Cerd Schiling

February 23-25, 2004

Presented to the C-Mod Program Advisory Committee

PPPL/C-Mod Collaboration
Overview - C-Mod Research Schedule

With PPPL foci and participation in red
Advanced Tokamak Recent Highlights

LHCD launcher development

- Achievement of Advanced Tokamak regimes requires an off-axis driven current, which together with high on-axis ICRF heating power should enable access and exploitation of these regimes. Achieving Advanced Tokamak regimes requires an off-axis driven current.

First MSE measurements

- Improvements to the MSE diagnostic have resulted in initial magnetic pitch angle measurements. Glass lenses and minor mirrors had been redesigned to withstand disruption-induced shocks. Metallic mirrors were fabricated as backup, and extensive calibrations and analyses are now in progress.

ITB discharges

- Bringing our experience from LH heating and current drive on PLT and PBX, PPPL has designed and fabricated a Lower Hybrid launcher in collaboration with C-Mod.
Proposed Advanced Tokamak Research

Achieve AT parameters

IIPA - transport & ITB, ITPA - steady state, non-inductive CD, steady state and energetic particles
IIPA 3.1 - steady state, ITPA 3.2 - high performance

Input to:

Extend the diagnosis and modeling of ITB discharges.
Continue to study internal transport barrier discharges.
Participate in the analysis and physics of current profile modification.
Continue to improve MSE optics and beam.
Determine current profile with MSE measurements.
Produce, measure and model ICRF-induced ITB's.
Determine effect on transport and stability.
Modify pressure profile with high power ICRF.
Modify current profile with off-axis LHCD.

Input to IPPA 3.1 - steady state, IPPA 3.2 - high performance
Burning Plasma Recent Highlights

Initial single-null/double-null studies

Comparison of single-null with double-null diverted discharges is in progress with enthusiastic participation by FIRE.
Proposed Burning Plasma Research

- Impact of SN/DN configuration on ETMs.
- Divertor and plasma boundary
  - Particle transport (peaked density profiles - fuel mix optimization).
  - Rotation with no momentum input.
  - Transport scaling in ITBs.
  - Similarity discharge studies.
  - Confinement scaling of H-mode with SN/DN and high triangularity.

- Transport studies
  - Extend ICRF heating power above 5 MW.
- ICRF heating at high power levels
  - Study double-null diverted discharges for FIRE.
  - Study single-null diverted discharges for ITER.
  - Compare single-null with double-null diverted discharges.
Transport Recent Highlights

Marginal stability and turbulence

- Temperature gradients measured on C-Mod exceed the estimates of the theoretical critical gradient for ion-temperature-gradient (ITG) modes.
- Nonlinear simulations using the gyrokinetic code GS2 show that the discrepancy can be understood as a substantial nonlinear upshift (Dimits shift) in the 'effective' critical gradient due to stabilization of ITG modes by zonal flows.

ITB modeling

- Linear and nonlinear calculations of gyrokinetic microturbulence have been carried out.
- Simulations have been extended to higher wavenumbers beyond the trigger time for formation of the ITB.
- Effective critical gradient due to stabilization of ITG modes by zonal flows can be understood as a substantial nonlinear upshift (Dimits shift) in the effective critical gradient for ion-temperature-gradient (ITG) modes.

Mariginal stability and turbulence

Conducted power (MW)

Measured R/LTe

IFS-PPPL model

Nonlinear simulations using the gyrokinetic code GS2
Proposed Transport Research

**Marginal stability and turbulence**
- Continue to upgrade the reflectometer diagnostic, support operation, and measure turbulent fluctuations.
- Perform detailed comparisons of data from all the C-Mod fluctuation diagnostics with nonlinear gyrokinetic simulations using GS2 and GYRO.
- Continue to upgrade the reflectometer diagnostic, support operation, and measure turbulent fluctuations.

**Electron transport**
- Measure electron gradient scale length to high precision and compare experimental and theoretical dependences of the electron temperature gradient on variations of important parameters such as the q profile.
- Nonlinear ITG calculations will be processed with the Nevins’ GKV post-processor, and heat and particle fluxes will be compared with transport analysis for off-axis ICRF.
- Perform detailed comparisons of data from all the C-Mod fluctuation diagnostics with nonlinear gyrokinetic simulations using GS2 and GYRO.

**ITP4 modeling**
- Initial GYRO code simulations will be extended and compared with those from GS2.
- Initial GYRO code simulations will be extended and compared with those from GS2.
- Nonlinear ITG calculations will be processed with the Nevins’ GKV post-processor, and heat and particle fluxes will be compared with transport analysis for off-axis ICRF.
- Nonlinear ITG calculations will be processed with the Nevins’ GKV post-processor, and heat and particle fluxes will be compared with transport analysis for off-axis ICRF.

Input to:
- IPPA 1.1 - turbulence and transport
- ITPA - transport & ITL, pedestal and edge, divertor and SOL
- ITPA - confinement scaling experiments extended over broader range *p*
- ITPA - transport & ITL, pedestal and edge, divertor and SOL

*Input to: IPPA 1.1 - turbulence and transport
- ITPA - transport & ITL, pedestal and edge, divertor and SOL
- ITPA - confinement scaling experiments extended over broader range *p*
Divertor and Plasma Boundary Recent Highlights

- Gas Puff Imaging edge turbulence visualization
  - The GPI diagnostic has been used to capture both “snapshots” and “movies” of plasma edge turbulence.
  - Comparisons with edge turbulence simulations have permitted the development of simple models of resistive ballooning mode as a dominant linear instability.
  - Comparisons with GPI edge turbulence simulations have been performed.

- Edge neutrals modeling
  - The extensive C-Mod diagnostics have permitted the development of simple models of neutral gas behavior.
  - DEGAS 2 Monte Carlo neutrals transport code has been examined by a stand-alone code such as the DEGAS 2 Monte Carlo neutrals transport code.
  - As a result, the neutral gas behavior can be examined by a stand-alone code such as the DEGAS 2 Monte Carlo neutrals transport code.

- Edge neutrals modeling
  - The extensive C-Mod diagnostics have permitted the development of simple models of neutral gas behavior.
  - DEGAS 2 Monte Carlo neutrals transport code has been examined by a stand-alone code such as the DEGAS 2 Monte Carlo neutrals transport code.
Proposed Divertor and Plasma Boundary Research

Edge turbulence visualization

- Explore edge turbulence behavior under a wide variety of conditions using an improved ultra-fast camera with >10 times the frame capacity (PSI-5 camera).
- Make detailed quantitative comparisons between turbulence measurements and theoretical simulation.
- Extend k-spectrum range to higher and/or lower k values.
- Perform 2-D imaging with two wavelengths for ne/T_e measurements.
- Extend 2-D imaging near the upper SOL and near the X-point.

Edge neutrals modeling

- Represent C-Mod vacuum vessel and sub-divertor by an axisymmetric object with local asymmetries.

Edge turbulence control

- Develop a new edge turbulence experiment for H-mode control.
- Extend k-spectrum range to higher and/or lower k.
- Perform 2-D imaging with two wavelengths for ne/T_e measurements.
- Extend 2-D imaging near the upper SOL and near the X-point.

Edge minority heating experiment

- Explore edge minority heating behavior under a wide variety of conditions using an improved ultra-fast camera with >10 times the frame capacity (PSI-5 camera).
RF (Wave-particle) Recent Highlights

Input to:

IPPA 1.3 - wave-particle interactions, 4.1 - plasma technologies

IPPA - high performance with $T_e$ = $T_i$.

RF (Wave-particle) Recent Highlights

Experiment participation

• Active participation in the D(H) minority heating experiments.
• Active participation in the Mode Conversion experiments.

ICRF modeling

• METS-1D all-order kinetic-wave solver has been used to analyze ICRF heating experiments.
• TRANSP time-dependent transport analysis code has been used to analyze ICRF processes in C-Mod.
• Benchmarking of the METS-1D code and the TORIC 2D code have identified regimes in which increased resolution in 2D was required to correctly model mode conversion.
• A Lower Hybrid package, LSC, has been incorporated into TRANSP and has been used to analyze ICRF.

Input to:

IPPA 1.3 - wave-particle interactions, 4.1 - plasma technologies

IPPA - high performance with $T_e$ = $T_i$.
Proposed RF (Wave-particle) Research

Active participation in ICRF experiments

- D(3He) minority heating experiments (PPPL experience from PLT experiments).
- FWCD experiments (PPPL experience from TFTR experiments).
- MCCD experiments (PPPL experience from TFTR experiments).
- Flow drive studies (PPPL experience from TFTR experiments).

Lower Hybrid wave physics

- Study LH wave launching, propagation, damping, and power deposition (PPPL experience from PLT, PBX-M experiments).
- Study LH wave launching, propagation, damping and power deposition (PPPL experience from PLT, PBX-M experiments).
- Flow drive studies (PPPL experience from TFTR experiments).
- MCCD experiments (PPPL experience from TFTR experiments).
- FWCD experiments (PPPL experience from TFTR experiments).
- D(3He) minority heating experiments (PPPL experience from PLT experiments).

RF modeling

- Utilize TRANSP/TORIC/LSC code package to analyze the transport properties of long-pulse AT discharges.
- Modify METS and TORIC codes to include effects of non-Maxwellian species on RF modeling.

Wave propagation and absorption (funded under the SciDAC initiative).
Proposed Global Stability (MHD) Research

Physics of pellet fueling.

- Currents.
- Energetic and peripheral.
- Stability of MHD and the behavior of ELMs.
- Nonlinear physics determining ELM particle modes.
- Energetic MHD modes - classical and neoclassical tearing modes.
- Sawtooth - energetic particle stabilization, coupling to other modes.

The following studies are especially relevant to C-MOD experiments:

- Strong interest on part of PPPL theorists for benchmarking on C-MOD.
- Important to benchmark these codes on existing experiments.
- Help to understand MHD on C-MOD.
- Predictive capability toward a burning plasma.

CAMINO, PEST-III, NOVA-K, HINST, VACUUM.
- Major macrostability codes supported by PPPL Theory Department

Proposed Global Stability (MHD) Research
Facility Recent Highlights - LHCD Launcher
Proposed Facility Research

Participate in design and commissioning of tunable RF cavities for ICRF transmitters #1 and #2

Participate in design, commissioning and operation of ICRF 4-strap antenna #2

Participate in design, commissioning and operation of LHCD launcher #2

- Commissioning
- RF power, controls hook up
- Checkout and testing, vacuum prep, installation
- Operation

Active PPPL participation in LHCD Launcher installation and commissioning
FY 2006B:

FINPLAN: $2050k
Ops: $ 250k
Science participation + support back to normal

FY 2006I:

$ 200k upgrade diagnostics (MSE, GPI, reflectometer)

FY 2005B:

FINPLAN: $2050k
Ops: $ 250k
Science participation + support LH repair + ICRF support

FY 2005I:

$ 200k restore research manpower to FY 2002 level

FY 2004B:

FINPLAN: $2070k
Ops: $ 460k Science participation marginal

BSDets (latest DoE guidance)
Research Manpower (FY 2004-2006)

<table>
<thead>
<tr>
<th>Year</th>
<th>Scientific</th>
<th>Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 2004</td>
<td>1.95 FTEs</td>
<td>3.85 FTEs</td>
</tr>
<tr>
<td>FY 2005</td>
<td>4.30 FTEs</td>
<td>1.50 FTEs</td>
</tr>
<tr>
<td>FY 2006</td>
<td>4.85 FTEs</td>
<td>1.20 FTEs</td>
</tr>
</tbody>
</table>

Additional "free" research support from PPPL Theory, SciDAC, FIRE, NSTX (this run campaign).

Incremental budgets for Science + Ops can help by allowing us to increase our research participation on all fronts.

Priority has been given to the Lower Hybrid system startup and experiments.
PPPL will continue to contribute strongly to the C-Mod program.

1. AT Physics
   • LHCD current drive, current distribution measurement, ICRF heating and current drive, modeling of transport and stability in AT regime.

2. Burning Plasma Issues
   • Drive model of transport and stability in AT regime.
   • LHCD current drive, current distribution measurement, ICRF heating and current drive.

3. Transport
   • Study single- and double-null discharges for ITER and FIRE.

4. Plasma Boundary
   • Model marginal stability and turbulence, ITBs; integrated modeling.

5. RF (Wave-particle)
   • Influence and transport modeling.
   • Edge influence visualization and measurement, edge influence modification.

6. Global Stability (MHD)
   • Heating experiments, current drive experiments, wave physics, RF modeling.
   • Benchmark PPPL stability codes against C-Mod experiments, use to help understand
   • Facility and design experiments.

7. RF Antenna Improvements/operation, LHCD launcher fabrication/operation.