0%	0%	0%	0%	0%
Hutchinson, Ian	27%	0%	0%	0%	0%	0%	27%
Parker, Ronald	17%	0%	0%	0%	0%	0%	17%
Porkolab, Miklos*	0%	0%	0%	0%	0%	0%	0%
TOTAL FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	0.44
RESEARCH STAFF - OTHER ACADEMIC							
Marmar, Earl S.	90%	10%	0%	0%	0%	0%	100%
Greenwald, Martin	73%	0%	0%	0%	20%	0%	93%
Lipschultz, Bruce	100%	0%	0%	0%	0%	0%	100%
Lin,Yijun -Post-Doc	100%	0%	0%	0%	0%	0%	100%
TBD-Post-Doc	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH STAFF	3.63	0.10	0.00	0.00	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF							
Bonoli, Paul T.	35%	0%	0%	0%	0%	0%	35%
Egedal-Pedersen, Jan	100%	0%	0%	0%	0%	0%	100%
Fiore, Catherine L.	50%	0%	0%	0%	0%	0%	50%
Granetz, Robert S.	90%	10%	0%	0%	0%	0%	100%
Hubbard, Amanda	100%	0%	0%	0%	0%	0%	100%
Irby, James	0%	100%	0%	0%	0%	0%	100%
LaBombard, Brian	100%	0%	0%	0%	0%	0%	100%
Mossessian, Dmitri	90%	10%	0%	0%	0%	0%	100%
Ramos, Jesus	45%	0%	0%	0%	0%	0%	45%
Rice, John E.	100%	0%	0%	0%	0%	0%	100%
Snipes, Joseph	100%	0%	0%	0%	0%	0%	100%
Terry, James	100%	0%	0%	0%	0%	0%	100%
Testa, Duccio	100%	0%	0%	0%	0%	0%	100%
Wolfe, Stephen	80%	20%	0%	0%	0%	0%	100%
Wukitch, Stephen	70%	30%	0%	0%	0%	0%	100%
Layoff Scientist	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL SCIENTIFIC RES. STAFF	13.60	1.70	0.00	0.00	0.00	0.00	15.30

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Detail of Person Years

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
ENGINEERS							
Andreyev, Sergey	0%	0%	0%	0%	0%	0%	0%
Beck, William	0%	100%	0%	0%	0%	0%	100%
Burke, William	0%	100%	0%	0%	0%	0%	100%
Byford, William G.	0%	100%	0%	0%	0%	0%	100%
Childs, Robert	0%	100%	0%	0%	0%	0%	100%
Cochran, William	0%	100%	0%	0%	0%	0%	100%
Dekow, Gary	0%	100%	0%	0%	0%	0%	100%
DiMaria, Michael	0%	100%	0%	0%	0%	0%	100%
Fitzgerald, Edward	0%	100%	0%	0%	0%	0%	100%
Grimes, Montgomery	0%	100%	0%	0%	0%	0%	100%
Gwinn, David	0%	0%	0%	0%	0%	0%	0%
Koert, Peter	0%	100%	0%	0%	0%	0%	100%
Murray, Richard	0%	100%	0%	0%	0%	0%	100%
Parkin, William	0%	100%	0%	0%	0%	0%	100%
Rokhman,Yuriy	0%	100%	0%	0%	0%	0%	100%
Rosati, James	0%	100%	0%	0%	0%	0%	100%
Terry, David R.	0%	100%	0%	0%	0%	0%	100%
Thomas, Paul	0%	64%	0%	0%	0%	0%	64%
Titus, Peter	0%	10%	0%	0%	0%	0%	10%
Vieira, Rui	0%	100%	0%	0%	0%	0%	100%
Woskov, Paul P.	0%	10%	0%	0%	0%	0%	10%
Zaks, James	0%	100%	0%	0%	0%	0%	100%
Zhong,Xiwen	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
TOTAL ENGINEERS	0.00	20.84	0.00	0.00	0.00	0.00	20.84
COMPUTER STAFF							
Bergler, Henry	5%	45%	0%	0%	0%	0%	50%
Fredian, Thomas	0%	49%	0%	0%	30%	0%	79%
Kreisel, Felix	30%	70%	0%	0%	0%	0%	100%
London, Mark	0%	10%	0%	0%	0%	0%	10%
Nelson, Donald	0%	50%	0%	0%	0%	0%	50%
Sherman, Stuart	15%	43%	0%	0%	21%	0%	79%
Stillerman, Joshua	24%	55%	0%	0%	0%	0%	79%
TOTAL COMPUTER STAFF	0.74	3.22	0.00	0.00	0.51	0.00	4.47

Detail of Person Years	FY03A Research	FY03A Facility Operations	FY03A Lower Hybrid	FY03A JET Collaboration	FY03A MDS+	FY03A FTU Collaboration	FY03A TOTAL
TECHNICIANS							
Anderson, Eric	0%	100%	0%	0%	0%	0%	100%
Arsenault, David	0%	100%	0%	0%	0%	0%	100%
Bellofatto, David	0%	100%	0%	0%	0%	0%	100%
Cauley, Charles	0%	100%	0%	0%	0%	0%	100%
Chicarello, James	0%	75%	0%	0%	0%	0%	75%
Danforth, Richard	0%	100%	0%	0%	0%	0%	100%
Gerolamo, Jerry	0%	80%	0%	0%	0%	0%	80%
Iverson, Mark	0%	100%	0%	0%	0%	0%	100%
Keating, William	0%	20%	0%	0%	0%	0%	20%
Mackay, George T.	0%	100%	0%	0%	0%	0%	100%
Muttart, Douglas B.	0%	100%	0%	0%	0%	0%	100%
Nickerson, John	0%	100%	0%	0%	0%	0%	100%
Pfeiffer, Andrew T.	0%	100%	0%	0%	0%	0%	100%
Pierson, Samuel	0%	100%	0%	0%	0%	0%	100%
Pina, Wanda	0%	100%	0%	0%	0%	0%	100%
Rettman, Kenneth	0%	100%	0%	0%	0%	0%	100%
Rollins, Edgar	0%	100%	0%	0%	0%	0%	100%
Rosati, Ronald	0%	100%	0%	0%	0%	0%	100%
Rowell, Michael	0%	100%	0%	0%	0%	0%	100%
Shefton, Frank	0%	100%	0%	0%	0%	0%	100%
Silveira, Maria	0%	80%	0%	0%	0%	0%	80%
Sylvia, Robert	0%	100%	0%	0%	0%	0%	100%
Szczepanowski, Wanda	0%	100%	0%	0%	0%	0%	100%
Tambini, Steven	0%	100%	0%	0%	0%	0%	100%
Telesmanick, Paul	0%	50%	0%	0%	0%	0%	50%
Toland, Thomas	0%	100%	0%	0%	0%	0%	100%
Vestal, David	0%	50%	0%	0%	0%	0%	50%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	0%	0%	0%	0%	0%	0%
New Tech TBN	0%	0%	0%	0%	0%	0%	0%
Overtime	0%	400%	0%	0%	0%	0%	400%
TOTAL TECHNICIANS	0.00	29.55	0.00	0.00	0.00	0.00	29.55

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Detail of Person Years			FY03A				FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
DRAFTERS							
Lienard,Paul	0%	100%	0%	0%	0%	0%	100%
Savelli, Henry	0%	100%	0%	0%	0%	0%	100%
TOTAL DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
ADMINISTRATIVE STAFF							
Censabella, Valerie	80%	0%	0%	0%	0%	0%	80%
Zibcevoc, Dragana	60%	40%	0%	0%	0%	0%	100%
TOTAL ADMINISTRATIVE STAFF	1.40	0.40	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE LAB SUPPORT							
Various	4.86	8.53	0.00	0.00	0.13	0.00	13.52
Detail of Research Assistant Effort							
RESEARCH ASSISTANTS							
Bai, Bo	100%	0%	0%	0%	0%	0%	100%
Boswell, Christopher	100%	0%	0%	0%	0%	0%	100%
Chung, Taekyun	100%	0%	0%	0%	0%	0%	100%
Decker, Joan	100%	0%	0%	0%	0%	0%	100%
Gangadhara, Sanjay	100%	0%	0%	0%	0%	0%	100%
Graves, Timothy	100%	0%	0%	0%	0%	0%	100%
Hughes, Jerry	100%	0%	0%	0%	0%	0%	100%
Jennings, Thomas M.	100%	0%	0%	0%	0%	0%	100%
Lee, William D.	100%	0%	0%	0%	0%	0%	100%
Liptac, John Edward, Jr.	100%	0%	0%	0%	0%	0%	100%
Marr, Kenneth David	100%	0%	0%	0%	0%	0%	100%
Nelson-Melby, Eric	0%	0%	0%	0%	0%	0%	0%
Sarlese, Justin A.	0%	0%	0%	0%	0%	0%	0%
Schmittdiel, David Anthony	100%	0%	0%	0%	0%	0%	100%
Tang, Vincent	100%	0%	0%	0%	0%	0%	100%
Thomas, Michael J.	100%	0%	0%	0%	0%	0%	100%
Thoms, Jon G.	100%	0%	0%	0%	0%	0%	100%
Youngblood, Brian J.	49%	0%	0%	0%	0%	0%	49%
Yuh, Howard Y.	100%	0%	0%	0%	0%	0%	100%
Zhurovich, Kirill	100%	0%	0%	0%	0%	0%	100%
New Student-TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH ASSISTANTS	17.49	0.00	0.00	0.00	0.00	0.00	17.49
Total Man-Years	42.16	66.34	0.00	0.00	0.84	0.00	109.34

Detail of Research Assistant Tuition

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
RESEARCH ASSISTANTS TUITION							
Bai, Bo	9,960	-	-	-	-	-	9,960
Boswell, Christopher	9,960	-	-	-	-	-	9,960
Chung, Taekyun	9,960	-	-	-	-	-	9,960
Decker, Joan	9,960	-	-	-	-	-	9,960
Gangadhara, Sanjay	9,960	-	-	-	-	-	9,960
Graves, Timothy	9,960	-	-	-	-	-	9,960
Hughes, Jerry	9,960	-	-	-	-	-	9,960
Jennings, Thomas M.	9,960	-	-	-	-	-	9,960
Lee, William D.	9,960	-	-	-	-	-	9,960
Liptac, John Edward, Jr.	9,960	-	-	-	-	-	9,960
Marr, Kenneth David	9,960	-	-	-	-	-	9,960
Nelson-Melby, Eric	-	-	-	-	-	-	-
Sarlese, Justin A.	-	-	-	-	-	-	-
Schmittdiel, David Anthony	9,960	-	-	-	-	-	9,960
Tang, Vincent	9,960	-	-	-	-	-	9,960
Thomas, Michael J.	9,960	-	-	-	-	-	9,960
Thoms, Jon G.	9,960	-	-	-	-	-	9,960
Youngblood, Brian J.	4,880	-	-	-	-	-	4,880
Yuh, Howard Y.	9,960	-	-	-	-	-	9,960
Zhurovich, Kirill	9,960	-	-	-	-	-	9,960
New Student-TBD	-	-	-	-	-	-	-
RA TUITION TOTAL	174,200	-	-	-	-	-	174,200

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Detail of Materials and Services

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
OFFICE MATERIALS AND SERVICES	45,000	45,000	-	-	-	-	90,000
Xeroxing	8,000	8,000	-	-	-	-	16,000
Telecommunications	12,000	12,000	-	-	-	-	24,000
Office Supplies	9,000	9,000	-	-	-	-	18,000
Postage/Shipping	4,000	4,000	-	-	-	-	8,000
Journals & Books	4,000	4,000	-	-	-	-	8,000
Equipment Rental (No O/H)	7,500	7,500	-	-	-	-	15,000
Graphic Arts	500	500	-	-	-	-	1,000
Computing Materials & Services	40,000	92,000	-	-	-	-	132,000
PSFC Computer Contribution	-	6,000	-	-	-	-	6,000
Computer Maintenance	30,000	50,000	-	-	-	-	80,000
Computer Software & Supplies	10,000	25,000	-	-	-	-	35,000
MIT Networking Charges	-	11,000	-	-	-	-	11,000
Operations Material & Services	-	1,102,510	-	-	-	-	1,102,510
Materials & Services	-	392,510	-	-	-	-	392,510
Safety	-	10,000	-	-	-	-	10,000
DNB Shipping	-	-	-	-	-	-	-
Boc Gases (Nitrogen)	-	600,000	-	-	-	-	600,000
N/Star (Cambridge Electric)	-	100,000	-	-	-	-	100,000
RF Materials & Services	30,000	-	-	-	-	-	30,000
Diagnostic Materials & Services	40,000	-	-	-	-	-	40,000
Lower Hybrid Materials & Services	35,000	-	-	-	-	-	35,000
Subcontracts (No O/H)	300,000	1,050,000	-	-	-	-	1,350,000
Plasma Surface Engineering	-	-	-	-	-	-	-
M Technology	140,000	40,000	-	-	-	-	180,000
University of Toronto	160,000	-	-	-	-	-	160,000
Flywheel Inspection	-	60,000	-	-	-	-	60,000
Alternator Inspection	-	950,000	-	-	-	-	950,000
SUBTOTAL MATERIALS & SERVICES	490,000	2,289,510	-	-	-	-	2,779,510
ALLOCATED EXPENSE	20,484	37,217	-	-	587	-	58,288

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Detail of Travel Costs

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
A. DOMESTIC:							
APS - FY2002, Long Beach, CA	0	0	0	0	0	0	0
APS - FY2003, Orlando,FL	42,930	0	0	0	0	0	42,930
APS - FY2004, Albuquerque, NM	0	0	0	0	0	0	0
Berkley, CA	0	0	0	0	0	0	0
Livermore, CA	1,537	0	0	0	0	0	1,537
San Diego, CA	19,981	0	0	0	0	0	19,981
Snowmass, CO	0	0	0	0	0	0	0
RF/Diag Conference	0	0	0	0	0	0	0
Princeton, NJ	17,504	0	0	0	0	0	17,504
Sherwood Theory - FY2002	0	0	0	0	0	0	0
Sherwood Theory - FY2003	954	0	0	0	0	0	954
Sherwood Theory - FY2004	0	0	0	0	0	0	0
Texas	0	0	0	0	0	0	0
Washington DC	7,420	0	0	0	0	0	7,420
Madison, WI	1,060	0	0	0	0	0	1,060
High Temp Plasma Conf	1,314	0	0	0	0	0	1,314
(TTF) FY02, Annapolis, MD	0	0	0	0	0	0	0
(TTF) FY03	9,540	0	0	0	0	0	9,540
(TTF) FY04	0	0	0	0	0	0	0
B. FOREIGN:							
England (JET)	11,430	0	0	0	0	0	11,430
EPS FY2002 - Switzerland	0	0	0	0	0	0	0
EPS FY2003	16,536	0	0	0	0	0	16,536
EPS FY2004	0	0	0	0	0	0	0
Germany	13,608	0	0	0	0	0	13,608
Italy (Frascati)	0	0	0	0	0	0	0
(IAEA) Lyon, France (FY03)	18,846	0	0	0	0	0	18,846
(IAEA) Tech Mtg (Arles, France)	0	0	0	0	0	0	0
Japan	7,950	0	0	0	0	0	7,950
Japan (PSI) - Fy2002	0	0	0	0	0	0	0
China (PSI) - Fy2004	0	0	0	0	0	0	0
Switzerland	1,390	0	0	0	0	0	1,390
TOTAL ESTIMATED TRAVEL COSTS	172,000	0	0	0	0	0	172,000

Detail of Fabrications and Upgrades	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Operations Fabs/Upgrades	0	95,000	0	0	0	0	95,000
Machine Upgrade	0	50,000	0	0	0	0	50,000
Cylinder Upgrade	0	0	0	0	0	0	0
EFC Upgrade	0	0	0	0	0	0	0
Cryostat Fab	0	0	0	0	0	0	0
EF2 Upgrade	0	0	0	0	0	0	0
Igloo	0	0	0	0	0	0	0
Control (paragon replacements)	0	25,000	0	0	0	0	25,000
Digital Control (Hybrid replace)	0	20,000	0	0	0	0	20,000
ICRF Fabs/Upgrades	0	345,000	0	0	0	0	345,000
Transmitter Upgrade Fab	0	55,000	0	0	0	0	55,000
Matching Fab	0	55,000	0	0	0	0	55,000
Instrumentation/Control Fab	0	140,000	0	0	0	0	140,000
RF Diagnostics Fab	0	5,000	0	0	0	0	5,000
Data Acquisition Fab	0	40,000	0	0	0	0	40,000
Access Grid (Display Technology)	0	0	0	0	0	0	0
ICRF Transmission Line Upgrade	0	15,000	0	0	0	0	15,000
ICRF Dummy Loads Fab	0	25,000	0	0	0	0	25,000
ICRF Antenna Fab	0	0	0	0	0	0	0
Antenna Upgrade (D&E)	0	10,000	0	0	0	0	10,000
New 4-Strap Antenna (1/2)	0	0	0	0	0	0	0
ICRF Power Supply Upgrade	0	0	0	0	0	0	0
Fast Ferrite Tuners	0	0	0	0	0	0	0
Divertor Fabs/Upgrades	0	240,000	0	0	0	0	240,000
Cryopump Fab	0	240,000	0	0	0	0	240,000
Divertor Upgrade	0	0	0	0	0	0	0
Outer Divertor Upgrade	0	0	0	0	0	0	0
OPS/EQUIPMENT	0	224,000	0	0	0	0	224,000
Miscellaneous	0	3,000	0	0	0	0	3,000
Workstations/Servers/PCs	0	120,000	0	0	0	0	120,000
Data Communications	0	6,000	0	0	0	0	6,000
Vacuum and Pumping	0	40,000	0	0	0	0	40,000
Test Equipment	0	40,000	0	0	0	0	40,000
Machine Tools	0	10,000	0	0	0	0	10,000
Safety Equipment	0	5,000	0	0	0	0	5,000
Switch Gear	0	0	0	0	0	0	0
ICRF Transmitter Tube	0	0	0	0	0	0	0
Lower Hybrid Fabs/Upgrades	0	227,000	0	0	0	0	227,000
Instrumentation/control	0	227,000	0	0	0	0	227,000
Lower Hybrid Upgrade	0	0	0	0	0	0	0

Detail of Fabrications and Upgrades (Continued)	FY03A Research	FY03A Facility Operations	FY03A Lower Hybrid	FY03A JET Collaboration	FY03A MDS+	FY03A FTU Collaboration	FY03A TOTAL
Diagnostic Fabs/Upgrades	425,000	0	0	0	0	0	425,000
Diagnostic Neutral Beam	0	0	0	0	0	0	0
Fast Thermocouples	0	0	0	0	0	0	0
MSE Fab	0	0	0	0	0	0	0
Fast Scanning Probe Fab	0	0	0	0	0	0	0
Active MHD Fab	0	0	0	0	0	0	0
EUV Spectrograph Upgrade	0	0	0	0	0	0	0
PCI Upgrade	0	0	0	0	0	0	0
Imaging X-Ray Spectrometer Fab	50,000	0	0	0	0	0	50,000
Core TS	0	0	0	0	0	0	0
Polarimetry Fab	0	0	0	0	0	0	0
2nd MHD antenna	65,000	0	0	0	0	0	65,000
Divertor IR camera	25,000	0	0	0	0	0	25,000
SOL Thomson upgrade	50,000	0	0	0	0	0	50,000
SOL Flow Diagnostic	0	0	0	0	0	0	0
Two -color Ne/Te Twiddle	25,000	0	0	0	0	0	25,000
Penning Gauges	5,000	0	0	0	0	0	5,000
D-Alpha imaging	10,000	0	0	0	0	0	10,000
CXRS telescope	15,000	0	0	0	0	0	15,000
CXRS Spectrometer (Kaiser)	60,000	0	0	0	0	0	60,000
Thomson digitizers	55,000	0	0	0	0	0	55,000
DNB upgrade (cap bank)	10,000	0	0	0	0	0	10,000
Long Pulse DNB	0	0	0	0	0	0	0
HIREX electronics	55,000	0	0	0	0	0	55,000
TOTAL FABS/UPGRADES	425,000	1,131,000	0	0	0	0	1,556,000

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Detail of Capital Equipment

	FY03A						FY03A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Data Acquisition Equipment							
Misc.	29,000	0	0	0	0	0	29,000
Crates & Controllers	0	0	0	0	0	0	0
Digitizers	0	0	0	0	0	0	0
Plasma Control Equipment							
Computer Equipment							
Computers, Workstations/Servers	0	0	0	0	0	0	0
Mass Storage	20,000	0	0	0	0	0	20,000
Other Equipment							
Video & Optical Equip. and Instr.	0	0	0	0	0	0	0
Electronic Equipment	0	0	0	0	0	0	0
CMOD TV System Fab	10,000	0	0	0	0	0	10,000
Flush Mount Array Upgrade Fab	0	0	0	0	0	0	0
Lower Hybrid							
Capital Equipment	0	0	419,000	0	0	0	419,000
Operations							
Safety Equipment	0	0	0	0	0	0	0
Switch Gear	40,000	0	0	0	0	0	40,000
TOTAL CAPITAL EQUIPMENT	99,000	0	419,000	0	0	0	518,000

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Summary of Total Budget

	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 1,475,512	$ 181,595	$ -	$ -	$ 21,872	$ -	$ 1,678,979
ENGINEERS	-	1,517,958	-	-	-	-	1,517,958
COMPUTER STAFF	54,568	276,344	-	-	43,311	-	374,223
TECHNICIANS	-	1,671,067	-	-	-	-	1,671,067
DRAFTERS	-	99,799	-	-	-	-	99,799
ADMINISTRATIVE STAFF	63,735	8,930	-	-	-	-	72,665
ADMINISTRATIVE ALLOCATION	251,309	463,421	-	-	6,975	-	721,705
RESEARCH ASSISTANTS	398,123	-	-	-	-	-	398,123
SUBTOTAL SALARIES & WAGES	$ 2,243,247	$ 4,219,114	$ -	$ -	$ 72,158	$ -	$ 6,534,519
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	499,862	1,160,257	-	-	19,843	-	1,679,962
TRAVEL	175,242	-	-	-	-	-	175,242
RA TUITION	182,805	-	-	-	-	-	182,805
MATERIALS & SERVICES	770,138	3,499,824	-	-	587	-	4,270,549
TOTAL DIRECT COSTS	$ 3,871,294	$ 8,879,195	$ -	$ -	$ 92,588	$ -	$ 12,843,077
BASE FOR F & A (SEE BELOW)	$ 2,778,177	$ 5,361,535	$ -	$ -	$ 83,072	-	8,222,784
FACILITIES & ADMINISTRATION COSTS	1,819,706	3,511,805	-	-	54,412	-	5,385,923
TOTAL EST. OPERATIONS	$ 5,691,000	$ 12,391,000	$ -	$ -	$ 147,000	$ -	$ 18,229,000
CAPITAL EQUIPMENT (See Attached)	99,000	-	-	-	-	-	99,000
TOTAL ESTIMATED COSTS	$ 5,790,000	$ 12,391,000	$ -	$ -	$ 147,000	$ -	$ 18,328,000
EXCLUSIONS FROM PRIMARY F&A BASE							
Administrative Allocation*	$ 251,309	$ 463,421	$ -	$ -	$ 6,975	$ -	$ 721,705
E.B. on Administrative Support*	70,367	129,758	-	-	1,953	-	202,078
Allocated Expense*	21,138	38,979	-	-	587	-	60,704
RA Tuition	182,805	-	-	-	-	-	182,805
Equipment Rental	7,500	7,500	-	-	-	-	15,000
Subcontracts >$25K	285,000	60,000	-	-	-	-	345,000
Cambridge Electric, Boc Gasses	-	700,000	-	-	-	-	700,000
Fabrications/Upgrades	275,000	2,118,000	-	-	-	-	2,393,000
TOTAL EXCL. FROM MTDC BASE :	$ 1,093,119	$ 3,517,658	$ -	$ -	$ 9,515	$ -	$ 4,620,292

Summary of Person-Years

	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SCIENTIFIC							
FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	0.44
OTHER ACADEMIC STAFF	3.63	0.10	0.00	0.00	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF	13.60	1.70	0.00	0.00	0.00	0.00	15.30
RESEARCH ASSISTANTS	17.49	0.00	0.00	0.00	0.00	0.00	17.49
SUBTOTAL SCIENTIFIC	35.16	1.80	0.00	0.00	0.20	0.00	37.16
TECHNICAL & ENGINEERING							
ENGINEERING RESEARCH STAFF	0.00	20.77	0.00	0.00	0.00	0.00	20.77
COMPUTER STAFF	0.74	3.25	0.00	0.00	0.48	0.00	4.47
TECHNICIANS	0.00	30.55	0.00	0.00	0.00	0.00	30.55
DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
SUBTOTAL ENGINEERING & TECH.	0.74	56.57	0.00	0.00	0.48	0.00	57.79
OTHER SUPPORT							
ADMINISTRATIVE STAFF	1.51	0.29	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE SUPPORT	4.84	8.93	0.00	0.00	0.13	0.00	13.90
SUBTOTAL OTHER	6.35	9.22	0.00	0.00	0.13	0.00	15.70
TOTAL MAN-YEARS	42.25	67.59	0.00	0.00	0.81	0.00	110.65

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Detail of Person Years	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
FACULTY							
Fasoli, Ambrogio F.	0%	0%	0%	0%	0%	0%	0%
Hutchinson, Ian	27%	0%	0%	0%	0%	0%	27%
Parker, Ronald	17%	0%	0%	0%	0%	0%	17%
Porkolab, Miklos*	0%	0%	0%	0%	0%	0%	0%
TOTAL FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	44%
RESEARCH STAFF - OTHER ACADEMIC							
Marmar, Earl S.	90%	10%	0%	0%	0%	0%	100%
Greenwald, Martin	73%	0%	0%	0%	20%	0%	93%
Lipschultz, Bruce	100%	0%	0%	0%	0%	0%	100%
Lin,Yijun -Post-Doc	100%	0%	0%	0%	0%	0%	100%
TBD-Post-Doc	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH STAFF	3.63	0.10	0.00	0.00	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF							
Bonoli, Paul T.	35%	0%	0%	0%	0%	0%	35%
Egedal-Pedersen, Jan	100%	0%	0%	0%	0%	0%	100%
Fiore, Catherine L.	50%	0%	0%	0%	0%	0%	50%
Granetz, Robert S.	90%	10%	0%	0%	0%	0%	100%
Hubbard, Amanda	100%	0%	0%	0%	0%	0%	100%
Irby, James	0%	100%	0%	0%	0%	0%	100%
LaBombard, Brian	100%	0%	0%	0%	0%	0%	100%
Mossessian, Dmitri	90%	10%	0%	0%	0%	0%	100%
Ramos, Jesus	45%	0%	0%	0%	0%	0%	45%
Rice, John E.	100%	0%	0%	0%	0%	0%	100%
Snipes, Joseph	100%	0%	0%	0%	0%	0%	100%
Terry, James	100%	0%	0%	0%	0%	0%	100%
Testa, Duccio	100%	0%	0%	0%	0%	0%	100%
Wolfe, Stephen	80%	20%	0%	0%	0%	0%	100%
Wukitch, Stephen	70%	30%	0%	0%	0%	0%	100%
Layoff Scientist	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL SCIENTIFIC RES. STAFF	13.60	1.70	0.00	0.00	0.00	0.00	15.30

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Detail of Person Years

	FY04A						FY04A
		Facility	Lower	JET		FTU	
	Research	Operations	Hybrid	Collaboration	MDS+	Collaboration	TOTAL
ENGINEERS							
Andreyev, Sergey	0%	0%	0%	0%	0%	0%	0%
Beck, William	0%	100%	0%	0%	0%	0%	100%
Burke, William	0%	100%	0%	0%	0%	0%	100%
Byford, William G.	0%	100%	0%	0%	0%	0%	100%
Childs, Robert	0%	100%	0%	0%	0%	0%	100%
Cochran, William	0%	100%	0%	0%	0%	0%	100%
Dekow, Gary	0%	100%	0%	0%	0%	0%	100%
DiMaria, Michael	0%	100%	0%	0%	0%	0%	100%
Fitzgerald, Edward	0%	100%	0%	0%	0%	0%	100%
Grimes, Montgomery	0%	100%	0%	0%	0%	0%	100%
Gwinn, David	0%	0%	0%	0%	0%	0%	0%
Koert, Peter	0%	100%	0%	0%	0%	0%	100%
Murray, Richard	0%	100%	0%	0%	0%	0%	100%
Parkin, William	0%	100%	0%	0%	0%	0%	100%
Rokhman,Yuriy	0%	100%	0%	0%	0%	0%	100%
Rosati, James	0%	100%	0%	0%	0%	0%	100%
Terry, David R.	0%	100%	0%	0%	0%	0%	100%
Thomas, Paul	0%	57%	0%	0%	0%	0%	57%
Titus, Peter	0%	10%	0%	0%	0%	0%	10%
Vieira, Rui	0%	100%	0%	0%	0%	0%	100%
Woskov, Paul P.	0%	10%	0%	0%	0%	0%	10%
Zaks, James	0%	100%	0%	0%	0%	0%	100%
Zhong,Xiwen	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	0%	0%	0%	0%	0%	0%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
TOTAL ENGINEERS	0.00	20.77	0.00	0.00	0.00	0.00	20.77
COMPUTER STAFF							
Bergler, Henry	5%	45%	0%	0%	0%	0%	50%
Fredian, Thomas	0%	49%	0%	0%	30%	0%	79%
Kreisel, Felix	30%	70%	0%	0%	0%	0%	100%
London, Mark	0%	10%	0%	0%	0%	0%	10%
Nelson, Donald	0%	50%	0%	0%	0%	0%	50%
Sherman, Stuart	15%	46%	0%	0%	18%	0%	79%
Stillerman, Joshua	24%	55%	0%	0%	0%	0%	79%
TOTAL COMPUTER STAFF	0.74	3.25	0.00	0.00	0.48	0.00	4.47

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Detail of Person Years	FY04A						FY04A
		Facility	Lower	JET		FTU	
	Research	Operations	Hybrid	Collaboration	MDS+	Collaboration	TOTAL
TECHNICIANS							
Anderson, Eric	0%	100%	0%	0%	0%	0%	100%
Arsenault, David	0%	100%	0%	0%	0%	0%	100%
Bellofatto, David	0%	100%	0%	0%	0%	0%	100%
Cauley, Charles	0%	100%	0%	0%	0%	0%	100%
Chicarello, James	0%	75%	0%	0%	0%	0%	75%
Danforth, Richard	0%	100%	0%	0%	0%	0%	100%
Gerolamo, Jerry	0%	80%	0%	0%	0%	0%	80%
Iverson, Mark	0%	100%	0%	0%	0%	0%	100%
Keating, William	0%	20%	0%	0%	0%	0%	20%
Mackay, George T.	0%	100%	0%	0%	0%	0%	100%
Muttart, Douglas B.	0%	100%	0%	0%	0%	0%	100%
Nickerson, John	0%	100%	0%	0%	0%	0%	100%
Pfeiffer, Andrew T.	0%	100%	0%	0%	0%	0%	100%
Pierson, Samuel	0%	100%	0%	0%	0%	0%	100%
Pina, Wanda	0%	100%	0%	0%	0%	0%	100%
Rettman, Kenneth	0%	100%	0%	0%	0%	0%	100%
Rollins, Edgar	0%	100%	0%	0%	0%	0%	100%
Rosati, Ronald	0%	100%	0%	0%	0%	0%	100%
Rowell, Michael	0%	100%	0%	0%	0%	0%	100%
Shefton, Frank	0%	100%	0%	0%	0%	0%	100%
Silveira, Maria	0%	80%	0%	0%	0%	0%	80%
Sylvia, Robert	0%	100%	0%	0%	0%	0%	100%
Szczepanowski, Wanda	0%	100%	0%	0%	0%	0%	100%
Tambini, Steven	0%	100%	0%	0%	0%	0%	100%
Telesmanick, Paul	0%	50%	0%	0%	0%	0%	50%
Toland, Thomas	0%	100%	0%	0%	0%	0%	100%
Vestal, David	0%	50%	0%	0%	0%	0%	50%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	0%	0%	0%	0%	0%	0%
Overtime	0%	400%	0%	0%	0%	0%	400%
TOTAL TECHNICIANS	0.00	30.55	0.00	0.00	0.00	0.00	30.55

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Detail of Person Years	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
DRAFTERS							
Lienard,Paul	0%	100%	0%	0%	0%	0%	100%
Savelli, Henry	0%	100%	0%	0%	0%	0%	100%
TOTAL DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
ADMINISTRATIVE STAFF							
Censabella, Valerie	80%	0%	0%	0%	0%	0%	80%
Zibcevoc, Dragana	71%	29%	0%	0%	0%	0%	100%
TOTAL ADMINISTRATIVE STAFF	1.51	0.29	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE LAB SUPPORT							
Various	4.84	8.93	0.00	0.00	0.13	0.00	13.90
Detail of Research Assistant Effort							
RESEARCH ASSISTANTS							
Bai, Bo	100%	0%	0%	0%	0%	0%	100%
Boswell, Christopher	100%	0%	0%	0%	0%	0%	100%
Chung, Taekyun	100%	0%	0%	0%	0%	0%	100%
Decker, Joan	100%	0%	0%	0%	0%	0%	100%
Gangadhara, Sanjay	100%	0%	0%	0%	0%	0%	100%
Graves, Timothy	100%	0%	0%	0%	0%	0%	100%
Hughes, Jerry	100%	0%	0%	0%	0%	0%	100%
Jennings, Thomas M.	100%	0%	0%	0%	0%	0%	100%
Lee, William D.	100%	0%	0%	0%	0%	0%	100%
Liptac, John Edward, Jr.	100%	0%	0%	0%	0%	0%	100%
Marr, Kenneth David	100%	0%	0%	0%	0%	0%	100%
Nelson-Melby, Eric	0%	0%	0%	0%	0%	0%	0%
Sarlese, Justin A.	0%	0%	0%	0%	0%	0%	0%
Schmittdiel, David Anthony	100%	0%	0%	0%	0%	0%	100%
Tang, Vincent	100%	0%	0%	0%	0%	0%	100%
Thomas, Michael J.	100%	0%	0%	0%	0%	0%	100%
Thoms, Jon G.	100%	0%	0%	0%	0%	0%	100%
Youngblood, Brian J.	49%	0%	0%	0%	0%	0%	49%
Yuh, Howard Y.	100%	0%	0%	0%	0%	0%	100%
Zhurovich, Kirill	100%	0%	0%	0%	0%	0%	100%
New Student-TBD	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH ASSISTANTS	17.49	0.00	0.00	0.00	0.00	0.00	17.49
Total Man-Years	42.25	67.59	0.00	0.00	0.81	0.00	110.65

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Detail of Research Assistant Tuition

	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
RESEARCH ASSISTANTS TUITION							
Bai, Bo	10,452	-	-	-	-	-	10,452
Boswell, Christopher	10,452	-	-	-	-	-	10,452
Chung, Taekyun	10,452	-	-	-	-	-	10,452
Decker, Joan	10,452	-	-	-	-	-	10,452
Gangadhara, Sanjay	10,452	-	-	-	-	-	10,452
Graves, Timothy	10,452	-	-	-	-	-	10,452
Hughes, Jerry	10,452	-	-	-	-	-	10,452
Jennings, Thomas M.	10,452	-	-	-	-	-	10,452
Lee, William D.	10,452	-	-	-	-	-	10,452
Liptac, John Edward, Jr.	10,452	-	-	-	-	-	10,452
Marr, Kenneth David	10,452	-	-	-	-	-	10,452
Nelson-Melby, Eric	-	-	-	-	-	-	-
Sarlese, Justin A.	-	-	-	-	-	-	-
Schmittdiel, David Anthony	10,452	-	-	-	-	-	10,452
Tang, Vincent	10,452	-	-	-	-	-	10,452
Thomas, Michael J.	10,452	-	-	-	-	-	10,452
Thoms, Jon G.	10,452	-	-	-	-	-	10,452
Youngblood, Brian J.	5,121	-	-	-	-	-	5,121
Yuh, Howard Y.	10,452	-	-	-	-	-	10,452
Zhurovich, Kirill	10,452	-	-	-	-	-	10,452
New Student-TBD	-	-	-	-	-	-	-
RA TUITION TOTAL	182,805	-	-	-	-	-	182,805

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Detail of Materials and Services

	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
OFFICE MATERIALS AND SERVICES	45,000	45,000	-	-	-	-	90,000
Xeroxing	8,000	8,000	-	-	-	-	16,000
Telecommunications	12,000	12,000	-	-	-	-	24,000
Office Supplies	9,000	9,000	-	-	-	-	18,000
Postage/Shipping	4,000	4,000	-	-	-	-	8,000
Journals & Books	4,000	4,000	-	-	-	-	8,000
Equipment Rental (No O/H)	7,500	7,500	-	-	-	-	15,000
Graphic Arts	500	500	-	-	-	-	1,000
Computing Materials & Services	44,000	96,000	-	-	-	-	140,000
PSFC Computer Contribution	-	6,000	-	-	-	-	6,000
Computer Maintenance	30,000	50,000	-	-	-	-	80,000
Computer Software & Supplies	14,000	29,000	-	-	-	-	43,000
MIT Networking Charges	-	11,000	-	-	-	-	11,000
Operations Material & Services	-	1,141,845	-	-	-	-	1,141,845
Materials & Services	-	396,845	-	-	-	-	396,845
Safety	-	10,000	-	-	-	-	10,000
DNB Shipping	-	35,000	-	-	-	-	35,000
Boc Gases (Nitrogen)	-	600,000	-	-	-	-	600,000
N/Star (Cambridge Electric)	-	100,000	-	-	-	-	100,000
RF Materials & Services	30,000	-	-	-	-	-	30,000
Diagnostic Materials & Services	40,000	-	-	-	-	-	40,000
Lower Hybrid Materials & Services	30,000	-	-	-	-	-	30,000
Subcontracts (No O/H)	285,000	60,000	-	-	-	-	345,000
Plasma Surface Engineering	-	-	-	-	-	-	-
M Technology	120,000	60,000	-	-	-	-	180,000
University of Toronto	165,000	-	-	-	-	-	165,000
Flywheel Inspection	-	-	-	-	-	-	-
Alternator Inspection	-	-	-	-	-	-	-
SUBTOTAL MATERIALS & SERVICES	474,000	1,342,845	-	-	-	-	1,816,845
ALLOCATED EXPENSE	21,138	38,979	-	-	587	-	60,704

Detail of Travel Costs

	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
A. DOMESTIC:							
APS - FY2002, Long Beach, CA	0	0	0	0	0	0	0
APS - FY2003, Orlando,FL	0	0	0	0	0	0	0
APS - FY2004, Albuquerque, NM	50,550	0	0	0	0	0	50,550
Berkley, CA	0	0	0	0	0	0	0
Livermore, CA	0	0	0	0	0	0	0
San Diego, CA	17,919	0	0	0	0	0	17,919
Snowmass, CO	0	0	0	0	0	0	0
RF/Diag Conference	1,124	0	0	0	0	0	1,124
Princeton, NJ	18,560	0	0	0	0	0	18,560
Sherwood Theory - FY2002	0	0	0	0	0	0	0
Sherwood Theory - FY2003	0	0	0	0	0	0	0
Sherwood Theory - FY2004	1,011	0	0	0	0	0	1,011
Texas	0	0	0	0	0	0	0
Washington DC	7,868	0	0	0	0	0	7,868
Madison, WI	0	0	0	0	0	0	0
High Temp Plasma Conf	0	0	0	0	0	0	0
(TTF) FY02, Annapolis, MD	0	0	0	0	0	0	0
(TTF) FY03	0	0	0	0	0	0	0
(TTF) FY04	10,116	0	0	0	0	0	10,116
B. FOREIGN:							
England (JET)	14,538	0	0	0	0	0	14,538
EPS FY2002 - Switzerland	0	0	0	0	0	0	0
EPS FY2003	0	0	0	0	0	0	0
EPS FY2004	15,540	0	0	0	0	0	15,540
Germany	9,616	0	0	0	0	0	9,616
Italy (Frascati)	0	0	0	0	0	0	0
(IAEA) Lyon, France (FY03)	0	0	0	0	0	0	0
(IAEA) Tech Mtg (Arles, France)	0	0	0	0	0	0	0
Japan	16,854	0	0	0	0	0	16,854
Japan (PSI) - Fy2002	0	0	0	0	0	0	0
China (PSI) - Fy2004	8,840	0	0	0	0	0	8,840
Switzerland	2,706	0	0	0	0	0	2,706
TOTAL ESTIMATED TRAVEL COSTS	175,242	0	0	0	0	0	175,242

Detail of Fabrications and Upgrades	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Operations Fabs/Upgrades	0	95,000	0	0	0	0	95,000
Machine Upgrade	0	50,000	0	0	0	0	50,000
Cylinder Upgrade	0	0	0	0	0	0	0
EFC Upgrade	0	0	0	0	0	0	0
Cryostat Fab	0	0	0	0	0	0	0
EF2 Upgrade	0	0	0	0	0	0	0
Igloo	0	0	0	0	0	0	0
Control (paragon replacements)	0	25,000	0	0	0	0	25,000
Digital Control (Hybrid replace)	0	20,000	0	0	0	0	20,000
ICRF Fabs/Upgrades	0	404,000	0	0	0	0	404,000
Transmitter Upgrade Fab	0	55,000	0	0	0	0	55,000
Matching Fab	0	30,000	0	0	0	0	30,000
Instrumentation/Control Fab	0	20,000	0	0	0	0	20,000
RF Diagnostics Fab	0	5,000	0	0	0	0	5,000
Data Acquisition Fab	0	64,000	0	0	0	0	64,000
Access Grid (Display Technology)	0	0	0	0	0	0	0
ICRF Transmission Line Upgrade	0	0	0	0	0	0	0
ICRF Dummy Loads Fab	0	0	0	0	0	0	0
ICRF Antenna Fab	0	0	0	0	0	0	0
Antenna Upgrade (D&E)	0	30,000	0	0	0	0	30,000
New 4-Strap Antenna (1/2)	0	200,000	0	0	0	0	200,000
ICRF Power Supply Upgrade	0	0	0	0	0	0	0
Fast Ferrite Tuners	0	0	0	0	0	0	0
Divertor Fabs/Upgrades	0	200,000	0	0	0	0	200,000
Cryopump Fab	0	200,000	0	0	0	0	200,000
Divertor Upgrade	0	0	0	0	0	0	0
Outer Divertor Upgrade	0	0	0	0	0	0	0
OPS/EQUIPMENT	0	334,000	0	0	0	0	334,000
Miscellaneous	0	3,000	0	0	0	0	3,000
Workstations/Servers/PCs	0	130,000	0	0	0	0	130,000
Data Communications	0	6,000	0	0	0	0	6,000
Vacuum and Pumping	0	40,000	0	0	0	0	40,000
Test Equipment	0	40,000	0	0	0	0	40,000
Machine Tools	0	10,000	0	0	0	0	10,000
Safety Equipment	0	5,000	0	0	0	0	5,000
Switch Gear	0	10,000	0	0	0	0	10,000
ICRF Transmitter Tube	0	90,000	0	0	0	0	90,000
Lower Hybrid Fabs/Upgrades	0	450,000	0	0	0	0	450,000
Instrumentation/control	0	50,000	0	0	0	0	50,000
Lower Hybrid Upgrade	0	400,000	0	0	0	0	400,000

Detail of Fabrications and Upgrades (Continued)	FY04A Research	FY04A Facility Operations	FY04A Lower Hybrid	FY04A JET Collaboration	FY04A MDS+	FY04A FTU Collaboration	FY04A TOTAL
Diagnostic Fabs/Upgrades	275,000	635,000	0	0	0	0	910,000
Diagnostic Neutral Beam	0	0	0	0	0	0	0
Fast Thermocouples	0	0	0	0	0	0	0
MSE Fab	0	0	0	0	0	0	0
Fast Scanning Probe Fab	0	0	0	0	0	0	0
Active MHD Fab	0	0	0	0	0	0	0
EUV Spectrograph Upgrade	0	0	0	0	0	0	0
PCI Upgrade	0	0	0	0	0	0	0
Imaging X-Ray Spectrometer Fab	0	0	0	0	0	0	0
Core TS	0	0	0	0	0	0	0
Polarimetry Fab	0	0	0	0	0	0	0
2nd MHD antenna	0	0	0	0	0	0	0
Divertor IR camera	25,000	0	0	0	0	0	25,000
SOL Thomson upgrade	70,000	0	0	0	0	0	70,000
SOL Flow Diagnostic	70,000	0	0	0	0	0	70,000
Two -color Ne/Te Twiddle	80,000	0	0	0	0	0	80,000
Penning Gauges	5,000	0	0	0	0	0	5,000
D-Alpha imaging	10,000	0	0	0	0	0	10,000
CXRS telescope	15,000	0	0	0	0	0	15,000
CXRS Spectrometer (Kaiser)	0	0	0	0	0	0	0
Thomson digitizers	0	0	0	0	0	0	0
DNB upgrade (cap bank)	0	0	0	0	0	0	0
Long Pulse DNB	0	635,000	0	0	0	0	635,000
HIREX electronics	0	0	0	0	0	0	0
TOTAL FABS/UPGRADES	275,000	2,118,000	0	0	0	0	2,393,000

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Detail of Capital Equipment

	FY04A						FY04A
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Data Acquisition Equipment							
Misc.	34,000	0	0	0	0	0	34,000
Crates & Controllers	0	0	0	0	0	0	0
Digitizers	0	0	0	0	0	0	0
Plasma Control Equipment							
Computer Equipment							
Computers, Workstations/Servers	0	0	0	0	0	0	0
Mass Storage	35,000	0	0	0	0	0	35,000
Other Equipment							
Video & Optical Equip. and Instr.	0	0	0	0	0	0	0
Electronic Equipment	0	0	0	0	0	0	0
CMOD TV System Fab	10,000	0	0	0	0	0	10,000
Flush Mount Array Upgrade Fab	0	0	0	0	0	0	0
Lower Hybrid							
Capital Equipment	0	0	0	0	0	0	0
Operations							
Safety Equipment	0	0	0	0	0	0	0
Switch Gear	20,000	0	0	0	0	0	20,000
TOTAL CAPITAL EQUIPMENT	99,000	0	0	0	0	0	99,000

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Summary of Total Budget

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 1,457,293	175453.82	$ -	$ 17,593	$ 21,133	$ 5,760	$ 1,677,233
ENGINEERS	-	$ 1,640,789	-	-	-	-	1,640,789
COMPUTER STAFF	52,732	265,232	-	-	44,050	-	362,014
TECHNICIANS	-	1,614,556	-	-	-	-	1,614,556
DRAFTERS	-	96,424	-	-	-	-	96,424
ADMINISTRATIVE STAFF	58,306	11,901	-	-	-	-	70,207
ADMINISTRATIVE ALLOCATION	249,319	467,707	-	3,105	6,975	843	727,949
RESEARCH ASSISTANTS	405,131	-	-	-	-	-	405,131
SUBTOTAL SALARIES & WAGES	$ 2,222,781	$ 4,272,063	$ -	$ 20,698	$ 72,158	$ 6,603	$ 6,594,303
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	492,562	1,174,817	-	5,692	19,843	1,816	1,694,730
TRAVEL	174,120	-	-	11,430	-	2,120	187,670
RA TUITION	184,160	-	-	-	-	-	184,160
MATERIALS & SERVICES	975,971	5,668,576	-	261	587	71	6,645,466
TOTAL DIRECT COSTS	$ 4,049,594	$ 11,115,456	$ -	$ 38,081	$ 92,588	$ 10,610	$ 15,306,329
BASE FOR F & A (SEE BELOW)	2,752,834	5,414,953	-	33,846	83,072	9,451	8,294,156
FACILITIES & ADMINISTRATION COSTS	1,803,106	3,546,794	-	22,169	54,412	6,190	5,432,671
TOTAL EST. OPERATIONS	$ 5,852,700	$ 14,662,250	$ -	$ 60,250	$ 147,000	$ 16,800	$ 20,739,000
CAPITAL EQUIPMENT (See Attached)	99,000	100,000	419,000	-	-	-	618,000
TOTAL ESTIMATED COSTS	$ 5,951,700	$ 14,762,250	$ 419,000	$ 60,250	$ 147,000	$ 16,800	$ 21,357,000
EXCLUSIONS FROM PRIMARY F&A BASE							
Administrative Allocation*	$ 249,319	$ 467,707	$ -	$ 3,105	$ 6,975	$ 843	$ 727,949
E.B. on Administrative Support*	69,809	130,958	-	869	1,953	244	203,833
Allocated Expense*	20,971	39,340	-	261	587	71	61,230
RA Tuition	184,160	-	-	-	-	-	184,160
Equipment Rental	7,500	7,500	-	-	-	-	15,000
Subcontracts >$25K	340,000	1,010,000	-	-	-	-	1,350,000
Cambridge Electric, Boc Gasses	-	700,000	-	-	-	-	700,000
Fabrications/Upgrades	425,000	3,345,000	-	-	-	-	3,770,000
TOTAL EXCL. FROM MTDC BASE :	$ 1,296,759	$ 5,700,505	$ -	$ 4,235	$ 9,515	$ 1,158	$ 7,012,172

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Summary of Person-Years

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
SCIENTIFIC							
FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	0.44
OTHER ACADEMIC STAFF	3.53	0.10	0.00	0.10	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF	14.42	1.70	0.00	0.10	0.00	0.08	16.30
RESEARCH ASSISTANTS	18.49	0.00	0.00	0.00	0.00	0.00	18.49
SUBTOTAL SCIENTIFIC	36.88	1.80	0.00	0.20	0.20	0.08	39.16
TECHNICAL & ENGINEERING							
ENGINEERING RESEARCH STAFF	0.00	23.18	0.00	0.00	0.00	0.00	23.18
COMPUTER STAFF	0.74	3.22	0.00	0.00	0.51	0.00	4.47
TECHNICIANS	0.00	31.55	0.00	0.00	0.00	0.00	31.55
DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
SUBTOTAL ENGINEERING & TECH.	0.74	59.95	0.00	0.00	0.51	0.00	61.20
OTHER SUPPORT							
ADMINISTRATIVE STAFF	1.40	0.40	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE SUPPORT	4.81	9.01	0.00	0.06	0.13	0.02	14.03
SUBTOTAL OTHER	6.21	9.41	0.00	0.06	0.13	0.02	15.83
TOTAL MAN-YEARS	43.83	71.16	0.00	0.26	0.84	0.10	116.19

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Detail of Person Years	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
FACULTY							
Fasoli, Ambrogio F.	0%	0%	0%	0%	0%	0%	0%
Hutchinson, Ian	27%	0%	0%	0%	0%	0%	27%
Parker, Ronald	17%	0%	0%	0%	0%	0%	17%
Porkolab, Miklos*	0%	0%	0%	0%	0%	0%	0%
TOTAL FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	44%
RESEARCH STAFF - OTHER ACADEMIC							
Marmar, Earl S.	90%	10%	0%	0%	0%	0%	100%
Greenwald, Martin	73%	0%	0%	0%	20%	0%	93%
Lipschultz, Bruce	90%	0%	0%	10%	0%	0%	100%
Lin,Yijun -Post-Doc	100%	0%	0%	0%	0%	0%	100%
TBD-Post-Doc	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH STAFF	3.53	0.10	0.00	0.10	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF							
Bonoli, Paul T.	35%	0%	0%	0%	0%	0%	35%
Egedal-Pedersen, Jan	100%	0%	0%	0%	0%	0%	100%
Fiore, Catherine L.	50%	0%	0%	0%	0%	0%	50%
Granetz, Robert S.	90%	10%	0%	0%	0%	0%	100%
Hubbard, Amanda	100%	0%	0%	0%	0%	0%	100%
Irby, James	0%	100%	0%	0%	0%	0%	100%
LaBombard, Brian	100%	0%	0%	0%	0%	0%	100%
Mossessian, Dmitri	90%	10%	0%	0%	0%	0%	100%
Ramos, Jesus	45%	0%	0%	0%	0%	0%	45%
Rice, John E.	100%	0%	0%	0%	0%	0%	100%
Snipes, Joseph	82%	0%	0%	10%	0%	8%	100%
Terry, James	100%	0%	0%	0%	0%	0%	100%
Testa, Duccio	100%	0%	0%	0%	0%	0%	100%
Wolfe, Stephen	80%	20%	0%	0%	0%	0%	100%
Wukitch, Stephen	70%	30%	0%	0%	0%	0%	100%
Layoff Scientist	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
TOTAL SCIENTIFIC RES. STAFF	14.42	1.70	0.00	0.10	0.00	0.08	16.30

* MIT fully supports the salary of Miklos Porkolab as Director of the Plasma Science and Fusion Center, but makes no specific commitment of time or salary to any individual research project.

Detail of Person Years

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
ENGINEERS							
Andreyev, Sergey	0%	0%	0%	0%	0%	0%	0%
Beck, William	0%	100%	0%	0%	0%	0%	100%
Burke, William	0%	100%	0%	0%	0%	0%	100%
Byford, William G.	0%	100%	0%	0%	0%	0%	100%
Childs, Robert	0%	100%	0%	0%	0%	0%	100%
Cochran, William	0%	100%	0%	0%	0%	0%	100%
Dekow, Gary	0%	100%	0%	0%	0%	0%	100%
DiMaria, Michael	0%	100%	0%	0%	0%	0%	100%
Fitzgerald, Edward	0%	100%	0%	0%	0%	0%	100%
Grimes, Montgomery	0%	100%	0%	0%	0%	0%	100%
Gwinn, David	0%	0%	0%	0%	0%	0%	0%
Koert, Peter	0%	100%	0%	0%	0%	0%	100%
Murray, Richard	0%	100%	0%	0%	0%	0%	100%
Parkin, William	0%	100%	0%	0%	0%	0%	100%
Rokhman,Yuriy	0%	100%	0%	0%	0%	0%	100%
Rosati, James	0%	100%	0%	0%	0%	0%	100%
Terry, David R.	0%	100%	0%	0%	0%	0%	100%
Thomas, Paul	0%	98%	0%	0%	0%	0%	98%
Titus, Peter	0%	10%	0%	0%	0%	0%	10%
Vieira, Rui	0%	100%	0%	0%	0%	0%	100%
Woskov, Paul P.	0%	10%	0%	0%	0%	0%	10%
Zaks, James	0%	100%	0%	0%	0%	0%	100%
Zhong,Xiwen	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
TOTAL ENGINEERS	0.00	23.18	0.00	0.00	0.00	0.00	23.18
COMPUTER STAFF							
Bergler, Henry	5%	45%	0%	0%	0%	0%	50%
Fredian, Thomas	0%	49%	0%	0%	30%	0%	79%
Kreisel, Felix	30%	70%	0%	0%	0%	0%	100%
London, Mark	0%	10%	0%	0%	0%	0%	10%
Nelson, Donald	0%	50%	0%	0%	0%	0%	50%
Sherman, Stuart	15%	43%	0%	0%	21%	0%	79%
Stillerman, Joshua	24%	55%	0%	0%	0%	0%	79%
TOTAL COMPUTER STAFF	0.74	3.22	0.00	0.00	0.51	0.00	4.47

Detail of Person Years	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
TECHNICIANS							
Anderson, Eric	0%	100%	0%	0%	0%	0%	100%
Arsenault, David	0%	100%	0%	0%	0%	0%	100%
Bellofatto, David	0%	100%	0%	0%	0%	0%	100%
Cauley, Charles	0%	100%	0%	0%	0%	0%	100%
Chicarello, James	0%	75%	0%	0%	0%	0%	75%
Danforth, Richard	0%	100%	0%	0%	0%	0%	100%
Gerolamo, Jerry	0%	80%	0%	0%	0%	0%	80%
Iverson, Mark	0%	100%	0%	0%	0%	0%	100%
Keating, William	0%	20%	0%	0%	0%	0%	20%
Mackay, George T.	0%	100%	0%	0%	0%	0%	100%
Muttart, Douglas B.	0%	100%	0%	0%	0%	0%	100%
Nickerson, John	0%	100%	0%	0%	0%	0%	100%
Pfeiffer, Andrew T.	0%	100%	0%	0%	0%	0%	100%
Pierson, Samuel	0%	100%	0%	0%	0%	0%	100%
Pina, Wanda	0%	100%	0%	0%	0%	0%	100%
Rettman, Kenneth	0%	100%	0%	0%	0%	0%	100%
Rollins, Edgar	0%	100%	0%	0%	0%	0%	100%
Rosati, Ronald	0%	100%	0%	0%	0%	0%	100%
Rowell, Michael	0%	100%	0%	0%	0%	0%	100%
Shefton, Frank	0%	100%	0%	0%	0%	0%	100%
Silveira, Maria	0%	80%	0%	0%	0%	0%	80%
Sylvia, Robert	0%	100%	0%	0%	0%	0%	100%
Szczepanowski, Wanda	0%	100%	0%	0%	0%	0%	100%
Tambini, Steven	0%	100%	0%	0%	0%	0%	100%
Telesmanick, Paul	0%	50%	0%	0%	0%	0%	50%
Toland, Thomas	0%	100%	0%	0%	0%	0%	100%
Vestal, David	0%	50%	0%	0%	0%	0%	50%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
Overtime	0%	400%	0%	0%	0%	0%	400%
TOTAL TECHNICIANS	0.00	31.55	0.00	0.00	0.00	0.00	31.55

Detail of Person Years	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
DRAFTERS							
Lienard,Paul	0%	100%	0%	0%	0%	0%	100%
Savelli, Henry	0%	100%	0%	0%	0%	0%	100%
TOTAL DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
ADMINISTRATIVE STAFF							
Censabella, Valerie	80%	0%	0%	0%	0%	0%	80%
Zibcevoc, Dragana	60%	40%	0%	0%	0%	0%	100%
TOTAL ADMINISTRATIVE STAFF	1.40	0.40	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE LAB SUPPORT							
Various	4.81	9.01	0.00	0.06	0.13	0.02	14.03
Detail of Research Assistant Effort							
RESEARCH ASSISTANTS							
Bai, Bo	100%	0%	0%	0%	0%	0%	100%
Boswell, Christopher	100%	0%	0%	0%	0%	0%	100%
Chung, Taekyun	100%	0%	0%	0%	0%	0%	100%
Decker, Joan	100%	0%	0%	0%	0%	0%	100%
Gangadhara, Sanjay	100%	0%	0%	0%	0%	0%	100%
Graves, Timothy	100%	0%	0%	0%	0%	0%	100%
Hughes, Jerry	100%	0%	0%	0%	0%	0%	100%
Jennings, Thomas M.	100%	0%	0%	0%	0%	0%	100%
Lee, William D.	100%	0%	0%	0%	0%	0%	100%
Liptac, John Edward, Jr.	100%	0%	0%	0%	0%	0%	100%
Marr, Kenneth David	100%	0%	0%	0%	0%	0%	100%
Nelson-Melby, Eric	0%	0%	0%	0%	0%	0%	0%
Sarlese, Justin A.	0%	0%	0%	0%	0%	0%	0%
Schmittdiel, David Anthony	100%	0%	0%	0%	0%	0%	100%
Tang, Vincent	100%	0%	0%	0%	0%	0%	100%
Thomas, Michael J.	100%	0%	0%	0%	0%	0%	100%
Thoms, Jon G.	100%	0%	0%	0%	0%	0%	100%
Youngblood, Brian J.	49%	0%	0%	0%	0%	0%	49%
Yuh, Howard Y.	100%	0%	0%	0%	0%	0%	100%
Zhurovich, Kirill	100%	0%	0%	0%	0%	0%	100%
New Student-TBD	100%	0%	0%	0%	0%	0%	100%
TOTAL RESEARCH ASSISTANTS	18.49	0.00	0.00	0.00	0.00	0.00	18.49
Total Man-Years	43.83	71.16	0.00	0.26	0.84	0.10	116.19

Detail of Research Assistant Tuition

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
RESEARCH ASSISTANTS TUITION							
Bai, Bo	9,960	-	-	-	-	-	9,960
Boswell, Christopher	9,960	-	-	-	-	-	9,960
Chung, Taekyun	9,960	-	-	-	-	-	9,960
Decker, Joan	9,960	-	-	-	-	-	9,960
Gangadhara, Sanjay	9,960	-	-	-	-	-	9,960
Graves, Timothy	9,960	-	-	-	-	-	9,960
Hughes, Jerry	9,960	-	-	-	-	-	9,960
Jennings, Thomas M.	9,960	-	-	-	-	-	9,960
Lee, William D.	9,960	-	-	-	-	-	9,960
Liptac, John Edward, Jr.	9,960	-	-	-	-	-	9,960
Marr, Kenneth David	9,960	-	-	-	-	-	9,960
Nelson-Melby, Eric	-	-	-	-	-	-	-
Sarlese, Justin A.	-	-	-	-	-	-	-
Schmittdiel, David Anthony	9,960	-	-	-	-	-	9,960
Tang, Vincent	9,960	-	-	-	-	-	9,960
Thomas, Michael J.	9,960	-	-	-	-	-	9,960
Thoms, Jon G.	9,960	-	-	-	-	-	9,960
Youngblood, Brian J.	4,880	-	-	-	-	-	4,880
Yuh, Howard Y.	9,960	-	-	-	-	-	9,960
Zhurovich, Kirill	9,960	-	-	-	-	-	9,960
New Student-TBD	9,960	-	-	-	-	-	9,960
RA TUITION TOTAL	184,160	-	-	-	-	-	184,160

Detail of Materials and Services

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
OFFICE MATERIALS AND SERVICES	45,000	45,000	-	-	-	-	90,000
Xeroxing	8,000	8,000	-	-	-	-	16,000
Telecommunications	12,000	12,000	-	-	-	-	24,000
Office Supplies	9,000	9,000	-	-	-	-	18,000
Postage/Shipping	4,000	4,000	-	-	-	-	8,000
Journals & Books	4,000	4,000	-	-	-	-	8,000
Equipment Rental (No O/H)	7,500	7,500	-	-	-	-	15,000
Graphic Arts	500	500	-	-	-	-	1,000
Computing Materials & Services	40,000	92,000	-	-	-	-	132,000
PSFC Computer Contribution	-	6,000	-	-	-	-	6,000
Computer Maintenance	30,000	50,000	-	-	-	-	80,000
Computer Software & Supplies	10,000	25,000	-	-	-	-	35,000
MIT Networking Charges	-	11,000	-	-	-	-	11,000
Operations Material & Services	-	1,137,236	-	-	-	-	1,137,236
Materials & Services	-	392,236	-	-	-	-	392,236
Safety	-	10,000	-	-	-	-	10,000
DNB Shipping	-	35,000	-	-	-	-	35,000
Boc Gases (Nitrogen)	-	600,000	-	-	-	-	600,000
N/Star (Cambridge Electric)	-	100,000	-	-	-	-	100,000
RF Materials & Services	30,000	-	-	-	-	-	30,000
Diagnostic Materials & Services	40,000	-	-	-	-	-	40,000
Lower Hybrid Materials & Services	35,000	-	-	-	-	-	35,000
Subcontracts (No O/H)	340,000	1,010,000	-	-	-	-	1,350,000
Plasma Surface Engineering	-	-	-	-	-	-	-
M Technology	180,000	-	-	-	-	-	180,000
University of Toronto	160,000	-	-	-	-	-	160,000
Flywheel Inspection	-	60,000	-	-	-	-	60,000
Alternator Inspection	-	950,000	-	-	-	-	950,000
SUBTOTAL MATERIALS & SERVICES	530,000	2,284,236	-	-	-	-	2,814,236
ALLOCATED EXPENSE	20,971	39,340	-	261	587	71	61,230

DOE COOPERATIVE AGREEMENT # DE-FC02-99ER54512
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Detail of Travel Costs

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
A. DOMESTIC:							
APS - FY2002, Long Beach, CA	0	0	0	0	0	0	0
APS - FY2003, Orlando,FL	42,930	0	0	0	0	0	42,930
APS - FY2004, Albuquerque, NM	0	0	0	0	0	0	0
Berkley, CA	0	0	0	0	0	0	0
Livermore, CA	1,537	0	0	0	0	0	1,537
San Diego, CA	19,981	0	0	0	0	0	19,981
Snowmass, CO	0	0	0	0	0	0	0
RF/Diag Conference	0	0	0	0	0	0	0
Princeton, NJ	17,504	0	0	0	0	0	17,504
Sherwood Theory - FY2002	0	0	0	0	0	0	0
Sherwood Theory - FY2003	954	0	0	0	0	0	954
Sherwood Theory - FY2004	0	0	0	0	0	0	0
Texas	0	0	0	0	0	0	0
Washington DC	7,420	0	0	0	0	0	7,420
Madison, WI	1,060	0	0	0	0	0	1,060
High Temp Plasma Conf	1,314	0	0	0	0	0	1,314
(TTF) FY02, Annapolis, MD	0	0	0	0	0	0	0
(TTF) FY03	9,540	0	0	0	0	0	9,540
(TTF) FY04	0	0	0	0	0	0	0
B. FOREIGN:							
England (JET)	11,430	0	0	11,430	0	0	22,860
EPS FY2002 - Switzerland	0	0	0	0	0	0	0
EPS FY2003	16,536	0	0	0	0	0	16,536
EPS FY2004	0	0	0	0	0	0	0
Germany	13,608	0	0	0	0	0	13,608
Italy (Frascati)	2,120	0	0	0	0	2,120	4,240
(IAEA) Lyon, France (FY03)	18,846	0	0	0	0	0	18,846
(IAEA) Tech Mtg (Arles, France)	0	0	0	0	0	0	0
Japan	7,950	0	0	0	0	0	7,950
Japan (PSI) - Fy2002	0	0	0	0	0	0	0
China (PSI) - Fy2004	0	0	0	0	0	0	0
Switzerland	1,390	0	0	0	0	0	1,390
TOTAL ESTIMATED TRAVEL COSTS	174,120	0	0	11,430	0	2,120	187,670

DOE COOPERATIVE AGREEMENT # DE-FC02-99ER54512
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Detail of Fabrications and Upgrades	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Operations Fabs/Upgrades	0	620,000	0	0	0	0	620,000
Machine Upgrade	0	100,000	0	0	0	0	100,000
Cylinder Upgrade	0	0	0	0	0	0	0
EFC Upgrade	0	180,000	0	0	0	0	180,000
Cryostat Fab	0	0	0	0	0	0	0
EF2 Upgrade	0	0	0	0	0	0	0
Igloo	0	0	0	0	0	0	0
Control (paragon replacements)	0	260,000	0	0	0	0	260,000
Digital Control (Hybrid replace)	0	80,000	0	0	0	0	80,000
ICRF Fabs/Upgrades	0	1,370,000	0	0	0	0	1,370,000
Transmitter Upgrade Fab	0	55,000	0	0	0	0	55,000
Matching Fab	0	55,000	0	0	0	0	55,000
Instrumentation/Control Fab	0	160,000	0	0	0	0	160,000
RF Diagnostics Fab	0	5,000	0	0	0	0	5,000
Data Acquisition Fab	0	40,000	0	0	0	0	40,000
Access Grid (Display Technology)	0	0	0	0	0	0	0
ICRF Transmission Line Upgrade	0	15,000	0	0	0	0	15,000
ICRF Dummy Loads Fab	0	25,000	0	0	0	0	25,000
ICRF Antenna Fab	0	0	0	0	0	0	0
Antenna Upgrade (D&E)	0	10,000	0	0	0	0	10,000
New 4-Strap Antenna (1/2)	0	0	0	0	0	0	0
ICRF Power Supply Upgrade	0	255,000	0	0	0	0	255,000
Fast Ferrite Tuners	0	750,000	0	0	0	0	750,000
Divertor Fabs/Upgrades	0	240,000	0	0	0	0	240,000
Cryopump Fab	0	240,000	0	0	0	0	240,000
Divertor Upgrade	0	0	0	0	0	0	0
Outer Divertor Upgrade	0	0	0	0	0	0	0
OPS/EQUIPMENT	0	254,000	0	0	0	0	254,000
Miscellaneous	0	3,000	0	0	0	0	3,000
Workstations/Servers/PCs	0	140,000	0	0	0	0	140,000
Data Communications	0	6,000	0	0	0	0	6,000
Vacuum and Pumping	0	40,000	0	0	0	0	40,000
Test Equipment	0	50,000	0	0	0	0	50,000
Machine Tools	0	10,000	0	0	0	0	10,000
Safety Equipment	0	5,000	0	0	0	0	5,000
Switch Gear	0	0	0	0	0	0	0
ICRF Transmitter Tube	0	0	0	0	0	0	0
Lower Hybrid Fabs/Upgrades	0	321,000	0	0	0	0	321,000
Instrumentation/control	0	40,000	0	0	0	0	40,000
Lower Hybrid Upgrade	0	281,000	0	0	0	0	281,000

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Detail of Fabrications and Upgrades (Continued)	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Diagnostic Fabs/Upgrades	425,000	540,000	0	0	0	0	965,000
Diagnostic Neutral Beam	0	0	0	0	0	0	0
Fast Thermocouples	0	0	0	0	0	0	0
MSE Fab	0	540,000	0	0	0	0	540,000
Fast Scanning Probe Fab	0	0	0	0	0	0	0
Active MHD Fab	0	0	0	0	0	0	0
EUV Spectrograph Upgrade	0	0	0	0	0	0	0
PCI Upgrade	0	0	0	0	0	0	0
Imaging X-Ray Spectrometer Fab	50,000	0	0	0	0	0	50,000
Core TS	0	0	0	0	0	0	0
Polarimetry Fab	0	0	0	0	0	0	0
2nd MHD antenna	65,000	0	0	0	0	0	65,000
Divertor IR camera	25,000	0	0	0	0	0	25,000
SOL Thomson upgrade	50,000	0	0	0	0	0	50,000
SOL Flow Diagnostic	0	0	0	0	0	0	0
Two -color Ne/Te Twiddle	25,000	0	0	0	0	0	25,000
Penning Gauges	5,000	0	0	0	0	0	5,000
D-Alpha imaging	10,000	0	0	0	0	0	10,000
CXRS telescope	15,000	0	0	0	0	0	15,000
CXRS Spectrometer (Kaiser)	60,000	0	0	0	0	0	60,000
Thomson digitizers	55,000	0	0	0	0	0	55,000
DNB upgrade (cap bank)	10,000	0	0	0	0	0	10,000
Long Pulse DNB	0	0	0	0	0	0	0
HIREX electronics	55,000	0	0	0	0	0	55,000
TOTAL FABS/UPGRADES	425,000	3,345,000	0	0	0	0	3,770,000

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Detail of Capital Equipment

	FY03B						FY03B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
Data Acquisition Equipment							
Misc.	29,000	100,000	0	0	0	0	129,000
Crates & Controllers	0	0	0	0	0	0	0
Digitizers	0	0	0	0	0	0	0
Plasma Control Equipment							
Computer Equipment							
Computers, Workstations/Servers	0	0	0	0	0	0	0
Mass Storage	20,000	0	0	0	0	0	20,000
Other Equipment							
Video & Optical Equip. and Instr.	0	0	0	0	0	0	0
Electronic Equipment	0	0	0	0	0	0	0
CMOD TV System Fab	10,000	0	0	0	0	0	10,000
Flush Mount Array Upgrade Fab	0	0	0	0	0	0	0
Lower Hybrid							
Capital Equipment	0	0	419,000	0	0	0	419,000
Operations							
Safety Equipment	0	0	0	0	0	0	0
Switch Gear	40,000	0	0	0	0	0	40,000
TOTAL CAPITAL EQUIPMENT	99,000	100,000	419,000	0	0	0	618,000

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Summary of Total Budget

	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 1,508,298	$ 181,595	$ -	$ 18,222	$ 21,872	$ 5,969	$ 1,735,956
ENGINEERS	-	1,691,341	-	-	-	-	1,691,341
COMPUTER STAFF	54,581	274,499	-	-	45,528	-	374,608
TECHNICIANS	-	1,750,364	-	-	-	-	1,750,364
DRAFTERS	-	99,799	-	-	-	-	99,799
ADMINISTRATIVE STAFF	60,347	12,317	-	-	-	-	72,664
ADMINISTRATIVE ALLOCATION	256,698	491,026	-	3,246	7,212	879	759,061
RESEARCH ASSISTANTS	419,321	-	-	-	-	-	419,321
SUBTOTAL SALARIES & WAGES	$ 2,299,245	$ 4,500,941	$ -	$ 21,468	$ 74,612	$ 6,848	$ 6,903,114
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	509,432	1,237,758	-	5,903	20,518	1,884	1,775,495
TRAVEL	175,000	-	-	12,115	-	2,247	189,362
RA TUITION	193,257	-	-	-	-	-	193,257
MATERIALS & SERVICES	860,591	5,797,911	-	273	607	74	6,659,456
TOTAL DIRECT COSTS	$ 4,037,525	$ 11,536,610	$ -	$ 39,759	$ 95,737	$ 11,053	$ 15,720,684
BASE FOR F & A (SEE BELOW)	2,836,603	5,689,297	-	35,330	85,898	9,843	8,656,971
FACILITIES & ADMINISTRATION COSTS	1,857,975	3,726,490	-	23,141	56,263	6,447	5,670,316
TOTAL EST. OPERATIONS	$ 5,895,500	$ 15,263,100	$ -	$ 62,900	$ 152,000	$ 17,500	$ 21,391,000
CAPITAL EQUIPMENT (See Attached)	99,000	110,000	-	-	-	-	209,000
TOTAL ESTIMATED COSTS	$ 5,994,500	$ 15,373,100	$ -	$ 62,900	$ 152,000	$ 17,500	$ 21,600,000
EXCLUSIONS FROM PRIMARY F&A BASE							
Administrative Allocation*	$ 256,698	$ 491,026	$ -	$ 3,246	$ 7,212	$ 879	$ 759,061
E.B. on Administrative Support*	71,875	137,487	-	909	2,019	255	212,545
Allocated Expense*	21,591	41,301	-	273	607	74	63,846
RA Tuition	193,257	-	-	-	-	-	193,257
Equipment Rental	7,500	7,500	-	-	-	-	15,000
Subcontracts >$25K	345,000	-	-	-	-	-	345,000
Cambridge Electric, Boc Gasses	-	725,000	-	-	-	-	725,000
Fabrications/Upgrades	305,000	4,445,000	-	-	-	-	4,750,000
TOTAL EXCL. FROM MTDC BASE :	$ 1,200,921	$ 5,847,314	$ -	$ 4,428	$ 9,838	$ 1,208	$ 7,063,709

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Summary of Person-Years

	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
SCIENTIFIC							
FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	0.44
OTHER ACADEMIC STAFF	3.53	0.10	0.00	0.10	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF	14.42	1.70	0.00	0.10	0.00	0.08	16.30
RESEARCH ASSISTANTS	18.49	0.00	0.00	0.00	0.00	0.00	18.49
SUBTOTAL SCIENTIFIC	36.88	1.80	0.00	0.20	0.20	0.08	39.16
TECHNICAL & ENGINEERING							
ENGINEERING RESEARCH STAFF	0.00	23.10	0.00	0.00	0.00	0.00	23.10
COMPUTER STAFF	0.74	3.22	0.00	0.00	0.51	0.00	4.47
TECHNICIANS	0.00	32.55	0.00	0.00	0.00	0.00	32.55
DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
SUBTOTAL ENGINEERING & TECH.	0.74	60.87	0.00	0.00	0.51	0.00	62.12
OTHER SUPPORT							
ADMINISTRATIVE STAFF	1.40	0.40	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE SUPPORT	4.95	9.46	0.00	0.06	0.14	0.02	14.63
SUBTOTAL OTHER	6.35	9.86	0.00	0.06	0.14	0.02	16.43
TOTAL MAN-YEARS	43.97	72.53	0.00	0.26	0.85	0.10	117.71

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Detail of Person Years	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
FACULTY							
Fasoli, Ambrogio F.	0%	0%	0%	0%	0%	0%	0%
Hutchinson, Ian	27%	0%	0%	0%	0%	0%	27%
Parker, Ronald	17%	0%	0%	0%	0%	0%	17%
Porkolab, Miklos*	0%	0%	0%	0%	0%	0%	0%
TOTAL FACULTY	0.44	0.00	0.00	0.00	0.00	0.00	44%
RESEARCH STAFF - OTHER ACADEMIC							
Marmar, Earl S.	90%	10%	0%	0%	0%	0%	100%
Greenwald, Martin	73%	0%	0%	0%	20%	0%	93%
Lipschultz, Bruce	90%	0%	0%	10%	0%	0%	100%
Lin,Yijun -Post-Doc	100%	0%	0%	0%	0%	0%	100%
TBD-Post-Doc	0%	0%	0%	0%	0%	0%	0%
TOTAL RESEARCH STAFF	3.53	0.10	0.00	0.10	0.20	0.00	3.93
SCIENTIFIC RESEARCH STAFF							
Bonoli, Paul T.	35%	0%	0%	0%	0%	0%	35%
Egedal-Pedersen, Jan	100%	0%	0%	0%	0%	0%	100%
Fiore, Catherine L.	50%	0%	0%	0%	0%	0%	50%
Granetz, Robert S.	90%	10%	0%	0%	0%	0%	100%
Hubbard, Amanda	100%	0%	0%	0%	0%	0%	100%
Irby, James	0%	100%	0%	0%	0%	0%	100%
LaBombard, Brian	100%	0%	0%	0%	0%	0%	100%
Mossessian, Dmitri	90%	10%	0%	0%	0%	0%	100%
Ramos, Jesus	45%	0%	0%	0%	0%	0%	45%
Rice, John E.	100%	0%	0%	0%	0%	0%	100%
Snipes, Joseph	82%	0%	0%	10%	0%	8%	100%
Terry, James	100%	0%	0%	0%	0%	0%	100%
Testa, Duccio	100%	0%	0%	0%	0%	0%	100%
Wolfe, Stephen	80%	20%	0%	0%	0%	0%	100%
Wukitch, Stephen	70%	30%	0%	0%	0%	0%	100%
Layoff Scientist	0%	0%	0%	0%	0%	0%	0%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
New Scientist-TBD	100%	0%	0%	0%	0%	0%	100%
TOTAL SCIENTIFIC RES. STAFF	14.42	1.70	0.00	10%	0%	8%	16.30

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Detail of Person Years

	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
ENGINEERS							
Andreyev, Sergey	0%	0%	0%	0%	0%	0%	0%
Beck, William	0%	100%	0%	0%	0%	0%	100%
Burke, William	0%	100%	0%	0%	0%	0%	100%
Byford, William G.	0%	100%	0%	0%	0%	0%	100%
Childs, Robert	0%	100%	0%	0%	0%	0%	100%
Cochran, William	0%	100%	0%	0%	0%	0%	100%
Dekow, Gary	0%	100%	0%	0%	0%	0%	100%
DiMaria, Michael	0%	100%	0%	0%	0%	0%	100%
Fitzgerald, Edward	0%	100%	0%	0%	0%	0%	100%
Grimes, Montgomery	0%	100%	0%	0%	0%	0%	100%
Gwinn, David	0%	0%	0%	0%	0%	0%	0%
Koert, Peter	0%	100%	0%	0%	0%	0%	100%
Murray, Richard	0%	100%	0%	0%	0%	0%	100%
Parkin, William	0%	100%	0%	0%	0%	0%	100%
Rokhman,Yuriy	0%	100%	0%	0%	0%	0%	100%
Rosati, James	0%	100%	0%	0%	0%	0%	100%
Terry, David R.	0%	100%	0%	0%	0%	0%	100%
Thomas, Paul	0%	90%	0%	0%	0%	0%	90%
Titus, Peter	0%	10%	0%	0%	0%	0%	10%
Vieira, Rui	0%	100%	0%	0%	0%	0%	100%
Woskov, Paul P.	0%	10%	0%	0%	0%	0%	10%
Zaks, James	0%	100%	0%	0%	0%	0%	100%
Zhong,Xiwen	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
Engineer TBD	0%	100%	0%	0%	0%	0%	100%
TOTAL ENGINEERS	0.00	23.10	0.00	0.00	0.00	0.00	23.10
COMPUTER STAFF							
Bergler, Henry	5%	45%	0%	0%	0%	0%	50%
Fredian, Thomas	0%	49%	0%	0%	30%	0%	79%
Kreisel, Felix	30%	70%	0%	0%	0%	0%	100%
London, Mark	0%	10%	0%	0%	0%	0%	10%
Nelson, Donald	0%	50%	0%	0%	0%	0%	50%
Sherman, Stuart	15%	43%	0%	0%	21%	0%	79%
Stillerman, Joshua	24%	55%	0%	0%	0%	0%	79%
TOTAL COMPUTER STAFF	0.74	3.22	0.00	0.00	0.51	0.00	4.47

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Detail of Person Years	FY04B Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	FY04B TOTAL
TECHNICIANS							
Anderson, Eric	0%	100%	0%	0%	0%	0%	100%
Arsenault, David	0%	100%	0%	0%	0%	0%	100%
Bellofatto, David	0%	100%	0%	0%	0%	0%	100%
Cauley, Charles	0%	100%	0%	0%	0%	0%	100%
Chicarello, James	0%	75%	0%	0%	0%	0%	75%
Danforth, Richard	0%	100%	0%	0%	0%	0%	100%
Gerolamo, Jerry	0%	80%	0%	0%	0%	0%	80%
Iverson, Mark	0%	100%	0%	0%	0%	0%	100%
Keating, William	0%	20%	0%	0%	0%	0%	20%
Mackay, George T.	0%	100%	0%	0%	0%	0%	100%
Muttart, Douglas B.	0%	100%	0%	0%	0%	0%	100%
Nickerson, John	0%	100%	0%	0%	0%	0%	100%
Pfeiffer, Andrew T.	0%	100%	0%	0%	0%	0%	100%
Pierson, Samuel	0%	100%	0%	0%	0%	0%	100%
Pina, Wanda	0%	100%	0%	0%	0%	0%	100%
Rettman, Kenneth	0%	100%	0%	0%	0%	0%	100%
Rollins, Edgar	0%	100%	0%	0%	0%	0%	100%
Rosati, Ronald	0%	100%	0%	0%	0%	0%	100%
Rowell, Michael	0%	100%	0%	0%	0%	0%	100%
Shefton, Frank	0%	100%	0%	0%	0%	0%	100%
Silveira, Maria	0%	80%	0%	0%	0%	0%	80%
Sylvia, Robert	0%	100%	0%	0%	0%	0%	100%
Szczepanowski, Wanda	0%	100%	0%	0%	0%	0%	100%
Tambini, Steven	0%	100%	0%	0%	0%	0%	100%
Telesmanick, Paul	0%	50%	0%	0%	0%	0%	50%
Toland, Thomas	0%	100%	0%	0%	0%	0%	100%
Vestal, David	0%	50%	0%	0%	0%	0%	50%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
New Tech TBN	0%	100%	0%	0%	0%	0%	100%
Overtime	0%	500%	0%	0%	0%	0%	500%
TOTAL TECHNICIANS	0.00	32.55	0.00	0.00	0.00	0.00	32.55

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Detail of Person Years	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
DRAFTERS							
Lienard,Paul	0%	100%	0%	0%	0%	0%	100%
Savelli, Henry	0%	100%	0%	0%	0%	0%	100%
TOTAL DRAFTERS	0.00	2.00	0.00	0.00	0.00	0.00	2.00
ADMINISTRATIVE STAFF							
Censabella, Valerie	80%	0%	0%	0%	0%	0%	80%
Zibcevoc, Dragana	60%	40%	0%	0%	0%	0%	100%
TOTAL ADMINISTRATIVE STAFF	1.40	0.40	0.00	0.00	0.00	0.00	1.80
ADMINISTRATIVE LAB SUPPORT							
Various	4.95	9.46	0.00	0.06	0.14	0.02	14.63
Detail of Research Assistant Effort							
RESEARCH ASSISTANTS							
Bai, Bo	100%	0%	0%	0%	0%	0%	100%
Boswell, Christopher	100%	0%	0%	0%	0%	0%	100%
Chung, Taekyun	100%	0%	0%	0%	0%	0%	100%
Decker, Joan	100%	0%	0%	0%	0%	0%	100%
Gangadhara, Sanjay	100%	0%	0%	0%	0%	0%	100%
Graves, Timothy	100%	0%	0%	0%	0%	0%	100%
Hughes, Jerry	100%	0%	0%	0%	0%	0%	100%
Jennings, Thomas M.	100%	0%	0%	0%	0%	0%	100%
Lee, William D.	100%	0%	0%	0%	0%	0%	100%
Liptac, John Edward, Jr.	100%	0%	0%	0%	0%	0%	100%
Marr, Kenneth David	100%	0%	0%	0%	0%	0%	100%
Nelson-Melby, Eric	0%	0%	0%	0%	0%	0%	0%
Sarlese, Justin A.	0%	0%	0%	0%	0%	0%	0%
Schmittdiel, David Anthony	100%	0%	0%	0%	0%	0%	100%
Tang, Vincent	100%	0%	0%	0%	0%	0%	100%
Thomas, Michael J.	100%	0%	0%	0%	0%	0%	100%
Thoms, Jon G.	100%	0%	0%	0%	0%	0%	100%
Youngblood, Brian J.	49%	0%	0%	0%	0%	0%	49%
Yuh, Howard Y.	100%	0%	0%	0%	0%	0%	100%
Zhurovich, Kirill	100%	0%	0%	0%	0%	0%	100%
New Student-TBD	100%	0%	0%	0%	0%	0%	100%
TOTAL RESEARCH ASSISTANTS	18.49	0.00	0.00	0.00	0.00	0.00	18.49
Total Man-Years	43.97	72.53	0.00	0.26	0.85	0.10	117.71

Detail of Research Assistant Tuition

	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
RESEARCH ASSISTANTS TUITION							
Bai, Bo	10,452	-	-	-	-	-	10,452
Boswell, Christopher	10,452	-	-	-	-	-	10,452
Chung, Taekyun	10,452	-	-	-	-	-	10,452
Decker, Joan	10,452	-	-	-	-	-	10,452
Gangadhara, Sanjay	10,452	-	-	-	-	-	10,452
Graves, Timothy	10,452	-	-	-	-	-	10,452
Hughes, Jerry	10,452	-	-	-	-	-	10,452
Jennings, Thomas M.	10,452	-	-	-	-	-	10,452
Lee, William D.	10,452	-	-	-	-	-	10,452
Liptac, John Edward, Jr.	10,452	-	-	-	-	-	10,452
Marr, Kenneth David	10,452	-	-	-	-	-	10,452
Nelson-Melby, Eric	-	-	-	-	-	-	-
Sarlese, Justin A.	-	-	-	-	-	-	-
Schmittdiel, David Anthony	10,452	-	-	-	-	-	10,452
Tang, Vincent	10,452	-	-	-	-	-	10,452
Thomas, Michael J.	10,452	-	-	-	-	-	10,452
Thoms, Jon G.	10,452	-	-	-	-	-	10,452
Youngblood, Brian J.	5,121	-	-	-	-	-	5,121
Yuh, Howard Y.	10,452	-	-	-	-	-	10,452
Zhurovich, Kirill	10,452	-	-	-	-	-	10,452
New Student-TBD	10,452	-	-	-	-	-	10,452
RA TUITION TOTAL	193,257	-	-	-	-	-	193,257

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Detail of Materials and Services

	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
OFFICE MATERIALS AND SERVICES	45,000	45,000	-	-	-	-	90,000
Xeroxing	8,000	8,000	-	-	-	-	16,000
Telecommunications	12,000	12,000	-	-	-	-	24,000
Office Supplies	9,000	9,000	-	-	-	-	18,000
Postage/Shipping	4,000	4,000	-	-	-	-	8,000
Journals & Books	4,000	4,000	-	-	-	-	8,000
Equipment Rental (No O/H)	7,500	7,500	-	-	-	-	15,000
Graphic Arts	500	500	-	-	-	-	1,000
Computing Materials & Services	44,000	96,000	-	-	-	-	140,000
PSFC Computer Contribution	-	6,000	-	-	-	-	6,000
Computer Maintenance	30,000	50,000	-	-	-	-	80,000
Computer Software & Supplies	14,000	29,000	-	-	-	-	43,000
MIT Networking Charges	-	11,000	-	-	-	-	11,000
Operations Material & Services	-	1,170,610	-	-	-	-	1,170,610
Materials & Services	-	400,610	-	-	-	-	400,610
Safety	-	10,000	-	-	-	-	10,000
DNB Shipping	-	35,000	-	-	-	-	35,000
Boc Gases (Nitrogen)	-	600,000	-	-	-	-	600,000
N/Star (Cambridge Electric)	-	125,000	-	-	-	-	125,000
RF Materials & Services	30,000	-	-	-	-	-	30,000
Diagnostic Materials & Services	40,000	-	-	-	-	-	40,000
Lower Hybrid Materials & Services	30,000	-	-	-	-	-	30,000
Subcontracts (No O/H)	345,000	-	-	-	-	-	345,000
Plasma Surface Engineering	-	-	-	-	-	-	-
M Technology	180,000	-	-	-	-	-	180,000
University of Toronto	165,000	-	-	-	-	-	165,000
Flywheel Inspection	-	-	-	-	-	-	-
Alternator Inspection	-	-	-	-	-	-	-
SUBTOTAL MATERIALS & SERVICES	534,000	1,311,610	-	-	-	-	1,845,610
ALLOCATED EXPENSE	21,591	41,301	-	273	607	74	63,846

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Detail of Travel Costs

				FY04B			FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
A. DOMESTIC:							
APS - FY2002, Long Beach, CA	0	0	0	0	0	0	0
APS - FY2003, Orlando,FL	0	0	0	0	0	0	0
APS - FY2004, Albuquerque, NM	50,550	0	0	0	0	0	50,550
Berkley, CA	0	0	0	0	0	0	0
Livermore, CA	0	0	0	0	0	0	0
San Diego, CA	17,919	0	0	0	0	0	17,919
Snowmass, CO	0	0	0	0	0	0	0
RF/Diag Conference	1,124	0	0	0	0	0	1,124
Princeton, NJ	18,560	0	0	0	0	0	18,560
Sherwood Theory - FY2002	0	0	0	0	0	0	0
Sherwood Theory - FY2003	0	0	0	0	0	0	0
Sherwood Theory - FY2004	1,011	0	0	0	0	0	1,011
Texas	0	0	0	0	0	0	0
Washington DC	7,868	0	0	0	0	0	7,868
Madison, WI	0	0	0	0	0	0	0
High Temp Plasma Conf	0	0	0	0	0	0	0
(TTF) FY02, Annapolis, MD	0	0	0	0	0	0	0
(TTF) FY03	0	0	0	0	0	0	0
(TTF) FY04	10,116	0	0	0	0	0	10,116
B. FOREIGN:							
England (JET)	14,538	0	0	12,115	0	0	26,653
EPS FY2002 - Switzerland	0	0	0	0	0	0	0
EPS FY2003	0	0	0	0	0	0	0
EPS FY2004	15,540	0	0	0	0	0	15,540
Germany	9,616	0	0	0	0	0	9,616
Italy (Frascati)	0	0	0	0	0	2,247	2,247
(IAEA) Lyon, France (FY03)	0	0	0	0	0	0	0
(IAEA) Tech Mtg (Arles, France)	0	0	0	0	0	0	0
Japan	16,854	0	0	0	0	0	16,854
Japan (PSI) - Fy2002	0	0	0	0	0	0	0
China (PSI) - Fy2004	8,840	0	0	0	0	0	8,840
Switzerland	2,464	0	0	0	0	0	2,464
TOTAL ESTIMATED TRAVEL COSTS	175,000	0	0	12,115	0	2,247	189,362

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Detail of Fabrications and Upgrades	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Operations Fabs/Upgrades	0	450,000	0	0	0	0	450,000
Machine Upgrade	0	50,000	0	0	0	0	50,000
Cylinder Upgrade	0	0	0	0	0	0	0
EFC Upgrade	0	0	0	0	0	0	0
Cryostat Fab	0	0	0	0	0	0	0
EF2 Upgrade	0	120,000	0	0	0	0	120,000
Igloo	0	0	0	0	0	0	0
Control (paragon replacements)	0	260,000	0	0	0	0	260,000
Digital Control (Hybrid replace)	0	20,000	0	0	0	0	20,000
ICRF Fabs/Upgrades	0	704,000	0	0	0	0	704,000
Transmitter Upgrade Fab	0	55,000	0	0	0	0	55,000
Matching Fab	0	30,000	0	0	0	0	30,000
Instrumentation/Control Fab	0	20,000	0	0	0	0	20,000
RF Diagnostics Fab	0	5,000	0	0	0	0	5,000
Data Acquisition Fab	0	64,000	0	0	0	0	64,000
Access Grid (Display Technology)	0	35,000	0	0	0	0	35,000
ICRF Transmission Line Upgrade	0	0	0	0	0	0	0
ICRF Dummy Loads Fab	0	0	0	0	0	0	0
ICRF Antenna Fab	0	0	0	0	0	0	0
Antenna Upgrade (D&E)	0	30,000	0	0	0	0	30,000
New 4-Strap Antenna (1/2)	0	200,000	0	0	0	0	200,000
ICRF Power Supply Upgrade	0	265,000	0	0	0	0	265,000
Fast Ferrite Tuners	0	0	0	0	0	0	0
Divertor Fabs/Upgrades	0	910,000	0	0	0	0	910,000
Cryopump Fab	0	200,000	0	0	0	0	200,000
Divertor Upgrade	0	0	0	0	0	0	0
Outer Divertor Upgrade	0	710,000	0	0	0	0	710,000
OPS/EQUIPMENT	0	476,000	0	0	0	0	476,000
Miscellaneous	0	150,000	0	0	0	0	150,000
Workstations/Servers/PCs	0	90,000	0	0	0	0	90,000
Data Communications	0	6,000	0	0	0	0	6,000
Vacuum and Pumping	0	40,000	0	0	0	0	40,000
Test Equipment	0	75,000	0	0	0	0	75,000
Machine Tools	0	10,000	0	0	0	0	10,000
Safety Equipment	0	5,000	0	0	0	0	5,000
Switch Gear	0	10,000	0	0	0	0	10,000
ICRF Transmitter Tube	0	90,000	0	0	0	0	90,000
Lower Hybrid Fabs/Upgrades	0	760,000	0	0	0	0	760,000
Instrumentation/control	0	50,000	0	0	0	0	50,000
Lower Hybrid Upgrade	0	710,000	0	0	0		710,000

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Detail of Fabrications and Upgrades (Continued)	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaboration	MDS+	FTU Collaboration	TOTAL
Diagnostic Fabs/Upgrades	305,000	1,145,000	0	0	0	0	1,450,000
Diagnostic Neutral Beam	0	0	0	0	0	0	0
Fast Thermocouples	0	0	0	0	0	0	0
MSE Fab	0	0	0	0	0	0	0
Fast Scanning Probe Fab	0	0	0	0	0	0	0
Active MHD Fab	0	0	0	0	0	0	0
EUV Spectrograph Upgrade	0	0	0	0	0	0	0
PCI Upgrade	0	0	0	0	0	0	0
Imaging X-Ray Spectrometer Fab	0	0	0	0	0	0	0
Core TS	0	0	0	0	0	0	0
Polarimetry Fab	0	465,000	0	0	0	0	465,000
2nd MHD antenna	0	0	0	0	0	0	0
Divertor IR camera	25,000	0	0	0	0	0	25,000
SOL Thomson upgrade	70,000	0	0	0	0	0	70,000
SOL Flow Diagnostic	70,000	0	0	0	0	0	70,000
Two -color Ne/Te Twiddle	110,000	0	0	0	0	0	110,000
Penning Gauges	5,000	0	0	0	0	0	5,000
D-Alpha imaging	10,000	0	0	0	0	0	10,000
CXRS telescope	15,000	0	0	0	0	0	15,000
CXRS Spectrometer (Kaiser)	0	0	0	0	0	0	0
Thomson digitizers	0	0	0	0	0	0	0
DNB upgrade (cap bank)	0	0	0	0	0	0	0
Long Pulse DNB	0	680,000	0	0	0	0	680,000
HIREX electronics	0	0	0	0	0	0	0
TOTAL FABS/UPGRADES	305,000	4,445,000	0	0	0	0	4,750,000

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Detail of Capital Equipment

	FY04B						FY04B
	Research	Facility Operations	Lower Hybrid	JET Collaborations	MDS+	FTU Collaboration	TOTAL
Data Acquisition Equipment							
Misc.	34,000	110,000	0	0	0	0	144,000
Crates & Controllers	0	0	0	0	0	0	0
Digitizers	0	0	0	0	0	0	0
Plasma Control Equipment							
Computer Equipment							
Computers, Workstations/Servers	0	0	0	0	0	0	0
Mass Storage	35,000	0	0	0	0	0	35,000
Other Equipment							
Video & Optical Equip. and Instr.	0	0	0	0	0	0	0
Electronic Equipment	0	0	0	0	0	0	0
CMOD TV System Fab	10,000	0	0	0	0	0	10,000
Flush Mount Array Upgrade Fab	0	0	0	0	0	0	0
Lower Hybrid							
Capital Equipment	0	0	0	0	0	0	0
Operations							
Safety Equipment	0	0	0	0	0	0	0
Switch Gear	20,000	0	0	0	0	0	20,000
TOTAL CAPITAL EQUIPMENT	99,000	110,000	0	0	0	0	209,000

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Summary of Total Budget

	FY02 TOTAL	FY03A TOTAL	FY04A TOTAL	FY03B TOTAL	FY04B TOTAL
SALARIES & WAGES					
FACULTY & RESEARCH STAFF	$ 1,446,423	$ 1,622,203	$ 1,678,979	$ 1,677,233	$ 1,735,956
ENGINEERS	1,194,579	1,472,438	1,517,958	1,640,789	1,691,341
COMPUTER STAFF	350,039	362,182	374,223	362,014	374,608
TECHNICIANS	1,266,145	1,581,712	1,671,067	1,614,556	1,750,364
DRAFTERS	93,164	96,424	99,799	96,424	99,799
ADMINISTRATIVE STAFF	67,833	70,207	72,665	70,207	72,664
ADMINISTRATIVE ALLOCATION	597,051	692,967	721,705	727,949	759,061
RESEARCH ASSISTANTS	372,862	384,650	398,123	405,131	419,321
SUBTOTAL SALARIES & WAGES	$ 5,388,096	$ 6,282,783	$ 6,534,519	$ 6,594,303	$ 6,903,114
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	1,372,143	1,614,694	1,679,962	1,694,730	1,775,495
TRAVEL	148,824	172,000	175,242	187,670	189,362
RA TUITION	165,565	174,200	182,805	184,160	193,257
MATERIALS & SERVICES	1,926,267	4,393,798	4,270,549	6,645,466	6,659,456
TOTAL DIRECT COSTS	$ 9,000,895	$ 12,637,475	$ 12,843,077	$ 15,306,329	$ 15,720,684
BASE FOR F & A (SEE BELOW)	6,784,891	7,896,985	8,222,784	8,294,156	8,656,971
FACILITIES & ADMINISTRATION COSTS	4,444,105	5,172,525	5,385,923	5,432,671	5,670,316
TOTAL EST. OPERATIONS	$ 13,445,000	$ 17,810,000	$ 18,229,000	$ 20,739,000	$ 21,391,000
CAPITAL EQUIPMENT (See Attached)	$ 809,000	$ 518,000	$ 99,000	$ 618,000	$ 209,000
TOTAL ESTIMATED COSTS	$ 14,254,000	$ 18,328,000	$ 18,328,000	$ 21,357,000	$ 21,600,000
EXCLUSIONS FROM PRIMARY F&A BASE					
Administrative Allocation*	$ 597,051	$ 692,967	$ 721,705	$ 727,949	$ 759,061
E.B. on Administrative Support*	167,174	194,031	202,078	203,833	212,545
Allocated Expense*	50,219	58,288	60,704	61,230	63,846
RA Tuition	165,565	174,200	182,805	184,160	193,257
Equipment Rental	15,000	15,000	15,000	15,000	15,000
Subcontracts >$25K	240,000	1,350,000	345,000	1,350,000	345,000
Cambridge Electric, Boc Gasses	387,000	700,000	700,000	700,000	725,000
Fabrications/Upgrades	594,000	1,556,000	2,393,000	3,770,000	4,750,000
TOTAL EXCL. FROM MTDC BASE :	$ 2,216,009	$ 4,740,486	$ 4,620,292	$ 7,012,172	$ 7,063,709

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Summary of Total Budget

	FY02-04 RESEARCH A BUDGET	FY02-04 FAC. OPS. A BUDGET	FY02-04 LHS A BUDGET	FY02-04 JET A BUDGET	FY02-04 MDS+ A BUDGET	FY02-04 FTU A BUDGET	FY02-04 TOTAL A BUDGET
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 4,315,146	$ 357,049	$ -	$ 11,987	$ 63,423	$ -	$ 4,747,605
ENGINEERS	-	4,184,975	-	-	-	-	4,184,975
COMPUTER STAFF	158,597	785,878	-	8,957	133,012	-	1,086,444
TECHNICIANS	-	4,518,924	-	-	-	-	4,518,924
DRAFTERS	-	289,387	-	-	-	-	289,387
ADMINISTRATIVE STAFF	175,501	35,204	-	-	-	-	210,705
ADMINISTRATIVE ALLOCATION	726,331	1,261,670	-	2,703	21,019	-	2,011,723
RESEARCH ASSISTANTS	1,155,635	-	-	-	-	-	1,155,635
SUBTOTAL SALARIES & WAGES	$ 6,531,210	$ 11,433,087	$ -	$ 23,647	$ 217,454	$ -	$ 18,205,398
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	1,456,399	3,144,099	-	6,502	59,799	-	4,666,799
TRAVEL	491,752	-	-	4,314	-	-	496,066
RA TUITION	522,570	-	-	-	-	-	522,570
MATERIALS & SERVICES	2,153,103	8,435,515	-	227	1,769	-	10,590,614
TOTAL DIRECT COSTS	$ 11,155,034	$ 23,012,701	$ -	$ 34,690	$ 279,022	$ -	$ 34,481,447
BASE FOR F & A (SEE BELOW)	8,041,169	14,582,136	-	31,007	250,348	-	22,904,660
FACILITIES & ADMINISTRATION COSTS	5,266,966	9,551,299	-	20,310	163,978	-	15,002,553
TOTAL EST. OPERATIONS	$ 16,422,000	$ 32,564,000	$ -	$ 55,000	$ 443,000	$ -	$ 49,484,000
CAPITAL EQUIPMENT (See Attached)	$ 297,000	$ -	$ 1,129,000	$ -	$ -	$ -	$ 1,426,000
TOTAL ESTIMATED COSTS	$ 16,719,000	$ 32,564,000	$ 1,129,000	$ 55,000	$ 443,000	$ -	$ 50,910,000
EXCLUSIONS FROM PRIMARY F&A BASE							
Administrative Allocation*	$ 726,331	$ 1,261,670	$ -	$ 2,703	$ 21,019	$ -	$ 2,011,723
E.B. on Administrative Support*	203,373	353,268	-	757	5,885	-	563,283
Allocated Expense*	61,093	106,122	-	227	1,769	-	169,211
RA Tuition	522,570	-	-	-	-	-	522,570
Equipment Rental	22,500	22,500	-	-	-	-	45,000
Subcontracts >$25K	765,000	1,170,000	-	-	-	-	1,935,000
Cambridge Electric, Boc Gasses	-	1,787,000	-	-	-	-	1,787,000
Fabrications/Upgrades	813,000	3,730,000	-	-	-	-	4,543,000
TOTAL EXCL. FROM MTDC BASE :	$ 3,113,867	$ 8,430,560	$ -	$ 3,687	$ 28,673	$ -	$ 11,576,787

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Summary of Total Budget

	FY02-04 RESEARCH B BUDGET	FY02-04 FAC. OPS. B BUDGET	FY02-04 LHS B BUDGET	FY02-04 JET B BUDGET	FY02-04 MDS+ B BUDGET	FY02-04 FTU B BUDGET	FY02-04 TOTAL B BUDGET
SALARIES & WAGES							
FACULTY & RESEARCH STAFF	$ 4,379,609	$ 357,049	$ -	$ 47,802	$ 63,423	$ 11,729	$ 4,859,612
ENGINEERS	-	4,526,709	-	-	-	-	4,526,709
COMPUTER STAFF	158,441	784,034	-	8,957	135,229	-	1,086,661
TECHNICIANS	-	4,631,065	-	-	-	-	4,631,065
DRAFTERS	-	289,387	-	-	-	-	289,387
ADMINISTRATIVE STAFF	172,113	38,591	-	-	-	-	210,704
ADMINISTRATIVE ALLOCATION	737,510	1,314,519	-	9,054	21,256	1,722	2,084,061
RESEARCH ASSISTANTS	1,197,314	-	-	-	-	-	1,197,314
SUBTOTAL SALARIES & WAGES	$ 6,644,987	$ 11,941,354	$ -	$ 65,813	$ 219,908	$ 13,451	$ 18,885,513
EMPLOYEE BENEFITS (Incl. Vacation Accrual)	1,476,226	3,283,871	-	18,097	60,474	3,700	4,842,368
TRAVEL	493,630	-	-	27,859	-	4,367	525,856
RA TUITION	542,982	-	-	-	-	-	542,982
MATERIALS & SERVICES	2,284,043	12,944,451	-	761	1,789	145	15,231,189
TOTAL DIRECT COSTS	$ 11,441,868	$ 28,169,676	$ -	$ 112,530	$ 282,171	$ 21,663	$ 40,027,908
BASE FOR F & A (SEE BELOW)	8,162,339	15,201,028	-	100,183	253,174	19,294	23,736,018
FACILITIES & ADMINISTRATION COSTS	5,346,332	9,956,674	-	65,620	165,829	12,637	15,547,092
TOTAL EST. OPERATIONS	$ 16,788,200	$ 38,126,350	$ -	$ 178,150	$ 448,000	$ 34,300	$ 55,575,000
CAPITAL EQUIPMENT (See Attached)	$ 297,000	$ 210,000	$ 1,129,000	$ -	$ -	$ -	$ 1,636,000
TOTAL ESTIMATED COSTS	$ 17,085,200	$ 38,336,350	$ 1,129,000	$ 178,150	$ 448,000	$ 34,300	$ 57,211,000
EXCLUSIONS FROM PRIMARY F&A BASE							
Administrative Allocation*	$ 737,510	$ 1,314,519	$ -	$ 9,054	$ 21,256	$ -	$ 2,082,339
E.B. on Administrative Support*	206,502	368,065	-	2,535	5,951	-	583,053
Allocated Expense*	62,033	110,567	-	761	1,789	-	175,150
RA Tuition	542,982	-	-	-	-	-	542,982
Equipment Rental	22,500	22,500	-	-	-	-	45,000
Subcontracts >$25K	865,000	1,070,000	-	-	-	-	1,935,000
Cambridge Electric, Boc Gasses	-	1,812,000	-	-	-	-	1,812,000
Fabrications/Upgrades	843,000	8,271,000	-	-	-	-	9,114,000
TOTAL EXCL. FROM MTDC BASE :	$ 3,279,527	$ 12,968,651	$ -	$ 12,350	$ 28,996	$ 2,366	$ 16,289,524

Appendix A
Alcator Publications - 2001

Papers Published in Referred Journals

Adams, M.L., Scott, H.A., Lee, R.W., Terry, J.L., et al., “Application of Magnetically-broadened Hydrogenic Line Profiles to Computational Modeling of a Plasma Experiment”, J. of Quantitative Spectroscopy & Radiative Transfer **71** No. 2-6 (2001) 117.

Boivin, R.L., Hughes, J.W., LaBombard, B., et al., “High Resolution Measurements of Neutral Density and Ionization Rate in the Main Chamber of the Alcator C-Mod Tokamak,” Rev. Sci. Instrum. **72** No. 1 (2001) 961.

Boivin, R.L., Goetz, J., Hubbard, A., et al., “High Resolution Measurements of Neutral Density and Ionization Rate in the Alcator C-Mod Tokamak,” Jour. Nucl. Materials **290-293** (2001) 542.

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Lipschultz, B., et al., "Using Variations in Plasma Equilibrium and Wall Geometry to Understand Radial Transport in the SOL."

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Adams, M.L., et al., "Interpreting Tangential Lyman-Alpha Measurements in Optically Thick Plasmas in Alcator C-Mod."

Bateman, G., et al., "Integrated Predictive Simulations of Gyro-radius and Collisionality Scans in Alcator C-Mod."

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Lee, W.D., et al., "Neutral Particle Analysis of ICRF Heated Discharges on Alcator C-Mod."

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APS Orals

Bonoli, P.T., et al., “Analysis of ICRF Heating Internal Transport Barrier Modes in Alcator C-Mod.”

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Hughes, J.W., et al., “Structure and Scalings of the H-Mode Pedestal on Alcator C-Mod.”

Irby, J.H., et al., “Recent Results from the Alcator C-Mod Tokamak.”

Lin, Y., et al., “Reflectometry Study of Enhanced D_α modes in Alcator C-Mod.”

Mossessian, D., et al., “Edge Dimensionless Similarity Experiments on C-Mod and DIII-D.”

Schilling, G., et al., “Alcator C-Mod ICRF Physics Results.”

Terry, J.L., et al., “Imaging of Edge Turbulence in Alcator C-Mod.”

APS Invited Talks

Mazurenko, A., “An Experimental Study of ICRF Wave Propagation and Mode Conversion to IBW by Phase Contrast Imaging in Alcator C-Mod.”

Porkolab, M., “Progress in Using Waves to Heat and to Drive Currents in Magnetically Confined Plasmas.”

Wukitch, S., “Double Transport Barrier Experiments on Alcator C-Mod.”

Zweben, S., “Edge Turbulence Imaging in Alcator C-Mod.”

APS Review Talk

Greenwald, M., “Density Limits in Toroidal Magnetic Confinement Experiments.”

Workshop Presentations

Transport Task Force Workshop
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Fiore, C., “Study of Internal Transport Barriers in Alcator C-Mod.”

Hughes, J.W., “Pedestal studies in EDA and ELM-free H-modes on Alcator C-Mod.”

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Bonoli, P.T., “RF Sci-Dac Plans for FY2002 at MIT,” presented at the RF Sci-Dac Planning Workshop, Princeton Plasma Physics Lab., July 2001.

Bonoli, P.T., “ICRF Physics and Transport Experiments in Alcator C-Mod,” presented at Physics Colloquium, Max Planck Institut für Plasmaphysik, Garching, Germany, Feb. 2001.

Hubbard, A.E., H-mode Pedestal and EDA Fluctuations in Alcator C-Mod,” presented at the Int. Workshop on Physics of Internal Transport Barriers,” Edge Pedestal and Steady-State Operation, Garching, Germany, April 2001.

Hubbard, A.E., “Understanding and Improving Energy Transport in Tokamak Plasmas,” (APS/DPP Distinguished Lecturers in Plasma Physics Program), presented at State Univ. of NY at Albany, Physics Dept. Colloquium, Nov. 2001.

Hubbard, A.E., “Edge Transport Barriers and Fluctuations on Alcator C-Mod,” presented at Columbia University, NYC, Plasma Physics Colloquium, April 2001.

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Porkolab, M., et al., “Progress in ICRF Experiments on Alcator C-Mod and Future Plans,” presented at the US-Japan Workshop on Plasma Control and Sustainment using RF Waves, GA, San Diego, CA, 27 Feb 2001.

Terry, J.T., “Experiments in Plasma Physics and Fusion Science on the Alcator C-Mod Tokamak,” presented at APS, Spring 2001.

Wukitch, S.J., “Recent ICRF Results on Alcator C-Mod,” presented at Workshop on Outstanding Issues in ICRF Technology, Oxnard, CA, May 2001.

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