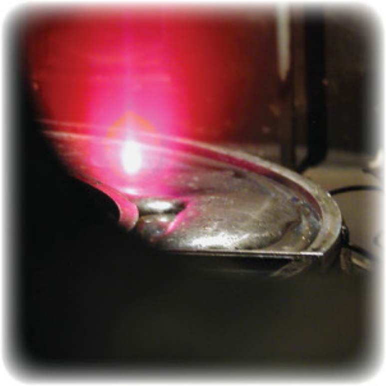
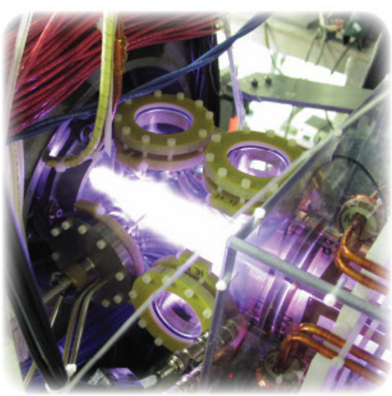
PRINCETON PLASMA PHYSICS LABORATORY

HIGHLIGHTS OF FISCAL YEAR 2007



PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY



About PPPL

The Princeton Plasma Physics Laboratory (PPPL) is dedicated to developing the scientific and technological knowledge base for fusion energy as a safe, economical, and environmentally attractive energy source for the world's long-term energy requirements.

Princeton University manages PPPL under contract with the U.S. Department of Energy. The fiscal year 2007 budget was approximately $77 million. The number of full-time regular employees at the end of the fiscal year was 427, not including 35 graduate students, subcontractors and limited-duration employees, and visiting research staff. The Laboratory is sited on 88 acres of Princeton University's James Forrestal Campus, about four miles from the main campus.

Through its efforts to build and operate magnetic fusion devices, PPPL has gained extensive capabilities in a host of disciplines including advanced computational simulations, vacuum technology, mechanics, materials science, electronics, computer technology, and high-voltage power systems.

PPPL scientists and engineers are applying knowledge gained in fusion research to other theoretical and experimental areas including the development of plasma thrusters and propagation of intense beams of ions. The Laboratory's Office of Technology Transfer assists industry, other universities, and state and local government in transferring these technologies to the commercial sector.

The Laboratory's graduate education and science education programs provide educational opportunities for students and teachers from elementary school through postgraduate studies.

On the Cover

Left column (from top): Photograph of an electron-beam striking the lithium in the toroidal tray of the of the Current Drive Experiment-Upgrade (CDX-U) device, fabrication of a National Compact Stellarator (NCSX) modular coil, a NCSX vacuum vessel segment, and participant in the PPPL summer student program.

Middle column (from top): The National Spherical Torus Experiment (NSTX) and a Princeton Field-reversed Configuration plasma (PFRC).

Right column (from top): The Magnetic Reconnection Experiment (MRX) and the Lyman Spitzer Building at PPPL.

This publication highlights activities at the Princeton Plasma Physics Laboratory for fiscal year 2007 — 1 October 2006 through 30 September 2007.

Mission

The U.S. Department of Energy's Princeton Plasma Physics Laboratory is a Collaborative National Center for plasma and fusion science. Its primary mission is to make the scientific discoveries and develop the key innovations that will lead to an attractive new energy source.

Associated missions include conducting world-leading research along the broad frontier of plasma science and technology, and providing the highest quality of scientific education.

Vision

Deepening the understanding of plasmas and creating key innovations to make fusion power a practical reality.

Advantages of Fusion Energy

- Worldwide availability of inexhaustible low-cost fuel.
- No chemical combustion products and therefore no contribution to acid rain or global warming.
- No runaway reaction or meltdown possible.
- Materials and by-products unsuitable for weapons production.
- Radiological hazards thousands of times less than from fission.
- Compact, steady energy source without need for large-area land use, large-scale energy storage, very long-distance transmission, or local carbon dioxide sequestration.
- Fusion complements other nearer-term energy technologies.

To go to a section, place the cursor over the section title or the page number and when the hand with the pointing finger appears click the mouse.

Table of Contents

Return to Table of Contents

From the Director

Robert J. Goldston

Fiscal year 2007 was a year of dramatic scientific advances on the Princeton Plasma Physics Laboratory's (PPPL) National Spherical Torus Experiment (NSTX) with new physics insights into electron turbulence, fast-ion physics, divertor heat-load reduction, nonaxisymmetric control, momentum confinement, radio-frequency wave propagation, and confinement improvement with lithium coatings. Crucial to these advances was an overall operational availability on NSTX of more than 90%. As will be discussed later, this was a difficult year for the National Compact Stellarator Experiment (NCSX) construction project.

A world-leading new diagnostic on NSTX, based on tangential scattering of microwaves, provided exciting new results on turbulence at the small electron-driven scale. The innovative scattering geometry provides a highly localized measurement, which made it possible to diagnose the effects of local gradients on short-wavelength turbulence, with detailed results that are, in most instances, consistent with the current theoretical understanding of electron-temperature gradient-driven instabilities. This is an area of fundamental mystery in toroidal confinement that is finally yielding to experimental observation on NSTX.

Fast-ion physics is a critical issue for ITER, and the national NSTX research team carefully mapped the variation from linear stability of Toroidal Alfvén Eigenmodes, to low-amplitude instability, to more powerful "chirping" behavior, and finally to the explosive growth of multiple modes. The team also confirmed the theoretically predicted beta stabilization of the Reversed-Shear Alfvén Eigenmodes that had been observed on the Tokamak Fusion Test Reactor (TFTR) and the DIII-D experiment at General Atomics in San Diego, but not on NSTX.

The spherical torus is a surprisingly good test-bed for divertor physics, because the divertor heat flux can be very high. This makes it attractive as the configuration for a future experiment to study the plasma-material boundary, but it also provides for near-term tests of heat-flux mitigation techniques, which were clearly demonstrated this year on NSTX. The NSTX also continued to push the frontiers in nonaxisymmetric discharge control, demonstrating substantial advantages of $n = 3$ error-field control. The same nonaxisymmetric coils provided a perturbative technique to study momentum transport, revealing a clear inward pinch of toroidal angular momentum, in surprisingly good agreement with theoretical prediction.

In the area of radio-frequency physics, experiments on NSTX elucidated the role of edge-localized waves in reducing the efficiency of central heating with high-harmonic ion-cyclotron waves. This could be an important issue for ITER, and points the way to more efficient coupling in NSTX. Experiments on TFTR and the Current Drive Experiment-Upgrade (CDX-U) had suggested that confinement could be improved with lithium, and liquid-lithium plasma-facing components have very attractive features for future fusion power systems. The results on NSTX were dramatic, providing improved electron energy confinement and higher edge electron temperatures — leading to the electron-Bernstein-wave result. Future research with a true liquid-lithium divertor surface on NSTX, and full wall coverage on the Lithium Tokamak Experiment (LTX), should be very exciting.

Off-site research, particularly at DIII-D and Alcator C-Mod at the Plasma Science and Fusion Center at the Massachusetts Institute of Technology, continues to be a very important element of PPPL's research program. The energetic particle work at DIII-D complements NSTX research very well, providing a stronger scientific basis for ITER. PPPL is also playing a large role in rotation measurements on DIII-D. Complementing the perturbative rotation studies on NSTX, we have found on DIII-D that varying the balance of co versus counter beams indicates a net co-rotation with zero torque input. This may be related to the momentum pinch identified on NSTX. Furthermore, we have seen the effects of Reversed-Shear Alfvén Eigenmodes on radial transport of angular momentum. On Alcator C-Mod, PPPL has been very engaged in understanding edge particle transport, and nonlinear turbulence in the edge, as on NSTX, making direct comparisons with theory. PPPL has also been very closely integrated in the successful lower-hybrid current-drive experiments, in experimental operations and analysis, and in providing the crucial motional Stark effect measurements of the current profile.

Theory and advanced simulations continued to score advances. A key issue, sometimes ignored, is that the most powerful codes can be quite complex, and verification of one complex nonlinear code against another can provide important insights, as came from using both the NIMROD and M3D codes to simulate sawtooth crashes in CDX-U. While advanced turbulence computations continue to march forward in their capabilities and comparison with experiment, perhaps most surprising this year was a simple analytic result on momentum transport, which gives very good agreement with NSTX results. Stellarator physics was advanced with new understanding of transport in stochastic fields, as well as the possible use of stellarator coils for improved vertical stability in tokamaks. Theoretical calculations of Toroidal Alfvén Eigenmode stability in ITER served to focus attention on toroidal mode numbers in the range of 5–10, and highlighted the importance of ITER's energetic beam ions as well as the alpha particles. PPPL's TRANSP code continues to grow as an international standard for tokamak data interpretation, and substantial advances are being made in parallelization and algorithm development for turbulence and MHD codes.

There were many advances in other areas, too numerous to describe here. However it should be acknowledged that this was a difficult year for the NCSX construction project. As the stage of machine assembly approached, it became clear that the interface between the complex modular coils needed much more design and R&D than had originally been anticipated. Furthermore, as solutions were developed the projected time and cost for assembly became very significantly larger than had been planned. The U.S. Department of Energy was informed of these difficulties, and a major effort was undertaken to reestimate the cost to complete the project. Good technical progress was made, and a path forward identified, but significant cost and schedule growth were experienced, while significant uncertainties still remained.

In sum, scientific excitement at PPPL in 2007 was at a high point, with many important advances, particularly on NSTX. However the cost and schedule growth for the NCSX project was a serious concern.

Return to Table of Contents

National Spherical Torus Experiment

National Spherical Torus Experiment

The NSTX (National Spherical Torus Experiment) is designed to study toroidal plasma confinement physics in a low-aspect-ratio tokamak configuration. The aspect ratio of NSTX can be as low as 1.25, and the experiment has significant heating power including 7 MW of neutral-beam power and 6 MW of 30-MHz high-harmonic fast-wave heating power. NSTX also has extensive plasma-shaping capability, passive stabilizing structures, and external nonaxisymmetric feedback control. These tools enable NSTX to uniquely investigate a high toroidal beta of approximately 40%, which is a primary advantage of the spherical torus (ST) as a confinement device. In addition, NSTX has unique access to several other physics regimes — such as high-energetic-particle speed and pressure fraction — which are highly relevant to burning-plasma experiments such as ITER. These capabilities allow NSTX to make vital contributions to toroidal confinement research while also offering the potential for future advances in plasma-material interface research in the proposed National High-power advanced Torus Experiment (NHTX), nuclear component testing in a Component Test Facility (CTF), and the demonstration of fusion power in a ST-DEMO.

On June 22, NSTX plasma operation for FY07 was completed successfully with 12.63 run weeks and 1,879 plasma discharges (90.4% availability); this exceeded the U.S. Department of Energy's Office of Fusion Energy Sciences fiscal year 2007 JOULE Milestone of 12 run weeks. During the 2007 experimental campaign, 40 experimental proposals were carried out yielding important experimental results in all topical science areas. Several new machine capabilities were introduced this year. An improved lithium evaporator was used routinely in several experiments yielding important scientific results. This year experiments continue to benefit from routine operation at a toroidal field of up to 0.55 T. A successful integrated system testing of the new plasma control system computers was also completed in preparation for the FY08 experimental campaign.

Plasma diagnostics on NSTX were also improved this year. A tangentially viewing microwave scattering system to measure density fluctuations with radial wavenumber in the range $k_r = 2–24\ cm^{-1}$, corresponding to fluctuations on the scale of the electron gyroradius in typical NSTX conditions (high-k), was upgraded with a longer focal length collection mirror and with its frequency bandwidth expanded from 600 kHz to 3 MHz to collect full turbulence spectra. The improved high-k system was used routinely in several experiments yielding very exciting new results for understanding electron transport. The interim configuration of the Poloidal CHarge-Exchange Recombination Spectroscopy (PCHERS) diagnostic was installed and commissioned to measure the spatial profile of the poloidal plasma flow in the outer half of the minor radius, providing new information on plasma flow while also successfully satisfying the FY07 diagnostic milestone. The preliminary data show the formation of a small region of negative poloidal flow (upwards at the outside in the chosen coordinate system) during the high-confinement mode (H-mode) phase of the discharge. An interim fast-ion D-alpha camera (FIDA) system was commissioned and obtained preliminary data on energetic particles. The Motional Stark Effect (MSE) diagnostic system for measuring the safety factor profile was upgraded to 16 spatial channels.

Electron Turbulence Measurements

Understanding electron gyroscale dynamics can provide insight into the long-standing mystery of anomalous electron thermal transport. With multiple detection channels, steerable optics, and access to the small plasma scales, the NSTX high-k system is a powerful turbulence diagnostic. The high-k diagnostic is a five-channel coherent scattering system and can be used for the measurement of turbulent fluctuations with perpendicular wavenumber $k_\perp < 20\ cm^{-1}$. The system employs a novel scattering geometry (Figure 1) taking advantage of the curvature of magnetic field lines for improving the radial resolution of measured signals. Wave vectors of fluctuations are mainly perpendicular to magnetic surfaces, but have also small components along the plasma diamagnetic velocity and the toroidal plasma current that could be used for determining the phase velocity of fluctuations.

Various theories and numerical simulations support the conjecture that the ubiquitous problem of anomalous electron transport in tokamaks may arise from a gyroscale turbulence driven by the electron temperature gradient. Initial measurements in NSTX plasmas with High-harmonic Fast-wave (HHFW) and neutral-

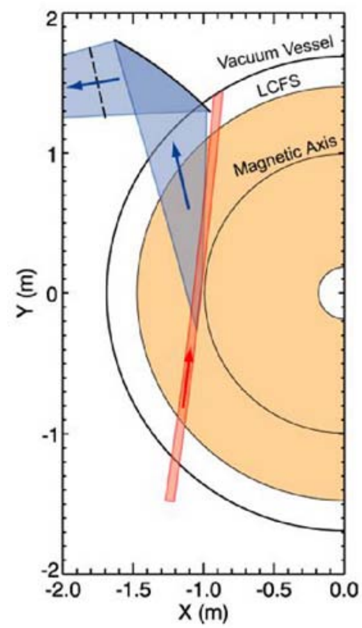


Figure 1. Top view of the scattering geometry for the NSTX high-k microwave scattering system diagnostic showing the probing beam (red) and scattered waves (blue).

beam-injection (NBI) heating confirm the existence of turbulent fluctuations with an electron gyroscale in both the core and outer region of NSTX plasmas. These fluctuations appear to be driven by the gradient of the electron temperature.

The NSTX high-k scattering system played a principal role in several turbulence and transport experiments in FY07. One experiment investigated electron gyroscale fluctuations in the core and outer region of NBI-heated discharges at various toroidal fields. The experiment was motivated by the observation in 2006 of a strong toroidal-field dependence of the electron thermal diffusivity. At higher toroidal field (5.5 kG) the inferred diffusivity was reduced near the plasma boundary and increased in the core relative to the values observed at lower toroidal field (3.5 kG). As shown in Figure 2, the measurements demonstrate the existence of electron gyroscale fluctuations in the core and outer region of NSTX plasmas. Importantly, the level of observed electron energy transport correlates with the measured turbulent fluctuation level, and the spatial variation of the turbulent fluctuation levels is consistent with the variation of the radial profile of the electron thermal diffusivity.

Another experiment investigated electron gyroscale fluctuations in HHFW-heated discharges. High-harmonic fast-wave heating produces strong core electron heating with a prominent electron internal

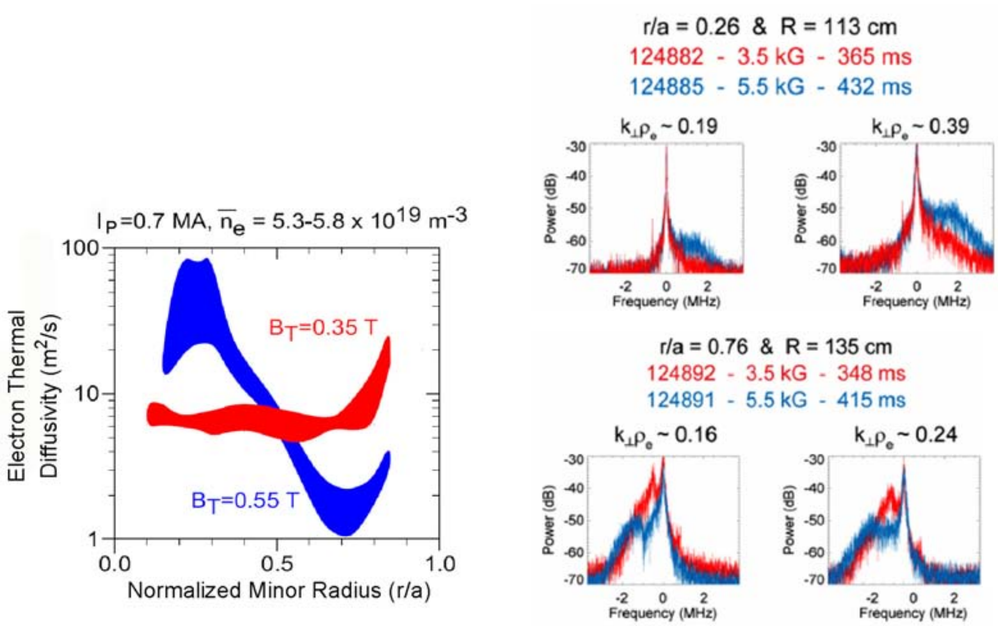


Figure 2. Using the NSTX high-k scattering system diagnostic, prominent electron gyroscale fluctuations were observed in the core and outer region of NSTX plasmas that correlate with changes in transport. The changes in transport were caused by varying the toroidal magnetic field from 0.35 T (red) to 0.55 T (blue).

transport barrier. The electron temperature (T_e) and electron temperature scale length (L_{Te}) are key parameters for electron temperature gradient (ETG) turbulence. These results are illustrated by Figure 3(a) showing the time evolution of the spectrum of fluctuations with normalized wavenumbers in the range $k_\perp\rho_s$ = 9–16 at major radius R = 1.2 m (ρ_s is the ion sound-speed Larmor radius). These fluctuations appear to be driven by the gradient of the electron temperature as illustrated in Figure 3(b), which shows the time evolution of the parameter R/L_{Te} (where R is the plasma major radius and $L_{Te} = T_e/(dT_e/dr)$ is the radial scale of T_e) together with the critical gradient for excitation of the electron temperature gradient mode. Note that plasma fluctuations begin to rise at the beginning of the radio-frequency pulse (0.15 s) when the measured value of R/L_{Te} (solid line) becomes larger than Jenko's critical value (dashed line) [F. Jenko, W. Dorland, and G.W. Hammett, "Critical Gradient Formula for Toroidal Electron Temperature Gradient Modes," Phys. Plasmas **8**:9 (September 2001) 4096–4104], and drop towards the end of the pulse when the opposite occurs. Finally, from the frequency asymmetries of measured spectra, it is concluded that fluctuations propagate in the electron diamagnetic direction. This, together with the large values of $k_\perp\rho_s$ of measured fluctuations and the fact that they are found in plasma regions with flat density profiles, indicates that neither the ion temperature gradient (ITG) mode nor the trapped-electron mode (TEM) is the source of the observed turbulence.

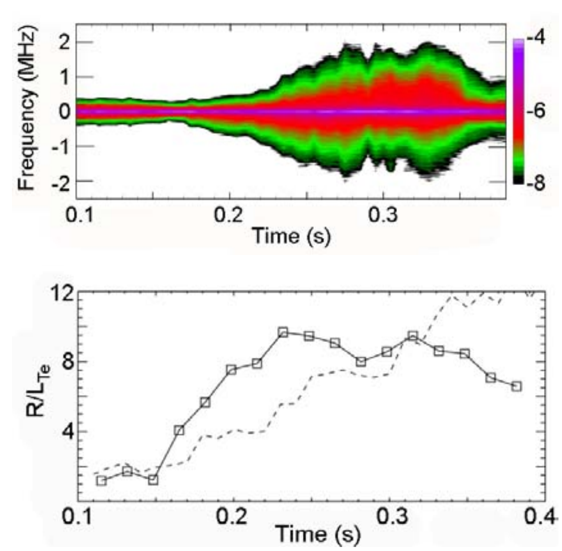
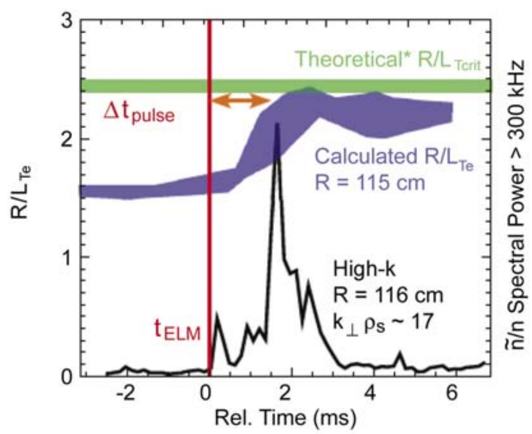


Figure 3. (top) Spectrogram of measured fluctuations at major radius R = 1.2 m in the range of normalized wavenumbers $k_\perp\rho_s$ = 9–16 during high-harmonic fast-wave (2 MW, Δt = 0.15–0.4 s). (bottom) Time evolution of measured R/L_{Te} (solid line) and Jenko's critical value for excitation of the electron temperature gradient mode (dashed line).

A third transport experiment investigated core electron gyroscale fluctuations in discharges with evolving reversed-shear profiles. Gyrokinetic simulations predict the amplitude of the electron temperature gradient turbulence drops substantially in regions of reversed shear. For some k-values, electron gyroscale fluctuations decrease as the shear reversal becomes stronger in agreement with simulations. However, the observed k-spectrum of the suppressed turbulence was narrow, which requires further investigation.

Finally, another experiment investigated the propagation of cold pulses associated with giant Type I ELMs (edge-localized modes). During an edge-localized mode, the local electron temperature gradient is modified within the cold pulse as it propagates from the edge to the core. As shown in Figure 4, the electron gyroscale fluctuations increase when the electron temperature gradient increases as the cold pulse propagates through the high-k measurement location, also in quantitative agreement with the critical temperature gradient scale length of Jenko's critical value.



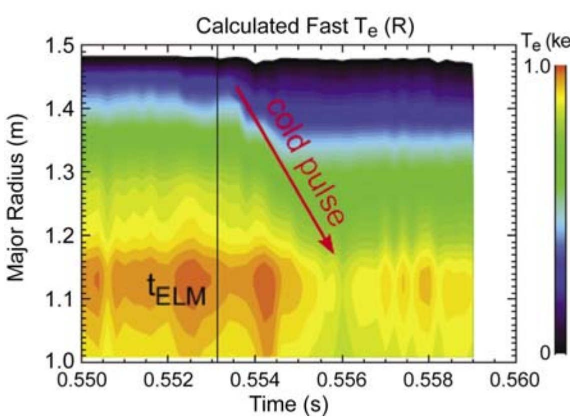


Figure 4. (a) A comparison of the measured normalized gradient scale length (R/L_{Te}, blue) to the theoretical critical value (green) along with the integrated spectral power from the high-k diagnostic (black) during an edge-localized mode (ELM). Increased turbulence explains the rapid heat transport during an ELM. (b) Time history of the electron temperature profile for the same time period.

Fast-ion Physics

Five experiments explicitly addressing fast-ion transport physics were carried out during the FY07 experimental campaign. The experiments included direct measurement of MHD-induced energetic-ion redistribution in space and energy with the vertically scanning Neutral Particle Analyzer (NPA) diagnostic, an experiment to study the suppression of Alfvén cascades (AC) at high-beta, documentation of the beta-induced Alfvén acoustic mode, and an investigation of ion transport using beam modulation. Finally, there was an experiment to study the transition from quiescent plasmas to strong toroidal Alfvén eigenmode (TAE) avalanches using a beam power scan.

In the 2007 experiments, the toroidal Alfvén eigenmode stability space — from no toroidal Alfvén eigenmodes up to the toroidal Alfvén eigenmode avalanche threshold — was mapped and comprehensively diagnosed for the first time in NSTX. The internal structure and amplitude of the multiple modes, as seen in Figure 5, was measured with an array of reflectometers. The bursts show increasing amplitude as the fast-ion distribution recovers from the previous avalanche event. Note the nearly factor of ten increase in amplitude for the last burst suggesting a synergistic interaction of the multiple modes. Attempts to simulate fast-ion transport during an avalanche are underway. The mode structure is simulated with the NOVA code and compared to reflectometer measurements (see Figure 6). The next step is to use these measured eigenmode amplitude and frequency evolutions in the ORBIT code to simulate the effect on confined fast ions. In parallel with this effort, nonlinear simulations of the full avalanche physics is being pursued with the M3D-k code based on this data.

Experiments were done at very low beta to investigate the prediction that Alfvén cascade modes are normally suppressed by the high-electron beta typical of NSTX plasmas. Modes with frequency that sweeps between the geodesic acoustic mode (GAM) and the toroidal Alfvén eigenmode frequency were seen (see Figure 7). The identification of the modes as Alfvén cascades was confirmed with an independent measurement of the q-profile evolution using the MSE diagnostic. The q-profile indeed has an off-axis minimum needed for the Alfvén cascade mode, and the evolution of the minimum safety factor q_{min} agrees

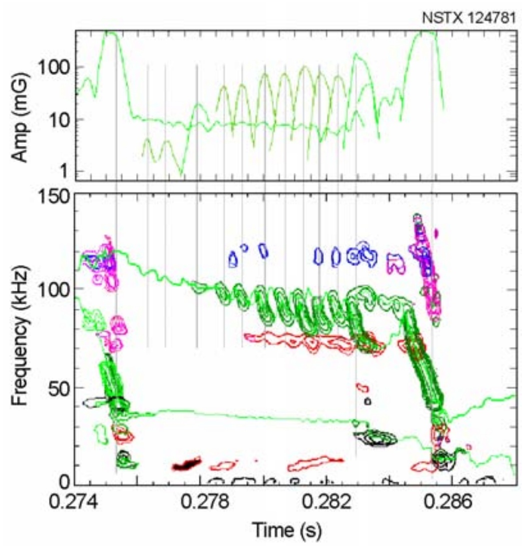


Figure 5. Typical avalanche cycle showing build-up of mode amplitude, culminating in one large burst of multiple modes.

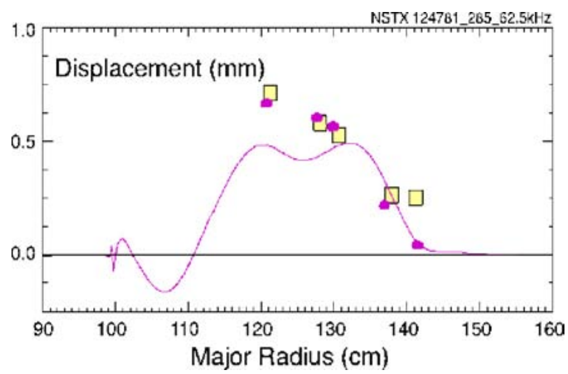


Figure 6. Displacements predicted by the NOVA code on outboard midplane. Magenta dots are simulated effective displacement seen by the reflectometer. Yellow squares are the reflectometer measurements.

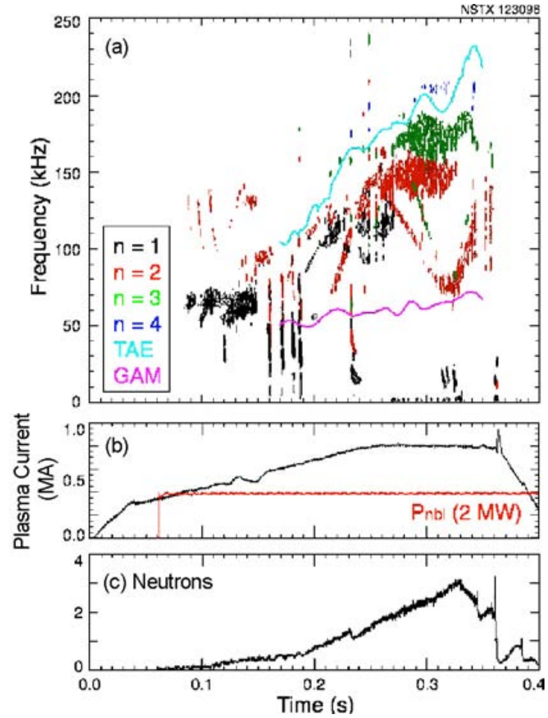


Figure 7. Spectrogram showing Alfvén cascade modes. Cyan and magenta curves indicate local toroidal Alfvén eigenmode (TAE) gap center and geodesic acoustic mode (GAM) frequencies, respectively.

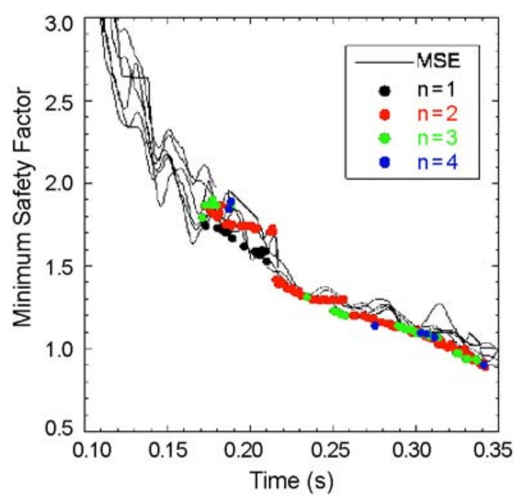


Figure 8. Evolution of minimum safety factor q_{min} deduced from spectrogram in Figure 7. Black lines indicate q_{min} evolution from the MSE diagnostic in similar plasma discharges.

well with that deduced from the Alfvén cascade mode frequencies (Figure 8). Further, the minimum frequency of the Alfvén cascade modes is in good agreement with estimates of the geodesic acoustic mode frequency, providing an important diagnostic tool to measure the specific heat of the plasma.

The coupling of Alfvén and acoustic waves can allow new waves at high beta. An instability identified as the beta-induced Alfvén acoustic eigenmode (BAAE) was discovered in experiments. Beta-induced Alfvén acoustic eigenmodes appear in the high-beta plasma conditions when Alfvén cascade modes are stabilized.

Redistribution and loss of fast ions correlated with a core-localized, fishbone-like mode was documented with a vertical scan of the viewing sightline for the Neutral Particle Analyzer diagnostic. Such redistribution was postulated to cause the central safety factor q(0) to remain higher than one in some NSTX discharges.

Integrated Scenario Development

The achievement of high plasma elongation is critical to the success of the spherical torus (ST) concept, since the bootstrap fraction increases as the square of the plasma elongation for fixed normalized beta $\beta_N = \beta_t a B_t / I_p$ (where I_p is the plasma current in units of mega-Amperes, B_t is the vacuum toroidal magnetic field at the plasma geometric center in Tesla, a is the plasma minor radius in meters, and β_t is the toroidal beta defined as the $\beta_t = \langle p \rangle/(B_t^2/2\mu_0)$ where $\langle p \rangle$ is the pressure averaged over the plasma volume). Achieving high-bootstrap current fraction is crucial for maintaining a spherical torus plasma, since there is little room in the center of the ST for a transformer that can drive current ohmically.

A primary motivation for discharge development on NSTX is the prototyping of operational scenarios for proposed future ST devices such as the NHTX (National High-power advanced Torus Experiment) and the CTF (Component Test Facility). Recently, equilibrium simulations have been performed to develop target operating scenarios for NHTX — a device projected to have an aspect ratio A = R/a ~ 1.8 to 2 (where R is the plasma major radius and a is the minor radius) and a planned elongation of 2.5 to 3. NHTX simulations are based on an engineering optimization for maximizing the sustainable plasma current using bootstrap and neutral-beam current drive as the primary current-drive tools while fixing the outboard major radius of the device. The simulated plasma was optimized for MHD stability with consistent current profiles using measured NSTX-like pressure profiles. The aspect ratio and elongation projected for NHTX are both higher than typical NSTX plasma geometric parameters A ~ 1.4 to 1.5 and κ ~ 2 to 2.5. Since vertical stability generally degrades with increasing aspect ratio and elongation, the proposed scenario represented an increase on the demands to the vertical control capabilities of NSTX. As a result, a scenario development experiment was undertaken to verify the accessibility of the higher-aspect-ratio high-elongation regime.

In 2007, as part of the above-mentioned effort, NSTX increased the maintained plasma elongation to κ ~ 2.6. The high elongation was maintained for the entire discharge duration of 0.7 s, and increased aspect ratio A ~ 1.55 to 1.6 was also sustained. The developed plasma shape was a lower single-null discharge with a downward bias parameter δR_{sep} = -1 cm, where δR_{sep} is the physical separation of the flux surfaces which pass through the upper and lower X-points, measured at the outboard midplane.

Figure 9 shows a comparison of the target NHTX plasma shape (left) as compared to the achieved plasma equilibrium. As is evident from this side-by-side comparison, the agreement between the two is quite good. There are some small differences, due to differences in the achieved and projected plasma parameters. In particular, the achieved plasma beta is about two-thirds the projected value. The cause of this would appear to be internal MHD modes that act to limit the confinement in the experiment. In addition, the achieved internal inductance ℓ_i of approximately 0.4 is somewhat lower than the predicted value.

Another interesting feature of these discharges is an early current hole and strong reversed shear that persists well into the current flattop. Figure 10 shows the time evolution of the q-profile for the same discharge in Figure 9. The q-profile is reconstructed using the measured-MSE field-line pitch angles, as well as using a constraint that the electron temperature is constant on a flux surface. The initial value of q(0) is greater than q at the 95% flux surface, and the minimum safety factor q_{min} remains above two for more than half of the discharge. The plasma is terminated by a large toroidal mode number n = 1 instability that rotates with a very low frequency of approximately 40–50 Hz.

Future work in this area will investigate the scaling of the noninductive fraction with plasma current and will

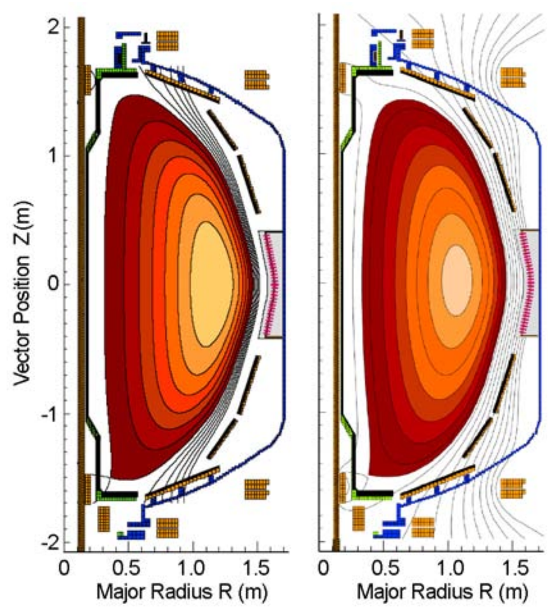


Figure 9. Side-by-side comparison of the calculated plasma equilibrium which is consistent with 100% noninductive current fraction and optimized MHD stability (left) and discharge 124058 at time t = 0.6 ms (right).

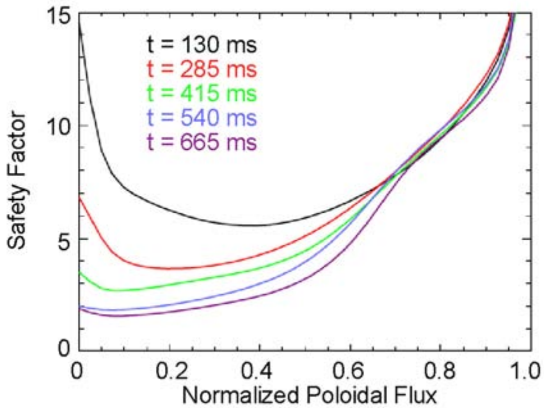


Figure 10. Profiles of the safety factor q showing the presence of a current hole early in the discharge.

also investigate variations in current ramp rate to understand the effect of the evolving current profile on stability and confinement. The effects of variations of various shape parameters such as δR_{sep}, outer gap, upper triangularity, and squareness will also be determined.

Divertor Heat-load Reduction

Divertor heat-load reduction is particularly challenging for the ST concept because of the small plasma-wetted divertor surface, small divertor plasma volume, and short connection length, as compared to a large-aspect-ratio device. On NSTX, peak heat fluxes of up to 10–12 MW/m^2 have been measured at the outer strike point in 6-MW NBI-heated H-mode plasmas in a low elongation and triangularity, lower single-null configuration. Scalings of the peak divertor heat flux developed for NSTX show a monotonic dependence on input power and plasma current. In previous years, access to the radiative divertor and reduced-peak-divertor heat flux was demonstrated on NSTX using divertor deuterium injection.

Improvements in the NSTX plasma control system enable access to higher elongation $\kappa \sim 2.1$–2.4 and triangularity $\delta \sim 0.5$–0.7. Improved plasma performance approaching the performance level of a CTF with high toroidal beta $\beta_t = 15$ to 25% and a high bootstrap current fraction $f_{bs} = 45$ to 50% sustained for several current redistribution times was achieved in highly shaped plasmas on NSTX. Higher plasma shaping factor also led to longer plasma pulses, and an H-mode regime with smaller edge-localized modes.

Routine attainment of high-performance plasmas presented an opportunity to study divertor properties in a high-flux expansion geometry. In 2007, the radiative divertor regime was extended to the highly shaped plasma configuration and demonstrated significant divertor heat-flux reduction in high-power H-modes without a degradation in confinement characteristics (stored energy, energy confinement time). Because of the higher area expansion, and the corresponding higher divertor wetted area, divertor heat-flux reduction in highly shaped plasmas comes as a natural benefit of the high-performance ST plasmas. Using divertor deuterium injection, the outer strike point heat flux was further reduced by up to 60% from 4–6 MW/m^2 to 0.5–2 MW/m^2 (e.g., Figures 11, 12) in the nearly highest achievable range of neu-

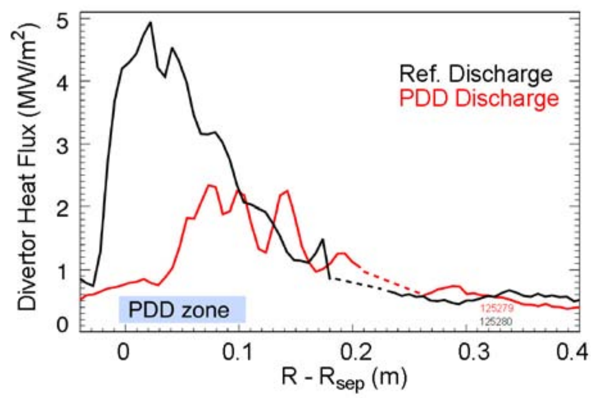


Figure 11. Divertor heat flux profiles measured in a reference 6-MW, 1-MA plasma discharge and a discharged with a partially detached divertor (PPD) outer strike point.

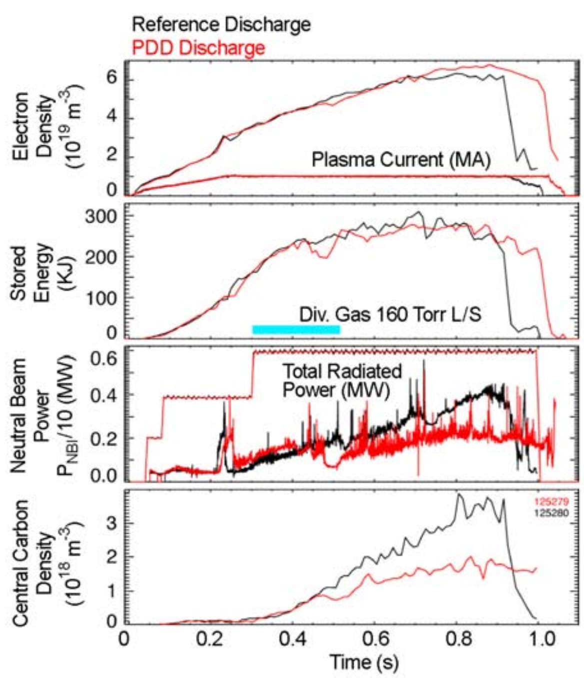


Figure 12. Time traces of core plasma parameters of the same reference H-mode and PDD discharges as in Figure 11.

tral-beam power P_{NBI} = 4–6 MW and plasma current I_p = 0.8–1.2 MA. The obtained partial detachment of the outer strike point was accompanied by significant increases in divertor radiated power, divertor neutral pressure, and volume recombination rate, features also observed in tokamak radiative divertors. These results form a basis for further development of the high-performance small-ELM partially detached divertor plasma regime as a reference regime for ST-based concepts, such as the NHTX or the ST-CTF.

Nonaxisymmetric Control

At high beta, error-field (EF) correction can aid sustainment of high toroidal rotation needed for passive (rotational) stabilization of the n = 1 resistive wall mode (RWM). In 2006, algorithms were developed to correct for a toroidal-field (TF) error field that results from motion of the toroidal-field coil induced by an electromagnetic interaction between the ohmic-heating (OH) and toroidal-field coils. Through use of real-time ohmic-heating and toroidal-field coil current measurements, incorporation of additional time lags and nonlinearity of the error field, and empirically minimizing the rotation damping near q = 2–3, significant pulse-length extensions were achieved for plasmas that were otherwise disruptive due to rotation damping and resistive-wall mode growth. With the addition of n = 1 active feedback control, the pulse-lengths were extended still further. In 2007, mechanical shims were place between the ohmic-heating and toroidal-field coils to reduce the relative motion of the toroidal-field coil. This motion reduction was successful when the ohmic-heating coil current was sufficiently close to zero, but not for large ohmic-heating coil currents. The toroidal-field error-field correction algorithm developed in 2006 was inadequate to follow the more complicated time dependence of the error field in 2007. Thus, in 2007, significant emphasis was placed on utilizing improved mode detection to better identify and suppress resonant field amplification (RFA) of the intrinsic error field. By utilizing the full complement (upper and lower versus upper only in 2006) of in-vessel poloidal-field sensors for mode identification, and by optimizing the relative phase of the upper and lower sensors to best discriminate between n = 1 and n > 1 fields, the detection capabilities of the NSTX in-vessel sensor array were significantly improved.

This improved detection increases the signal-to-noise ratio, improves mode detection during any mode deformation, and allows for increased proportional gain during feedback-controlled suppression of resonant field amplification. In fact, in 2007, using optimized poloidal magnetic field (B_p) sensors in the control system allowed feedback to provide all of the n = 1 error-field correction at high beta, whereas previous n = 1 error-field correction required an a priori estimate of the intrinsic error field. In 2007, the intrinsic error field was sufficiently small near the time of zero ohmic-heating current that rotation collapse did not occur naturally. Thus, to "train" the resonant field amplification suppression system, an n = 1 error field was purposely applied to reduce the plasma rotation and destabilize the n = 1 resistive wall mode. Then, phase scans were performed to find the corrective feedback phase that reduced the purposely applied error-field currents. As shown in Figure 13, the gain was then increased until the applied error-field currents were nearly completely nulled and plasma stability restored. Then, the externally applied error field was removed, and the feedback system was allowed to respond to any subsequent amplified error fields as the coil currents evolved in time. Importantly, the same gain and phase settings used to suppress resonant field amplification of the intrinsic error field were also useful to suppress unstable resistive wall modes when the rotation was insufficient to passively stabilize the resistive wall mode.

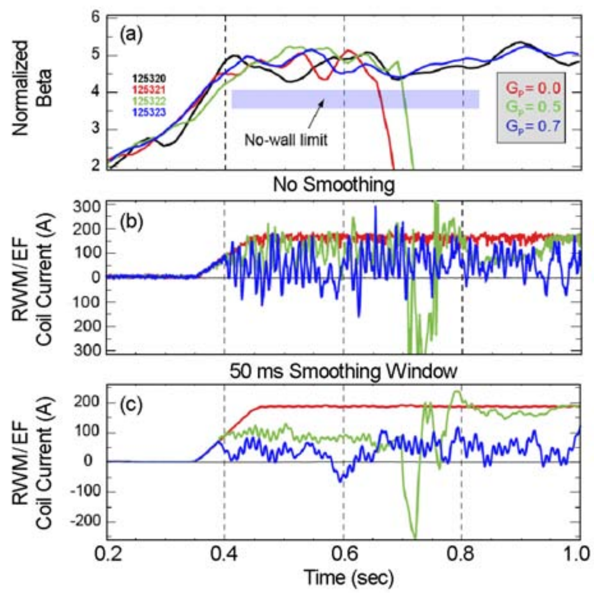


Figure 13. (a) Normalized beta as a function of applied error field and feedback gain during error-field suppression experiments designed to optimize error-field correction. G_P is proportional gain. (b) Unfiltered resistive wall mode/error-field (RWM/EF) coil current [applied n = 1 component plus current from resonant field amplification (RFA) feedback] as a function of applied error field and gain. (c) Filtered RWM/EF coil current using a 50-ms smoothing window.

Beyond n = 1 error fields, n > 1 error fields were found to be important in NSTX in 2007. In particular, it was discovered that high-n error fields (n = 3) could be important at high-normalized beta. As shown in Figure 14, in experiments that varied the polarity and amplitude of an applied n = 3 error field, plasma pulse-lengths varied by as much as a factor of two depending on n = 3 polarity. The anticorrective polarity of n = 3 error field increases the rotational damping, which destabilizes the n = 1 resistive wall mode and leads to plasma current and beta collapse. The magnitude of the correction current for n = 3 is similar to that for n = 1 correction, and the possible sources of the n = 3 error field are being assessed.

It is noteworthy that n > 1 error fields are not commonly addressed in present devices or in future burning plasma devices such as ITER. Clearly, if multiple-n error fields are present, correcting all known error fields is expected to optimize performance. In 2007, using simultaneous feedback control of n = 1 poloidal magnetic field resonant field amplification combined with preprogrammed n = 3 error-field correction resulted in a record pulse-length discharge at I_p = 900 kA. As shown in Figure 15(a), the core plasma rotation decreases with increasing density, but unusually and favorably, for radii with R > 1.2 m the rotation is either constant or slowly increases until a large edge-localized mode event at time t = 1.1 s takes the plasma irreversibly out of the H-mode. Typically, without the combined n = 1 and n = 3 error-field control, the edge rotation is lower than shown in the figure, and/or slowly decreases with time. As is also evident from Figure 15(b), there is a long period free of core low-frequency MHD activity during the period when the rotation is sustained, and high-beta equal to 18 to 20% is sustained for two current redistribution times.

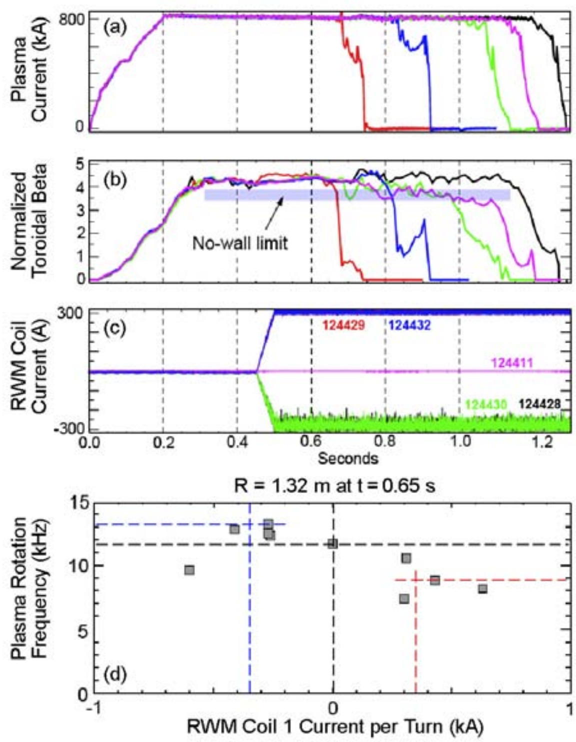


Figure 14. Plasma current (a) and normalized toroidal beta (b) versus externally applied n = 3 field polarity (at I_{COIL} = ±0.3 kA/turn) (c) showing that the maximum plasma pulse length depends strongly on the direction of applied n = 3 field indicating the presence of an n = 3 intrinsic error field. Plasma rotation frequency near the edge (d) versus n = 3 field amplitude and sign.

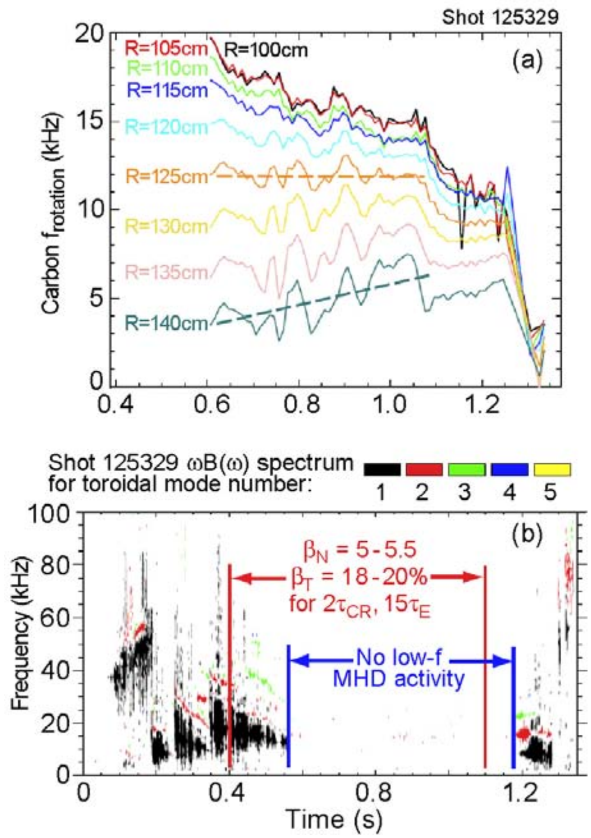


Figure 15. (a) Rotation profile evolution versus time for a discharge with combined optimal n = 1 resonant field amplification suppression via active feedback (as shown in Figure 13) and optimal n = 3 error-field correction (see Figure 14), and (b) MHD activity spectrum versus time.

HHFW Heating and Current Drive

A dramatic increase in core heating efficiency at higher toroidal magnetic field B_t and lower edge density is observed on NSTX for current drive (CD) phasing of the antenna (phase between adjacent straps, $\phi = 90°$ central wavenumber of launched spectrum, $k_\phi = 8\ m^{-1}$). This increase provides a heating efficiency comparable to that obtained for heating phasing of the antenna ($\phi = 180°$, $k_\phi = 14\ m^{-1}$) and has supported more efficient heating and current-drive studies for current-drive antenna phasing in 2007. The improved efficiency is attributed to moving the onset density (n_{onset}) for perpendicular wave propagation ($n_{onset} \propto B \times k_{||}^2/\omega$, where B is the magnetic field, ω is the wave angular frequency, and $k_{||}$ is the parallel wave number) away from the antenna and plasma-facing materials and thereby reducing the radio-frequency power losses due to direct fast-wave damping in the vicinity of the antenna and the surrounding structures. The heating efficiency continues to be degraded at antenna phases for which $|\phi| < 90°$, and understanding the trade-off between the reduced single-pass damping in the core of the plasma and the enhancement of edge power losses with the onset density pushed against the antenna and plasma-facing structures was also studied in 2007. For both the heating and current-drive studies, advanced radio-frequency codes were employed to model the radio-frequency propagation and current drive to help understand the implications of the experimental results.

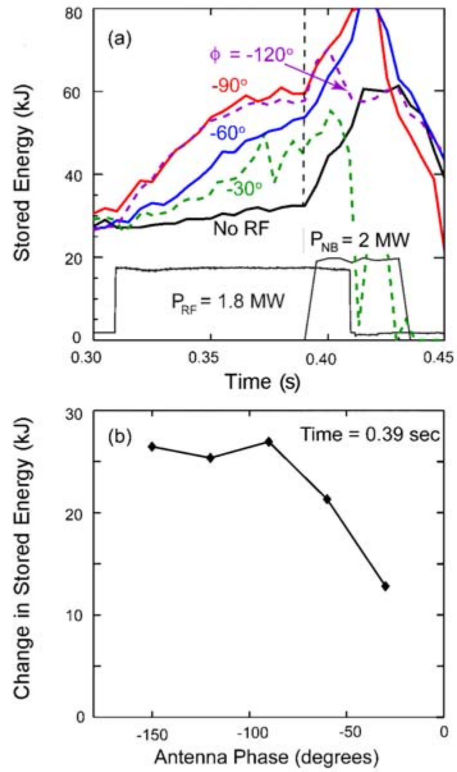


Figure 16. (a) Time evolution of total stored energy during HHFW heating as a function of antenna phasing and (b) stored energy increase from HHFW at time t = 0.39 s versus antenna phasing.

Reduction of Heating Efficiency at Longer Wavelengths

Since the onset density is so strongly dependent on the parallel wavenumber along the magnetic field and correspondingly the associated toroidal wavenumber launched by the antenna (k_ϕ), the heating falls off as the antenna phase amplitude is reduced below -90° as shown in Figure 16. Curves of total stored energy (W_T) versus time are shown in Figure 16(a) for several antenna phases (-150° is not shown for clarity) for a constant radio-frequency power pulse. The reduction of the change in stored energy (ΔW_T) at longer wavelengths ($\phi = -60°$ and -30° in Figure 16(b) suggests again that surface losses are higher with the density at the antenna/wall above the onset density in these cases. The change in stored energy produced at $\phi = -30°$ is about half that obtained for phases of $\phi = -90°$ and above, which is actually higher than expected from the electron heating observed on axis. The explanation for the higher energy increment is that there is a broadening and elevation of the density profile for the $\phi = -30°$ case relative to those for the higher phases, as indicated by the Thomson scattering profiles. This result suggests the radio-frequency power may be affecting transport, producing high core temperature and broad density profiles when core damping is strong and surface damping is weak, and vice versa.

The competition between core and edge damping was investigated with the GENRAY code and it is predicted that due to the wave properties for HHFW in the low-aspect-ratio, low-field NSTX device, the single-pass core damping of the wave is large (~70%) even for $\phi = -30°$ (corresponding to $k_\phi = -3\ m^{-1}$). This suggests that most of the edge damping occurs in the vicinity of the antenna. Upon increasing the electron temperature on axis to above 2 keV with a preheat pulse with $\phi = -90°$, subsequent heating at $\phi = -30°$ was not able to sustain the core heating even though the single-pass damping was increased to above 90%. Again, this shows that most of the edge power loss occurs in the vicinity of the antenna.

This result suggests that care must be taken to avoid having the onset density layer in contact with the antenna and surrounding structures for any ion cyclotron range of frequency and should be considered in the operation of the ITER antenna for which the wavenumber is low for current-drive phasing of the antenna ($k_\phi \sim 4\ m^{-1}$). Also, the large single-pass damping for the HHFW regime on NSTX affords and ideal test bed for benchmarking the advanced full-wave codes once the edge damping processes have been incorporated into them.

High-k Scattering Studies with HHFW Electron Heating

Heating with current-drive phasing was used successfully in 2007 to produce steep electron temperature gradients at the scattering radius of the high-k system used to measure short wavelength electron-temperature-gradient scale turbulence, both without and with neutral-beam injection. Because the temperature profile achieved using HHFW heating is substantially different than that achieved with neutral-beam injection, HHFW is a powerful tool for investigating the dependence of turbulent fluctuations on the local temperature gradient scale length.

Initial MSE Measurements of HHFW Current Drive

Initial measurements of HHFW current drive were made with the MSE diagnostic on NSTX. These are not easy measurements at the powers delivered to date (~1.2 MW into the core of the plasma). Nevertheless, indication of driven radio-frequency current density near the axis of the plasma is obtained for -90° current-drive phasing as shown in Figure 17. TORIC and AORSA code estimates for radio-frequency current density j_{RF} are rather peaked within normalized minor radius $\rho \sim 0.2$, which is in reasonable agreement with the location of the toroidal current density J_ϕ perturbation measured with the MSE diagnostic.

The TORIC and AORSA code predictions for total radio-frequency current are higher than the apparent driven current deduced from the MSE measurements (37 kA from TORIC and 26 kA from AORSA, compared with a maximum MSE value of ~15 kA). It is likely that the radio-frequency power was not applied long enough to reach equilibrium and that a back electro-motive force from the inductive drive is impacting the results. However, it is clear from these initial current-drive results that the current driven is rather small for the small aspect ratio regime of NSTX for which electron trapping strongly reduces the current drive. Considerably more radio-frequency power and longer radio-frequency pulses are needed to enhance the current drive to a level to where more definitive measurements can be made. Also, further modeling with the advanced radio-frequency codes being developed under the USDOE Radio-frequency Scientific Discovery through Advance Computing (SciDAC) program is needed to both determine the best conditions on NSTX for enhancing heating and current drive while avoiding surface losses, and for benchmarking the codes for future applications generally.

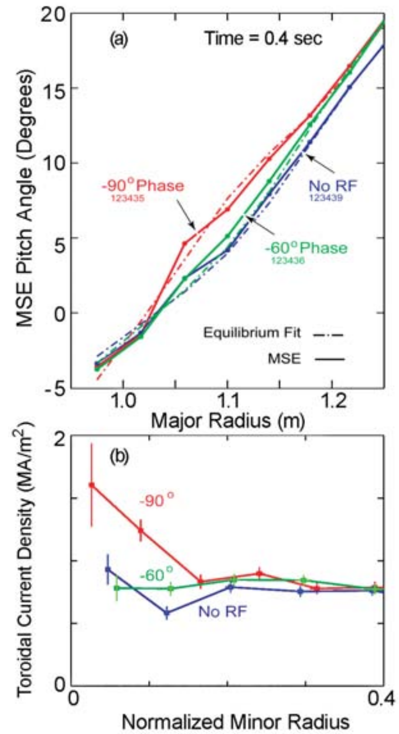


Figure 17. (a) MSE diagnostic pitch-angle change during HHFW current drive versus antenna phasing and (b) inferred change in toroidal current density due to HHFW current drive.

EBW Emission Measurements

Electron Bernstein waves (EBW) offer a promising way to heat electrons and provide efficient off-axis current drive in the over-dense plasma conditions of the Spherical Torus. The primary challenge of using these waves is achieving efficient coupling of wave power from the launcher to the plasma core. For the past several years, wave emission measurements have been performed on NSTX to better understand the EBW coupling process. In 2007, reproducibly high-thermal EBW emission was achieved in H-mode plasmas for the first time. With the injection of lithium vapor, the calculated transmission efficiency of fundamental frequency EBW emission at 18 GHz, thermally emitted from near the core of NSTX high-confinement mode plasmas, increased from 5–10% to 55–70%. Correspondingly, the second-harmonic EBW transmission from near the plasma core increased from 5–10% to 50% with the addition of lithium-plasma conditioning.

Figure 18(a) shows the central electron temperature $T_e(0)$ time evolution for two I_p = 0.8 MA, H-mode plasmas, one without lithium evaporation (discharge 124284, solid black line) and the other with 19 mg per minute of lithium evaporation, after 286 mg of lithium had already been evaporated into the NSTX vacuum vessel (discharge 124309, dashed red line). Both discharges had low-to-high confinement mode (L- to H-mode) transitions at 0.14 s (indicated by the vertical dashed line in Figure 18). In the plasma without lithium conditioning, the central electron temperature increases to about 0.8 keV following the transition to the H-mode, while on the plasma with lithium conditioning, the central electron temperature initially increases to 0.950 keV following the transition to the H-mode and then decreases to 0.8 keV.

Figure 18(b) shows the evolution of the EBW radiation temperature (T_{rad}) at 18 GHz, emitted from the core of the two plasmas. The discharge without lithium conditioning exhibits a collapse of the EBW radiation temperature from 0.3 keV immediately before the L- to H-mode transition to about 0.05–0.1 keV during the H-mode phase. In contrast, the plasma with lithium conditioning has a large rise in the EBW radiation temperature after the L- to H-mode transition, initially to 0.4 keV and then to 0.5–0.6 keV later in the H-mode phase.

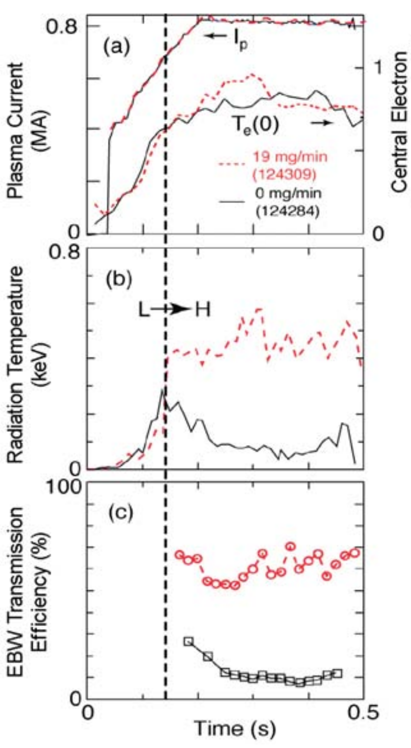


Figure 18. (a) Plasma current and central electron temperature $T_e(0)$ evolution for two H-mode plasmas, one without lithium conditioning (black solid line) and one with lithium conditioning (red dashed line). (b) Time evolution of EBW radiation temperature for fundamental emission from the plasma core at 18 GHz for the two plasmas in (a). (c) EBW transmission efficiency from the core to the EBW radiometer antenna.

Figure 18(c) shows the EBW transmission efficiency from the plasma core to the EBW radiometer antenna following mode conversion in the plasma scrape-off layer. The EBW transmission efficiency is less than 10% during the H-mode phase for the plasma without lithium conditioning but is 50 to 70% throughout the H-mode phase of the plasma with lithium conditioning. These EBW emission measurements were compared to results from an EBW emission simulation code that includes the magnetic plasma equilibrium and electron temperature and density profiles from laser Thomson scattering. The dramatic increase in EBW transmission efficiency with the addition of lithium evaporation during NSTX H-mode plasmas is consistent with a large decrease in EBW collisional damping prior to mode conversion in the scrape-off layer.

Coupling Coaxial Helicity Injection to Ohmic Ramp-up

During FY06, the method of plasma current generation in tokamaks called transient coaxial helicity injection (CHI) was successfully applied in NSTX for the generation of a record 160 kA of closed-flux plasma current without using a central solenoid to induce the current. The NSTX experiments also demonstrated a remarkable current multiplication factor, defined as the ratio of the plasma current to the injected current, of up to 60. During 2007, coaxial helicity injection discharges were produced using less than half the stored energy as that used during 2006 and the discharges were coupled to induction using the central solenoid.

While the CHI method has previously been studied in smaller experiments, such as the Helicity Injected Tokamak (HIT-II) at the University of Washington, Seattle, the results from the much larger NSTX demonstrate the exciting potential of this method. The CHI method is also applicable to tokamaks and could be used to simplify the design of a future tokamak reactor.

Coaxial helicity injection is implemented in NSTX by driving current along field lines that connect the inner and outer lower divertor plates, which are electrically separated by toroidal insulating breaks. The standard operating condition for CHI in NSTX uses the inner divertor plates and inner wall as the cathode while the outer divertor plates and passive-stabilizing plates are the anodes.

The operational sequence for CHI involves first energizing the toroidal-field coils and the poloidal-field coils to produce the desired flux conditions in the injector region. The CHI voltage is then applied to the inner and outer divertor plates and a preprogrammed amount of gas is injected in to a cavity below the lower divertor plates. The gas ionizes and current begins to flow along helical magnetic field lines connecting the lower divertor plates. The applied toroidal field causes the current in the plasma to develop a strong toroidal component, the beginning of the desired toroidal plasma current. If the injector current exceeds a threshold value, the resulting stress across the current layer exceeds the field-line tension of the injector flux causing the helicity and plasma in the lower divertor region to move into the main torus chamber.

As shown in Figure 19, during 2006, a 45-mF capacitor bank was used at up to 1.75 kV to provide the injector current. During 2007, by reducing the number of capacitors to four (20 mF), the same amount of CHI-produced toroidal current was generated. This also resulted in the absorber-arc current being reduced to half that in 2006. Absorber arcs are generated when the injected current bridges the upper ceramic insulator region and flows along the vessel walls instead of flowing through the main plasma load. During the occurrence of an absorber arc, while some current still flows through the plasma load, most of the injected current is believed to flow along this undesired path. Reducing the size of the capacitor is one easy way to control the extent of absorber-arc current. The other method is to reduce

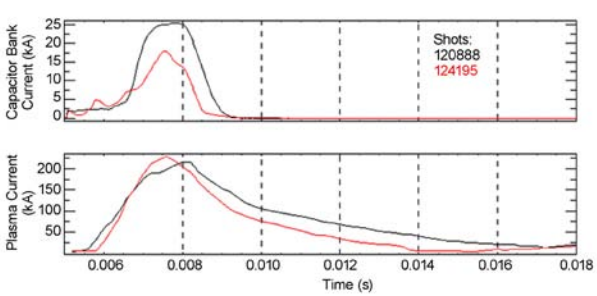


Figure 19. The red trace shows a discharge produced during 2007 using four capacitor modules. The black trace shows a similar discharge produced during 2006 using nine capacitor modules.

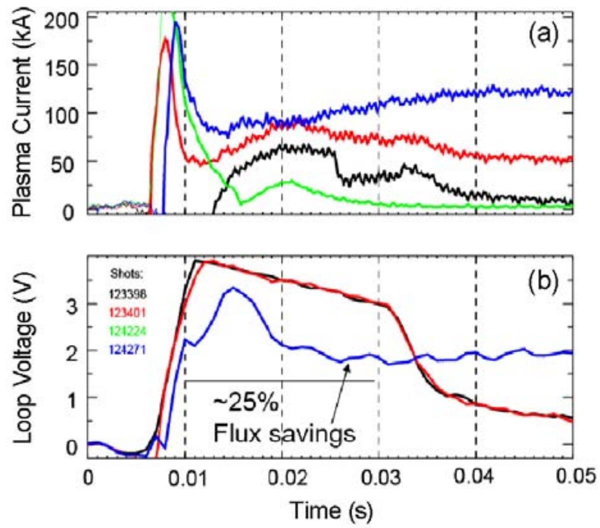


Figure 20. Plasma current (a) and loop voltage (b) traces for discharges with and without coupling to induction from the central solenoid.

the magnitude of the poloidal field in the upper divertor region so that most of the field lines are toroidal. The toroidal-field line structure increases the impedance for the current to bridge the absorber gap thereby reducing or eliminating it as shown on the smaller HIT-II concept exploration device at the University of Washington.

In another experiment, the CHI-produced current was further driven using induction from the central solenoid. This is shown in Figure 20. The green trace shows plasma current from a CHI-produced discharge. In the discharges shown in red and blue, during the decay phase of the CHI-produced toroidal current, loop voltage is applied using the central solenoid with zero initial precharge. When compared to the discharge shown in green, the plasma current is sustained and in the blue discharge ramps up, demonstrating coupling of a CHI-produced discharge to induction. Even though the applied loop voltage is lower for the discharge shown in blue, the coupling is improved. This is because of improved wall conditions for discharge 124271, which was conducted after a vessel boronization. For comparison, an inductive-only discharge is shown by the black trace. The current here is very low as NSTX researchers have not devoted time to developing scenarios that start with zero precharge in the central solenoid. Future experiments will improve on these results by improving the divertor surface conditions and using a precharged central solenoid to ramp the resulting current too much higher levels.

Beta Scaling of Confinement

Because of the low toroidal magnetic field in NSTX plasmas, the range of accessible toroidal beta is typically a factor of five greater than that in conventional-aspect-ratio tokamaks. This large range of beta potentially allows for high leverage in determining the scaling of confinement with this parameter, an important issue for the performance of the advanced operating scenario in ITER. The results of a power/beta scan at constant safety factor and toroidal magnetic field in strongly shaped plasmas ($\kappa \sim 2.1$, $\delta \sim 0.6$) are shown in Figure 21(a). In this scan, density was adjusted so that the variation in collisionality and normalized gyroradius was kept constant to within 20% across the scan. Only small edge-localized modes were present in the discharges in this scan. The beta scaling of both total and thermal confinement resulting from this scan is seen to be quite weak, if not zero.

Results from other devices suggest that plasma shaping can play an important role in the beta scaling, and to test this effect, the scan in Figure 21(a) was redone in more weakly shaped plasmas ($\kappa \sim 1.8$, $\delta \sim 0.4$). Unlike the strongly shaped plasma scan, the nature of the edge-localized modes seen in the weaker-shaped plasmas changed from Type III to Type I, with power losses from 2 to 5%, as the power increased from the 2-MW level up to the 4-MW level and beyond. There is, however, a clear degradation of confinement with increasing beta in this case, as is shown in Figure 21(b), where the total confinement time is plotted against the total toroidal beta (fast-ion component included), along with a fit to the data. Time periods, during which Type III ELMs were present, just after the L- to H-mode transition, were not included in this plot as the discharges were still evolving. This result points to the importance of the stability of the edge, which in our case manifests as a variation in edge-localized mode severity, for controlling the magnitude of the scaling of confinement with beta.

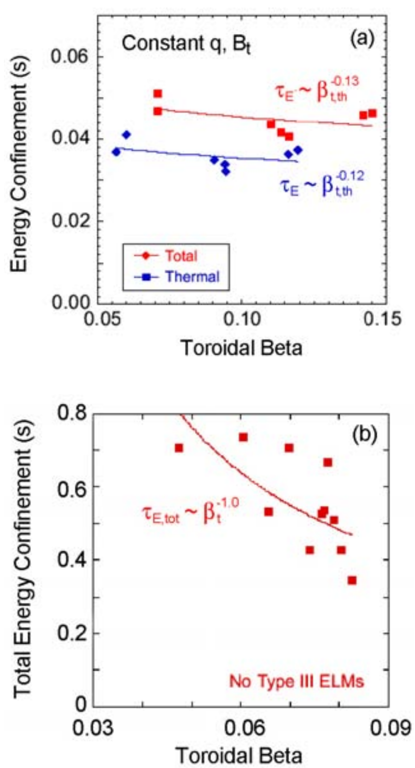


Figure 21. (a) Energy confinement (τ_E) dependence on toroidal beta β_t for strongly shaped plasmas with $\kappa \sim 2.1$ and $\delta \sim 0.6$, and (b) for more weakly shaped plasmas with $\kappa = 1.8$ and $\delta = 0.4$.

Momentum Confinement and Rotation

Rotation physics and the effect of rotation on transport is of particular importance in NSTX due to the relatively high-rotation velocities, with central rotation speeds reaching 300 km/s, and due to strong **E** × **B** shearing rates, in the 0.1 to 1-MHz range. Indeed, as to the **E** × **B** shearing rate, it is the magnitude of this rate, in addition to geometric effects, that is partly responsible for the believed suppression of long-wavelength ion temperature gradient and possibly trapped-electron modes.

An interesting question arises as to the source and scaling of the momentum diffusivity if these long wavelength modes are indeed suppressed. In conventional-aspect-ratio tokamaks, the momentum diffusivity generally scales with the ion thermal diffusivity and the magnitudes of the two are within a factor of a few. In NSTX, with the low-k modes suppressed, a different scaling might be expected. In Figure 22, ion thermal diffusivity (χ_i) is plotted as a function of momentum diffusivity (χ_ϕ) at r/a = 0.4, and it is seen that these two parameters do not exhibit a linear relation as in conventional-aspect-ratio tokamaks. The momentum diffusivity is typically a factor of several to a factor of ten, but can be up to a factor of 40, greater than the ion thermal diffusivity.

The low value of the experimental momentum diffusivity is nevertheless greater than the range expected for neoclassical momentum transport, as determined by GTC-NEO code. Further, the momentum diffusivity decreases monotonically with increasing toroidal magnetic field, similar to the scaling of electron thermal diffusivity (χ_e), and thus it appears that momentum diffusivity scales more with the electron thermal diffusivity rather than the ion thermal diffusivity. A more comprehensive study of the momentum trans-

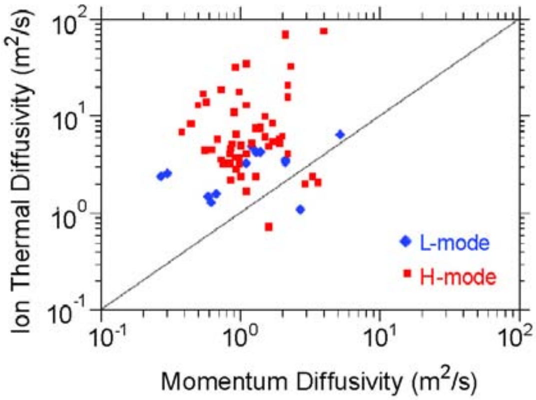


Figure 22. Experimental ion thermal diffusivity plotted against momentum diffusivity for low-confinement (L-mode, blue) and high-confinement (H-mode, red) modes.

port physics is based on results from dedicated scans that use applied n = 3 fields to magnetically brake the plasma rotation. Both perturbative and steady-state power balance determinations of the momentum confinement time (τ_ϕ) indicate a momentum confinement time in excess of 150 ms, greater than the energy confinement time by a factor of three, and consistent with the inference of low momentum diffusivity. Further, momentum pinch velocities up to 40 m/s were inferred from these experiments [Figure 23(a)] with the momentum flux due to the pinch being significant as compared to the outward diffusive momentum flux.

The inferred pinch velocities are described well by theories of momentum pinch by Peeters [A.G. Peeters, C. Angioni, and D. Strintzi, "Toroidal Momentum Pinch Velocity due to the Coriolis Drift Effect on Small Scale Instabilities in a Toroidal Plasma," Phys. Rev. Lett. **98** (29 June 2007) Article No. 265003] and Hahm [T.S. Hahm, P.H. Diamond, O.D. Gurcan, and G. Rewoldt, "Nonlinear Gyrokinetic Theory of Toroidal Momentum Pinch," Phys. Plasmas **14**:7 (July 2007) Article No. 072302 (22 pages)].

Lithium Coating of the Plasma-facing Components

In 2005, NSTX researchers began investigating lithium coatings of the plasma-facing components as a method to reduce recycling of the hydrogenic plasma components. This recycling is believed to be responsible for the secular increase in density observed in NSTX high-confinement mode discharges. The increasing density reduces the amount of current driven by the neutral beams and thereby limits the pulse length achievable in NSTX plasmas. Simulations had shown that in order to achieve its ultimate goals for sustaining high-beta plasmas with minimal inductive flux consumption, control of the density rise would be required.

The experiments in 2005 used the Lithium-pellet Injector (LPI) to introduce the lithium into the outboard scrape-off layer of ohmically heated helium plasmas where it was ionized and flowed along field

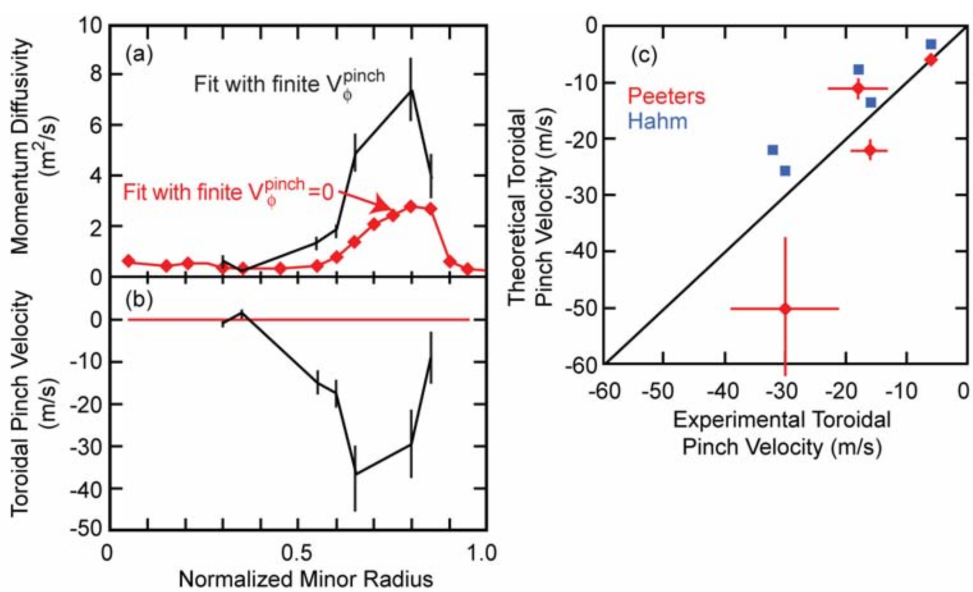


Figure 23. (a) Momentum diffusivity inferred from n = 3 magnetic braking experiment including (black solid) and excluding (red dashed) finite toroidal pinch velocity, (b) pinch velocities assumed for (a), and (c) comparison of theoretically predicted pinch velocities to the experimentally inferred values.

lines to be deposited on the divertor plates near the strike points. This technique produced a dramatic (factor 2) reduction in the density of subsequent deuterium neutral-beam-heated L-mode plasmas run in the same configuration.

The experiments in 2006 used an electrically heated lithium evaporator, dubbed LITER, mounted from a port at the top of the vacuum vessel to coat the lower divertor and center stack with lithium between discharges. Amounts ranging from 14 mg to 4.8 g of lithium were applied between discharges; a total of about 9 g was applied altogether. In these experiments, the reference discharges used to assess the effects of lithium were neutral-beam-heated deuterium H-mode plasmas in a lower single-null divertor configuration. These experiments showed a modest 10 to 15% density decrease after lithium coating late in H-mode discharges without the need for helium-discharge conditioning to "degas" the carbon beforehand. The evaporated lithium coating was observed to have a more pronounced effect on other discharge parameters: in the best cases, the electron and ion temperatures increased by up to 25% and 40% respectively, the global confinement improved by up to 20% and there was a significant reduction in the effective ion charge.

Encouraged by these findings, the evaporator was upgraded for the 2007 experimental campaign. The reservoir and the exit duct were enlarged, the duct was angled to aim at the lower divertor rather than the lower center stack, and more robust radiant electrical heaters were used to permit higher temperatures for faster evaporation. A consequence of these changes was that the thermal time constant of the LITER increased significantly and so it continued evaporating for many minutes after being turned off. It was decided therefore to run the evaporator essentially continuously during the lithium experiments, including during periods of helium glow-discharge cleaning which continued to be used routinely between discharges, and also during the high-power plasma discharges. Experiments using LITER became routine during the latter half of the 2007 NSTX experimental campaign with lithium applied prior to more than 300 plasma discharges. Lithium deposition rates up to about 60 mg per minute were used and the amount of lithium applied prior to a discharge ranged from a few milligrams to more than 2 g. The evaporator was refilled once during the experimental campaign after its initial charge was exhausted. A total of 93 g of lithium was evaporated by the end of the 2007 experiments.

The plasma response to lithium coating in 2007 was somewhat different from that observed in 2006; the differences are possibly the result of the changes in the way that LITER was operated. In reference 1-MA, NBI-heated, deuterium H-mode plasmas, similar to those used for reference in 2006, there was, on average, an increase in the total plasma stored energy of about 12% which was mainly attributable to an increase in the electron stored energy as a result of a broadening of the electron temperature profile. In contrast to the 2006 experience, however, there was almost no reduction in the electron density and essentially no improvement in either the thermal ion temperature or the total thermal ion energy. Figure 24 shows both the total and the electron-stored energy for the groups of reference discharges run without and with lithium application. While considerable variability is evident, it is clear that all of the best discharges in terms of confinement, benefited from lithium. Figure 25 shows the electron density and temperature profiles for two of the best plasma discharges without and with lithium and also shows the electron thermal diffusivity calculated by the analysis code TRANSP. There is a clear decrease in the thermal diffusivity in the outer region of the plasma as a result of lithium coating.

After lithium was introduced, an increase in the helium level was observed in the plasmas that were nominally fueled only by deuterium gas puffing and the deuterium neutral-beam injection. This increase in helium is attributed to the continued lithium deposition during the helium glow-discharge cleaning which may have trapped helium in interstitial voids, as has been observed in laboratory experiments. The helium

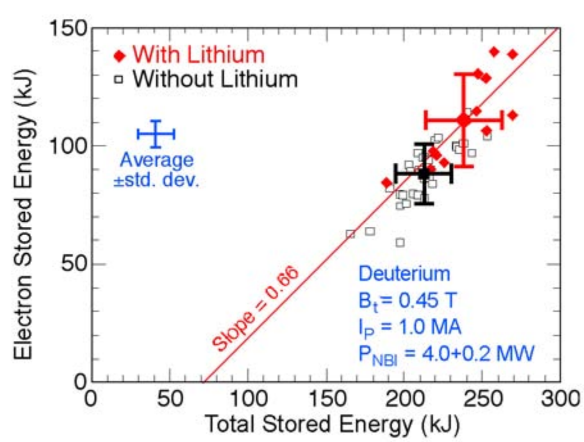


Figure 24. Electron stored energy and total energy for the groups of reference discharges run in 2007 without (open black squares) and with lithium coating (red diamonds).

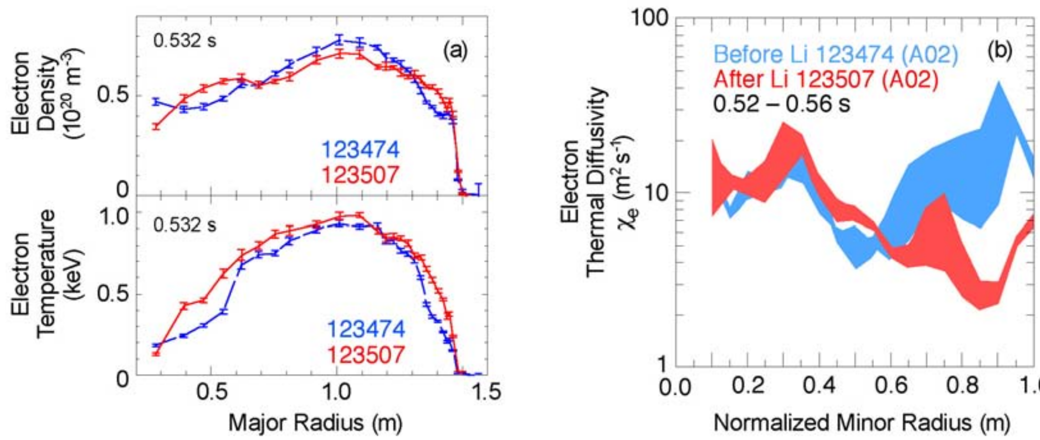


Figure 25. (a) Electron density and temperature profiles versus major radius R as measured by Thomson scattering for two similar discharges with (red) and without (blue) lithium wall conditioning. (b) Electron thermal diffusivity (χ_e) profiles inferred by the analysis code TRANSP for the same discharges versus the normalized minor radius (r/a).

was then released when the lithium surface was heated by plasma contact and became incorporated in the plasma. This helium content may have masked the expected reduction in the deuterium density by the lithium and adversely affected the ion confinement.

The lithium coating produced significant changes in the nature and frequency of edge-localized modes during the H-mode phases. Figure 26 shows an example of a reduction in frequency of the edge-localized modes, which appear as “spikes” in the level of D_α emission from the plasma edge, following lithium deposition; there is an extended edge-localized-mode-free period from 0.45 to 0.8 s. In addition to the

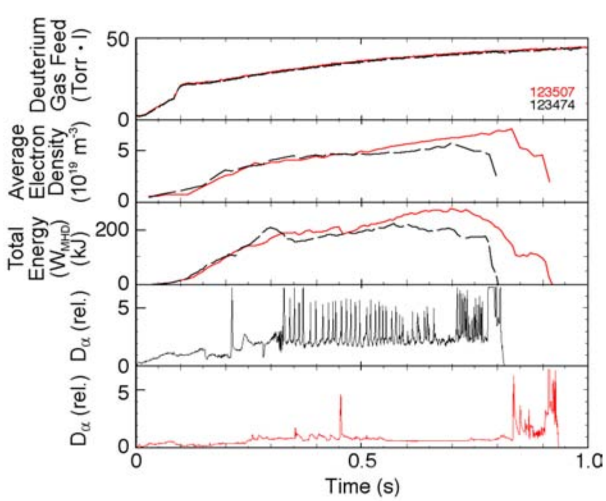


Figure 26. Comparison of similar plasma discharges with (123507, red curve) and without (123474, black curve) lithium coating showing its effect on the nature and frequency of edge-localized modes (shown as spikes in the level of D_α emission from the plasma edge).

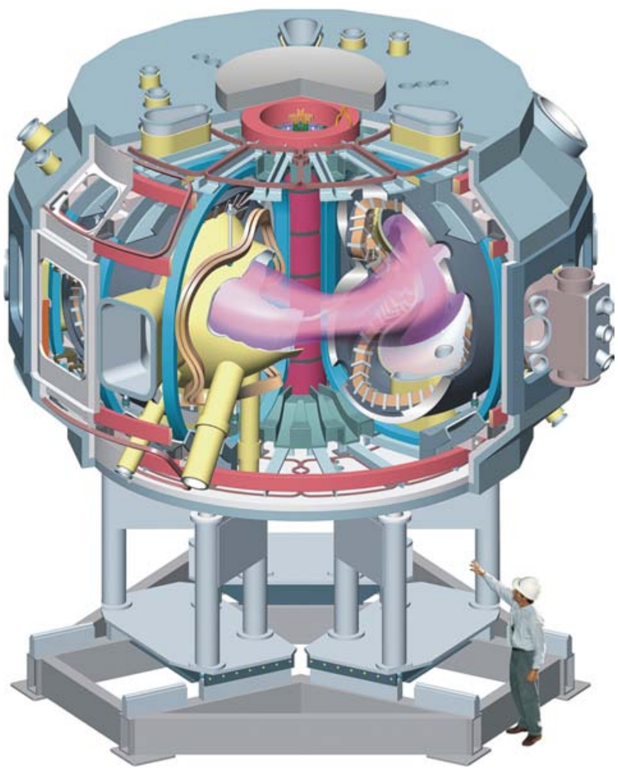
reduction in the edge D_α emission, the levels of carbon (CII), and oxygen (OII) radiation from the edge decreased.

Through the 2007 experimental campaign, some discharges with high-power neutral-beam-injection heating developed high, centrally peaked profiles of radiated power late in the discharge. Such discharges had occurred before the start of the lithium experiments, but it appeared that their frequency increased after the introduction lithium. Spectroscopy revealed the presence of metals, including constituents of (a) stainless steel, (b) titanium and molybdenum, and (c) boron and nitrogen, suggesting a significant interaction of the plasma with the HHFW antenna where all these elements are present in the antenna structure. While the plasma surface was no closer to the antenna than in previous operation, it is possible that a combination of higher plasma temperature at the edge and a reduction in the density of neutral hydrogen surrounding the plasma produced by the lithium increased sputtering by the plasma from the antenna and other nearby surfaces.

In addition to the experiments with LITER, the injection of lithium powder into the plasma was investigated for coating the plasma-facing surfaces. The lithium powder is a newly available commercial product in which the active surface of the lithium grains is stabilized by a very thin inert coating. This experiment used a special elongated sabot in the Lithium-pellet Injector to deliver the powder at low velocity, ~5 m/s, so that it vaporized in the scrape-off layer and was transported to the divertor plates. The amount of lithium reaching the plasma from the injector was estimated to be between 5 and 50 mg per discharge. Benefits similar to those previously seen with solid lithium-pellet injection, including an increase in central electron temperature and reductions in density and radiated power, were observed on discharges immediately following the powder injection.

Return to Table of Contents

National Compact Stellarator Experiment



National Compact Stellarator Experiment

The National Compact Stellarator Experiment (NCSX) is a new magnetic confinement fusion experiment, currently being constructed at the Princeton Plasma Physics Laboratory (PPPL) in partnership with the Oak Ridge National Laboratory (ORNL). It will be used to acquire physics data needed to evaluate the compact stellarator as a fusion concept and to advance the physics understanding of 3-D plasmas for fusion and basic science. In addition, NCSX construction activities make important contributions to fusion technology, such as in the application of advanced metrology techniques in achieving dimensional tolerances of ±0.5 mm or less in the manufacture of NCSX coils and subassemblies.

Among the family of toroidal magnetic plasma configurations, stellarators are of interest because they solve important problems for fusion energy — achieving steady-state operation and avoiding plasma disruptions. Stellarators have unique flexibility to resolve scientific issues, for example the effects of 3-D plasma shaping and of strong external control on confinement, that are important to all magnetic configurations.

The compact stellarator shares the attractive properties of existing stellarators but has the additional advantages of a lower aspect ratio (closer to tokamaks) and a quasi-symmetric magnetic field structure. In a quasi-*axi*symmetric stellarator (QAS) like NCSX, the charged-particle trajectories and plasma flow damping are similar to those of its axisymmetric relative, the tokamak, so a QAS is expected to share the tokamak's good confinement performance.

This physics link with tokamaks means compact stellarators can advance rapidly and economically, building on advances in the more mature tokamak concept, including the expected future advances in burning plasma physics and technology from ITER.

NCSX Design Innovations

The compact stellarator is a result of large advances in plasma physics understanding and computation that have occurred in recent years. The NCSX was designed by performing computer simulations of hundreds of thousands of plasma configurations to optimize the physics properties: stability at high beta, degree of quasi-axisymmetry, quality of magnetic surfaces, and aspect ratio. Algorithms based on free-boundary stellarator equilibrium codes were used to optimize the coil geometry, targeting the desired physics properties while satisfying coil feasibility constraints to ensure a practical design. Research on NCSX will test this modern approach to experiment design.

The NCSX will operate at high beta (4%). The plasma is designed to have an aspect ratio of 4.4; to have a quasi-axisymmetric magnetic field with an effective ripple less than 1.5%; to be MHD stable without active feedback control, current drive, or rotation drive; and to have good magnetic surfaces. The magnet system consists of eighteen modular coils, six each of three different shapes (Figure 1), plus toroidal-field coils, poloidal-field coils, and helical-field trim coils. These coils generate the 3-D magnetic fields required to realize the target physics properties and provide the flexibility needed to vary the plasma configuration and test physics understanding. The device size (major radius R = 1.4 m), magnetic field range (B = 1.2–2.0 Tesla), pulse length (0.3–1.2 s), and planned plasma heating power (up to 12 MW) were chosen to produce the plasma conditions and profiles needed to test critical physics issues over a range of beta and collisionality values. The NCSX machine was designed on the basis of this configuration and these parameters and is now well into construction.

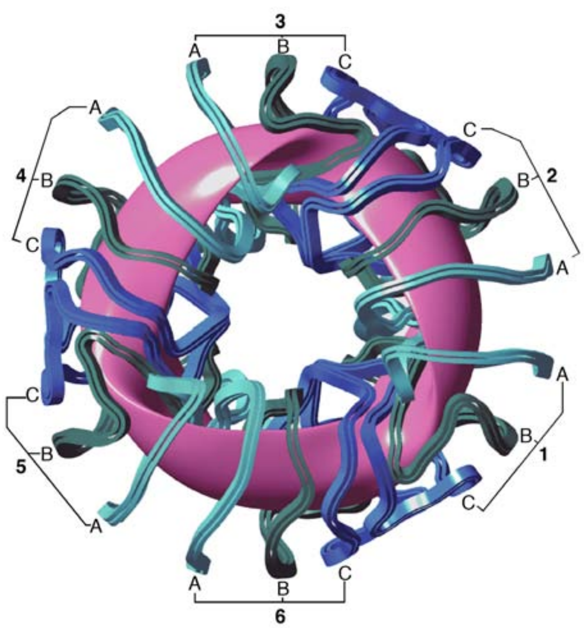


Figure 1. NCSX plasma and modular coils.

NCSX Construction Progress

The last of the three vacuum vessel subassemblies was delivered to PPPL in September 2006. In FY07, production of major device components continued, particularly the modular coils and toroidal-field coils, and assembly activities began.

Modular Coils

Each modular coil is wound on the interior of a cast and machined stainless steel ring-like structure called a modular coil winding form (MCWF), as shown in Figure 2. A flexible copper cable conductor is used to facilitate handling and placement on the form. After winding, the conductor bundle is measured using a coordinate measuring arm to achieve the necessary precision (0.1 mm). The engineering staff analyses metrology data to determine the set of bundle adjustments needed to position the current center with the required ±0.5-mm accuracy. After the winding team makes these adjustments, the completed winding pack assembly, consisting of conductor, insulation, copper cooling strips, and cooling

Figure 2. Winding of an NCSX modular coil on the Modular Coil Winding Form (WCWF) at the Princeton Plasma Physics Laboratory.

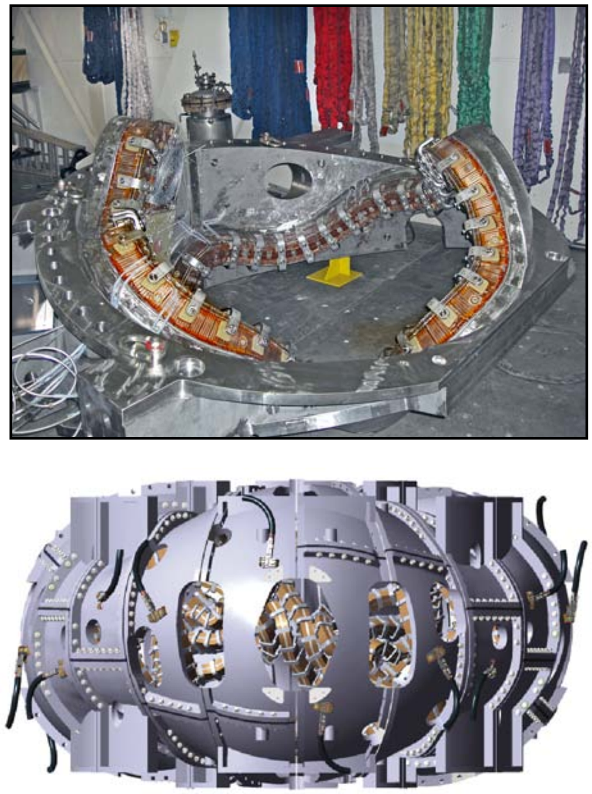


Figure 3. (Top) Completed NCSX modular coil. (Bottom) Completed toroidal structure shell.

tubes, is epoxy encapsulated to secure the dimensions and provide structural rigidity. A completed coil is shown in Figure 3 (top).

When fully assembled, the eighteen coils will be joined at mating flanges to form a toroidal structural shell, as shown in Figure 3 (bottom). Shims will be installed at each joint to control the inter-coil spacing and locate the windings within ±1.5 mm of their nominal positions in the completed device. The joints will be secured with high-strength bolts outboard and structural welds inboard to produce a rigid structure that essentially eliminates coil deflections under operating loads.

In FY07, the last nine modular coil winding forms were delivered to PPPL, completing the Project's largest industrial fabrication subcontract. The MCWF suppliers, Energy Industries of Ohio, Inc. and their machining partner Major Tool and Machine, Inc., overcame manufacturing challenges to establish a reliable delivery schedule. The last fourteen winding forms were delivered according to that schedule, with all technical requirements met.

At PPPL, modular coil winding operations proceeded smoothly throughout FY07. Nine coils were wound and epoxy-impregnated, bringing the total completed by the end of the year to fourteen. All coils were fabricated within their tolerance, except for acceptable deviations over less than 10% of the circumference, and passed electrical and pressure tests.

Toroidal-field Coils

The NCSX machine includes an array of eighteen planar toroidal-field (TF) coils to provide experimental flexibility. The inner legs, which must be positioned to an accuracy of ±3 mm to reduce field errors, are supported by wedging. The wound coils are epoxy impregnated and assembled to steel wedge support pieces cast from a low-permeability ($\mu < 1.02\mu_0$) alloy and machined to near-final dimensions. The wedge faces are machined after assembly to ensure the accuracy of the final dimensions.

In FY06 a contract was awarded to Everson Tesla, Inc. of Nazareth, PA, to supply the TF coil assemblies. Tooling preparations and material purchases began in FY06 and continued through the first several months of FY07. Though much less complex than the modular coils, the TF coils nonetheless presented some manufacturing challenges due to the tight tolerances (±3 mm) on their D-shape and to wedge fabrication and assembly issues. Additional tooling had to be fabricated in order to maintain the shape throughout the manufacturing process. Although this resulted in delivery delays, there was no impact on the Project schedule since the TF coils are well off the critical path. By the end of FY07, two coils were delivered to PPPL, with four more in production and a smooth production process established. A completed coil assembly is shown undergoing final acceptance testing in Figure 4.

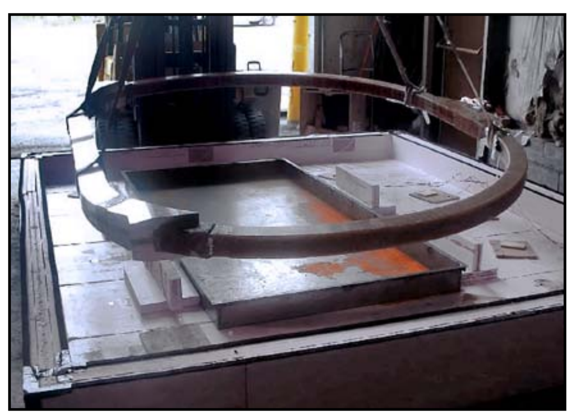


Figure 4. Completed NCSX toroidal-field coil undergoing final cryogenic acceptance testing at Everson Tesla, Inc.

Field-period Assembly

The NCSX device is to be assembled in three toroidal sectors called field periods (Figure 5), which will then be joined to form a complete torus. Each field period includes a vacuum vessel sector, two modular coil half-periods (3 coils each), and six toroidal field coils. The field periods are assembled in a series of subassembly stages.

In assembly Stage 1, the three vacuum vessel sectors were outfitted with magnetic diagnostic loops, heating and cooling hoses, heater tapes, and thermocouples installed on the exterior of the vessel shell and ports. A completed vacuum vessel sector is shown in Figure 6. Stage 1 activities proceeded smoothly and well off the critical path throughout the year. All major Stage 1 installation tasks were completed in FY07.

The Project's stellarator design team worked in FY07 to address challenging coil interface requirements, namely to accurately position the coil windings relative to their nominal design and maintain that accuracy in the presence of complex operational loads. In addition, insulating breaks are needed in certain places to inhibit long-lived eddy currents. Design and supporting R&D efforts led to practical solutions.

The design is basically a bolted connection, with compact in-situ tensioners ("Supernuts") used to preload the bolts. Intercoil spacing is controlled by custom-thickness shims, with an alumina coating applied to enhance friction and provide insulation.

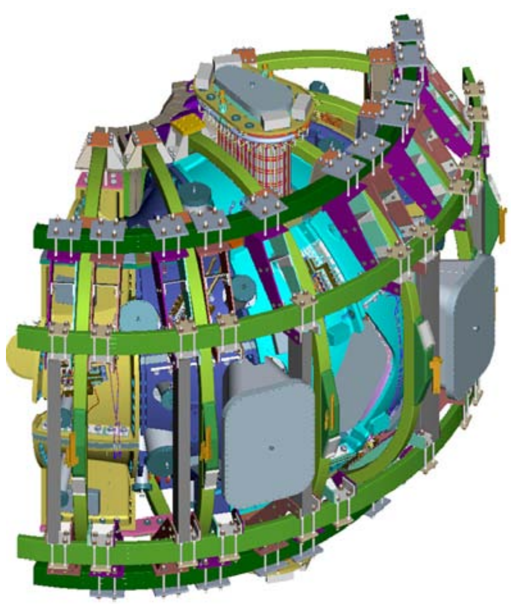


Figure 5. One of three toroidal sectors called field-periods that will be joined to form a complete torus.

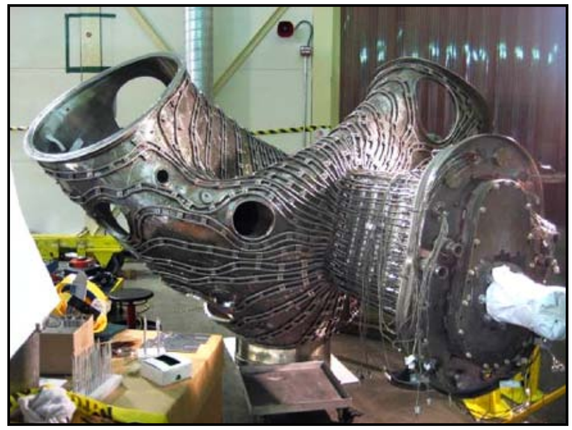


Figure 6. NCSX vacuum vessel sector with services installed.

In in-board regions where there is insufficient space or access for bolts, a welded connection is used. The risk of distortion during welding operations was reduced by careful design and choice of weld technique. A design satisfying all requirements was presented at a series of successful design reviews in late FY07. Parts procurement was initiated in preparation for assembly Stage 2, half-period assembly, to begin in FY08.

Cost and Schedule Reestimating

Reestimating the cost and schedule to complete NCSX construction was a major focus for the Project team throughout FY07. The Project began a bottom-up estimating activity in January 2007, following the recommendations of a U.S. Department of Energy Office of Science Project Review in December 2006. Cost account managers thoroughly analyzed and estimated all of the remaining work. Each job was assigned an uncertainty range based on the job's design maturity and complexity. All estimates went through an internal review process, chaired by the PPPL Head of Engineering, to ensure that all work was identified, analyzed, and realistically estimated. A probabilistic approach was used to estimate cost and schedule contingencies, using the job estimate uncertainty ranges and potential risk impacts as inputs to Monte Carlo simulations. A series of reviews was conducted by Princeton University as part of the estimating process, providing an independent perspective and feedback from outside experts. The proposed new baseline was judged to be achievable by a U.S. Department of Energy Office of Science "Lehman" Review Committee in August 2007.

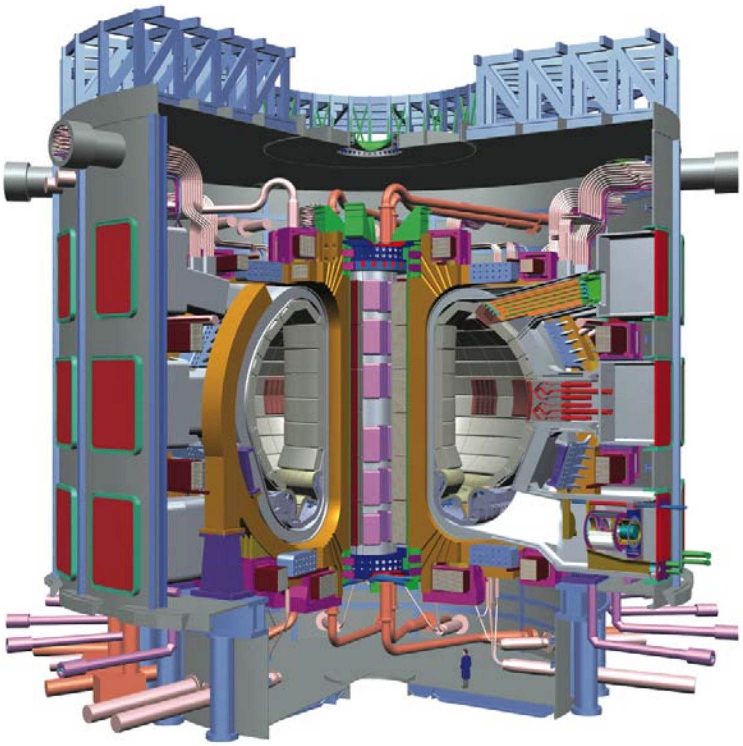
Summary

In FY07, the third year of NCSX construction, the Project continued to make good progress in component production. The highlight in that area was the delivery of the last modular coil winding form, completing a major technical achievement by the Project and its suppliers. Assembly activities began in FY07 and the first stage, the installation of vacuum vessel services, was completed. Modular coil interface design proved to be more challenging and take more time than expected due to the combination of tight tolerances and demanding structural requirements. However, following a concerted engineering design and R&D effort, a robust interface design solution was developed. As a result, the second assembly stage, the modular coil half-period assembly, will proceed in 2008.

The Project also completed a thorough reestimate of the cost and schedule to complete NCSX. The experience gained in component design and fabrication provided an improved understanding of the technical issues and hence an improved technical basis for estimating the remaining work. Improvements were also made in estimating methodology.

Return to Table of Contents

ITER Project Contributions



ITER

On the international front, the ITER Agreement will likely be ratified in early FY08, formally establishing the Project as a legal entity, and committing the seven ITER parties to contribute their full shares to the construction. The international ITER Design Review will be concluded about the same time, and remaining technical issues brought into focus.

Here in the U.S., during FY07, the ITER team continued to grow in capability and effectiveness, the integrated schedule and cost estimates for development of U.S. contributions matured, the technical work transitioned to greater engagement of industry, and the U.S. fusion community applied its understandings to ITER's outstanding scientific issues.

Strongly supporting ITER as a Partner Laboratory in the U.S. ITER Project with the Oak Ridge National Laboratory (ORNL), the Princeton Plasma Physics Laboratory (PPPL) has the lead role for providing in-kind contributions in diagnostics and in the steady-state electric power network (SSEPN). In FY07 PPPL played a strong supporting role as well in the magnet area and in providing secondees. As part of the ITER Design Review, many members of PPPL's research and engineering staffs contributed to various Working Groups assessing the ITER design and proposing some important changes to the design.

Steady-state Electric Power Network

The SSEPN is the network supplying conventional (non-pulsed) loads for the ITER complex. The design for this network is being done in Europe. The U.S. role is to procure major network components like transformers, switch gear, and distributions centers. In FY07, the Work Breakdown Structure (WBS) Manager for this work, C. Neumeyer, was involved in drafting specifications for this system, in selection of software tools for the design, and in monitoring the design activities. He updated cost and schedule estimates for this work. In addition, he advised the ITER Organization in planning for the ITER pulsed-power systems.

Diagnostics

The U.S. is responsible for providing five diagnostic port plugs for ITER and seven diagnostic systems. The plugs are large steel structures that house the diagnostics while at the same time providing radiation shielding. Six of the diagnostic systems include front-end signal-collection components housed in the port plugs. These components and their access routes through the shielding in the plugs require custom design and R&D. Diagnostics also include components to transmit the signals through the bio-shield to the diagnostic hall, where custom-designed source and detector hardware will be located.

The port plug design and the integration of the front-end components into the plugs were begun in FY07 by a team of PPPL engineers and design draftsmen. D. Loesser, the lead engineer, participated in a meeting of the Port Engineering Task Force in Cadarache and in a Japanese-Korean Workshop on Port Plug Engineering, where he presented the U.S. approaches to port plug design issues. One of these approaches uses radially removable cassettes for each diagnostic within a plug. Figure 1 shows this concept for one of the U.S. equatorial plugs.

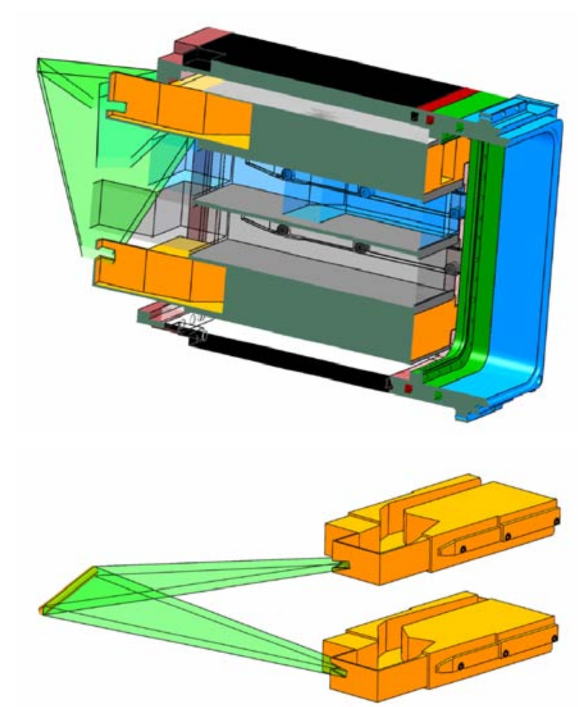


Figure 1. ITER equatorial port plug with radially removable diagnostic shield cassettes.

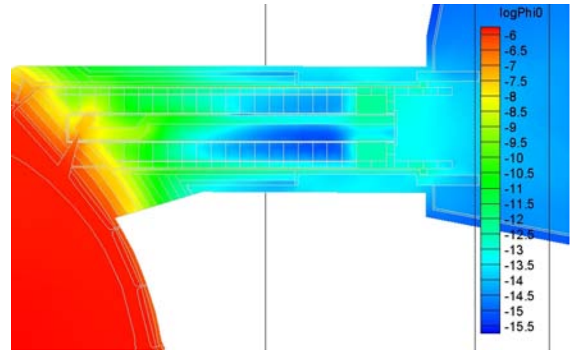


Figure 2. Contour plot of neutron streaming in an ITER diagnostic upper port plug with an endoscopic viewing system.

An important part of this design work is neutronics analysis, to demonstrate the adequacy of the radiation shielding. During FY07, PPPL engineer R. Feder worked with the University of California -Los Angeles (UCLA) collaborators to benchmark a commercial neutronics code, ATTILA, for this purpose. They were successful in gaining ITER approval for this code. PPPL hosted a three-day neutronics workshop in August, with participation by several experts from the U.S., the European Union, and the ITER Organization. Figure 2 shows the computed neutron flux in a diagnostic upper port plug housing an endoscopic viewing system.

The WBS Manager in Diagnostics, D. Johnson, oversaw the procurement of a number of design assessment and costing studies for the U.S. ITER diagnostics. The reports from the first phase of design studies, which focused on defining the front-end configurations, were presented at a U.S. Burning Plasma Organization Workshop at General Atomics in early March 2007, and at an International Tokamak Physics Activity Diagnostics meeting at PPPL in April 2007. Procurement of a second set of design studies also started in FY07. Table 1 shows the status of these contracts and the U.S. institutions involved at the end of FY07.

In order to more clearly define the scope in the diagnostic area, the U.S. successfully requested an ITER Diagnostics Design Review as part of the ITER Design Review process. E. Marmar (Massachusetts Institute of Technology, MIT) chaired the review committee with D. Johnson serving as the other U.S. delegate. B. Stratton and D. Johnson worked with members of the ITER Organization Diagnostics Division through the summer of 2007 to draft one of six ITER Organization/U.S. Procurement Arrangements in the diagnostics area. The ITER Department at PPPL also worked with a scheduling consultant to develop

Table 1. U.S. Involvement in ITER Diagnostics in Fiscal Year 2007.

Package	Design/R&D Task Summary	Institutions	Phase 1			Phase 2		
			Cost	Design	R&D	Cost	Design	R&D
Upper Visible/IR Camera	Assess Optical Design, Central Tube Concept	LLNL		C		C	O	
LFS Reflectometer	Determine Optimum Frequency Bands and Polarizations	UCLA		C				
LFS Reflectometer		ORNL	C					
Motional Stark Effect	Assess Usefulness of |B| Determination	NOVA			C	C		O
Motional Stark Effect	Performance Simulation of Conventional Polarimetry Approach	PPPL		C				
Motional Stark Effect	Optimization of Optical Design	LLNL		C		C	O	
Electron Cyclotron Emission	Investigate Nonthermal Issues, Use of Oblique View	PPPL			C			
Electron Cyclotron Emission	Review Reference Design, Hot Source R&D	Univ Texas/Univ Maryland/MIT		C				O
Electron Cyclotron Emission		ORNL	C					
Divertor Interferometer	Develop Conceptual Design	UCLA/GA		C		C		
Tangential Interferometer/ Polarimeter	Optimize Reference Design	GA/UCLA		C		C		
RGA	Develop Conceptual Design	ORNL		C		C		
Neutronics Analysis	Develop Neutronics Models for Plug Integration using ATTILA Code	UCLA			C			O
First Mirror R&D	Model Erosion/Deposition on First Mirrors	ANL			C			O

C = Complete, O = Ongoing

a Primavera schedule for the U.S. diagnostics. This scheduler subsequently worked with the ITER Organization to develop such a schedule for the full ITER diagnostics set.

Magnet Support

During FY07, PPPL engineers P. Heitzenroeder and R. Simmons were part of the expert team supporting U.S. ITER Project Office Magnet WBS Manager J. Miller. They contributed to the development of the overall U.S. strategy in this area. They developed a research plan to address the issue of toroidal-field conductor degradation, under cyclic load, which was reported by the European Union early in FY07. They completed several Statements of Work to support this plan, which were used by the U.S. ITER Project Office to procure a tube mill, cable variants, perforated cooling tubing and jacket tubing. PPPL took delivery of the tube mill at the end of FY07 and is planning to use it to produce short toroidal-field conductor sample lengths in early FY08. Figure 3 shows the tube mill in its location in the C-site MG area.

Secondees

Until mid-FY07, PPPL administrator S. Schoen handled secondee arrangements for the U.S. ITER Project Office, and had up to four contracts for experts residing in Cadarache working for the ITER Organization In July, engineer Chang Jun became the first PPPL ITER secondee, and moved his family to France. Jun is responsible for structural analysis of the ITER vacuum vessel.

Design Review Working Group Support

The ITER Design Review effort was organized around Working Groups. R. Hawryluk was active in the Physics Requirements Working Group. C. Neumeyer worked on the Buildings Working Group. J. Hosea and L. Grisham served on the Heating and Current Drive Working Group. C. Skinner and D. Johnson worked on the In-Vessel Components Working Group.

Figure 3. Tube mill for jacketing ITER toroidal-field conductor (installed in the PPPL C-site MG area).

Those listed above typically participated in numerous teleconferences, one to three meetings in Cadarache, and hundreds of email communications to carry out their reviews, which resulted in reports. In some cases, Design Change Requests (DCRs) were produced. If the ITER Organization approved these requests for study, and if subsequent proposals for particular party experts for supporting work were funded by the U.S. ITER Project Office, specific tasks were undertaken by members of the fusion community. Approximately 15 PPPL researchers contributed to these activities.

There are numerous examples of significant contributions from this PPPL involvement, most leading to Design Change Requests. C. Kessel looked at the poloidal-field coil capabilities to control the plasma shape and vertical stability. R. Hawryluk coordinated activities related to edge-localized mode (ELM) control and disruption mitigation. L. Grisham advocated for increasing the size of the ducts and apertures for the heating neutral beams and the diagnostic neutral beam. C. Neumeyer made recommendations concerning stray magnetic fields, the presence of ferromagnetic structural materials in the buildings, and electrical isolation. C. Skinner promoted the need to develop credible strategies to control dust and tritium accumulation in the ITER vessel.

In the case of a Design Change Request associated with the addition of in-vessel coils to control edge-localized modes and resistive wall modes, PPPL port engineering lead D. Loesser and his design team were requested by the ITER Organization to investigate the engineering feasibility of such coils. At the end of FY07, they submitted a report with design concepts and cost estimates. Figure 4 shows one of these options, which locates the coils between the first-wall shield module and the inside of the vacuum vessel.

Finally, PPPL Director R. Goldston served on the Science and Technology Advisory Committee, reporting to the ITER Council. This committee met at the end of FY07 to review the progress of the ITER Design Review and advise the ITER Council of issues requiring further focused attention.

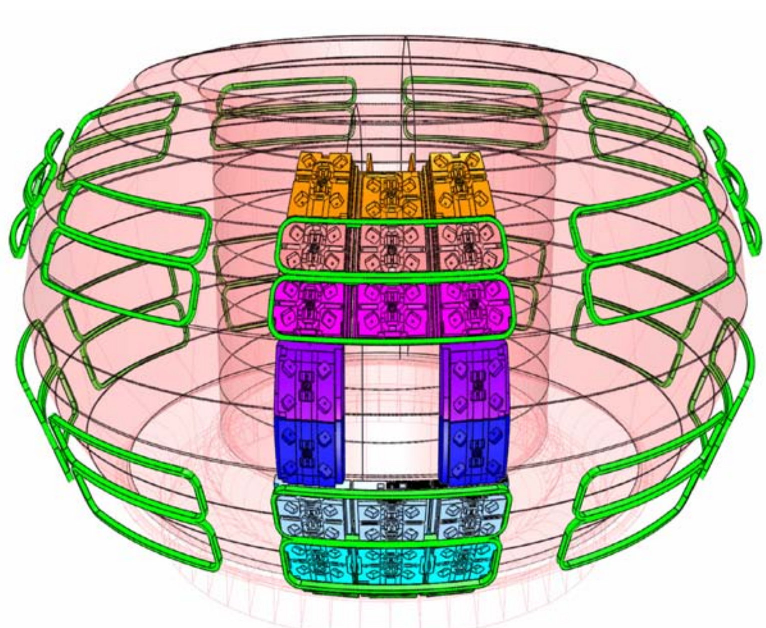


Figure 4. CAD model showing one of several options for locating the ITER ELM-control coils, shown in green. This option places them between the first-wall blanket modules and the vacuum vessel.

Return to Table of Contents

Theory and Advanced Simulations

The Theory Department at the Princeton Plasma Physics Laboratory (PPPL) plays a major role in advancing fusion science through the study of a variety of topical areas. These include: magnetohydrodynamics (MHD), turbulent transport, energetic particles' interaction with MHD, and boundary physics. The methods used include analytical theory and numerical codes that are applied to advancing the understanding of tokamaks, spherical torii, and stellarators. The goal is to achieve predictive capability, relevant to future devices, which might be used as energy sources. In addition to the study of magnetic confinement, the Department also engages in research in heavy ion and space plasma physics.

In FY07, the PPPL Theory Department researchers published 78 scientific and technical papers in refereed journals. Of these, six were Physics Review Letters. Theory team members also presented 47 invited scientific and technical papers at major conferences including the American Physical Society Division of Plasma Physics and the U.S. Department of Energy's (DOE) Office of Science's Scientific Discovery through Advanced Computing Program (SciDAC) conferences.

Progress was made on several fronts, key topics include: chaotic magnetic fields; kinetic stabilization of toroidal mode numbers $n < 3$ MHD instabilities; momentum transport; turbulence spreading; energetic particle-driven modes, including the discovery of new modes and validation from experiment; transport in stellarators; novel feedback techniques for vertical displacement; support for the National Compact Stellarator Experiment (NCSX), the National Spherical Torus Experiment (NSTX), the Lithium Tokamak Experiment (LTX), and the Current Drive Experiment-Upgrade (CDX-U) at PPPL, as well as for devices at other institutions. These are described in the following sections.

In FY07, all of the milestones for the theory of tokamaks and alternates, advanced computing, and SciDACs were achieved. These included a U.S. Department of Energy high-level National JOULE Milestone to improve the simulation resolution of the linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal mode numbers used from one to 15.

Magnetohydrodynamics

Sawtooth Modeling with M3D

As part of the SciDAC Center for Extended MHD Modeling (CEMM), the PPPL M3D code team participated in an ambitious code-benchmarking exercise with the NIMROD code team in which a plasma instability (the sawtooth mode) is allowed to grow from small amplitude and is followed far into the nonlinear regime where it exhibits repetitive cycles. The parameters used were those of a modest-sized tokamak at PPPL, the CDX-U. The time evolutions of the two codes agree in such things as the amount of energy in the different wavelengths (Figure 1), the details of the breakup and reforming of the magnetic surfaces

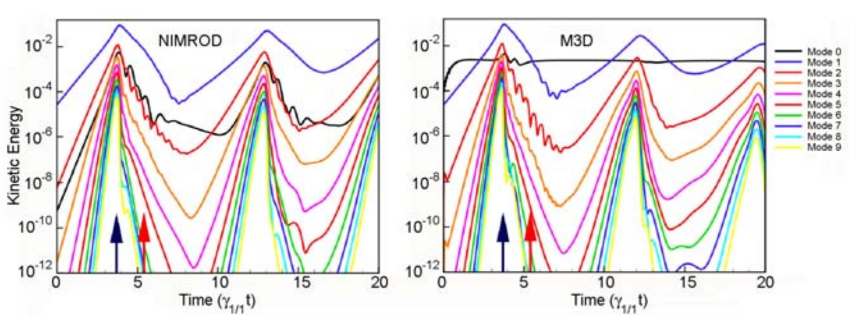


Figure 1. A comparison of NIMROD and M3D code simulations of kinetic energies over multiple sawtooth periods show excellent agreement. The arrows indicate the times at which plots in Figures 2 and 3 are shown.

during the crash phase of the cycle (Figure 2), and the effect of the instability on the plasma temperature distribution during the event (Figure 3). The exercise also led to discoveries that proved valuable in improving the accuracy of both codes — for example, a more conservative current-evolution formulation in M3D and an improved method for recalculating the equilibrium current density during initialization in NIMROD — both of which were necessary for achieving agreement. The differences in the Mode 0 energies in the two codes arises from small differences in the way that the initial axisymmetric equilibrium configuration is represented in the two codes and is not believed to be significant in the nonlinear dynamics.

Thermal Transport in Chaotic Magnetic Fields

Magnetic fields in fusion devices often have stochastic regions, which can significantly affect the cross-field transport. This has implications for phenomena where MHD stability and transport are linked, as with sawteeth and edge-localized modes (ELMs). The PPPL Theory Department made significant advances in FY07 in the understanding and modeling of chaotic fields. In a series of articles, the roles of cantori and chaotic coordinates and their relation to heat transport in tokamaks were discussed.

Figure 4 is an illustration of the construction of cantori, invariant phase space structures that restrict magnetic field line flow in chaotic regions. On the right is the result of solving for the conduction-diffusion of a scalar (e.g., heat) in these chaotic, divergence-free fields. The ghost curves form chaotic coordinates, and in these chaotic coordinates the temperature profile is a smoothed Devil's staircase. This is expected to be a general result for anisotropic scalar transport in chaotic fields. A fast method to model chaotic fields was developed which is now being applied in order to improve the modeling of heat transport during the crash phase of the sawtooth when modeled with the M3D code.

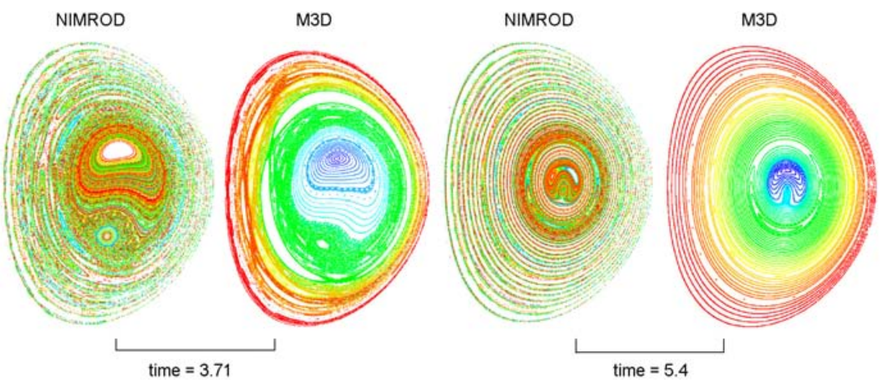


Figure 2. NIMROD (1st and 3rd plots) and M3D (2nd and 4th plots) simulations of Poincaré surface of section at times $\gamma_{1/1}t = 3.71$ (1st and 2nd plots) and $\gamma_{1/1}t = 5.4$ (3rd and 4th plots).

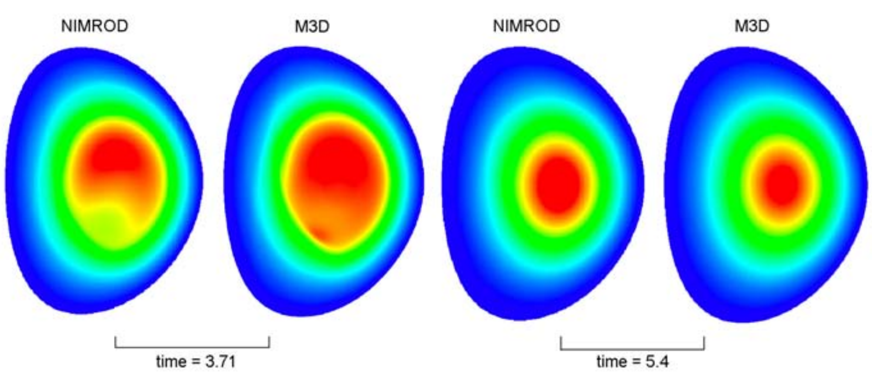


Figure 3. NIMROD (1st and 3rd plots) and M3D (2nd and 4th plots) simulations of temperature contours at the same times as in Figure 2.

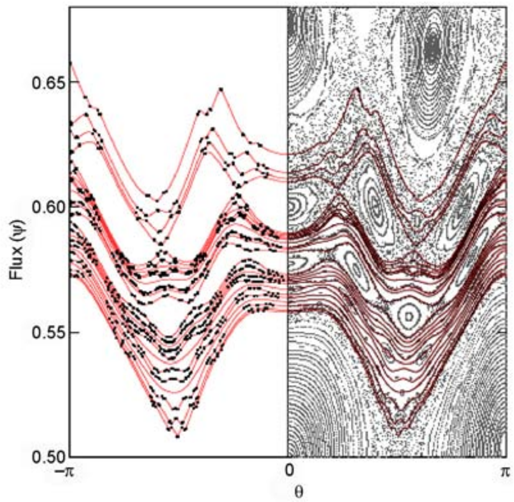


Figure 4. On the left (θ < 0) are shown ghost curves (red lines) and cantori (black square dots) obtained from analyzing the magnetic field structure. On the right is shown Poincaré plot (gray dots), ghost curves (red lines), and the temperature contours (black lines).

Normal Mode Analysis Code

In FY07, the mode deformation analysis in the resistive wall mode (RWM) modeling of ITER using the multi-mode feature of the Normal Mode Analysis (NMA) code was started. The goal is to better understand and optimize the efficiency of the feedback system. Results from the NMA code, developed in collaboration with General Atomics, showing the plasma deformation resulting from magnetic feedback are given in Figure 5. The multi-mode deformation is indicated by the field patterns on an ITER-like plasma surface without feedback (bottom), and in the presence of feedback with only the mid-plane coil (top), and with both the mid-plane and off-mid-plane coils (middle) energized. The helicity can be reversed if the feedback coils are driven sufficiently out of phase with respect to the mode.

Kinetic Effects on Low-n Instabilities

Continuing the work on kinetic effects for low-n modes using a kinetic energy principle and PEST, in conjunction with the University of Rochester, a study of the kinetic stability of the internal kink mode in ITER was completed. The results show complete stabilization of the low-frequency branch for the standard ITER scenarios. However, the high-frequency fishbone-branch may be unstable depending on the beta and radius of the q = 1 surface. Note that this model uses the fluid solution for the unstable eigenfunction.

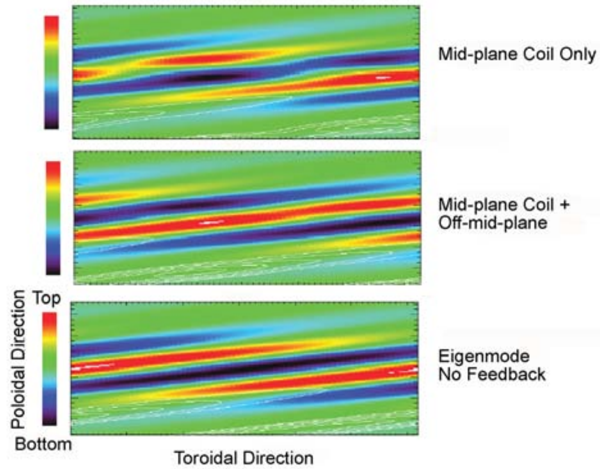


Figure 5. Contours of the normal component of the magnetic field at the plasma surface for different combinations of feedback coils for a modeled ITER equilibrium.

Transport and Turbulence

A novel momentum pinch mechanism was identified, which originates from the symmetry breaking due to magnetic curvature. This analytic prediction is being compared to NSTX results. Studies on the nonlinear interaction between parallel acceleration of the particles and zonal flow generation in turbulence simulations using particle codes were completed and it was found that this type of collisionless dissipation is essential for maintaining the zonal flow damping in the turbulent steady state for ITER-size tokamaks. An accompanied study also showed that profile modification has negligible effect on the amplitude of the steady-state transport in this type of simulation.

Momentum Transport

Significant analytic progress was made in identifying toroidal momentum pinch from the curvature modification of parallel acceleration in the modern nonlinear gyrokinetic equation and elucidation of physics in the context of turbulent equipartition theory. It was shown that mean $\mathbf{E} \times \mathbf{B}$ shear can produce nondiffusive momentum flux, which should be characterized as residual stress rather than a pinch. Its potential role in spontaneous rotation in high-confinement mode (H-mode) plasmas is being studied.

Edge Turbulence

Energy-conserving and phase-space preserving, generalized nonlinear gyrokinetic equations were derived, applicable to edge turbulence with steep gradients in pressure and radial electric field. The differential geometric understanding of the gyrokinetic Vlasov equation derived a few years ago has mature. The generalized and usable form of the gyrokinetic Maxwell equations and energy invariants still remain to be derived.

Turbulence Simulations

The role of **E** × **B** shear flows (both mean flows and turbulence-driven zonal flows) in reducing turbulence spreading was elucidated from GTS simulations. It was shown that the local **E** × **B** shearing rate governs the reduction of spreading speed. A two-field analytic model illustrated that the zonal flows reduce turbulence spreading and internal energy can, in general, spread faster than the kinetic energy.

For the past year, a validation exercise using global gyrokinetic particle simulations was also carried out to investigate both turbulent and neoclassical transport for the fusion experiments in axisysmmetric devices. For example, the results using GTC-NEO, a global PIC simulation code, support the experimental observation that the ion transport is at neoclassical levels in NSTX plasmas. On the other hand, nonlinear turbulence simulations using GTS, a global turbulence simulation code for shaped plasmas, show that ion-temperature-gradient-driven turbulence has significant fluctuation amplitude, but drives insignificant amount of ion-energy transport in NSTX plasmas (about the same as the neoclassical level, sometimes even below it) as shown in Figure 6. This feature is in contrast to the anomalous transport observed in the simulations for the other machines, such as DIII-D, where ion-temperature-gradient turbulence is shown to drive large transport (ten times neoclassical level), even though the mean turbulence fluctuation levels for the two discharges are actually comparable. It is also found that self-consistent neoclassical equilibrium **E** × **B** flows calculated by GTC-NEO can strongly stabilize ion-temperature-gradient modes. For realistic plasma parameters of NSTX and DIII-D, the enhancement of ion-temperature-gradient-driven thermal transport due to ion-ion collisions is insignificant.

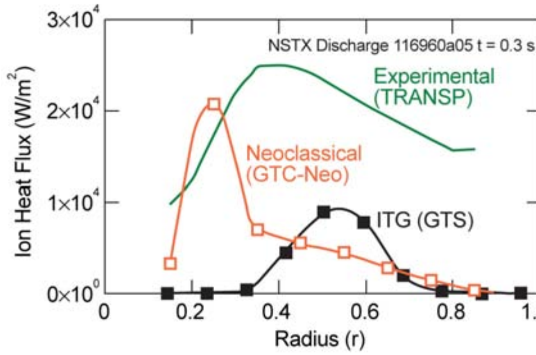


Figure 6. GTS code simulations show that ion-temperature-gradient turbulence-driven ion-thermal transport is about the same as the neoclassical level in NSTX plasmas.

Nonlinear energy coupling in wavenumber space in global gyrokinetic turbulence was also studied. It is found that the nonlinear toroidal couplings are the dominant activities in the wavenumber space for the nonlinear saturation of ion-temperature-gradient modes, which cause energy transfer to the damped longer wavelength modes, forming a downshifted toroidal spectrum in the fully-developed turbulence regime. This toroidal spectral cascade behavior in ion-temperature-gradient dynamics observed in the simulations, as shown in Figure 7, is also qualitatively similar to that found in electron-temperature-gradient dynamics, although there is stronger zonal flow generation during the saturation process in ion-temperature gradients than in that for electron-temperature gradients. The self-generated zonal flows in ion-temperature-gradient turbulence certainly play an important role in determining the fluctuation level, both locally

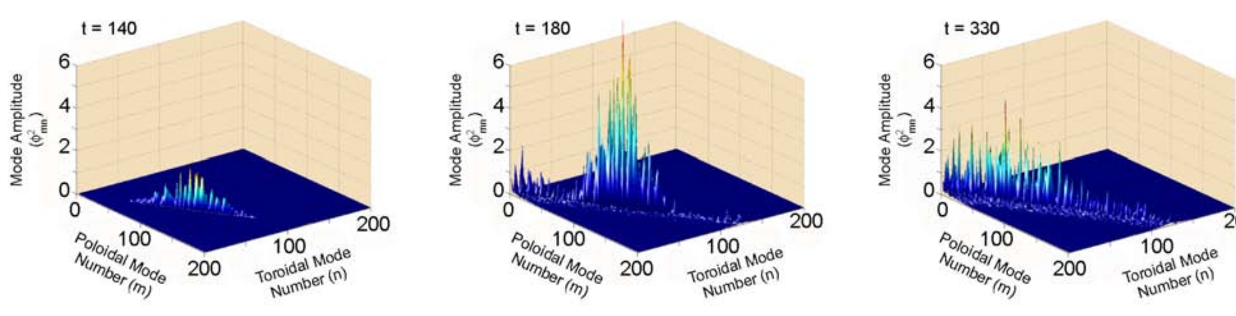


Figure 7. Simulations show that nonlinear toroidal couplings as a fundamental process are strongly correlated with ion-temperature-gradient saturation and are responsible for the formation of a downshifted toroidal spectrum in the fully developed turbulence regime.

through a regulating effect including both shear flow decorrelation and turbulence energy extraction, as well as globally through effects on turbulence spreading. However, the zonal flows are not a necessary component to saturate the turbulence, as the fluctuations can be saturated in the absence of zonal flows. The nonlinear toroidal couplings as a fundamental process appear robust in the drift wave turbulence dynamics of toroidal systems.

Motivated by experimental concerns with regard to the CHarge-exchange Recombination Spectrometer (CHERS) diagnostic for measurements of ion temperature, anisotropic properties of neoclassical equilibrium were also investigated. GTC-NEO code simulations of low-aspect-ratio plasmas in NSTX show that there is significant variation of ion temperature on a magnetic surface, with up to 20% difference in ion temperature between the outer and inner sides on the midplane. As a consequence, plasma pressure iso-surfaces are shifted from magnetic surfaces. This finite-orbit-width toroidal effect is enhanced as the ratio of ion-orbit width to temperature gradient scale length is increased, but is insensitive to the density gradient. It is most pronounced in the low-collisionality regime. On the other hand, the temperature anisotropy between parallel and perpendicular direction is shown to be small. The results are given in Figure 8.

Simulations of ion-temperature-gradient modes were also carried out using the global GTC code for a simplified toroidal system. It was found that the parallel acceleration of the ions due to the perturbed electric field play an important role in the observed steady-state turbulent transport. This parallel velocity space nonlinearity not only enhances the amplitude of the zonal flows but also reduces the steady-state ion-

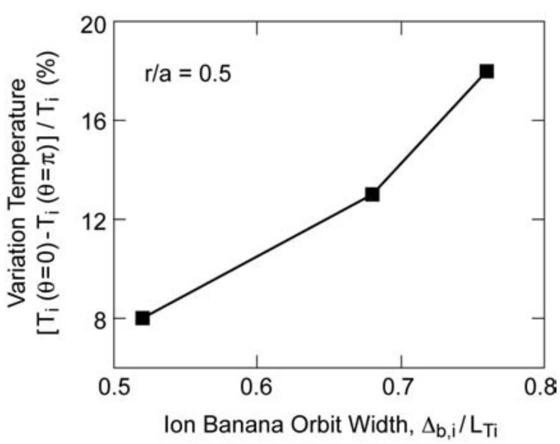


Figure 8. Variation of ion temperature on a magnetic surface is enhanced as the ratio of ion-orbit width over temperature gradient scale length is increased.

energy flux. The question of "stiffness" for the ion-temperature-gradient drift modes was also addressed using the GTC code. The results using the perturbed (delta-f) simulation model indicated that profile relaxation has negligible effects on the level of the steady-state ion-thermal transport.

Analysis of issues relating to sampling noise and long-time steady states in gyrokinetic particle simulations showed that discrete particle noise should not influence turbulent simulation under normal conditions.

In preparation for the integrated simulation of fusion plasmas, the wave heating schemes based on high-frequency gyrokinetic formulation and the shear-Alfvén model for the low-frequency gyrokinetic finite-beta physics was developed with the plan to implement them into GTS in the future.

Boundary Physics

During FY07, DEGAS-2 modeling of particle balance in CDX-U was supported. A quantitative ray-tracing code was used to estimate the contributions of in-vessel light reflections to the filterscope used to view deuterium recycling light above the liquid-lithium tray in CDX-U. These contributions were found to be negligible, eliminating the need for a more self-consistent (and time consuming) treatment.

Most blob analyses and simulations have used electrostatic approximations. However, it has been shown that the relevant regime for the NSTX plasma edge is electromagnetic. Normally such a description requires a nonlinear three-field model. However, a reduced one-field model that should capture the essential behavior, including the role of the shear-Alfvén waves in regulating the dissipative properties of the turbulence, was derived. This equation, which seems to predict a preferred scale and preferred region (just inside the separatrix) for blob formation is presently being analyzed. Results from this analysis should become available during the next fiscal year.

Stellarator Physics

Transport Optimization

An analytic calculation was completed showing that the damping of zonal flows in drift-optimized stellarators is reduced relative to that in conventional stellarators, so that the level of turbulence should be reduced relative to that in conventional stellarators. This result shows that optimization of neoclassical transport in stellarators also reduces turbulent transport. Researchers on the Large Helical Device (LHD) stellarator in Japan report that when they shift their magnetic axis inward to improve neoclassical transport, they also get reduced anomalous losses, and PPPL Theory Department calculations provide at least a partial explanation for this observation. For the National Compact Stellarator Experiment (NCSX), being constructed at PPPL, tokamak confinement scaling laws predict better confinement times than do stellarator scaling laws. This calculation suggests that the more favorable tokamak scaling is the appropriate one to use in NCSX. More generally, the result has important implications for stellarator design, i.e., that turbulent transport losses can be reduced by targeting neoclassical confinement. The results were obtained using an action-angle formalism without expansion in small parameters of radial excursion and time scale.

Nonaxisymmetric Fields

It has been shown that vertical instability of a tokamak plasma can be controlled by nonaxisymmetric magnetic fields localized near the plasma edge at the bottom and top of the torus. The required magnetic fields can be produced by a relatively simple set of parallelogram-shaped coils (see Figure 9). By providing stable equilibria with more highly elongated cross-sections, these coils can potentially lead to devices with improved performance in terms of beta limits and/or confinement.

Convergence studies were done comparing PIES code solutions for helical equilibria with magnetic islands (with varying numbers of Fourier components and radial grid points) with those obtained by a helical Grad-Shafranov solver. One focus here has been the calculation of equilibria relevant for neoclassical tearing mode studies (i.e., with reduced current in the island interior).

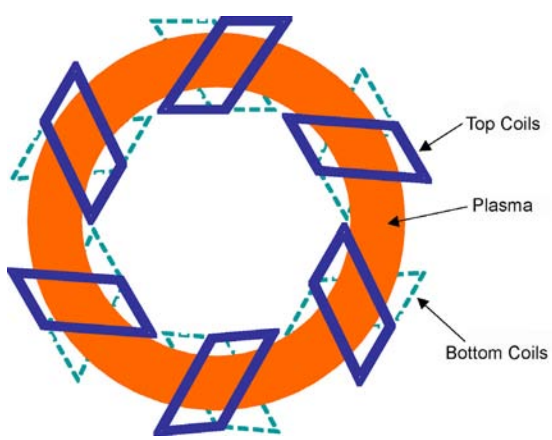


Figure 9. View from above showing parallelogram-shaped coils above a tokamak plasma, with portions of the coils below the plasma also visible.

Stellarator Equilibrium Analysis

A Newton-Krylov scheme was implemented for the PIES code. This scheme has thus far been tested on helically symmetric equilibria with magnetic islands and has been found to substantially accelerate the convergence of the code. A dynamic preconditioner was developed and implemented and was found to further accelerate convergence.

Work in direct support of the NCSX Project continued, with calculations of the impact of construction tolerances on neoclassical transport and on magnetic islands.

Energetic Particle Physics

TAE Analysis of ITER

The PPPL Theory Department led and successfully completed the fiscal year 2007 DOE JOULE milestone to improve the simulation resolution of the linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal mode numbers used from n = 1 to n = 15. The Tokamak Startup Code (TSC) and the plasma transport simulation code TRANSP were used to develop three fiducial equilibria for the three main ITER scenarios: the high-confinement edge-localized-mode, hybrid, and advanced (Advanced Tokamak or reversed-shear) plasma regimes.

The stability of Alfvén eigenmodes with frequencies up to the Torodicity-induced Alfvén Eigenmode (TAE) and the Ellipticity-induced Alfvén Eigenmode (EAE) gaps was simulated numerically with n ranging from 1 to 20. The hybrid MHD/kinetic code NOVA-K was applied. In H-mode and hybrid plasmas, the neutral-beam injection angle was varied to investigate the possibility of TAE stability control. In both scenarios the expected medium to high-n range of TAEs unstable was found when the neutral-beam injection was aimed slightly off axis, 10–20 cm vertically away from the mid-plane. On-axis heating was marginally unstable due to strong central ion-Landau damping. Overall it was found that hybrid and Advanced Tokamak plasmas are the most unstable, with the damping rates for the unstable modes approaching 3 to 5%. As an example, in Figure 10 is shown the growth rate of TAEs in a ITER Advanced Tokamak plasma with moderate shear reversal and with the fusion power approximately 0.5 GW. This figure shows the typical spectrum of unstable TAEs with low- to high-n numbers. Because of multiple instabilities, TAEs can create such effects as avalanches in radial transport.

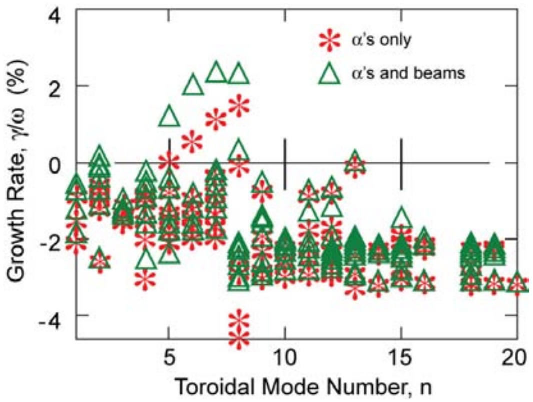


Figure 10. Torodicity-induced Alfvén Eigenmode growth rate dependence on the toroidal mode number driven by fusion alphas only (stars) and by alphas and beam ions (triangles).

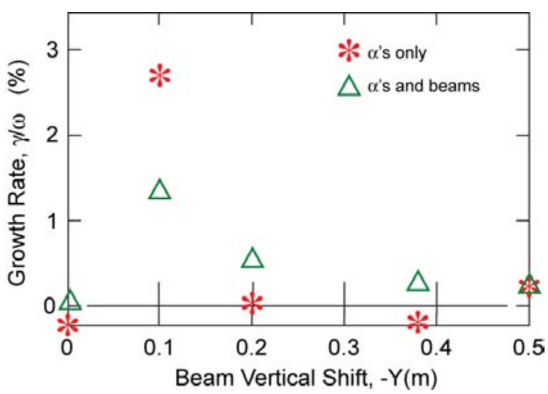


Figure 11. Torodicity-induced Alfvén Eigenmode growth rates for ITER plasmas with different negative-ion-based neutral-beam injection geometries aiming above the magnetic axis. The degree of the vertical shift is Y.

Figure 11 shows another example where the role of negative-ion-based neutral-beam injection (NNBI) angles were studied. This clearly shows that aiming the NNBI can be used for TAE stability control. This is of great importance for future ITER experiments.

Alfvén Eigenmode Analysis of NSTX

Working with the NSTX experimental group a new instability, the beta-induced Alfvén Acoustic eigenmode (BAAEs), was discovered. These are hybrid modes resulting from the coupling of Alfvén waves and acoustic waves. Good agreement between the numerical simulations of NOVA and measured BAAE frequencies and structures was found. These modes are expected to be present in the reactors based on the Spherical Torus.

Nonlinear TAE Studies

The M3D-K code was applied to study multiple beam-driven Alfvén modes in NSTX and DIII-D plasmas. The results for NSTX show wave particle resonance overlap due to multiple modes enhances significantly the mode saturation level. The results of DIII-D show excitation of n = 1 to n = 3 TAE-like modes with mode frequencies comparable to measured values. These results will be presented as an invited talk at the *2007 American Physical Society Division of Plasma Physics Meeting* in Orlando, Florida.

Relationships with Other Projects

The research program in the Theory Department is integrated with activities under several projects. The Department has strong ties with experimental projects, including: NSTX, NCSX, LTX, DIII-D, C-Mod, JET (Joint European Torus) and ITER. The Department has a significant presence in several advanced computing activities. Notably, the Advanced Scientific Computing Research Program is an integral part of code development and also provides national leadership through the Plasmas Science Advanced Scientific Computing Institute (PSACI), which also plays a key role in the coordination of the Fusion Energy Science projects within DOE's SciDAC Program.

The SciDAC portfolio includes four Office of Fusion Energy Sciences (OFES) SciDAC Centers in basic science: Gyrokinetic Particle Simulations of Turbulence, Gyrokinetic Fluid Simulation of Turbulence, Extended MHD Modeling, and Simulation of RF Wave-Particle Interactions with MHD. In addition the Department has a strong presence in the two SciDAC Fusion Simulation Project (FSP) Proto-type or Pilot Centers on the integrated simulation of the plasma edge/boundary region and the integrated simulation of wave interactions with MHD.

The Multi-scaly Gyrokinetics Project, sponsored by the Office of Advanced Scientific Computing Research (OASCR) MMRE (Multiscale Mathematics Research and Education) initiative, has been in the Theory Department for the past two years. The purpose of the Project is to develop mathematical models and numerical algorithms in support of the integrated simulation capabilities for GTC-S on DOE's leadership computing facilities in the future.

Return to Table of Contents

Computational Plasma Physics

The Computational Plasma Physics Group (CPPG) at the Princeton Plasma Physics Laboratory (PPPL), develops and applies advanced computational techniques in the areas of production running of analysis codes, scientific visualization, parallel scaling, and algorithmic development. Some of the highlights of the FY07 year are given below.

TRANSP Run Production

In its fifth year of operation, utilization of PPPL's FusionGrid TRANSP computational service continued its rapid growth. TRANSP runs are used for time-dependent analysis and simulation of tokamak experiments — the software has been under continuous development at PPPL and elsewhere for more than 30 years. Fiscal year 2007 saw the introduction of parallelized neutral-beam particle simulations into TRANSP code run production. The PTRANSP (predictive TRANSP) project was resumed in FY07; numerical stability enhancements in temperature prediction enabled the code to be used for a major ITER study. Figure 1 shows the growth in usage in TRANSP over the last three years and the distribution of this set of runs by tokamak device.

Documentation, scripts, and utility code to help prepare and submit runs to the service are provided at http://w3.pppl.gov/transp. Users of the service monitor the progress of their runs at http://w3.pppl.gov/transp/transpgrid_monitor, which gives links to log files and browser enabled graphics of the input data and namelist selected runtime data. Any runs which experience problems during execution are examined by a PPPL expert and the result of this analysis is communicated back to the user through the web interface or by email. Security for the service and the user's data is provided through the use of FusionGrid Certificates (standard internet protocols) as described at the web site. About 100 research users are presently registered with the TRANSP compute service. Access is granted to new users as a routine matter (as a first step, users apply for a PPPL computer account and agree to PPPL Cyber-security policies).

Free-boundary Equilibrium Solver in TRANSP/PTRANSP

TRANSP is being enhanced with new predictive capabilities as part of the PTRANSP project. In support of this effort the reconstruction of the MHD equilibrium with a free-boundary solver has been added to TRANSP. The free-boundary solution improves the fidelity of the magnetic field outside the plasma for the radio-frequency and neutral-beam models and provides a framework for the future coupling of the magnetic field diffusion with the coil and circuit equations. Longer term, it will enable coupling of PTRANSP to a scrape-off layer plasma model. The

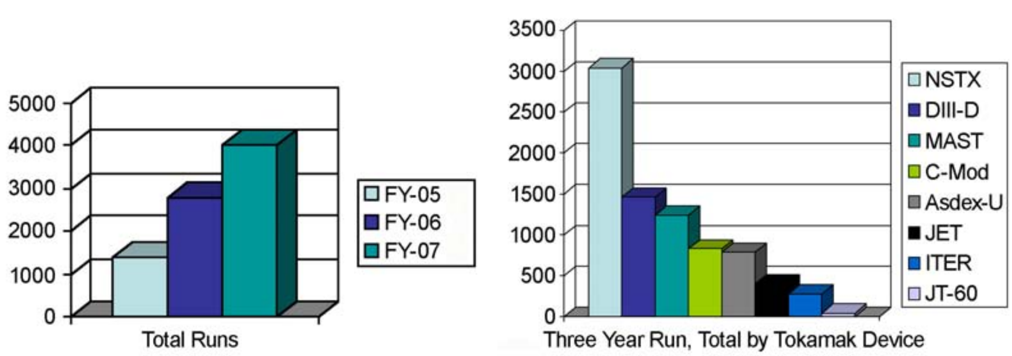


Figure 1. TRANSP run production FY05–07. There were 8,188 runs produced in the last three years, with an increase of about 300% in production in FY07 compared to FY05. More than 60% of the runs were for experiments not sited at PPPL.

free-boundary solver within the TEQ code from the Lawrence Livermore National Laboratory was integrated into TRANSP. Preliminary testing was done on PTRANSP code runs. Figure 2, shows the magnetic flux surfaces in an ITER simulation.

Web Services for Fusion Codes

Based on previous experience in programming methods, the CPPG has begun deploying efficient web-based graphical interfaces that run from a browser and provide secure Internet access to site-specific data and computational physics applications. Graphical user interfaces, running in web browsers for portability and convenient access, communicate with fusion codes running on compute servers maintained at PPPL (Figure 3). The web service approach facilitates collaboration, enforces security, eliminates software installation, and provides broad access to scientific applications. This approach adds visualization to applications with minimal changes to the simulation codes. The client software is written in Java so it is portable across users' computer platforms. The clients send requests to the web server where they are managed by PPPL's Visualization Servlet program. Fusion programs such as RPLOT and GTC-S run on the compute servers and return results to the client for interactive visualization.

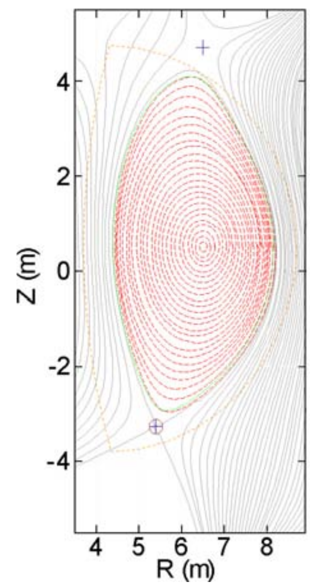


Figure 2. Plot of a poloidal magnetic flux surface reconstruction from the TEQ free-boundary solver during a PTRANSP code run for an ITER plasma.

New Performance Milestones Achieved by the GTC-S Code

The GTC-S code, which was developed based on a generalized gyrokinetic particle model using the

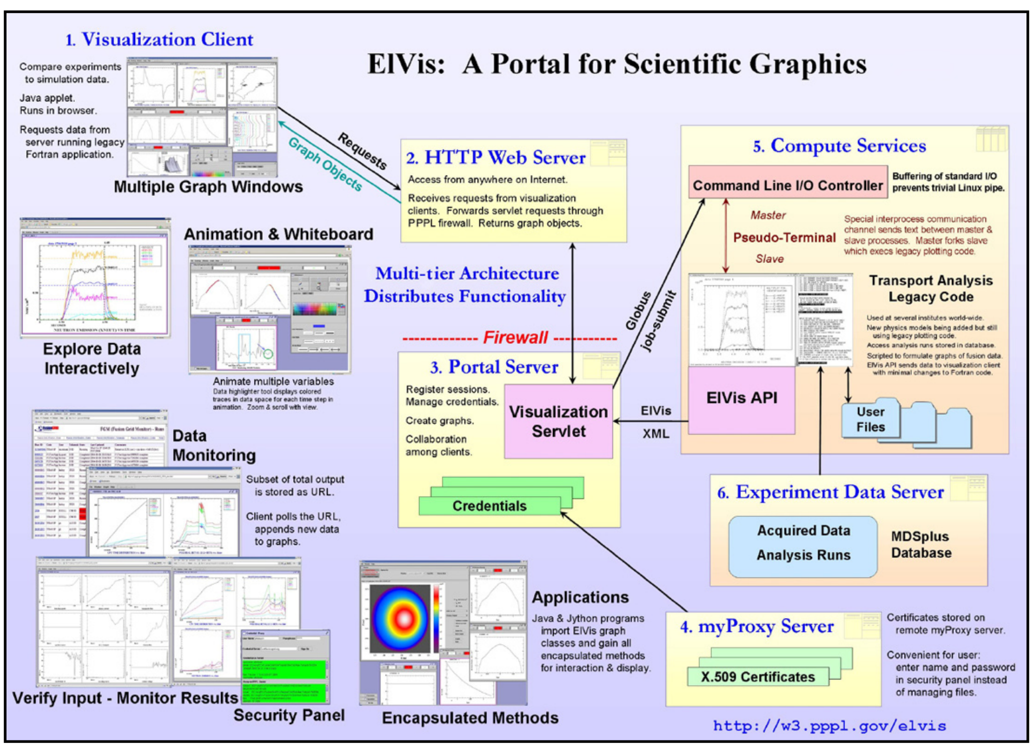


Figure 3. This diagram illustrates a multi-tier architecture for implementing web services to fusion codes.

original Gyrokinetic Toroidal Code (GTC) architecture, simulates plasma microturbulence and associated transport in toroidal (tokamak) experiments. GTC-S was chosen by the Office of Advanced Scientific Computing Research (OASCR) as one of three large-scale applications to fulfill the FY07 JOULE Milestones set by the Office of Management and Budget (OMB). Every year for the past few years, the OMB has set milestones for the most intensive large-scale scientific applications to be run on the OASCR-funded Cray XT4 system, Jaguar, located at the Oak Ridge National Laboratory (ORNL). The FY07 milestones called for a doubling in overall performance of the applications.

Unlike the original GTC, the GTC-S code can treat globally consistent, shaped cross-section tokamak plasmas by directly importing experimental profiles of plasma temperature, density, and rotation, along with the related numerical MHD equilibrium. It can also include equilibrium mean electric field and Coulomb collisions. Those important effects strongly influence the dynamics of the fusion plasmas and are crucial for true validation with experiments and for achieving predictive capability. Although most of the work on GTC-S has been focused on the physics upgrade, the JOULE exercise stimulated significant effort to improve its performance and concurrency through the involvement of CPPG.

Having been specifically developed on the IBM SP at the National Energy Research Supercomputer Center (NERSC), the GTC-S code was first ported and optimized on the Cray XT4 at ORNL. All dependencies on third-party libraries were removed and

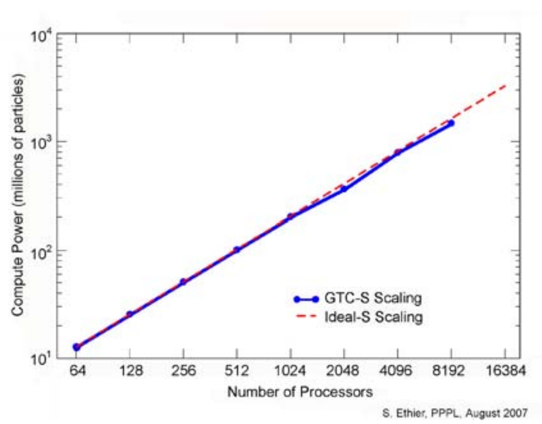


Figure 4. Weak scaling study of the newly improved GTC-S code on the Cray XT4 system (Jaguar) at ORNL. The blue curve shows the number of particles (in millions) moved one step in one second by the GTC code, and the red curve shows the corresponding theoretical maximum assuming ideal scaling.

replaced by Open Source alternatives, which required thorough testing for accuracy and performance. A new level of parallelism was then added to the original toroidal domain decomposition and OpenMP loop-level multithreading by implementing a particle distribution algorithm. This resulted in a considerable increase of concurrency, from a few hundred processors originally on the Cray XT4 to several thousands with the new algorithm.

All of the improvements implemented in the GTC-S code allowed it to easily exceed the FY07 JOULE milestones set by the OMB. Scalability was demonstrated from 64 cores, the original limitation, to 8192 cores, the maximum number of cores available on Jaguar at the time. Figure 4 shows the weak scaling performance of the improved GTC-S on the ORNL Cray XT4 at ORNL.

Strong Scaling of 3-D MHD Codes to Large Numbers of Processors

The M3D code is used for simulating global instabilities in magnetic fusion devices. It is one of the major workhorse codes in use by several of the U.S. Department of Energy (DOE) Office of Science's Scientific Discovery through Advanced Computing Program projects: the Center for Extended MHD Modeling (CEMM, see http://w3.pppl.gov/CEMM), the Center for Simulation of RF Wave Interactions with Magnetohydrodynamics (SWIM, see http://cswim.org/), and the Center for Plasma Edge Simulation (CPES, see http://www.cims.nyu.edu/cpes). It is a high priority for each of these centers to have the M3D code run efficiently on the present and the next generation of DOE computers. The multi-scale multi-physics nature of the M3D code necessitates the use of partially implicit algorithms, which are known to be a challenge to implement efficiently on massively parallel computers.

Previous scaling studies with M3D involved what is known as "weak scaling." In these studies, one begins with a small problem run on a small number of processors. As the problem size (number of mesh points) is repeatedly doubled, the number of processors is simultaneously increased to keep ratio of mesh points to number of processors fixed. Perfect weak scaling would imply that the wall clock time to problem completion stays fixed as you continue to do this. This is by far the most common type of scaling study.

However, what is more relevant for the needs of the above Centers is "strong scaling." In this, one fixes the number of mesh points required for adequate spatial resolution and time the run using more and more processors for that given mesh. In perfect strong scaling, the running time would decrease (or the run would speed up) proportional to the number of processors that is added. Since the demonstration of strong scaling is essential in order to study tokamaks with ITER parameters, this was the focus in FY07.

Building on previous accomplishments during the previous year's weak scaling campaigns, considerable progress was made in improving the strong parallel scaling properties of the M3D code This was accomplished primarily by: tuning the HYPRE multigrid Poisson solver, further optimizing the algorithm for distributing the mesh points over the processors, eliminating some inefficiency in the inter-processor communications that set in when operating at more than 1,000 processors, and working with the Center consultants to track down bugs in the operating system that only occur for the largest problems. As seen in Figure 5, favorable strong scaling has now been demonstrated up to 5,000 processors on the ORNL Jaguar computer with a parallel efficiency of more than 70%.

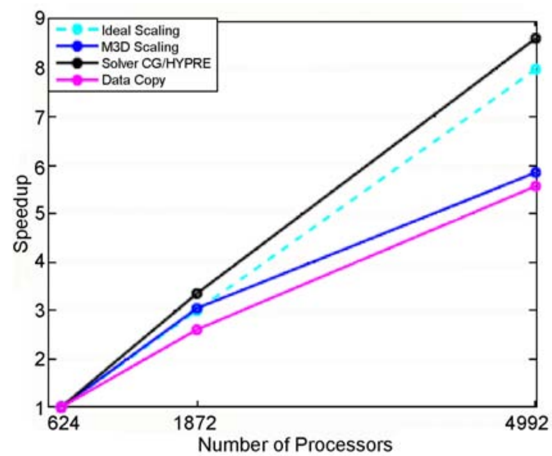


Figure 5. Speedup relative to 624 processors for strong scaling of the M3D code on the massively parallel ORNL computer, Jaguar. The blue curve reflects the overall running time. Future emphasis will be in improving the parallel scaling properties of the "data copy" segment of the code.

A Fully Implicit Method for Resistive MHD

It is widely recognized that temporal stiffness induced by the ideal-MHD characteristics generally make it impractical to simulate resistive MHD phenomena using an explicit time-stepping method. In a close collaboration between the APDEC (Applied Partial Differential Equations Center), TOPS (Towards Optimal Petascale Simulations), and CEMM SciDAC Centers, a fully nonlinearly implicit Newton-Krylov (NK) method was developed for resistive MHD. The equations are written in a fashion such that all the unknown quantities (and their derivatives) are written as a nonlinear function, which is solved using the multivariable Newton method. Each step in the Newton method requires the inversion of a rather large linear system.

The key to achieving a scalable implicit method is to solve these linear systems using a Krylov technique (such as GMRES), which does not require explicit storage or computation of the Jacobian at each Newton step. Hence these methods are often dubbed "Jacobian-Free Newton-Krylov (JFNK)." Furthermore, at the heart of efficient JFNK methods often lies an effective preconditioner, which approximates the Jacobian, resulting in a fast solution during the Krylov step. An operator-based preconditioner applicable to any general system of hyperbolic conservation laws was developed and applied to the resistive MHD system.

The idea behind this preconditioning approach is that because the stiffness of the ideal-MHD system results from the fast compressive and Alfvén MHD waves, an approximate decomposition of the system into its component waves can be developed and preconditioning is done only on the stiffness-inducing parts. This approximate decomposition is based on a second-order time accurate operator splitting of the MHD system into its directional components. Each component then forms a system of eight coupled, one-dimensional advection equations, which are projected into a set of decoupled characteristic equations. The result of this decoupling is a linear block-tridiagonal system of equations which can be easily solved. Within this strategy each characteristic equation is solved independently, enabling solution of only those components inducing stiffness to the fully implicit system, while leaving the slower components alone.

Upon solution of these decoupled equations, the preconditioned solutions are projected back into their original conserved variables, resulting in the approximate solution of the original linear Jacobian system. This approach gives one the freedom to choose to precondition the fast compressive wave, or both the fast compressive and Alfvén waves, or all the waves in the MHD system.

Results of small-amplitude wave propagation tests are shown in Figure 6. Other nonlinear tests also

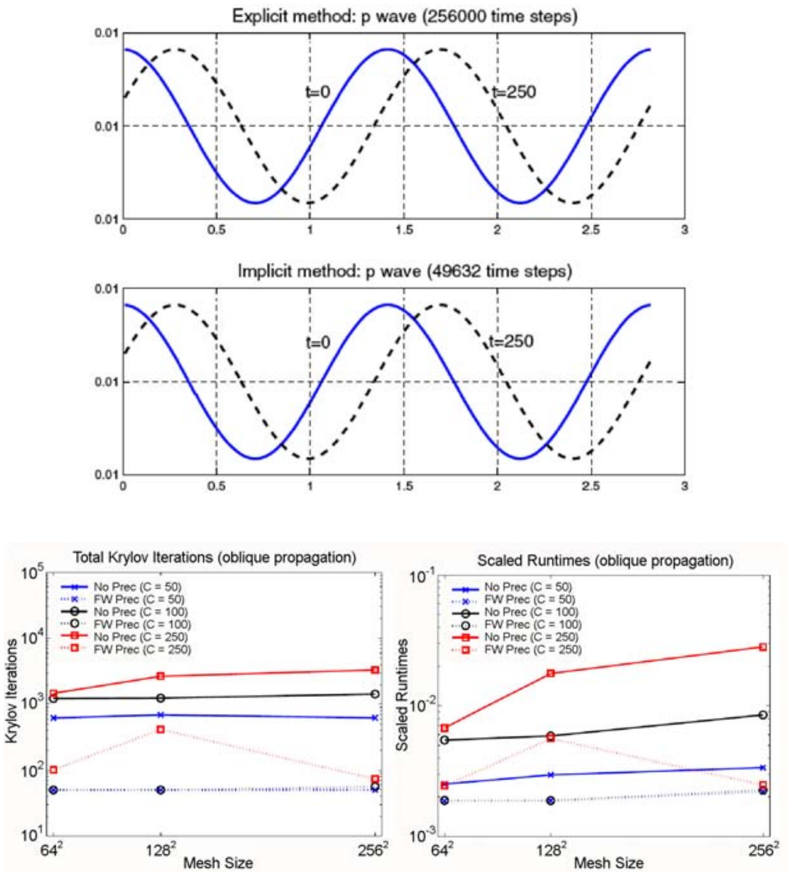


Figure 6. Wave propagation test: The top two panels show a comparison of the implicit solution versus an explicit solution method after 88 transit periods. The bottom panel shows that the number of Krylov iterations decreases as a result of preconditioning (left) and that the scaled CPU time (CPU time per mesh point so that a horizontal line implies perfect scaling) shows good scalability (right). Note: C is the ratio of the time step taken in the implicit method to the Courant-Fredrichs-Lewy-constrained time step of an explicit method.

showed improvements of the preconditioned JFNK over explicit and un-preconditioned methods. Other salient features of this method are: it is conservative and preserves the solenoidal property of the magnetic field.

Development of the M3D-C^1 code for 3-D Two-fluid MHD Studies

Work continued on the development of a new form of the M3D code using a strongly implicit algorithm that is made possible by the use of finite elements with continuous first derivatives (C^1). Significant progress was made in a number of areas.

A new implicit time advance was implemented that exhibits improved numerical stability, especially at the highest spatial resolution, and also improved convergence in the time step Δt, especially for the steady-state solutions. This has allowed use of this code to calculate toroidal equilibrium with flow as shown in Figure 7.

The geometry of the 2-D code was generalized to now be toroidal, with fully unstructured triangular elements. This now uses routines from the Rensselaer Polytechnic Institute (RPI) Scientific Computational Research Center (SCOREC) to hide parallelism and provide mesh functions that allow adaptivity. The code was also generalized to use sparse matrix solvers through the PETSc interface. This makes it possible to easily compare different solvers, and gives a natural path for an extension to 3-D.

These improvements have enabled two new physics studies in 2-D geometry: the study of toroidal two-fluid equilibrium with gyroviscosity and flow and the study of 2-D magnetic reconnection in the presence

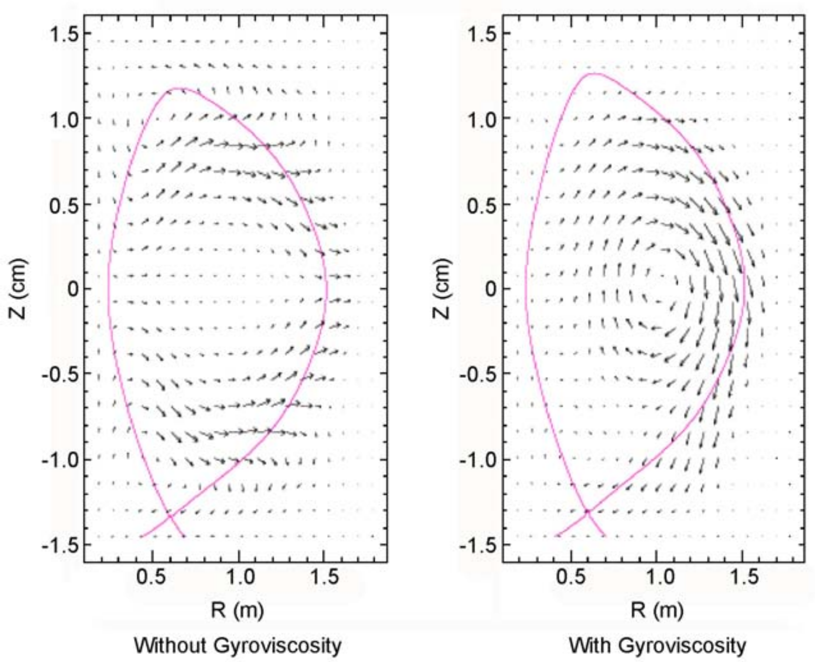


Figure 7. Steady-state toroidal equilibrium on all time scales as calculated as a steady state of the 2-D toroidal M3D-C^1 code. Solution on the left does not include gyroviscosity and does not exhibit rotation. Solution on the right includes gyroviscosity and exhibits spontaneous poloidal rotation.

of a strong guide field. This latter study shows that a guide field can strongly inhibit the onset of fast reconnection. A large parameter regime is being studied to put this result in context, but the fact that the simulations exhibit excellent energy and flux conservation and have been confirmed by an initial comparison with a similar NIMROD code calculation gives confidence in these results.

Return to Table of Contents

Space Plasma Physics

The Space Physics Group at the Princeton Plasma Physics Laboratory (PPPL) has been modeling the dynamical evolution of solar wind interactions with magnetospheres to understand how energy and momentum are coupled between the sun, magnetosphere, and ionosphere of earth and the other terrestrial planets. In this report, the progress in understanding (a) entropy transport on the earth's plasma sheet associated with substorms and (b) field line resonances at Mercury is described.

Entropy Transport Associated with Substorms

Substorms are dynamical events that reconfigure the magnetosphere and are associated with significant deposition of energy into the ionosphere, shedding of plasma and magnetic flux in the form of plasmoids in the magnetotail. The dynamical evolution of the substorm is divided into several phases. The growth phase occurs prior to the onset of the substorm, and it is during this phase that energy is stored in the magnetotail by the addition of magnetic flux. The increased magnetic pressure leads to a compression and elongation of the magnetotail and the intensification of the cross-tail current sheet. At the substorm onset, there is a large-scale dynamical transition in the magnetospheric state as energy stored in the tail is released and the magnetic field dipolarizes. The released energy is manifest in the energization of ring current particles, particle precipitation, Joule heating, and the ejection of plasmoids. The expansion phase is followed by a recovery where the magnetic field and plasma flow return to quite-time conditions.

To gain insight regarding the dynamical process leading to the new state, it is useful to consider properties of the magnetospheric state prior to and following the substorm onset. It is particularly interesting to examine the entropy. Nonconservation of entropy results from nonadiabatic processes such as turbulent transport, thermal energy transport due to nonadiabatic particle drifts or precipitation and may indicate which processes are most important in the transition to the new state of the system.

For this study, statistically averaged states prior to and after substorm onset were considered. A set of 180 substorm events for which plasma sheet parameters are inferred were used. The data is from low-altitude Defense Meteorological Satellite Program (DMSP) satellites. In the case where mass is conserved on a flux tube, a useful conserved quantity is $S = \int p^{1/\gamma}\, ds/B$ where p is the pressure and B is the magnetic field. Although not precisely the entropy, the quantity S is entropy-like in nature and is commonly referred to as the entropy per unit flux or total entropy. For isotropic pressure (as assumed in the mapping) and the system near equilibrium in the initial and final configuration, the pressure is constant along field lines, and total entropy ($p^{1/\gamma} V$, where V is the flux tube volume) should be conserved. This extensive parameter is proportional to the mass and/or system size.

To compare the entropy change in the transition from growth phase to expansion phase, the flux tube volumes for field lines that share the same footpoint as shown in Figure 1 were considered. In doing so, the slow slippage of the footpoints on a convective timescale are ignored. Entropy is compared at two lat-

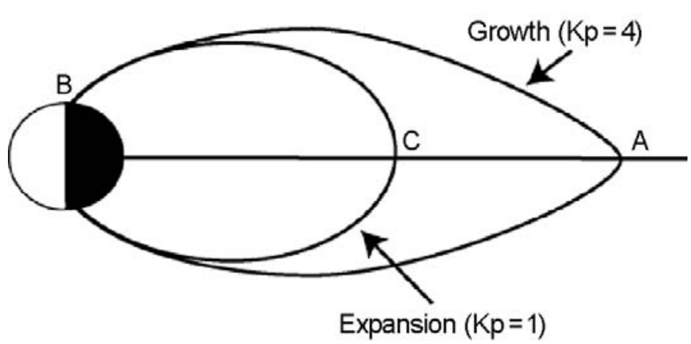


Figure 1. Schematic depiciting the magnetic field line configurations for growth (Kp = 4) and expansion (Kp = 1) phase consistent with the assumptions of the mapping model.

Table 1. Flux tube volume, ion pressure, total entropy, density, and specificy entropy for growth and expansion phases in the midnight meridian.

Substorm Phase	Location (X, Y, Z) R_E	Flux Tube Volume	Ion Pressure (nPa)	Total Entropy $S = p^{1/\gamma}V$	Denisty (cm^{-3})	Specific Entropy p/n^{γ}
Midtail						
Growth	A = (-30, 0, 0)	8724	0.31	4320	0.49	1.0
Expansion	C = (-20, 0, 0)	7899	0.55	5518	0.83	0.75
Near-earth						
Growth	A = (-20, 0, 0)	3976	0.53	2717	0.89	0.65
Expansion	C = (-7, 0, 0)	379	0.90	356	1.2	0.66

itudes that map to -30 R_E and -20 R_E prior to the onset and -20 R_E and -7 R_E (where R_E is earth radius) following the onset corresponding to the dipolarization of the field. The results in Table 1, show that there is a substantial decrease (a factor of eight) in the entropy for dipolarized field lines and a slight increase in total energy further down the tail.

The role of entropy conservation and loss governing substorm phases have recently been studied. [Birn, J., Hesse, M., and Schindler, K., "On the Role of Entropy Conservation and Entropy Loss Governing Substorm Phases," in *Proceedings of the Eighth International Conference on Substorms (ICS-8)*, edited by Syrjäsuo and Donovan (University of Calgary, Alberta, Canada, 2007) pp 18–24. It was found that the formation of a plasmoid in the tail leads to a loss of total entropy (essentially by the shedding of mass in the plasmoid), which is also described as a plasma bubble. However, it was also found that there is global conservation of entropy in that the total entropy, which is the sum of the plasmoid entropy and the entropy of the reconnected closed field line attached to earth, remains nearly constant.

The specific entropy, p/ρ^{γ}, which is an intensive variable of the system and should not depend on the system size (e.g., flux tube volume) was also examined. In this case, $p/\rho^{\gamma} \propto p/n^{\gamma}$ (assuming a single-ion species) appears to be roughly conserved in the near-earth region before and after onset. This result would be consistent with volume (mass) reduction without significant plasma heating or heat flux, e.g., plasmoid. In contrast, there is a slight reduction of specific entropy in the midtail region.

Another view of substorm expansion is that it occurs when field lines diffuse through a turbulent region. In this case, the particles per fluid are not frozen to the field lines and a decrease in entropy may be expected as the flux tube volume decreases and plasma is lost. However, it is uncertain whether the specific entropy would be conserved through such particle transport. Estimating how total entropy would change for various candidate transport models, and whether specific entropy would remain relatively invariant is an important topic for further consideration.

Field-line Resonances at Mercury

Mercury is by far the least explored of the terrestrial planets. The only close-up measurements so far were obtained by the National Aeronautics and Space Administration (NASA) probe Mariner 10 in 1974–75. But, in the last few years, there has been heightened interest in Mercury's exosphere and magnetosphere because of the launch of the U.S. Space Mission Messenger, which will have its first encounter in January 2008, and because of the development of the European Space Mission BepiColombo to be launched in 2013.

Mariner 10 found that Mercury possesses a sufficiently strong internal magnetic field for a typical magnetosphere to form. Plasma sources for Mercury's magnetosphere are the solar wind, supplying hydrogen and helium, as well as sputtering from the planetary surface. Sodium and potassium atoms can be seen in the exosphere of Mercury, because they are very efficient at scattering sunlight. The contributions of ionized potassium to the magnetospheric plasma are negligible compared with that of sodium. Thus protons and sodium ions are the main constituents at Mercury. From analysis of the sodium exosphere and from ionized sodium tracing, it is suggested that ionized sodium could make up between 10% to 50% of the magnetospheric ion plasma composition.

Observations of ultra-low frequency (ULF) pulsations in the terrestrial magnetosphere are numerous. The central theory that explains the features of the majority of observed ultra-low frequency pulsations is the concept of the field-line resonance (FLR). When incident compressional magnetohydrodynamic (MHD) waves arrive at a region where their phase speed parallel to the ambient magnetic field is equal to the local Alfvén speed, the wave energy is transferred to shear Alfvén waves. This is called the Alfvén resonance, and, because the magnetic field lines are bounded by the ionospheres, it is known as a field-line resonance. In multi-ion plasmas, the resonance condition has several branches: the ion-ion hybrid (IIH) resonance between ion gyrofrequencies and the Alfvén resonance lower than the heaviest ion gyrofrequency with frequency shift.

During the first encounter with Mercury's magnetosphere, a narrow-band ultra-low frequency pulsation with frequency about 0.5 Hz in the nightside magnetosphere was observed (Figure 2). This frequency lies between the local gyrofrequency of protons, 1.31 Hz, and sodium, 0.057 Hz, and the observed wave frequency was at 38% of the local gyrofrequency of the protons. Thus these waves are well outside MHD frequency range, which is valid only when the wave frequency is much smaller than the ion gyrofrequency. Because the heavy ions are abundant at Mercury, a multi-fluid treatment is required.

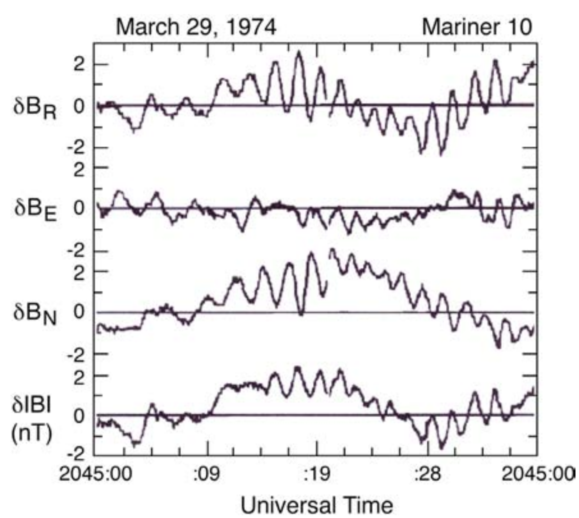


Figure 2. Mariner 10 40-msec magnetic field records deep in the magnetosphere expressed in radial east (δB_E) and north (δB_N) coordinates (δB_R is the radial direction). The average magnetic field has been removed. [Russell, C.T., "ULF Waves in the Mercury Magnetosphere," Geophys. Res. Lett. 16:11 (November 1989) 1253–1256. Copyright 1989 by the American Geophysical Union. Reproduced by permission of the American Geophysical Union.]

Several authors have suggested that the observed waves at Mercury are FLRs because they appeared in a narrow frequency band that is typical for FLRs at the earth. However, there is some question about this conclusion because the observed waves have a compressional component and polarization aligned in the north and radial directions rather than the east-west direction (azimuthal), as would be expected for a FLR. Therefore FLRs at Mercury's magnetosphere were considered in more detail. Two questions are: (1) What is the mechanism for FLRs at Mercury? (2) Are the observed waves FLRs at Mercury?

To examine FLRs at Mercury, wave simulations for electron-proton-sodium plasmas were performed. The time-dependent model includes the effects of multiple ion species and electrons and enables the study of a wide range of fluid waves for an arbitrarily inhomogeneous system. In this simulation, the background magnetic field and the electron density were assumed to be constant, and typical values relevant to Mercury's magnetosphere were used. A compressional impulse was excited at the boundary, which is similar to an impulse from the outer magnetosphere, as is quite common due to solar wind variability.

The power spectra of electric and magnetic field components were obtained through the Fourier transform at each grid point. Because perfectly reflecting boundary conditions were assumed, the compressional waves appear as a global cavity mode, while the resonant waves appear as a continuous band. In Figure 3(b), the transverse mode (B_Y) exhibits the strong continuous spectrum of resonances which corresponds to the ion-ion hybrid resonant condition in Figure 3(d). But the compressional components B_X and B_Z show the compressional cavity mode in Figure 3(a) and (c).

The time histories at the resonance location enable the examination of the wave energy flow. Figure 4 shows time histories of **E** (electric field) and c**B** (magnetic field) at this resonant point, which are obtained by applying the inverse Fourier transform [marked by a diamond in Figure 3(a) at $\omega/\omega_{cH} = 0.2$]. In this figure, the transverse components (E_X and B_Y) are dominant and grow in time, while the other components (E_Y, B_X, and B_Z) damp. These spectral characteristics of the waves are opposite to the spectral feature of the ultra-low frequency waves observed at Mercury [B_X and B_Z (corresponding to δB_R and δB_N in Figure 2, respectively) are dominant and B_Y (δB_E in Figure 2) is less dominant]. In addition, the Poynting flux is parallel to the background magnetic field. The simulation results are evidence that the compressional waves can

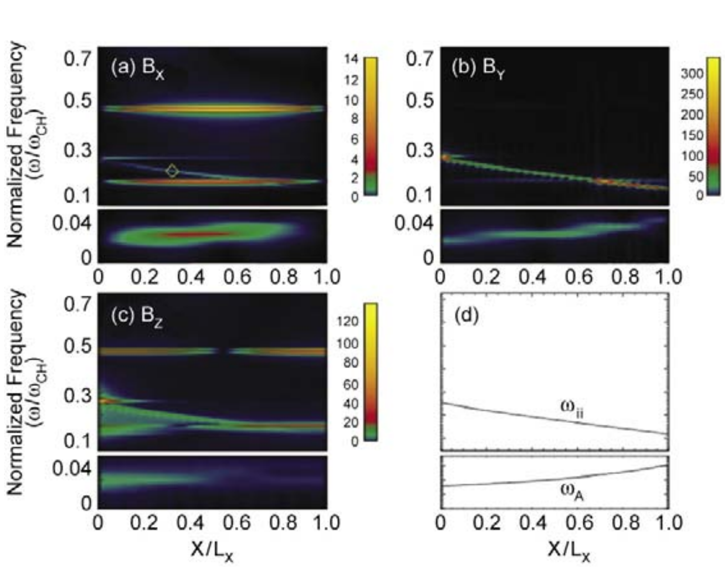


Figure 3. (a)-(c) The wave spectra of the perturbed magnetic field (B) is shown at each spatial location across the direction of the density gradient, X/L_X. The frequency range of the spectrum has been divided into two ranges with different scale (0 to 0.045 ω/ω_{cH} and 0.045 to 0.75 ω/ω_{cH}) so that the resonant frequencies can be clearly resolved because of the large mass difference between ionized sodium and ionized hydrogen. The diamond marks the point chosen for the time history. Here, B_Y (b) is a transverse component and B_Z (c) represents the pure compressional mode. (d) The calculated ion-ion hybrid resonance (ω_{ii}) and Alfvén continua (ω_A).

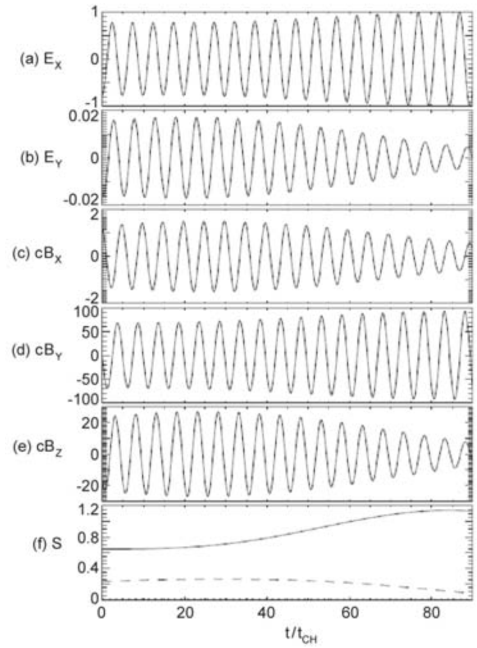


Figure 4. (a)-(c) Time histories of electromagnetic fields and (f) the Poynting flux S of a transversed mode-converted wave at the ion-ion hybrid resonance marked as a diamond for $\omega/\omega_{cH} = 0.2$ on Figure 3(a). In (f), the dotted, dashed, and solid lines are S_X, S_Y, and S_Z, respectively.

be mode-converted into ion-ion hybrid waves near the ion-ion hybrid resonance region and that the waves are guided along the magnetic field.

Therefore, the results show that: (1) the ion-ion hybrid resonance as well as the Alfvén resonance can be a mechanism for FLRs at Mercury and (2) the waves previously observed at Mercury are not likely FLRs. These results are expected to improve understanding and classification of observations from the Messenger and/or the BepiColombo missions.

Return to Table of Contents

Off-site Research

The Princeton Plasma Physics Laboratory's (PPPL) Off-site Research Department seeks to broaden the contributions of the Laboratory's engineers and scientists by providing access to leading fusion research facilities worldwide. Working side-by-side with their colleagues in multi-institutional teams allows PPPL researchers to learn from others, as well as to impart their knowledge and experience. Integrated teams of experimentalists, theorists, and engineers can tackle the important scientific and technical issues on a variety of devices, comparing and contrasting phenomena on different scales, and in different configurations. In particular, the Off-site Research program provides PPPL researchers with access to the leading tokamak facilities throughout the world.

In FY07, PPPL Off-site Department researchers published more than 50 scientific papers in referred journals and conference proceedings. They gave more than 25 talks and poster presentations at major national and international meetings, including invited talks at the *34th European Physical Society Conference on Plasma Physics* and the *17th Topical Conference on Radio-Frequency Power in Plasmas*.

DIII-D Collaboration

Researchers have made new contributions to fusion science in the physics and technology of the Advanced Tokamak on the DIII-D device at General Atomics (GA) in California. The U.S. Department of Energy's (DOE) mission for the Advanced Tokamak is to develop the scientific basis of a high-pressure self-sustained tokamak plasma discharge. Contributions to this mission are seen in the rapid advances in key technologies critical to the future success of the Advanced Tokamak. These advances are highlighted by publication of leading edge results and invited talks at key scientific meetings. Areas where PPPL researchers have contributed to Advamced Tokamak development are:

- Energetic Particle Physics
- Transport Physics
- RWM Control
- Radio Frequency Heating and Current Drive

Energetic Particle Physics

Researchers have made seminal contributions to the understanding of Alfvén waves driven by energetic particles. The key development led by PPPL physicists in the past 12 months is the verification of the radial structure of Alfvén eigenmodes based on the measurement and simulation of electron cyclotron emission fluctuations. Detailed validation of PPPL theory codes (particularly NOVA-K) by comparison of their predictions with the measured radial structure of Alfvén eigenmodes represents world-leading research in the field of energetic particles. One impact of the PPPL-led effort on DIII-D is that the study of collective effects of fast ions has now become a central element of the DIII-D science program, with a focus on ITER performance and extrapolation to the burning plasma regime.

In FY07, PPPL researchers began a new collaboration with the University of Wisconsin to upgrade the beam emission spectroscopy system to incorporate an additional one-dimensional radial array. The upgrade will be used to simultaneously measure the radial density and temperature fluctuations of Alfvén eigenmodes, paving the way for new scientific breakthroughs in this field of research. Eight of the required 32 signal detectors were installed and the partially upgraded system has already begun taking data. System completion is expected in April 2008 when the full compliment of 32 detectors will be installed. Figure 1 displays the fiber holder for the linear array. This holder will support 32 channels that are imaged across the plasma radius with a resolution of about one centimeter.

All the results on energetic particle physics from the DIII-D, the Alcator C-Mod at the Massachusetts Institute of Technology, the National Spherical Torus Experiment (NSTX) at PPPL and many results from international facilities such as the Joint European Torus (JET) in the United Kingdom and the JT-60U in Japan are based on the NOVA-K linear stability code that was developed at PPPL. The NOVA-K code is arguably the most effective and robust tool for the numerical simulation of Alfvén eigenmodes in fusion plasmas.

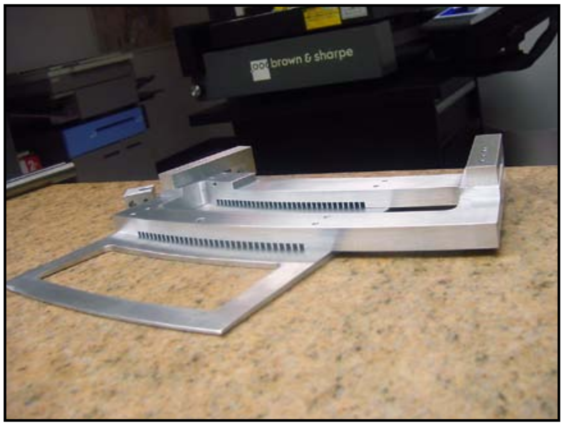


Figure 1. Linear array fiber optic mount for the beam emission spectroscopy (BES) diagnostic upgrade being done by PPPL and the University of Wisconsin for the DIII-D tokamak.

During FY07, PPPL scientists headed an effort on DIII-D to quantify the role of magnetohydrodynamics (MHD) in the maintenance of the central safety factor q(0) above unity in hybrid plasmas. PPPL researchers proposed and executed experiments to study the correlation between fast-ion confinement and neoclassical tearing modes (NTMs). The radial structure of the neoclassical tearing modes was identified and its harmonic content inferred. Experimentalists worked with GA and PPPL theorists to quantify the role of MHD in fast-ion transport. The results were presented at the *34th European Physical Society Conference on Plasma Physics* in July 2007 in Warsaw, Poland.

Transport Physics

PPPL-led experiments on DIII-D have produced the first reliable measurements of poloidal plasma rotation in fusion plasmas. To build on these advances, PPPL researchers are leading an effort to address the transport of momentum in the core of DIII-D plasmas. The central questions to be addressed by these studies include determining the origin of plasma rotation and, ultimately, understanding how and to what extent a reactor-grade plasma will rotate in the laboratory frame of reference. The answers to these questions will have profound implications for the macroscopic and microscopic stability of a fusion plasma and, hence, on the maximum pressure and level of thermal confinement that the plasma can sustain. PPPL scientists provided leadership support in these studies through the design and execution of experiments and through the application of theoretical tools to the analysis of the data.

In FY07, PPPL researchers directed the execution and analysis of experiments that produced the first identification of an anomalous momentum source in beam-heated plasmas. This represents a keynote accomplishment for the DIII-D science program. The importance of this work was recognized with an invitation to present the results as an invited talk at the *34th European Physical Society Conference on Plasma Physics* in Warsaw, Poland, in July, and by the corresponding publication in Plasma Physics and Controlled Fusion.

The focus on momentum transport has also brought together an interesting convergence of energetic particle physics and transport physics. Reversed-shear Alfvén eigenmodes (RSAE) were identified as a cause of enhanced momentum diffusivity in the core of DIII-D plasmas (see Figure 2). These modes are found to alter the plasma rotation profile without changing the total stored mechanical angular momentum, indicating that the associated fast-ion transport leads to a radial redistribution rather than a loss of fast ions. Matching the global and local momentum transport quantities in plasma discharges with and without these modes provides a new technique for extracting the anomalous fast-ion diffusion profile associated

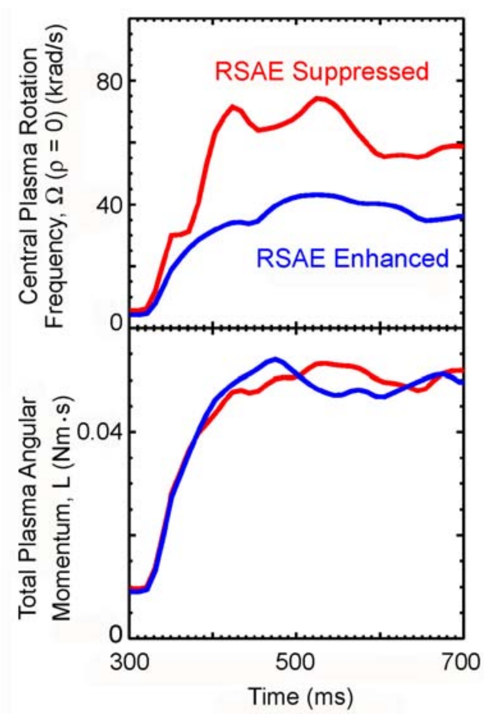


Figure 2. Central plasma rotation frequency Ω (top) and total plasma angular momentum (bottom) for plasma with strong core Alfvén mode activity (blue) and weak mode activity (red). Although the total angular momentum is similar for the two plasmas, the central rotation is much reduced for the one with strong mode activity.

with the modes. The inferred profiles are qualitatively consistent with diffusivity models used to match neutron rates.

A new version of the TRANSP code that allows for predictive rotation analysis with both a diffusion and momentum pinch was initiated this year. This is a vital upgrade for modulated momentum transport studies on DIII-D. This new version also incorporates anomalous fast-ion convection.

On the simulation front, the GTC-NEO code was upgraded to model DIII-D plasma discharges with anomalous poloidal rotation. The code begins with a supplied experimental radial electric field and determines the relative contributions of the toroidal velocity and the poloidal velocity to the radial force balance. Analysis indicates that the poloidal rotation may make a significant contribution to the radial electric field for the main ion species inside of $\rho < 0.4$ [where ρ is the plasma radius normalized to the minor radius (e.g., r/a)], especially at low-toroidal rotation. Comparison with the NCLASS code is underway.

In the past year, PPPL researchers have also made significant advances in the 3-D simulation of microwave propagation in fusion plasmas. This new tool, called the full-wave reflectometer (FWR) code, has already been instrumental in performing a detailed design analysis of microwave systems planned for ITER. This analysis capability is unique in the world and was developed through the PPPL/DIII-D collaboration program in conjunction with the PPPL Theory and Computer Departments.

Resistive Wall Mode Control

The primary concern for the Advanced Tokamak is the accessibility of stable or controllable high-pressure regimes. High pressure is essential for efficient fusion energy production and for driving the pressure-driven current that will enable the plasma to maintain itself in a steady state. The primary instability preventing access to high pressure is the resistive wall mode (RWM). PPPL is a leading institution in the understanding and control of resistive wall modes, and the DIII-D science program is a primary focus of PPPL's research effort in this area.

PPPL met a major program milestone this year with the upgrade of the RWM control system to 24 audio amplifiers and the use of the system to explore RWM stability and resonant field amplification. A key result of this work is the successful stabilization of the toroidal mode number n = 1 between edge-localized modes (ELMs) and the demonstration of active error-field control with the fast feedback system.

Since its discovery, dynamic error-field correction has been applied in an empirical manner with little attention to detailed understanding. This year, a simple model was developed that predicts the resonant field amplification of error fields and was tested using a known error field generated by the C-coils. It was found that the empirical method of iteratively determining the optimized error-field correction with the I-coils is highly accurate. This is a nice confirmation of the procedure used for several years to compensate for ambient error fields in DIII-D.

The normal mode analysis (NMA) code continued to be developed by PPPL and GA researchers and has been applied toward the investigation of resistive wall mode control in ITER. The NMA code was used to model the limitations of resistive wall mode feedback due to the coupling of multiple modes, the stable (negative helicity) with the unstable (positive helicity) RWM branches. The code was applied to ITER plasmas simulating the use of only mid-plane coils, equivalent to port plug coils. These coils have no ability to select the mode helicity, which can lead to the coupling of positive and negative helicity modes. The results of the simulation indicate that the coupling of the resistive wall mode to the negative helicity mode is highly sensitive to the relative phase of the feedback signal and the mode. In the case where the phase is not optimized, the resistive wall mode can couple to the negative helicity branch, resulting in a loss of feedback control at sufficiently high gain, with a corresponding decrease in the maximum achievable beta.

In addition to theoretical and experimental advances in RWM physics, PPPL continues to provide the engineering and design leadership for the implementation of the RWM system upgrades.

Radio-frequency Heating and Current Drive

PPPL researchers played a key role in the development of radio-frequency heating and current drive systems on DIII-D with the completion of a major program milestone by the commissioning of the EIMAC tube upgrade in one of the ion cyclotron range of frequencies (ICRF) transmitters. Figure 3 shows the socket assembly fabricated by PPPL and installed in DIII-D in collaboration with GA and Oak Ridge National Laboratory staff. The DIII-D fast-wave system reached an important milestone in FY07 when fast-wave power levels of approximately 2.5 MW were coupled into a series of low-confinement mode (L-mode) discharges with a small plasma/antenna gap. Each of the two ABB transmitters produced pulses of

Return to Table of Contents

Figure 3. Socket assembly for the new high-power EIMAC tube for one of the ICRF transmitters on DIII-D capable of delivering 2 MW of fast-wave power into the plasma at approximately 100 MHz.

1.35 MW, and the FMIT/285/300 system contributed another few hundred kW of coupled power.

Experiments were also conducted in high-confinement mode (H-mode) plasmas with a large outer gap. In one experiment resonant magnetic perturbations were used to stabilize the edge-localized mode activity; such a regime seems natural for successful fast-wave heating. Some fast-wave power was coupled into these plasmas, although further optimization is required.

Prizes, Awards, and Recognition

The American Physical Society's 2007 John Dawson Award for Excellence in Plasma Physics Research was awarded to Andrea M. Garofalo, Edward J. Strait, Gerald A. Navratil, and Michio Okabayashi for experiments that demonstrated the stabilization of the resistive wall mode and sustained operation of a tokamak above the conventional free-boundary stability limit.

Alcator C-Mod Collaboration

The PPPL-PSFC (Plasma Science and Fusion Center) Alcator C-Mod collaboration program concentrates on issues associated with Advanced Tokamak development and ITER-relevant tokamak research utilizing the Alcator C-Mod tokamak at the PSFC at the Massachusetts Institute of Technology (MIT) in Cambridge Massachusetts. PPPL collaborators play an active role in diagnostic development and support (Motional Stark Effect, microwave reflectometry, X-ray measurements, and gas-puff imaging measurements) and also in heating-system research and technical support.

Lower-hybrid Current Drive

Lower-hybrid current-drive (LHCD) experiments continued in FY07 utilizing the 4.6-GHz lower-hybrid radio-frequency system built jointly by PPPL and PSFC. Injected powers of up to 900 kW of LHCD over a wide range of parallel normalized wavenumbers ($n_{||}$ = 1.6–4) were applied to Alcator C-Mod plasmas. During this period, LHCD was applied for the first time in Alcator C-Mod to H-mode plasmas and plasmas with simultaneous ion cyclotron range of frequency (ICRF) heating. These plasmas were expected to be more difficult to couple power to based on previous experience. It was found that there were conditions under which the power could be successfully applied. Analysis of the results by comparison to the Karney-Fisch theory of current drive in the presence of a DC electric field was carried out for a large number of LHCD discharges and found in good agreement. Measurements via X-ray emission and with the Motional Stark Effect diagnostic (Figure 4) confirmed that the current was being driven off-axis as will be required for formation and sustainment of Advanced Tokamak current profiles. Results of these experiments were presented in an invited talk at the *17th Topical Conference on Radio Frequency Power in Plasmas*, 7–9 May 2007, Clearwater, Florida.

Radio-frequency Physics

Using PPPL's extensive modeling tools, PPPL physicists continue to look for new regimes of radio-frequency heating and current drive. Resonant absorp-

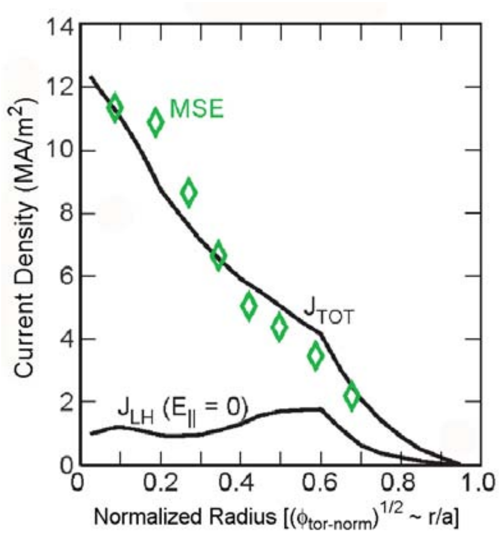


Figure 4. Comparison of current profile measured by the MSE diagnostic (green diamonds) with CQL3D code prediction (black line) during lower-hybrid current drive heating.

tion of low-frequency radio-frequency waves ($\omega < \omega_{ci}$ everywhere for all ions in the plasma) near the shear Alfvén wave layer has been suggested as a possible means of inducing the formation of internal transport barriers via localized radio-frequency-driven shear flow. New studies with the TORIC 2-D full-wave finite Larmor-radius code show that a global slow wave structure is excited via mode conversion and fills an annular region with r/a > 0.5 (where r is the plasma radius and a is the plasma minor radius). Alcator C-Mod has the capability to launch waves at frequencies below the cyclotron frequency and using the phase contrast imaging (PCI) diagnostic, the capability of detecting the mode-converted waves. Such experiments have been proposed for FY08.

Edge Turbulence

During FY07, PPPL scientists continued their studies of edge turbulence on the Alcator C-Mod tokamak. A new gas-puff imaging telescope was designed and installed on Alcator C-Mod to view the lower-divertor region. Initial data shows a new and interesting radial "finger-like" structure just above the X-point, which has not been seen before (Figure 5). Preliminary comparisons with the BOUT edge turbulence code show a similar structure.

During this period, experiments were carried out on Alcator C-Mod that directly compared the measured edge turbulence with the GEM code simulation of Bruce Scott. The main conclusion of this comparison was that the radial and poloidal correlation lengths of the edge turbulence are nearly independent of the toroidal magnetic field strength in both the simulation and the data. This is qualitatively different than the prediction of linear drift wave theory.

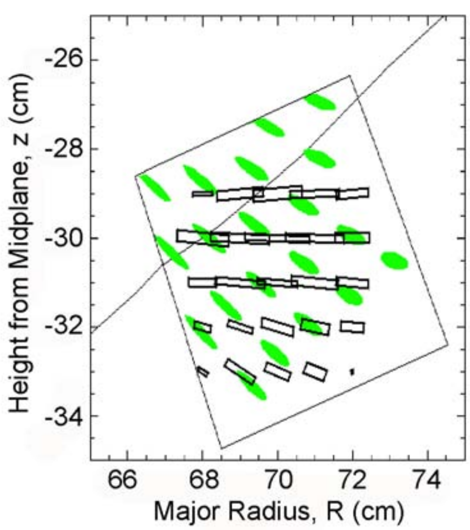


Figure 5. Two-dimensional image of edge turbulence blobs (green) and model predictions (black) showing new finger-like structures that have not been seen before.

X-Ray Crystal Spectrometer

Plasma rotation and momentum transport are presently areas of intense study. To facilitate these studies on Alcator C-Mod, PPPL in conjunction with MIT fabricated, installed, calibrated, and operated a novel curved-crystal X-ray spectrometer that provides profile measurements of ion temperature and rotation speed by viewing X-Ray emission from hydrogen- and helium-like argon. This system provides for effective 30 to 50 radial chordal profile measurements with about 10-ms time resolution. This diagnostic has proven to be extremely effective on C-Mod and now is being considered as an add-on for ITER.

Effect of Secondary Beam Neutrals on MSE Calibration

PPPL scientists continued to develop the Motional Stark Effect (MSE) diagnostic on Alcator C-Mod. The physics of effects of "secondary" emission of Hα light by beam neutrals on MSE beam-into-gas calibrations has been studied. Beam neutrals ionize through collisions with gas, gyrate about magnetic field lines thereby changing their angle with respect to the magnetic field, and then recharge exchange into the n = 3 state and emit an Hα photon.

An extensive series of experiments were carried out to determine why the polarization angles measured by the MSE diagnostic are not reproducible. The present understanding is that the variability results from stress-induced birefringence on the MSE in-vessel lenses, where the stress originates from plasma heating of the MSE optical canister. The support mechanism is now being redesigned to significantly reduce the thermal stresses that are transmitted to the lenses.

For the first time on Alcator C-Mod during lower-hybrid current-drive experiments, the MSE diagnostic measured changes in the local pitch angle (about 0.5°) in channels off-axis. This supports the assertion that LHCD should be concentrated well away from the center of the current channel.

International Collaborations

To take full advantage of the world's investment in fusion research facilities and to better prepare PPPL researchers for the ITER project, The U.S. Department of Energy funds a program in international collaborations. This allows PPPL researchers access to the Joint European Tokamak (JET) tokamak in the United Kingdom and to the JT-60U tokamak in Japan, both of which have plasma parameters closest to ITER. Laboratory staff also have access to the new long-pulse superconducting tokamaks being constructed in Korea and Japan and to stellarator devices worldwide in preparation for the U.S. revival in stellarator research.

JET Collaboration

The Princeton Plasma Physics Laboratory's participation on the JET device is comprised of several distinctively different research efforts with the primary focus being the PPPL-installed microwave interferometer and the escaping alpha detectors.

The PPPL microwave reflectometer is fully operational and is routinely used for the detection of short-scale turbulent fluctuations and Alfvén waves on the JET tokamak. Studies of the radial scale of density fluctuations and Alfvén waves were performed.

Noise evaluations of the lost-alpha system were conducted during four visits to JET. These evaluations tested Faraday cup loss diagnostic instrumentation, isolated failed channels, and resulted in reduced noise levels registered by the detectors. The detectors also supplied data during two JET experiments on toroidal-field ripple loss of energetic ions.

Collaboration continued both in using and in developing the TRANSP code for JET plasmas. During the past year, at the request of the JET users, a number of minor improvements to the TRANSP run production system were performed. Support was also provided for maintenance of the TRANSP run production system that operates at the JET site. Additionally, PPPL staff did troubleshooting on several crashed JET TRANSP code runs, and answered many questions from the JET TRANSP users. Though most of the JET run productions are done at JET, PPPL also processed a number of JET runs. The rate of PPPL JET runs has gone up significantly; fiscal year 2007 saw 309 runs compared to 51 runs in FY06 and 33 runs in FY05.

NOVA-K code analysis was performed on JET plasmas to identify the nature of the excitation mechanism for Alfvén eigenmodes driven by neutral-beam ions at high toroidal field. Analysis indicates that substantial drive comes from the anisotropy of the beam-ion distribution. Beam-ion velocities below one-third the Alfvén speed were still effective in exciting toroidicity-induced Alfvén eigenmodes (TAEs) in JET plasmas, indicating that the fundamental resonance condition is not satisfied. Reversed-shear Alfvén eigenmodes were observed during the current ramp-up phases in JET discharges, and were deduced to occur due to elongation effects.

The EDGE2D code was run from PPPL concentrating on carbon migration studies and explaining the observed ^{13}C deposition following the 2004 JET experimental campaign. Significant progress was made in understanding the role of carbon neutrals in the migration.

KSTAR Collaboration

The Annual U.S.-Korean Meeting was held at Taejon, Korea, 12-13 September 2007. Transition from the engineering construction phase to the operation phase of KSTAR was quite notable. A series of presentations from the KSTAR team explained the operation plan and research milestones for KSTAR. The PPPL team presented updates on research and work discussed at the FY06 Princeton meeting. A summary of the conventional profile diagnostics (Thomson scattering, Motional Stark Effect, and Charge-exchange Recombination Spectroscopy) and pellet injection was presented and the results will be used by KSTAR in their research.

There was a special session for plasma operation and control with U.S. experts who attended the Experimental Advanced Superconducting Tokamak (EAST) startup operation last year in Hefei, China. KSTAR has requested participation of plasma operation experts from the U.S. for first plasma. PPPL personnel will participate as they did for the EAST tokamak start-up. An official ceremony marking the completion of KSTAR construction was held at the end of the US-Korean Meeting. The President of Korea and many other national and foreign dignitaries including PPPL representatives attended this ceremony.

In a separate contract with the Korean National Fusion Research Institute, PPPL fabricated an innovative shutter system for the Thomson scattering system on KSTAR. The system was fully tested at PPPL and shipped to the National Fusion Research Institute.

JT-60U Collaboration

As part of the continuing PPPL/Japanese Atomic Energy Agency collaboration, PPPL scientists worked with the JT-60U Negative Ion Group to understand the physical processes limiting the performance of the first generation of large negative-ion sources and to use this knowledge to improve the next generation for ITER and other large devices such as JT-60SA (Advanced Superconducting Tokamak). The Japanese collaboration is synergistic with tasks relating to the heating and current drive for the ITER Design Review Working Group.

Princeton Plasma Physics Laboratory researchers proposed a novel type of negative-ion neutralizer using a supersonic lithium vapor jet. If implemented on the ITER neutral beams or on beams for fusion power plants, it would reduce the total gas load into the beamline by 75 to 80%, resulting in a factor of four to five increase in the run time between cryopanel regeneration, making steady-state beam operation feasible with advanced pumping techniques. This would not be practical with the present gas loads. The lithium jet would also permit higher neutralization efficiencies, reduce the heat load on the accelerator, ion source, and beam duct, and would increase the electrical efficiency and total beam power by 15 to 20% or more.

As part of the ITER design review work, PPPL researchers oversaw a study conducted in Japan to understand why beamlet steering using aperture-offset steering failed to work in the JT-60U accelerator. The study was conducted to determine whether beamlet steering could be made to work in the ITER accelerator using a different distribution of offsets as suggested by PPPL. This study is still underway and appears to be yielding plausible results.

About six years ago researchers recognized that the reason the original beamlet steering design failed on JT-60U was because the steering forces were inadequate to overcome the opposing space-charge forces that resulted when the overall beam envelope was compressed within the accelerator. PPPL researchers proposed that a hollow beam would be much easier to compress. The hollow beam could be produced by eliminating the central two columns of beamlet apertures. This would have the added major advantage of making it practical to use a supercusp magnetic filter (more recently called a tent filter) of the sort used on positive-ion sources in the 1970s and 1980s. This resulted in much more uniform plasmas than the filters used on the Japanese negative-ion sources of the past 18 years. The disadvantage of the tent filter is that the magnetic field reaches a null on the centerline of the source. While not a problem in positive-ion sources, this would result in large co-extracted electron currents in a negative-ion accelerator. A solution to this problem is to eliminate beam extraction from the centerline of the source. The improved beam uniformity and beam profile focusing would likely compensate for the loss of some current extraction area.

While examining the profile on the beamline electron dump this last spring, researchers realized that the electrons were being focused by the fringe field of the plasma grid magnetic filter. While perfectly plausible, it was not expected that the fringe field would have enough structure to produce an electron focal length of only a few meters. The ion focal length was estimated, but researchers concluded that it was too long to be of more than minor help on JT-60SA or ITER.

Reasonably routine monitoring of the oxygen levels in the negative ion source was started this year. If pursued systematically enough, this may allow a determination of the ultimate origin of the oxygen, which deactivates the cesium used to enhance negative-ion production.

PPPL's Negative Neutral Beam Injection collaboration with the National Institute for Fusion Science (NIFS) in Japan also continued during FY07. NIFS has used spectroscopic techniques to measure oxygen levels and cesium evolution during beam extraction, as well as beam stripping in the accelerator.

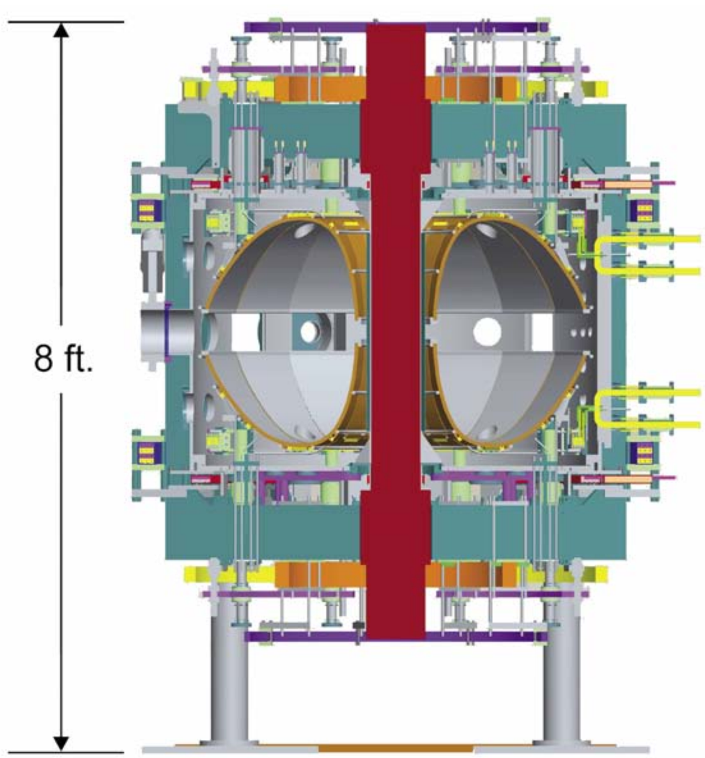
A paper on neutralizer techniques and the lithium jet neutralizer, which increases the reactor relevance of neutral beams, was published in Physics of Plasmas. There were also several co-authored papers from the JT-60U collaboration.

Stellarator Collaborations

PPPL maintains a variety of collaborations on stellarators worldwide in preparation for research on the National Compact Stellarator Experiment (NCSX). These included experiments on Alfvén eigenmodes on the H-1 device in Australia, continued analysis of data from the German W7-AS stellarator on beta limits, and gas-puff imaging experiments on the TJ-II device in Spain. A long-term agreement between the Institut für Plasmaphysik (IPP) Garching, Germany and PPPL on Electron Cyclotron Heating research was signed, which included transfer of 70-GHz equipment from IPP to PPPL. PPPL personnel participated in international workshops leading to formation of an international database on confinement data in stellarators.

Return to Table of Contents

Lithium Tokamak Experiment



Lithium Tokamak Experiment

The primary goal of the Lithium Tokamak Experiment (LTX) is to investigate liquid lithium as a plasma-facing component (PFC). The LTX program extends the successful experiments on the Current Drive Experiment-Upgrade (CDX-U), where large-area liquid-lithium PFCs were first used. These were concluded in 2005, during the initial construction phase of LTX. A promising characteristic of liquid-lithium PFCs is that they drastically reduce recycling, or the reintroduction of cold gas back into the plasma from the vacuum chamber walls. This is a result of the high chemical reactivity lithium has with atomic hydrogen, which is then retained in the PFC.

Major accomplishments on CDX-U included discharges with global recycling coefficients of ~75%, and a factor of six relative improvement in the energy confinement time for ohmic discharges. Both of these results are world records for the tokamak program, and constitute a strong justification for the research program on LTX. In FY07, a first-principles transport model implemented within the ASTRA code was successfully used to simulate the CDX-U confinement results. Performance projections for LTX based on this model indicate that confinement times of order 50 ms can be achieved in this modest-scale device, with very low recycling walls. Their confirmation will be a major objective of LTX plasma operations, which are scheduled to begin in FY08.

Modeling of Recycling in CDX-U

On CDX-U, the amount of visible light emitted by atomic deuterium (D_α emission) was used to determine how much of it was absorbed by the lithium PFCs, and hence determine the degree of deuterium recycling. However, the mirror-like surface of the liquid lithium also reflected light from other sources beyond the direct view of the detector. This stray light could lead to an underestimate of the deuterium absorbed by the lithium, and computer modeling was used to estimate the magnitude of this effect.

The D_α emission from CDX-U plasmas was measured with detectors called filterscopes. These consisted of telescopes connected by optical fibers to photomultiplier tubes with interference filters in the visible D_α wavelength. The telescopes were oriented to view the toroidal liquid-lithium limiter on the bottom of vacuum vessel and the center stack. The measurements were used as input for the DEGAS 2 neutral transport code. This program takes into account the exact machine geometry [Figure 1(a)], and uses Monte-Carlo techniques to evaluate the role of charge-exchange, ionization, dissociation, recombination, and excitation in plasma-neutral interactions when calculating the recycling coefficient (R) for CDX-U discharges.

The commercial ray-tracing code RADIANCE was used to determine the effects of reflections on filterscope signals, and hence their influence on the recycling coefficient as obtained with the DEGAS 2 program. Figure 1(b) shows the interior of the CDX-U vacuum vessel as modeled with the RADIANCE code. Light from the excitation of neutral gas from a gas puffer illuminates the center stack. This casts a shadow across the liquid-lithium limiter, which appears as a semicircle across the figure. The circle indicates the field-of-view the filterscope has of the limiter. The gas puffer is the largest source of stray light, and the RADIANCE calculations indicated that, at most, it had a ten percent effect on the values of the recycling coefficient from the DEGAS 2 code. Nonetheless, this is the first time that D_α emission data have been corrected for the reflectivity of PFCs. It could be important for future metal-wall machines like ITER.

Development of Lyman-α Diagnostic for LTX

The problems associated with the reflection of visible light will be reduced in LTX with the detection of ultraviolet Lyman-alpha (Ly-α) emission to measure recycling. This is because liquid lithium reflects very little ultraviolet light. A prototype Lyman-alpha diagnostic was assembled and tested. The detector consisted of a photodiode, sensitive to extreme ultraviolet wavelengths, with a filter for Ly-α light deposited directly onto its surface. This forms a compact package that is compatible with vacuum.

Calibration of visible detectors is straightforward with light sources of known intensity and geometry. It is much more difficult to calibrate photodiodes at shorter wavelengths, however. The approach used for the Ly-α diagnostic was to mount it on a test facility that included a hydrogen beam and a target chamber (Figure 2). A visible avalanche photodiode (APD) detector of known characteristics was also installed to view the same region. The Ly-α diagnostic could then be calibrated by comparing its signals with measurements from the APD detector.

The emission from the hydrogen beam is due to collisionally-induced fluorescence (CIF) as it interacts with the gas in the target chamber. To determine the CIF signals expected in the visible and Ly-α wavelengths, the populations of excited atomic states need to be found. They are determined by various processes, including excitation by collisions, ionization, neutralization of ions into specific states, spontaneous emission, and dissociative collisions. With the known collisional cross sections for each

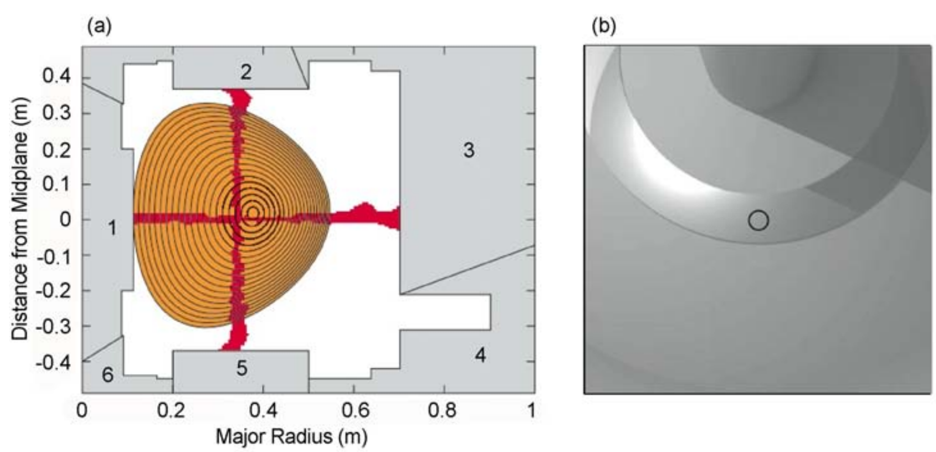


Figure 1. (a) DEGAS2 code cross section of CDX-U. The numbered segments indicate the different plasma-facing regions used in the modeling, and the irregular horizontal and vertical lines represent the paths over which the filterscope signals are integrated. (b) Representation of CDX-U in RADIANCE code. The view shows the bottom of the vacuum vessel, with the base of the center stack at the top and the liquid-lithium limiter forming an arc below it.

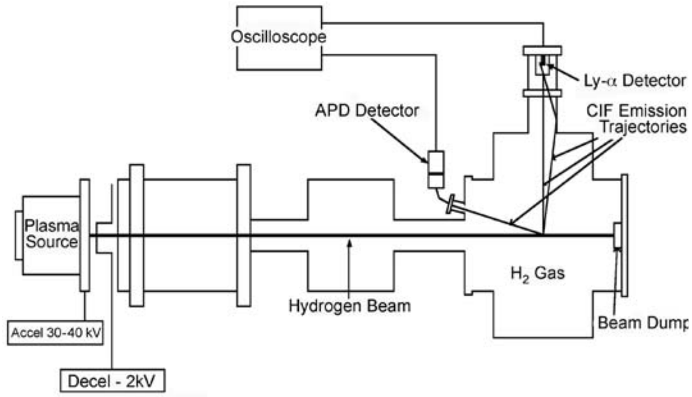


Figure 2. Schematic of test facility for calibrating prototype Ly-α diagnostic. The visible avalanche photodiode (APD) and the Ly-α detectors view the same region where the collisionally-induced fluorescence (CIF) of the hydrogen beam occurs. One of the CIF emission trajectories indicates reflection from the side of the Ly-α detector mounting tube.

process, the population of each atomic level can be calculated.

The CIF calculations were performed for the hydrogen beam on the test facility. The measured Ly-α signals, however, were significantly higher than the modeling predictions. Sources of uncertainty include the hydrogen beam profile and the relatively high reflectivity of stainless steel at Ly-α wavelengths. This is a concern because the Ly-α diagnostic was mounted on a relatively long stainless steel tube on the test facility. This geometry will be avoided when the system is implemented on LTX.

Figure 3. Lower vacuum vessel lid showing external coil mounting structures and new poloidal-field coil (red). The wheels are attached temporarily to allow ease of movement from the assembly area to the machine room where LTX will be operated.

Fabrication of Components for LTX

The LTX device will combine existing CDX-U hardware with new features such as a conformal lithium-coated wall and new poloidal-field coils and power supplies. The former will be accomplished with an internal-heated shell that conforms to the plasma boundary. The shell provides a low-recycling PFC, which is created by evaporating a thin layer of lithium on its inner surface. The supports for the shell not only have to bear its weight, but provide electrical isolation as well. These structures were fabricated in FY07, and the set that supports one of the new poloidal-field coils is shown on the lower vacuum vessel lid in Figure 3.

The LTX device is designed to operate at higher plasma currents and have improved equilibrium control compared to CDX-U. This necessitated the fabrication of six new poloidal-field coils. They include two pairs of 12-turn vertical-field coils (Figure 4), which were fabricated by an external vendor. The third set is a pair of five-turn coils that are being wound

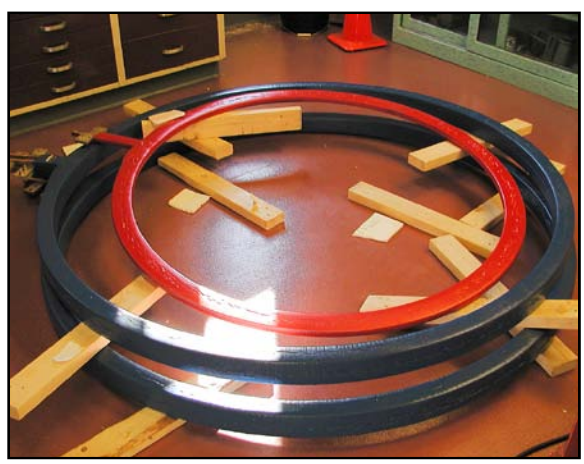


Figure 4. New external poloidal-field coils for LTX prior to installation (internal coils not shown).

at the Princeton Plasma Physics Laboratory and will be mounted inside the LTX vacuum vessel to provide fast response for plasma control.

Numerous additional modifications to the CDX-U vacuum vessel were required to accommodate the new support structures and other features of LTX. These were completed in FY07, and the vacuum vessel was reassembled. Major concerns included the integrity of the new welds and the effects of changes to O-ring configurations. They were shown not be an issue with the successful pumpdown of the vacuum vessel (Figure 5) at the end of FY07.

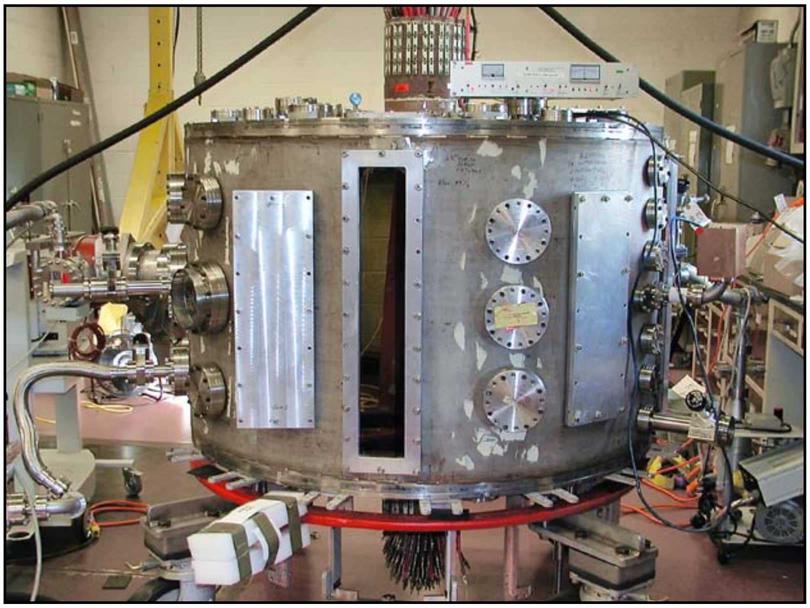
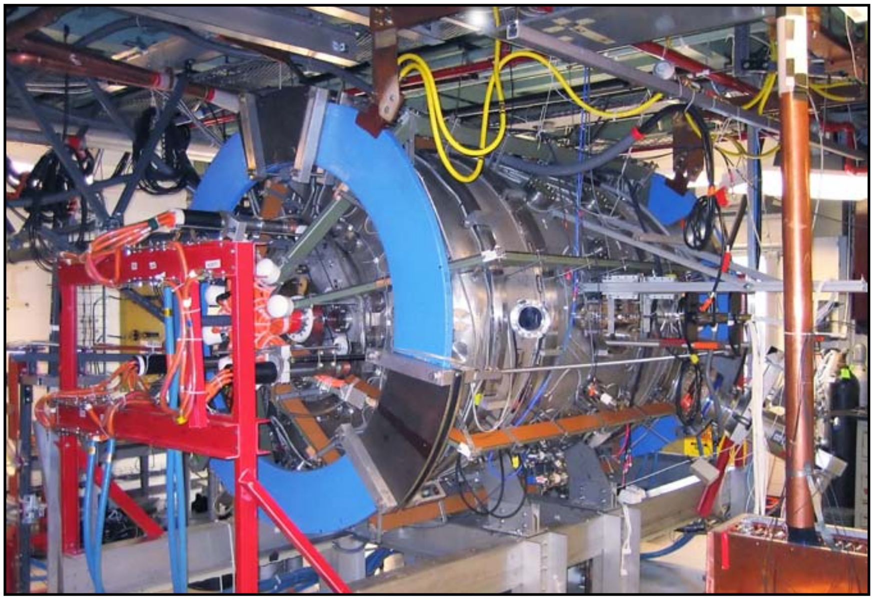


Figure 5. Assembled LTX vacuum vessel attached to pumping station.

Return to Table of Contents

Magnetic Reconnection Experiment



Magnetic Reconnection Experiment

The Magnetic Reconnection Experiment was built to study magnetic reconnection (Figure 1) as a fundamental plasma process in a controlled laboratory environment. Magnetic Reconnection — the topological breaking, annihilation, and reconnection of magnetic field lines — occurs in virtually all magnetized plasmas, both in the laboratory and in nature. Reconnection plays an important role in the evolution of solar flares, coronal heating, and in the dynamics of the Earth's magnetosphere. Reconnection at the dayside magnetopause is often considered as the onset and triggering of such events as auroral substorms and geomagnetic storms.

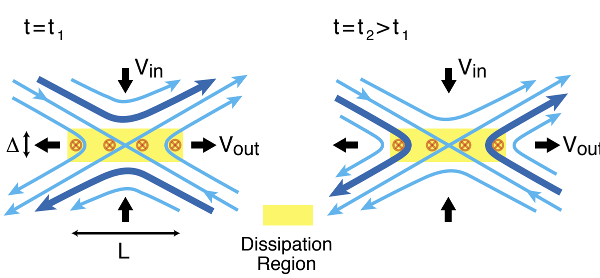


Figure 1. The process of magnetic reconnection. The dark field lines in the left frame move toward the dissipation region and magnetic reconnection occurs. After reconnection, the field lines move into the outflow region, as illustrated in the right frame.

Figure 2 illustrates the solar-wind interaction with the magnetosphere. The plasma on the incoming solar wind is embedded on solar wind lines that are different from the magnetospheric lines. If the field lines are in fully conductive plasmas, there is no way, according to classical theory, for the solar wind field and energetic particles to penetrate into the earth's magnetosphere. The solar wind would be accordingly forced to move around the magnetosphere. This is where magnetic reconnection comes into play. Because of the occurrence of magnetic reconnection in the interface region where plasma is not infinitely conducting, the solar wind lines can break near the surface separating them, and they can reattach to lines in the

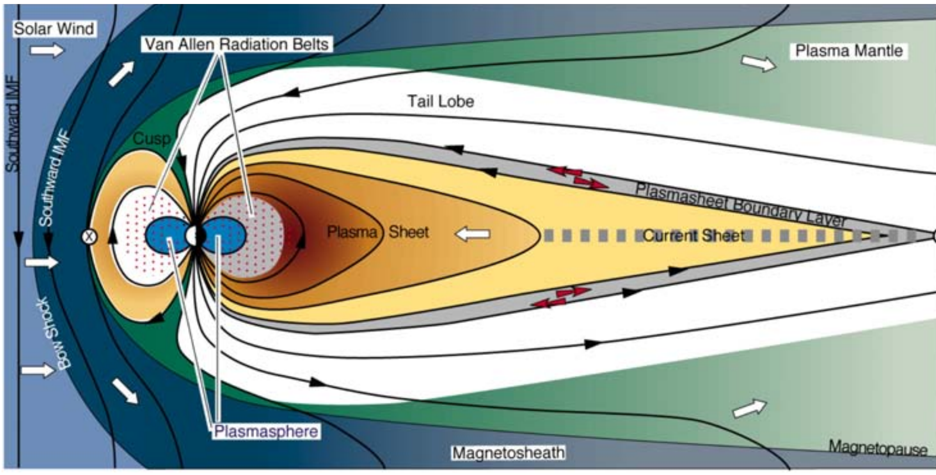


Figure 2. Cross section of the simplest model of the magnetosphere in the day and night meridian. (Courtesy of Rice Space Institute, Rice University, Houston, Texas. Figure can be found at: http://space.rice.edu/IMAGE/livefrom/5_magnetosphere.jpg.)

magnetosphere, which also break. As a result some of the solar wind lines end up attached to the magnetosphere, and the solar wind plasma can then penetrate the magnetosphere.

In spite of its omnipresence in magnetized plasma, magnetic reconnection is not well understood. The predictions of the classical magnetohydodynamic (MHD) theories as to how fast magnetic reconnection should occur conflict with measured rate, both in laboratory and space, and realistic particle-in-cell simulations are not possible. All of this makes experimental studies vital to the understanding of magnetic reconnection.

The Magnetic Reconnection Experiment (MRX) has been very productive since it was built in 1995, contributing immensely to both science and education, with countless papers and many Ph.D. theses. Because of its importance, MRX is jointly supported by U.S. Department of Energy (DOE), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA).

Research Objectives

The primary purpose of MRX is the comprehensive analysis of magnetic reconnection and related physics, crucial for understanding self-organization phenomena of fusion plasmas as well as solar and magnetospheric plasmas. The analysis focuses on the coupling between local microscale features of the reconnection layer and global properties such as external driving force, MHD flows, and the evolution of the plasma equilibrium. In particular, MRX has the following research goals:

- Test 2-D and 3-D theoretical models of reconnection layers, and compare the results to state-of-the-art numerical simulations.
- Investigate the role of effects beyond resistive MHD (turbulence and Hall-MHD) in determining the reconnection rate and spatial structure of the reconnection layer.
- Study the mechanisms of conversion of magnetic energy to plasma kinetic and thermal energy.
- Explore the role of boundary effects on the rate and spatial structure of magnetic reconnection.
- Explore the application of magnetic reconnection science to fusion concepts, including spheromak merging for the formation of large-flux field-reversed configurations (FRCs).

MRX has achieved many important results in the field of magnetic reconnection, and continues to provide high-quality data for comparison with analytic theory, numerical simulation, and space and solar observations. Previous research demonstrated that reconnection in MRX can be accurately modeled using a generalized Sweet-Parker model, as long as the model is generalized to include the effects of downstream pressure and a phenomenological effective resistivity. This effective resistivity, which can be much larger than that caused by simple collisions, provides the enhanced dissipation required to break magnetic field lines. There are many physical processes that can provide the source of this resistivity, and studying these processes is a key goal of MRX research.

Subsequent measurements indicated that substantial magnetic fluctuations can occur at the current sheet center. These fluctuations were shown to be correlated with the enhanced effective resistivity, indicating that they may play an important role in causing fast reconnection. Theoretically, it was shown that the large relative drift between electrons and ions in the current sheet can give rise to electromagnetic waves, and that these waves can lead to enhanced resistivity.

Further research also yielded the first-ever measurement of the Hall effect in a laboratory plasma, by studying the quadrapole out-of-plane magnetic field. The Hall effect is due to the decoupling of electron and ion motions in the vicinity of the reconnection region. This decoupling allows the ions to avoid passing through the center of the reconnection layer, enabling fast reconnection. The decoupling also leads to currents in the plane of magnetic reconnection, which produce the quadruple out-of-plane field. It is important to note, however, that the Hall effect cannot cause the dissipation required to break magnetic field lines: the reconnection rate can be determined by the Hall effect, but a full physics understanding requires a further examination of the detailed region where magnetic field lines are broken.

A campaign of experiments included further studies of the "fine-structure" of the diffusion region, yielding the first ever identification of the electron diffusion region in a laboratory plasma.

Extensive field-reversed configuration studies have been done in MRX, and a better understanding of the dependency of field-reversed configuration stability on plasma shape and kinetic parameters has been obtained. Oblate field-reversed configuration plasmas have been sustained for up to 350 μs.

Experimental Device

The key components of the MRX device are two flux cores: doughnut-shaped devices containing multiple magnet windings that inductively produce the plasma and magnetic fields in MRX. These flux cores allow two distinct magnetic reconnection geometries in MRX. In the geometry that has been utilized most frequently to date, plasma is formed around the cores and then the currents in the windings are quickly decreased. This has the effect of pulling oppositely directed magnetic fields together, causing magnetic reconnection to occur and a current sheet to form. This geometry causes long-lived and stable current sheets, allowing detailed study of reconnection physics. The flexibility of this configuration is further enhanced by the ability to form current sheets with a guide-field (co-helicity), or without a guide-field (null-helicity) (see Figure 3). In the second type of configuration, the programming of the currents in the flux cores is changed, so that two independent toroidal plasmas (spheromaks) are formed adjacent to the flux cores, and then allowed to merge via their mutual attractive force. Magnetic reconnection occurs during this merging, and a fusion-relevant field-reversed configuration is formed.

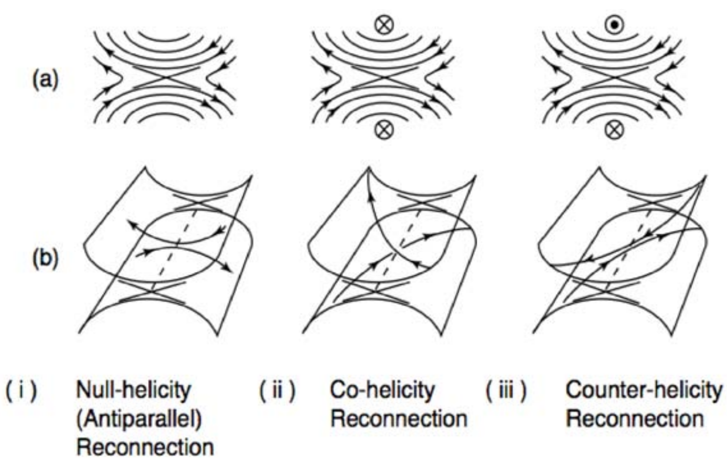


Figure 3. Illustration of three-component field-line reconnection. (a) Two-dimensional picture is independent of out-of-plane field, but (b) three-dimenswional picture is clearly different. Out-of-plane magnetic fields in the merging plasmas are (i) zero for null-helicity, (ii) finite and add for co-helicity, and (iii) finite and cancel for counter-helicity.

A set of carefully chosen diagnostics provides insight into the physics of magnetic reconnection and real-time monitoring of MRX plasmas. These include Langmuir probes (electron density, electron temperature, and plasma flows), spectroscopic probes (ion temperature and flows), magnetic probes (spatial and temporal structure of the magnetic field) and large pick-up loops (global currents and magnetic fluxes).

Fiscal Year Highlights

Electron Diffusion Region

Previously, an electron diffusion region was identified for the first time in a laboratory plasma. A kinetic numerical simulation, with boundary conditions similar to the MRX, was carried out using a PIC (particle-in-cell code) by W. Daughton . Simulation parameters are chosen such that the global reconnection rate and the current sheet thickness on the ion scale match the observations. An example of comparison is shown in Figure 4(d-f) in the same format as in Figure 4(a-c). Most of the observed features, including geometrical shapes and out-of-plane magnetic component, are reproduced. However, the quantitative agreement between experiment and simulation is found for the global ion dynamics but not for the detailed local electron dynamics. The fact that the observed elec-

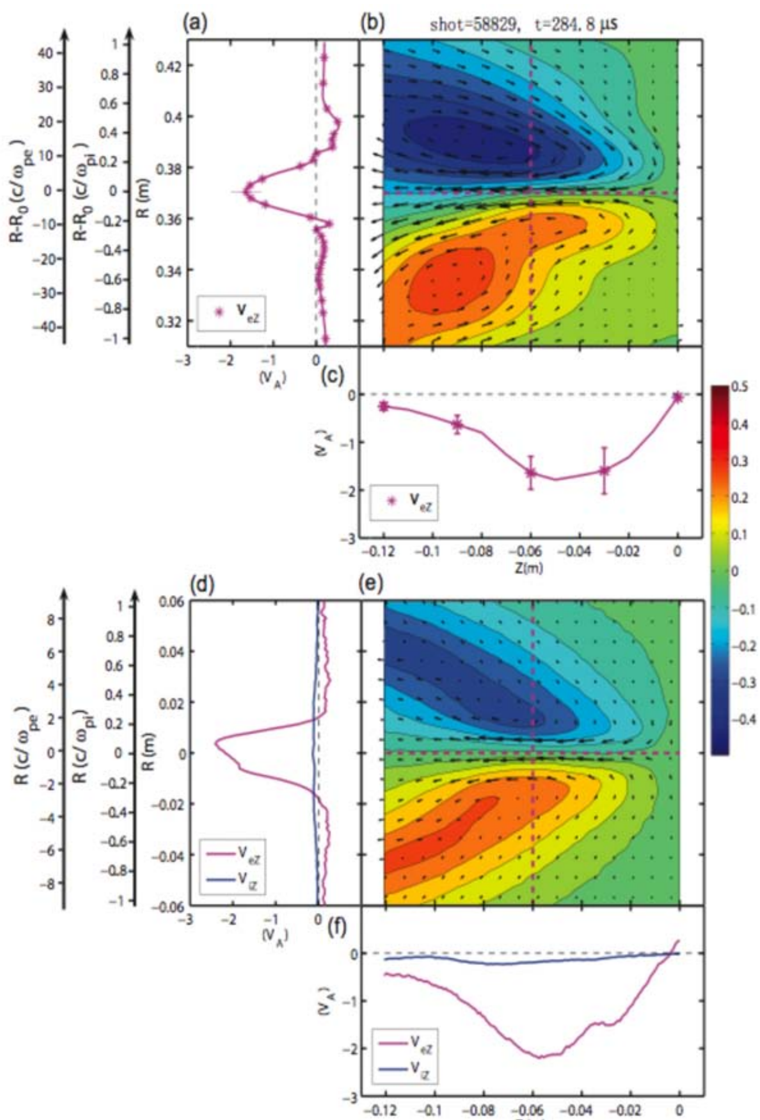


Figure 4. Identification of electron dissipation layer. The top three panels (a-c) show an experimental example taken from a hydrogen plasma with a fill pressure of 2 mTorr. Results from a corresponding simulation are: initial density = 2.6 × 10^{19} cm^{-3}, $m_i = m_{hydrogen}$, $m_e = m_{hydrogen}/75$, where m_i is ion mass and m_e is electron mass.

tron layers are substantially broader than the numerical predictions implies different dissipation mechanisms operating between these two cases. Because the kinetic model contains all possible collisionless kinetic mechanisms operative in 2-D, these dominant mechanisms might be 3-D in character. More studies will be carried out in the future.

Effects of Guide Field on Reconnection

In FY07, the MRX device went through a minor upgrade. In nature magnetic reconnection is always 3-D, i.e., the reconnecting field lines merge at an angle. To study systematically the effects of guide field, a new toroidal-field coil set powered by a 50-kJ capacitor bank capable of producing a uniform guide field with strengths up to 1,000 G was installed on MRX. An additional feature of the guide-field reconnection is that one can produce more reproducible plasmas compared to the original method, which uses the internal toroidal-field coils to inductively produce the plasma. Extensive guide-field studies are planned as one of the main ongoing research topics on MRX.

Effects of Boundary Conditions and Local Collisionality on Reconnection

Effect of local collisionality and boundary conditions was investigated in MRX. For the first time in a laboratory plasma, it was shown that the reconnection rate is determined generally as a result of an interplay between collisionality-dependent local dynamics and global boundary conditions. At a given system size, the current sheet is shortened and the effective resistivity is enhanced when the collisionality is lowered. Figure 5 shows key physical quantities versus inverse plasma collisionality. When the fill pressure, and thus the collisionality, is reduced, the effective resistivity η becomes larger than the Spitzer value, while the current sheet length becomes shorter. This provides strong evidence that the current sheet length is not simply set by the system size, as assumed in the classical Sweet-Parker model, but rather is collisionality dependent. Therefore, the resistivity enhancement and current sheet shortening are closely coupled in MRX, in sharp contrast to traditional theories. This can be understood as a consequence of the fact that the current sheet thickness is limited by the ion-skin depth. When the system size is increased at a fixed collisionality, the current sheet length increases, resulting in slower reconnection. These results quantitatively agree with a generalized Sweet-Parker analysis.

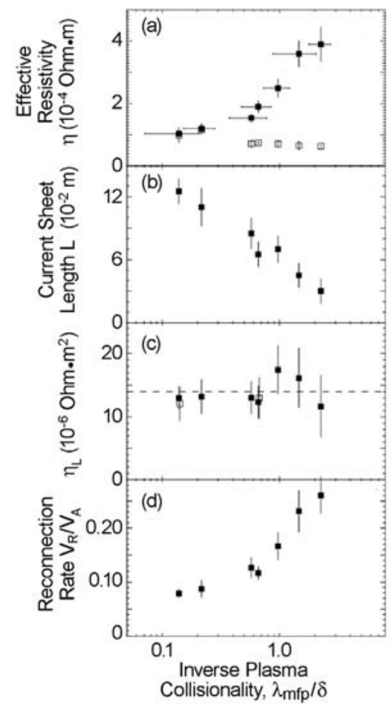


Figure 5 (a) Effective resistivity (filled squares) along with the Spitzer resistivity (open squares), (b) current sheet length, (c) product of the effective resistivity and the current sheet length (filled squares) and prediction of the generalized Sweet-Parker model (open squares), and (d) reconnection rate V_R/V_{VA} versus inverse plasma collisionality, λ_{mfp}/δ at Z_0 = 50 cm.

A New Method for Formation of a Sustainable Field-reversed Configuration

The center solenoid is a tightly wound cylindrical coil, with a radius of 10 cm, inserted down the center of the MRX device (see Figure 6). This coil acts as the primary coil of a transformer, while the plasma acts as the secondary coil. In MRX this inductive current drive has been utilized to convert a spheromak into an field-reversed configuration (FRC) (see Figure 7).

These results have important implications for the understanding of FRC formation and equilibrium. Spheromak formation via co-helicity merging was utilized for convenience in MRX; however, it is possible to use a single flux-core to produce a single spheromak, which could be "converted" to an FRC utilizing solenoid induction. The FRC could then be translated away from this formation region and into a simply connected "confinement" region. This scheme allows for a "black-box" plasma source capable of forming either a low-beta spheromak or a high-beta FRC, depending on the utilization of the solenoid, with the exact same hardware.

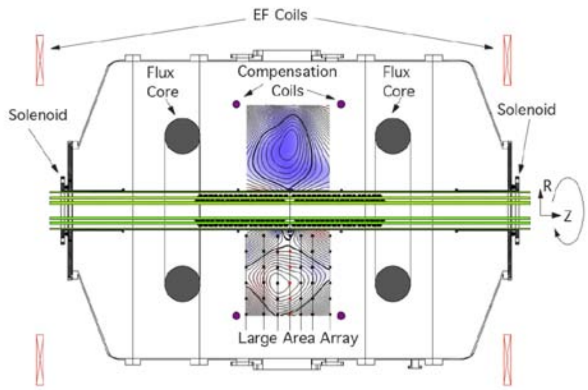


Figure 6. Schematic of the MRX device showing the poloidal flux (contours) and toroidal field (colors) of a typical spheromak (top) and a field-reversed configuration (bottom). Studies of the sustainment of field-reversed configuration plasmas using an inductive center solenoid that started at the end of FY06 were completed. [S.P. Gerhardt E.V. Belova, M. Yamada, et al., "Inductive Sustainment of a Field-Reversed Configuration Stabilized by Shaping, Magnetic Diffusion, and Finite-Larmor-Radius Effects," Phys. Rev. Lett. 99:24 (14 December 2007) Article No. 245003; S.P Gerhardt, E.V. Belova, M. Yamada, et al., "Inductive Sustainment of Oblate Field-reversed Configurations with the Assistance of Magnetic Diffusion, Shaping, and Finite-Larmor Radius Stabilization," Phys. Plasmas 15:2 (February 2008) Article No. 022503].

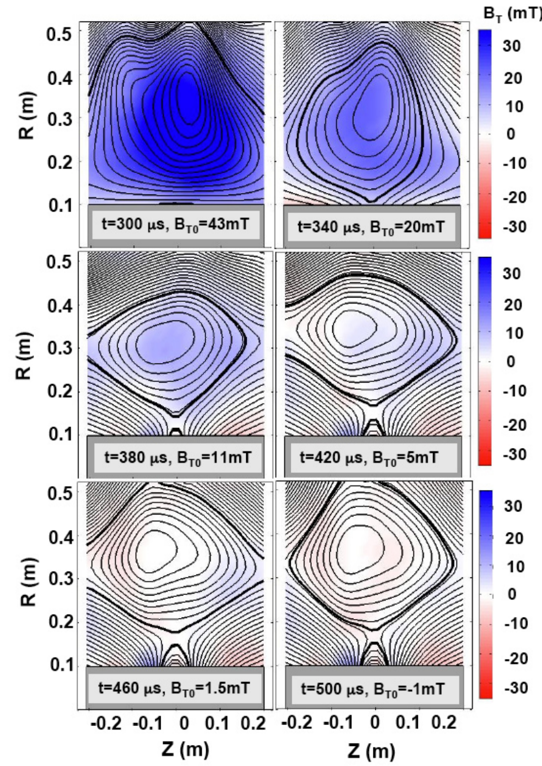


Figure 7. Two-dimensional measurements of the poloidal flux (contours) and toroidal field (colors, with central value listed) during the transition of a spheromak to an field-reversed configuration.

Return to Table of Contents

Plasma Science and Technology

The Princeton Plasma Physics Laboratory has an active program in Plasma Science and Technology that supports the Laboratory's mission to create new knowledge in plasma science and to use this knowledge to develop new plasma technologies. These projects generally consist of small experiments focused on a specific topic of interest. All of these projects have strong graduate and undergraduate participation, and many of them have ties to work being done in the PPPL Theory Department. The Lithium Tokamak Experiment, the Magnetic Reconnection Experiment, and Applications Research and Technology Transfer, discussed elsewhere in this report, form part of this program.

Some of these basic physics experiments lie at the frontiers of fusion research. For example, the novel Field-reversed Configuration Experiment is designed to create a remarkably efficient magnetic confinement system which could eventually be used to burn advanced fusion fuels, while the heavy ion fusion research aims to create and focus extremely high-intensity ion beams onto an inertial fusion target. These and all the other small experiments are strongly coupled to plasma physics research at other national laboratories and universities.

These experiments also have an important role in creating links between plasma physics and other areas of science and technology. For example, the work on high-intensity accelerators is directly applicable to future experiments in high-energy physics, and the Hall Thruster Experiment may develop into superior propulsion technologies for spacecraft.

Magnetorotational Instability Experiment

Accretion disks — the gas, dust, and plasma orbiting around strong gravitational sources — are responsible for the high luminosity of active galactic nuclei, neutron stars, and white dwarfs and facilitate star and planet formation. The rate of accretion is governed by how quickly angular momentum can be transported through the disk. Observations of accretion disk luminosity suggest that viscous transport is insufficient and so turbulence models are invoked to explain the enhanced rates of accretion. The instability responsible for the turbulent mixing in accretion disks is the magnetorotational instability or MRI.

The MRI is a local instability resulting from the Maxwell stress introduced by an ambient magnetic field coupled to the Keplerian sheared flow. The magnetic stress couples two fluid elements sharing a magnetic field line. If one fluid element is perturbed radially inward toward higher rotation rates, it will experience a loss of angular momentum due to the magnetic stress. The fluid element would then fall further inward. The other fluid element perturbed radially outward will gain angular momentum thereby pushing it farther outward. The instability is suppressed if the magnetic field is too strong to be stretched or if the resistive diffusion rearranges the magnetic field faster than the flow distorts it.

The MRI is sufficiently generic that it should be reproducible in an experimental apparatus known as a Taylor-Couette experiment where fluid flow is generated between rotating concentric cylinders. The MRI experiment at the Princeton Plasma Physics Laboratory (PPPL) is unique among Taylor-Couette devices due to the implementation of segmented rings that form the end-caps between the two cylinders. The differentially rotating rings substantially reduce the secondary circulation, known as Ekman pumping, created when standard end-caps are used. This secondary circulation would otherwise redistribute angular momentum, hindering identification of the MRI.

Previous hydrodynamic experiments using water in the apparatus have demonstrated that quasi-Keplerian flows (where the angular velocity decreases with radius whereas the angular momentum increases) generated by rotating cylinders and end-cap rings are essentially laminar for Reynolds numbers up to 2×10^6. The MRI experiment at PPPL has since been modified to use a liquid metal to perform the magnetohydrodynamic (MHD) experiments to demonstrate the MRI. The liquid metal used is a gallium alloy which is liquid at room temperature and which has sufficiently high conductivity to produce the magnetorotational instability.

The MRI apparatus consists of stainless steel inner and outer cylinders with acrylic rings that form the segmented end-caps described above. Six magnetic field coils coaxial with the cylinders create an axial magnetic field up to 0.5 Tesla. Diagnostics include an array of 39 pickup coils, six saddle coils, and eight Hall effect sensors for measuring the magnetic perturbations induced by the instability. A custom amplifier board with switched capacitor filtering was designed and built to measure the extremely faint signature of the MRI (10^{-3} gauss per second) despite the background noise from the motors and external field power supply.

A campaign of experiments was conducted to measure the induced radial magnetic field for a variety of velocity shear profiles. Figure 1 shows an example of a hydrodynamically turbulent flow created with the outer cylinder stationary. The inner cylinder and inner ring motors rotate for 60 seconds before the external magnetic field is turned on. The radial magnetic field, measured by a pickup coil near the midplane of the experiment, shows a growing oscillation when a 2.5-kG axial field is applied to an already turbulent flow. Further investigations are underway to determine the relevance of these oscillations to the magnetorotational instability.

A hydrodynamic wing to introduce pressure and magnetic field sensors into the fluid with minimal impact to the flow was built. The internal measurements will be used to measure the nonlinear saturation of the MRI. A torque sleeve has been proposed to measure the global angular momentum transport produced by the MRI and ultrasonic Doppler velocimetry will be used to measure the velocity profile. Results from the experiments will provide valuable insight into a fundamental astrophysical process critical to the understanding of star and planet formation.

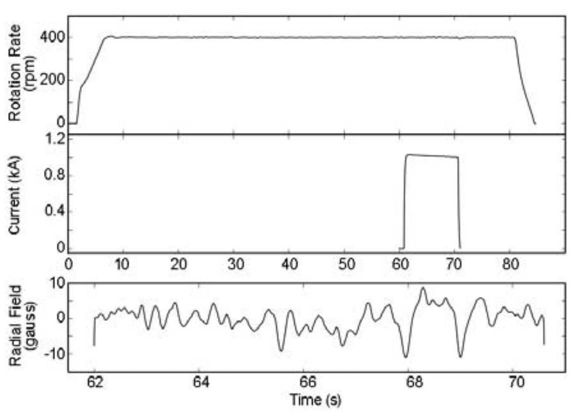


Figure 1. Time series measurements from turbulent flow with an applied magnetic field. The plots starting from the top include the inner cylinder rotation rate, the measured current in the external magnetic field coils, and the integrated signal from a pickup coil diagnostic.

Liquid Metal Experiment

Most MHD experiments using liquid metals have concentrated on instabilities and turbulence with closed boundaries. The Liquid Metal Experiment (LMX) is a small-scale laboratory experiment designed to explore the less developed field of free-surface MHDs.

Surface waves and turbulence are an essential component to processes in both astrophysical and laboratory plasmas. Energetic events such as X-ray bursts from neutron stars are thought to be related to the free-surface flows generated by accretion of material onto the dense plasma ocean on the star surface. Interest in using liquid metals in a first-wall application in fusion devices raises important questions about the stability of a free-surface flow of liquid metal subject to strong magnetic fields and high heat flux. The goal of LMX is to address the basic physics of MHD open-channel flow through experiments using a gallium alloy that is a liquid metal at room temperature.

Several questions on the basic physics of MHD channel flow will be addressed in LMX. The effects of the magnetic field on the flow profile have been shown to depend on the aspect ratio of the channel, i.e., the ratio of flow height to width. Experiments using large-aspect-ratio channels documented in the literature demonstrated flattening of the cross-channel velocity profile with increased transverse magnetic field strength. Previous LMX studies with a small aspect ratio channel, however, showed velocity profile peaking due to a reduction in the influence of the boundary layers on the channel walls. The LMX will be used to study the flow profile as a function of magnetic field, aspect ratio, and flow speed.

Changes to the stability of flow to surface waves will also be explored. Previous results indicate that driven surface waves are not affected by a magnetic field applied in the perpendicular direction of wave propagation while the waves are damped with a parallel magnetic field, in agreement with a linear stability analysis. Further exploration of nonlinear effects such as solitary waves is also planned.

Experiments will be conducted to assess MHD effects on shear stability, namely whether the flow is stabilized by the suppression of cross-field perturbations or destabilized by the introduction of new boundary layers or is subject to critical layer instabilities arising from a matching of the flow speed with the surface wave phase speed. Changes to heat trans-

Return to Table of Contents

port due to thermal convection will also be studied by applying both horizontal and vertical temperature gradients.

Velocimetry experiments to characterize the flow profile of a fast-moving thin layer of fluid through a wide channel were continued in FY07. The channel dimensions are shown in Figure 2. Surface fluctuations increase substantially due to gravity waves which are excited when the Froude number $Fr = v/(gh)^{1/2}$ exceeds unity where v is the flow velocity, g is the acceleration due to gravity, and h is the flow height. Typical flows are one centimeter thick with a critical surface flow speed of 30 cm/s. Laser Doppler velocimetry (LDV) measurements, shown in Figure 3, demonstrate that the flow profile is well modeled by a turbulent boundary layer using a log-wake law fitting model. Visualization experiments were performed by adding a rheoscopic fluid to the water. They revealed that the turbulent boundary layer is composed of numerous longitudinal (downstream) vortices with lengths varying from one to several times the flow thickness.

The channel was prepared for operation with a liquid metal. A new pump was designed that will minimize oxidization of the liquid metal and the channel and associated plumbing was pressure tested to assure the complete flow loop is gas tight. The channel was connected to an inert gas pneumatic transfer system that will convey the liquid metal between the channel and a storage tank. The magnet that will provide either a vertical or spanwise magnetic field across the channel was tested up to 3 kG. A 16-channel potential probe array diagnostic was developed to perform velocimetry by measuring the voltage induced between two electrodes when the magnetic field is applied and was demonstrated to provide adequate signals when it was immersed in the liquid metal flowing past a permanent magnet.

The upcoming liquid metal experiments should improve the general understanding of free-surface MHD flows and its application to both fusion and astrophysics.

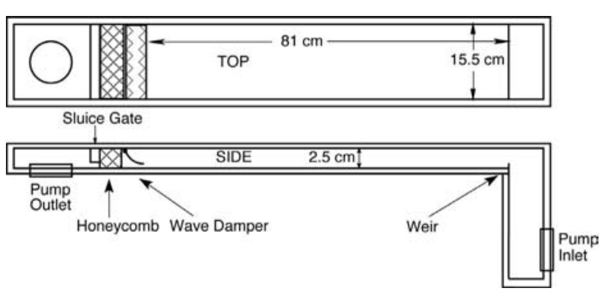


Figure 2. Schematic of the channel used in the Liquid Metal Experiment.

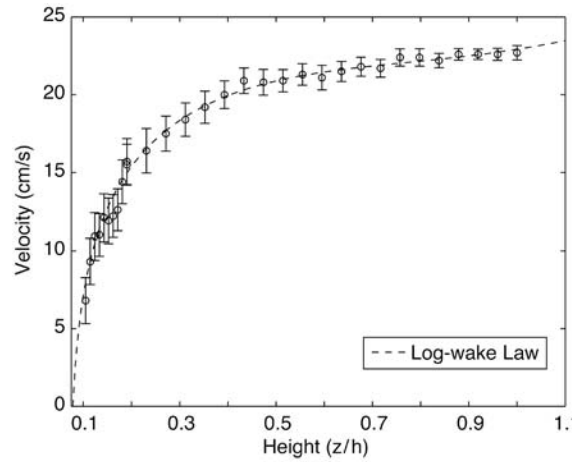


Figure 3. A fit of the laser Doppler velocimetry measurements of the flow profile to the Coles log-wake law for a turbulent boundary layer.

Magnetic Nozzle Experiment

The Magnetic Nozzle Experiment (MNX) studies the physics of mirror-geometry helicon-heated plasmas expanding through magnetic field gradients or mechanical apertures. Applications of MNX research are to fusion science, solar physics, and spacecraft propulsion. A productive collaboration with Professor E. Scime, West Virginia University (WVU), continued. In FY07, one graduate student, A. Sefkow, performed research on MNX.

Experimental investigations during FY07 included two-dimensional mappings of ion flow speed in a plasma column, performed at WVU with a laser-induced-fluorescence system. Ion acceleration to supersonic speeds occurred by passage through a double layer formed by magnetic expansion of argon plasmas sustained by absorption of helicon waves. A directed energy of ~$5T_e$ energy was achieved. These results were presented the *28th International Conference on Phenomena in Ionized Gases* [I.A. Biloiu, E.E. Scime, C. Biloiu, and S.A. Cohen, “Bimodal Argon Ion Velocity Distribution Functions Downstream of an Expanding Helicon Source Plasma,” in the *Proceedings of the 28th International Conference on Phenomena in Ionized Gases* (15–20 July 2007, Prague, Czech Republic), edited by J. Schmidt, M. Simek, S. Pekárek, and V. Prukner, pp 1537–1540.

Theoretical studies on the mechanisms determining the strength of the double layer were begun by Adam Sefkow using the particle-in-cell (PIC) code

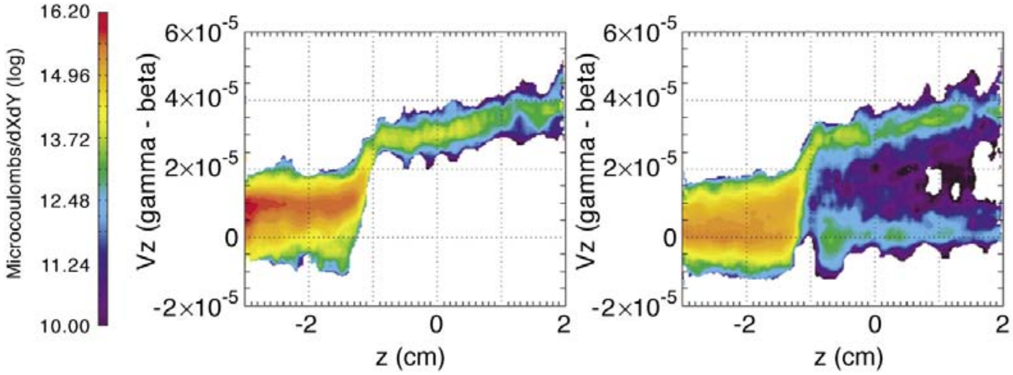


Figure 4. Particle-in Cell code simulations: velocity distribution of bulk argon ions (left panel) and newly formed ions (right panel), as a function of axial position. The double layer is located at z = -1.4 to -1 cm.

LSP (Large Plasma Simulations). The results were presented in an invited talk at the Helicon Mini-conference on Helicon Plasma Sources held at the *49th Annual Meeting of the American Physical Society Division of Plasma Physics* held in Orlando, Florida, 12–14 November 2007. The PIC simulations duplicate the experimental results of ion acceleration (see Figure 4) and have shown the presence of a superthermal electron component, generated by electron flow up the double layer. A strong correlation was noted between the strength of the double layer and the inverse of the mechanical aperture radius used in MNX. This implies that the ion transmission coefficient is an important element in determining the directed ion energy. Plasma oscillations, consistent with ion-acoustic waves, were also evident in the PIC simulations. Their role in ion acceleration is under study.

Princeton Field-reversed Configuration Experiment

The Princeton Field-reversed Configuration Experiment (PFRC) was built to study the physics of odd-parity rotating magnetic fields (RMF_o) interacting with magnetized plasmas. Theory predicts that field-reversed configurations (FRCs) formed by odd-parity rotating magnetic fields should develop a simple closed magnetic-field-line configuration, hence superior energy-confinement properties. Other favorable theoretical predictions for odd-parity rotating magnetic fields are excellent ion heating in the ion-cyclotron-range-of-frequencies and good electron heating, even far below the electron-cyclotron-resonance frequency. The PFRC was designed to use commercially available equipment and to operate at low power. Both choices improve facility safety and lower facility costs, important aspects to the eventual commercial success of fusion power.

Theoretical investigations during FY07 were continuations of studies on the mechanism for odd-parity rotating magnetic fields heating of ions. Findings were published in “Stochastic Ion Heating in an FRC by Rotating Magnetic Fields,” S.A. Cohen, A.S. Landsman, and A.H. Glasser, Phys. Plasmas **14**:7 (July 2007) Article No. 072508 (12 pages). They quantitatively show how ion energy depends on ion mass and how this will allow increased He^3 energy in a D-He^3 mixture, thus reducing neutron generation from D-D fusion (see Figure 5).

Results achieved in the experimental program continued to improve. High-beta hydrogen plasmas with a low Coulomb collisionality ($\nu^* < 4 \times 10^{-4}$) were formed using up to 20 kW of radio-frequency power applied to a 4-cm radius plasma column. The electron temperatures, measured by both diamagnetic loops and X-ray detectors, exceeded 300 eV. Full penetration of the odd-parity rotating magnetic fields to the major axis was observed at these higher powers. The published results are: “Formation of Collisionless High-beta Plasmas by Odd-parity Rotating Magnetic fields,” S.A. Cohen, B. Berlinger, C. Brunkhorst, A. Brooks, N. Ferraro, D.P. Lundberg, A. Roach, and A.H. Glasser, Phys. Rev. Lett. **98**:14 (29 July 2007) Article No. 145002. A description of the radio-frequency system used in these experiments was presented at the *Symposium on Fusion Engineering 2007* [C. Brunkhorst, B. Berlinger, N. Ferraro, and S.A. Cohen, “The Princeton FRC Rotating-magnetic-field Experiment RF System,” in the Proceeding of the *22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (SOFE2007), (17–21 June 2007, Albuquerque, New Mexico) pp.1–4]. Work begun on construction and testing of high-temperature superconducting flux conservers for the next-step FRC experiment.

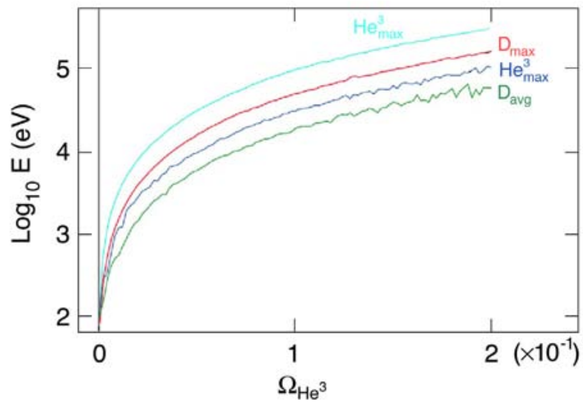


Figure 5. Hamiltonian ion-heating simulations performed for a reactor-scale field-revered configuration with 10-cm radius and 20-kG axial field. The frequency dependence of the maximum and average energy — denoted by subscript "max" and "avg" in the figure – of D and He^3 ions heated by odd-parity rotating magnetic fields (RMF_o) of strength 128 G are shown. The abscissa is the RMF_o frequency normalized to the ion cyclotron frequency of He^3. The abscissa for deuterium has been multiplied by 4/3, so that the physical frequency on the abscissa is the same for both ions.

In FY07, four graduate students, N. Ferraro, K. Ghantous, C. Myers, and A. Stepanov, performed PFRC research. The research strongly benefited from collaborations with theoreticians at the Los Alamos National Laboratory (A. Glasser) and the Naval Research Laboratory (A. Landsman).

Hall Thruster Experiment

Hall thrusters are plasma-based propulsion systems used to propel space vehicles. Presently, the vast majority of satellites worldwide rely on chemical thrusters, but chemical thrusters have very limited fuel exhaust speed. The amount of fuel that a satellite must carry depends on the speed with which the thruster can eject it. Plasmas can be ejected at much higher speeds, therefore less fuel need be carried onboard.

A Hall Thruster Experiment (HTX) was established at the Princeton Plasma Physics Laboratory (PPPL) in 1999. The PPPL effort was the result of a collaborative theoretical research effort with the Center for Technological Innovation at Holon, Israel. This initial study identified improvements that might make Hall Thrusters more attractive for commercial and military applications.

Hall Thruster Operation

A conventional ion thruster consists of two grids, an anode and a cathode, between which a voltage drop occurs. Positively charged ions accelerate away from the anode toward the cathode grid and through it. After the ions get past the cathode, electrons are added to the flow, neutralizing the output to keep it moving. A thrust is exerted on the anode-cathode system, in a direction opposite to that of the flow. Unfortunately, a positive charge builds up in the space between the grids, limiting the ion flow and, therefore, the magnitude of the thrust that can be attained.

In contrast, in a Hall Thruster, electrons injected into a radial magnetic field neutralize the space charge. The magnitude of the field is approximately 200 gauss, strong enough to trap the electrons by causing them to spiral around the field lines. The magnetic field and a trapped electron cloud together serve as a virtual cathode (see Figure 6). The ions, too heavy to be affected by the field, continue their journey through the virtual cathode. The movement of the positive and negative electrical charges through the system results in a net force on the thruster in a direction opposite that of the ion flow.

Plasma thrusters for space applications currently employ xenon propellant. Xenon is relatively easy to ionize and store onboard the spacecraft. It also has a high atomic number (54), which means a lot of mass per ionization energy expended. The ionization energy is an unavoidable inefficiency in the range of exhaust velocities most useful for current space applications, about 15 km/sec. The energy loss for once-ionized xenon is less than 10 percent of the exhaust energy. (If the weight per atom were half, this percentage would double.)

Hall Thruster Applications

Thrusters are used to compensate for atmospheric drag on satellites in low-earth orbit, to reposition satellites in geosynchronous orbit, or to raise a satellite from a lower orbit to geosynchronous orbit. For each kilogram of satellite mass, it turns out that about one

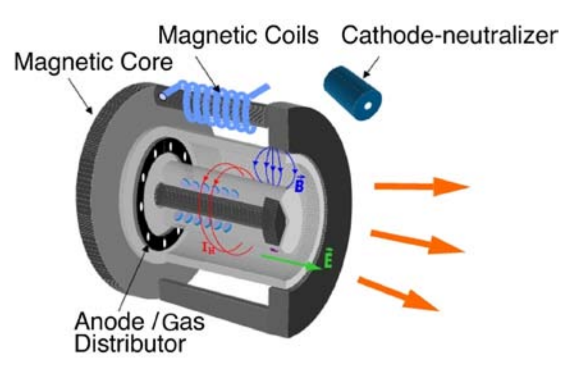


Figure 6. The Hall Thruster Concept.

or two watts of on-board power are available. Hall Thrusters ranging from below a hundred watts to more than two kilowatts have been built at PPPL. Researchers at PPPL hope that their ideas can be useful both for thrusters operating at many thousands of watts, like for planetary missions, as well as, in the small power limit, for very small satellites with masses of 50 to 100 kilograms.

Thruster Results

One of the main innovations of the HTX facility was the demonstration of how steep voltage drops could be localized and controlled in a Hall-thruster geometry using segmented electrodes. These techniques now support new thruster configurations and new methods to focus neutralized ion beams thereby achieving significant beam current densities. Experiments on the HTX facility have challenged accepted limits on the magnetic insulation properties of plasma. With unique plasma probe diagnostics, the importance of plasma-wall interactions and the role of secondary electron emission in power losses at the walls and electron cross-field transport have been demonstrated.

In addition to imagining larger, more powerful thrusters capable of accelerating satellites more quickly or powering larger satellites, scientists also envision a large satellite disbursing hundreds of smaller ones for the exploration of a planet or as a space-based radar array. The PPPL Hall microthruster was invented to scale to low power. This device employs a cylindrical rather than the conventional annular configuration. Because of its low surface to volume ratio, the cylindrical geometry is better adapted for microthruster operation. The technological problems associated with scaling to low power are by no means straightforward. The power density tends to grow at small sizes, and the smaller features are more susceptible to heat loading. In attacking these technological constraints, in the cylindrical design, the central magnetic pole is almost eliminated, as shown in Figures 7 and 8.

The cylindrical thruster geometry is fundamentally different from the conventional configuration in the way the electrons are confined in the discharge and the ion space charge is neutralized. Here, the electrons in the cylindrical part of the channel are trapped axially in a hybrid magneto-electrostatic trap: on the anode side, they are reflected by the strong magnetic mirror, while on the cathode side they are reflected by the potential drop in the plume. Electrons neutralize the ion space charge not by being held axially by the radial magnetic field, like in the conventional thruster,

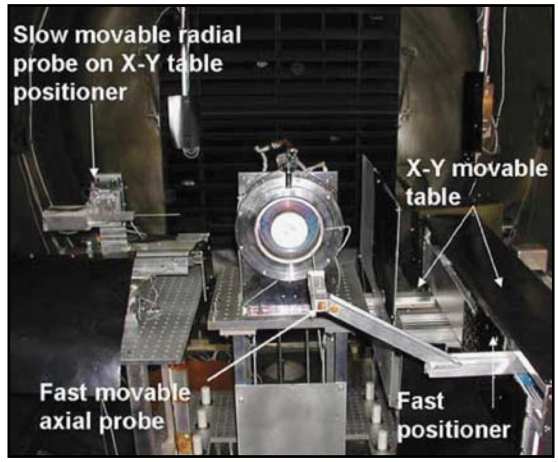


Figure 7. Interior view of the Hall Thruster vacuum chamber.

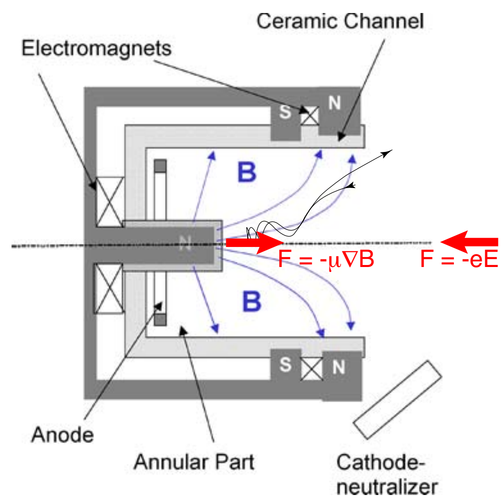


Figure 8. Schematic of the Hall microthruster with cylindrical geometry.

instead the electrons are allowed to move axially back and forth, while being trapped axially in the hybrid trap. Therefore, one of the fundamental constraints of the conventional thruster configuration is loosened, and the associated physics of this new thruster is quite different. The PPPL Hall Microthruster has been operating at high efficiency below the 100-watt range, useful for very small satellites with masses of 50 to 100 kilograms.

Several low-power cylindrical Hall thrusters built along the lines of the PPPL thruster were characterized at the Air Force Research Laboratory, Edwards, California, and at the NASA Marshall Space Flight Center in Alabama. The thruster efficiencies were determined through collaboration with the Mechanical and Aerospace Engineering Department at Princeton Uni-

Return to Table of Contents

versity. Because of the larger volume-to-surface ratio, cylindrical Hall thrusters are expected to last longer than conventional Hall thrusters with similar efficiencies. The cylindrical Hall thruster concept pioneered at PPPL has now captured attention in Japan, France, Korea and Germany.

During FY06, PPPL scientists achieved the further result of 40% plume narrowing, which resulted in an almost 70% increase of the anode efficiency with stable operation in the voltage regime 50–600 V. An anode efficiency of about 40% was achieved in the power range of 100–200 W through optimization of the magnetic field distribution, discharge parameters, and the use of segmented electrodes. In this voltage and power regime, these efficiencies exceed previous state-of-the-art efficiencies for microthruster electrical propulsion. In FY07, these remarkable results were corroborated in experiments with the PPPL cylindrical Hall thruster at The Aerospace Corporation — a federally funded research and development center supporting national security, civil, and commercial space programs.

In FY07 experiments, two current-limited regimes of the magnetized thruster discharge were identified: the "self-sustained" regime and the "non-self-sustained" regime. For the normal self-sustained operation, it is the electron supply from the cathode that limits the current in the cylindrical Hall thruster. In the non-self-sustained regime, an increase of the electron supply to the thruster discharge leads to the plume narrowing and sharp increases in the electric field.

In analyzing experimental results, a corollary to the isorotation theorem was introduced. The isorotation theorem states that all particles entrained on azimuthally symmetric magnetic surfaces that are also equipotential surfaces rotate with the same azimuthal frequency. The corollary states that particles entrained on magnetic surfaces that are isorotating lose kinetic energy exactly twice their rotational energy as they move along the surface. Both cylindrical Hall thrusters and conventional Hall thrusters operate in a regime where the consequences of this corollary turn out to be important.

Nonneutral Plasma, High-intensity Accelerators, and High Energy Density Physics

A nonneutral plasma is a many-body collection of charged particles in which there is not overall charge neutrality. Such systems are characterized by intense self-electric fields and, in high-current configurations, by intense self-magnetic fields. Nonneutral plasmas, like electrically neutral plasmas, exhibit a broad range of collective properties, such as plasma waves and instabilities. The intense self-fields in a nonneutral plasma can have a large influence on detailed plasma equilibrium, stability, and confinement properties, as well as on the nonlinear dynamics of the system.

There are many practical applications of nonneutral plasmas. These include:

- improved atomic clocks;
- positron and antiproton ion sources;
- antimatter plasmas, with application to antihydrogen production;
- coherent electromagnetic radiation generation, including free electron lasers, cyclotron masers, and magnetrons;
- advanced accelerator concepts with high acceleration gradients;
- investigation of nonlinear collective processes and chaotic particle dynamics in high-intensity charged-particle beams; and
- applications of intense ion beams to studies of high energy density physics properties of warm dense matter and heavy ion fusion.

Research on nonneutral plasmas and high-intensity accelerators at PPPL focuses on three areas:

- basic experimental investigations of nonneutral plasmas confined in a Paul trap with oscillatory wall voltages, used to simulate intense beam propagation through a periodic quadrupole field configuration;
- analytical and numerical studies of the nonlinear dynamics and collective processes in intense nonneutral beams propagating in periodic-focusing accelerators and transport systems, with particular emphasis on next-generation accelerators for ion-beam-driven high energy density physics and fusion, spallation neutron sources, and high-energy physics applications of intense charged-particle beams; and
- experimental investigations of advanced plasma sources for intense ion beam space-charge neutralization; experimental and theoretical studies of ionization and stripping cross sections, and multielectron loss events; optimization of negative ion beams for heavy ion drivers; and

application of halogen ion-ion plasmas to warm dense matter studies.

Paul Trap Simulator Experiment

The Paul Trap Simulator Experiment (PTSX) is a compact experiment that simulates intense beam propagation through periodic focusing magnetic alternating-gradient transport systems over distances of tens of kilometers by placing the physicist in the frame-of-reference of the beam. The transverse dynamics of the particles in the two systems is the same. Plasmas are trapped for hundreds of milliseconds in the PTSX device, which corresponds to equivalent propagation distances of tens of kilometers. The PTSX device confines cesium or barium ions in the transverse plane by applying oscillatory voltages to the four quadrants of a 2-m-long 20-cm-diameter, segmented primary cylinder. Static voltages, applied on 40-cm-long end cylinders, provide axial confinement of the trapped one-component pure ion plasma. The amplitude and frequency of the oscillating voltage in PTSX correspond to the amplitude and spacing of the magnets in the actual alternating-gradient transport system.

Experiments have been performed in which the frequency of the oscillating voltage in PTSX has been decreased over a time τ during the course of the experiment in order to compress the transverse dimensions of the beam. Decreasing the frequency from its initial value f_i, therefore, increases the amount of on-axis charge. This technique works well, even if the decrease in frequency is not monotonic; for example, if the frequency "undershoots" before reaching its final value. In this case however, as seen in the data in Figure 9, the decrease in frequency cannot be made so quickly that the number of periods τf_i over which the transition is made is too small. For a given difference in initial and final frequencies, there is a critical time τ_c below which the plasma is lost when making these frequency changes.

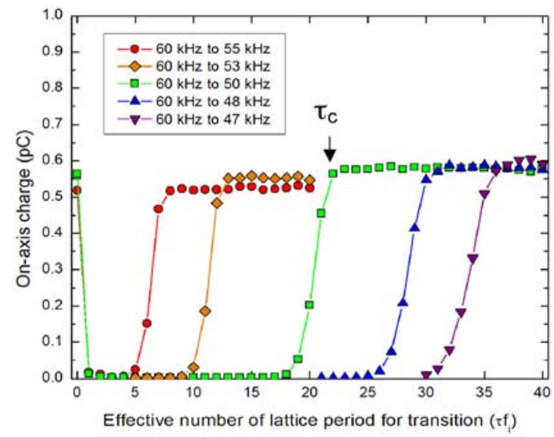


Figure 9. Decreasing the frequency from 60 kHz compresses the plasma and increases the on-axis charge. For frequency decreases in which there is an intentional "undershoot," there is shortest time τ_c over which the frequency decrease may be made without losing the plasma.

Collective Effects in Bunched Beams

In 3-D high-intensity bunched beams, collective effects with strong coupling between the longitudinal and transverse dynamics are of fundamental importance. A direct consequence of this coupling effect is that the particle dynamics does not conserve transverse energy and longitudinal energy separately, and there exists no exact kinetic equilibrium that has an anisotropic energy in the transverse and longitudinal directions. The strong coupling also introduces a mechanism for the electrostatic Harris-type instability, which is driven by the energy anisotropy and exists naturally for intense beams, to occur. The self-consistent Vlasov-Maxwell equations have been applied to high-intensity bunched beams, and a generalized low-noise δf particle simulation algorithm has been developed for bunched beams with or without energy anisotropy.

To overcome a numerical instability associated with the δf method for the large weight function at the nonlinear phase, a modified δf algorithm was developed. In order to reduce the simulation noise, the δf method is often used for particle simulations of collective dynamics and instabilities in high-intensity charged-particle beams. This is accomplished by advancing a weight function along with particle's trajectories in the phase space. However, for some collective instabilities, the weight function can become large at the late nonlinear stages due to the resonance between simulation particles and the collective dynamics. For example, the absolute value of the weight function can become much larger than unity during the δf simulations of the energy anisotropy instability (Harris instability) for high-intensity beams, when the effective beam temperature increases nonlinearly in the longitudinal direction. In these scenarios, the low-noise advantage associated with the small weight function is diminished, and it is desirable to switch back to the conventional total-f method to avoid the numerical instability associated with the δf method for the large weight function during the nonlinear phase. The modified δf method, which can switch smoothly between the δf method and the total-f method, was developed for this purpose.

In the modified δf method, the particle distribution is partitioned as $f = \alpha f_0 + F$, where f_0 is the equilibrium distribution, and F is the simulated distribution. The time-dependent coefficient α takes on values between 0 and 1, with α = 0 corresponding to the total-f method, and α = 1 corresponding to the δf method. The weight function is defined as w = F/f, and the dynamics of the weight function is governed by

$$dw/dt = (w-1)(f_0^{-1})(df_0/dt) + (w-1)(\alpha^{-1}\, d\alpha/dt) .$$

The dynamics of α can be either prescribed or determined from some rules coupled to the amplitude of w. When α varies smoothly from 1 to 0 during the simulation, the simulation is smoothly switched from the δf method to the total-f method.

A typical simulation result for the nonlinear energy-anisotropy instability in a 3-D bunched beam with such a smooth switching is shown in Figure 10, where the smooth switch happens around time t = $50/\omega_\beta$, where ω_β is the betatron frequency. The simulated beam is a high-intensity anisotropic charge bunch with a normalized intensity $s_b = 0.8$, $T_z/T_\perp = 1/36$, and $z_b/r_b = 40$, where T_z, $T_\perp$, z_b, and r_b are the longitudinal temperature, the transverse temperature, the bunch half-length, and the bunch radius, respectively. The fast timescale dynamics is dominantly the ω = 2ωβ collective excitation which is driven unstable by the energy anisotropy, and the slow timescale dynamics is associated with the background evolution $(df_0/dt)_0$ of the reference equilibrium state and the overall nonlinear evolution of the system. At the late stages of the instability, the perturbations saturate nonlinearly at about the 5% level. Note also that the instability does not completely remove the energy anisotropy, even though a nonlinear increase in the longitudinal temperature of 10-fold is observed in the longitudinal direction. The simulation results using the modified δf method demonstrate that it is a highly robust approach in advanced simulation studies.

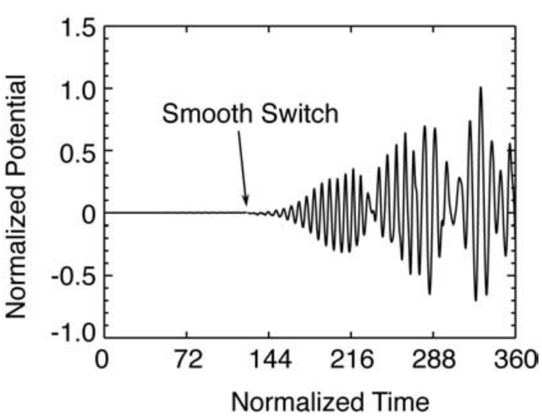


Figure 10. Time history of the unstable perturbed potential driven by energy anisotropy in a high-intensity 3-D bunched beam. The simulation is carried out using the newly developed modified δf method with a smooth switch from the δf method to the total-f method. The perturbation saturated nonlinearly at the 5% level, and a nonlinear increase in the longitudinal temperature of 10-fold is observed in the longitudinal direction.

Neutralized Transport

Space-charge-dominated ion beam pulses for warm dense matter and heavy ion fusion applications must undergo simultaneous transverse and longitudinal compression in order to reach the desired high-beam intensities at the target. Longitudinal focusing is achieved by imposing an axial velocity tilt on the beam and subsequently neutralizing its space-charge and current in a drift region filled with high-density plasma. A strong solenoid (multi-Tesla) near the end of the drift region to transversely focus the beam to a submillimeter spot size coincident with the longitudinal focal plane is modeled. The neutralization provided by the background plasma is critical in determining the total achievable compression of the beam pulse. Long-time and large-space-scale plasma flow simulations indicate that adequate plasma densities can be provided throughout the drift region for ion beam charge neutralization in near-term focusing experiments.

The application of a small solenoidal magnetic field can drastically change the self-magnetic and self-electric fields of the beam pulse, thus allowing effective control of the beam transport through the background plasma. An analytical model was developed to describe the self-magnetic field of a finite-length ion-beam pulse propagating in a cold background plasma in a solenoidal magnetic field. The analytical studies show that the solenoidal magnetic field starts to influence the self-electric and self-magnetic fields when $\omega_{ce} > \omega_{pe}\beta_b$, where ω_{ce} = eB/mc is the electron gyrofrequency, ω_{pe} is the electron plasma frequency, and β_b is the ion-beam velocity relative to the speed of light. Theory predicts that when $\omega_{ce} \sim \omega_{pe}\beta_b$ there is a sizable enhancement of the self-electric and self-magnetic fields due to the dynamo effect. This threshold value of the solenoidal magnetic field is relatively small for nonrelativistic beams.

The dynamo effect occurs due to the electron rotation, which twists the applied magnetic field and generates a self-magnetic field that is much larger than in the limit with no applied magnetic field. Another effect is the generation of a large radial electric field.

Because in a steady state the **v** × **B** force should be balanced by a radial electric field, the electron rotation results in a plasma polarization and produces a much larger self-electric field than in the limit with no applied magnetic field. A third unexpected effect is that the joint system consisting of the ion-beam pulse and the background plasma act as a paramagnetic medium, i.e., the solenoidal magnetic field is enhanced inside of the ion-beam pulse. For larger values of the solenoidal magnetic field, the beam can generate whistler and lower-hybrid waves. In the presence of the solenoidal magnetic field, the radial force acting on the beam ions can change sign from focusing to defocusing, because the radial electric field increases more rapidly than the magnetic force, as the solenoidal magnetic field increases, as shown in Figure 11.

Fields from the magnets can also change the nature of collective instabilities experienced by the compressing beam when it propagates in neutralizing plasma. Low-frequency electrostatic instabilities are now possible for sufficiently strong magnetic field with $\omega_{ce} > \omega_{pe}\beta_b$. The growth rates of possible instabilities are plotted versus longitudinal ($k_{||}$) and transverse ($k_{\perp}$) wavenumbers as shown in Figure 12.

The two vertical regions in Figure 12(a) correspond to coupling of beam ions and background ions to the upper-hybrid electrostatic branch. The two curved regions in Figure 12(a) correspond to coupling of beam ions and background ions to the lower-hybrid electrostatic branch. The vertical region in Figure 12(b) corresponds to coupling of beam ions and background ions to the lower-hybrid oscillation. The growth rate of the Weibel instability is modified by the

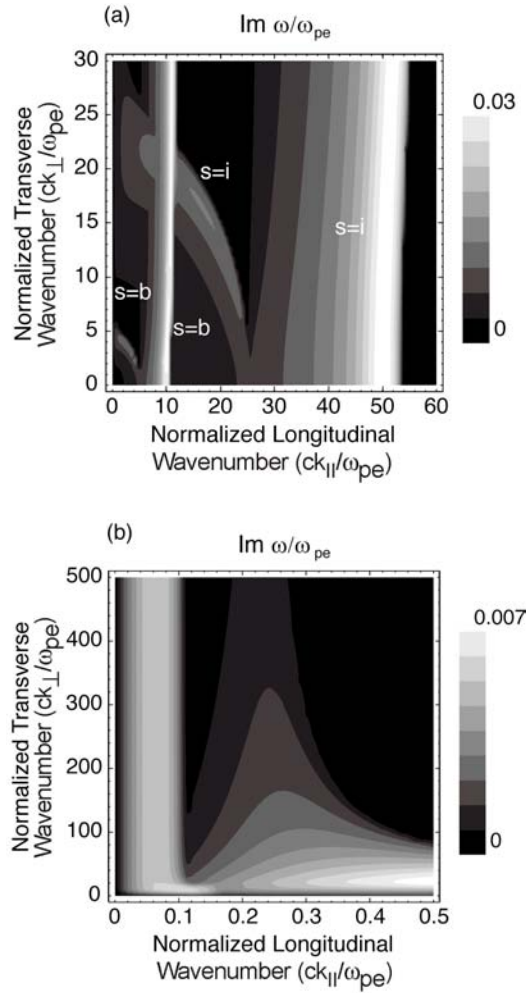


Figure 12. Plot of the growth rates of possible instabilities for an ion-beam pulse propagating in a background plasma as a function of the normalized wavenumbers. Beam and plasma parameters are: $n_b/n_e = 3/7$, $\omega_{pb}/\omega_{pe} = 0.01$, $\omega_{pi}/\omega_{pb} = 1$, and $\beta_b = 0.1$. Figure 12(b) is a blow up of Figure 12(a) for small longitudinal wavenumbers $k_{||}$.

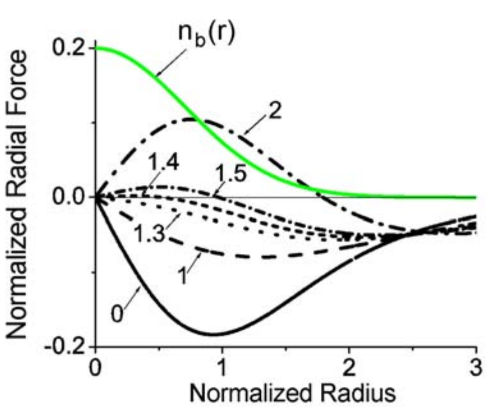


Figure 11. The normalized radial force acting on the beam particles for different values of the parameter $(\omega_{ce}/\omega_{pe}\beta_b)^2$. The green curve shows the Gaussian density profile multiplied by 0.2 in order to fit the profile into the plot. The beam radius is equal to the skin depth in the figure.

magnetic field. The growth rate is modified because in a strong enough magnetic field, the background electrons are unable to move transversely, and the transverse filamentation instability is only between the beam ions and background plasma ions.

Figure 13(a) shows LSP code simulations of a potassium ion-beam (K^+) propagating in the y-direction for several values of magnetic field strength. Figure 13(b) shows contour plots of the phase for the density perturbations excited by the modified two-stream instability obtained theoretically using asymptotic analysis. This characteristic shape of the wavefronts is due to the instability. Further dispersion of the wavefronts takes place outside of the beam pulse where the

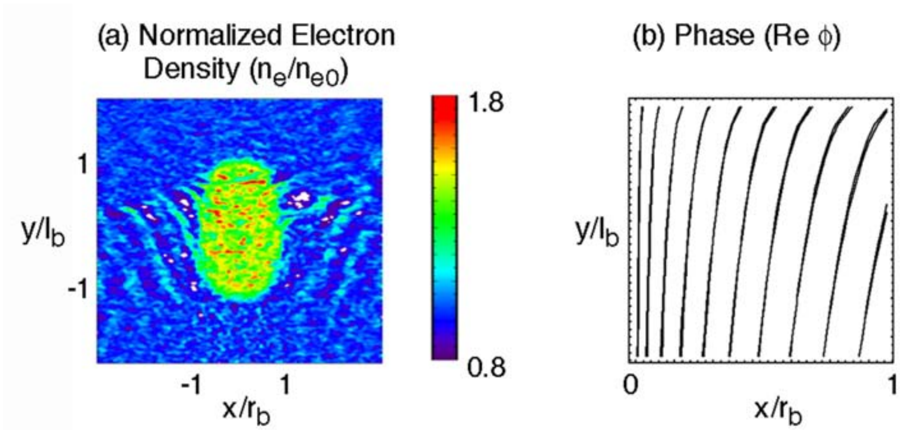


Figure 13. (a) LSP code simulations of a potassium ion-beam (K^+) propagating through neutralizing background plasma upward along a solenoidal magnetic field in the y-direction for several values of magnetic field strength, and $n_b/n_e = 0.5$, $\beta_b = 0.2$, $r_b = 1.5c/\omega_{pe}$ and $l_b = 10r_b$ where r_b is the bunch radius and l_b is the bunch half-length. (b) Contour plots of the phase for the density perturbations excited by the modified two-stream instability obtained theoretically using asymptotic analysis for the case $\omega_{ce}/\omega_{pe} = 1.4$ and $\beta_b = 0.2$.

perturbations amplified by the instability inside of the pulse propagate away with group velocity perpendicular to the wavevector k.

Plasma Sources and Neutralization Experiments

Researchers at PPPL have developed advanced plasma sources to support the charge neutralization studies conducted on the Neutralized Drift Compression Experiment (NDCX) at the Lawrence Berkeley National Laboratory (LBNL). To create plasmas that are one-meter long, as required for NDCX, a ferroelectric ceramic plasma source has been built and tested. Barium-titanate ceramic rings, with a relative dielectric coefficient of several thousand, are stacked together to form a one-meter long, three-inch-diameter, thin-walled cylinder. A 9-kV pulse applied between the outer surface and the inner surface creates a strong radial electric field that is greatly enhanced at the inner surface of the cylinder because of the large relative dielectric coefficient of the ceramic. The ceramic material itself is vaporized at the inner surface and converted into a plasma. Measurements show that plasmas with densities of 10^{10} cm^{-3} and temperatures around 10 eV are created.

Experiments performed on NDCX in which a potassium ion-beam is allowed to transversely compress while drifting through a plasma demonstrate that the present ferroelectric plasma source operation has been optimized. The short-lived plasma's properties evolve with time, and it is important that the potassium ion-beam passes through the plasma at precisely the right time. The results in Figure 14 show that the densest, most compact, and nearly circular beam spot is achieved when the plasma source is pre-triggered by four microseconds.

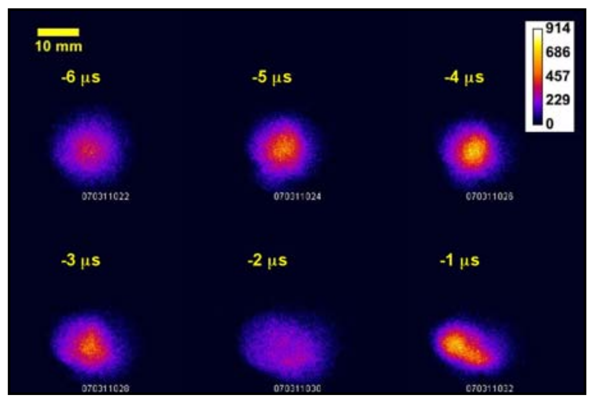


Figure 14. Image of a transversely compressing beam in the Neutralized Drift Compression Experiment (NDCX) is the densest, most compact, and nearly circular when the plasma source is pre-triggered by four microseconds.

Ionization and Stripping Cross Sections

A classical trajectory Monte Carlo simulation (CTMC) has been used to calculate the ionization and charge-exchange cross sections for hydrogen and helium targets bombarded by many different ions. Despite the fact that the simulations only account for classical mechanics, the calculations compare favorably with experimental results for projectile velocities near the maximum cross section velocity. At higher or lower velocities, quantum mechanical effects become more significant, and the CTMC results agree less

Return to Table of Contents

well with measured values. Simulations were performed for many different projectiles (see Figures 15 and 16). For highly charged ions as large as gold, it has been shown that most processes occur at large impact parameters, and the internal structure of the ion can be neglected, and the projectile can be treated as if it were a fully stripped ion of the same charge. With smaller ions such as argon, impact parameters smaller than the ion's size are important and the accurate calculation of the projectile potential is necessary. For the most part, the two argon cross sections resemble the fully stripped ions (H^+ and Li^{+3}) in their basic shape and curvature. For instance, note the similarities between the lithium case Li^{+3} and the argon case Ar^{+3} in Figure 15. One difference is that the Ar^{+3} cross section does not approach the $5Z^2/3$ Bohr limit (where Z = 3 is the projectile charge) at high velocities (straight magenta line in Figure 15), unlike those of the fully stripped ions (H^+ and Li^{+3}) due to the contribution of the ion core to the ionization process. Also,

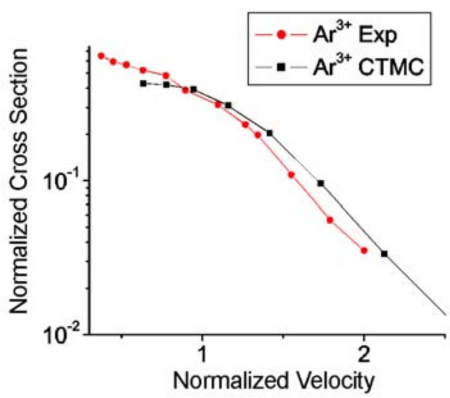


Figure 15. Ionization cross sections of hydrogen and fully stripped lithium ions and partially stripped argon ions on atomic hydrogen.

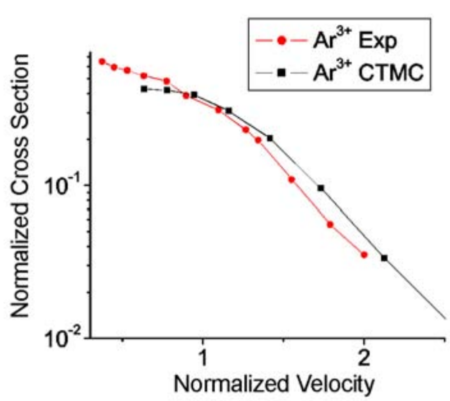


Figure 16. Normalized charge exchange cross section for Ar^{+3} ions on hydrogen.

the experimental results do not have the same basic shape as the fully stripped ions (H^+ and Li^{+3}). This is due to the large amount of ionization that occurs at low energies, called auto-ionization, which is only accounted for using quantum mechanical methods and cannot be described by the CTMC method.

Negative Ions and Warm Dense Matter

An invited review article was prepared in FY07 to be published in 2008 for *IEEE Transactions on Plasma Science* on the topic of negative halogen ion sources (L.R. Grisham, "Negative Halogen Ion Sources," IEEE Transactions on Plasma Science, to be published in August 2008.) This paper discuss;ed the experiments carried out by PPPL in collaboration with LBNL and Lawrence Livermore National Laboratory (LLNL) over the past several years to demonstrate the production of beams of negative chlorine at the high current density and low emittance required for applications as a heavy ion driver for inertial confinement fusion or as a lithography beam in the semiconductor industry. The paper also discussed the novel state of matter, ion-ion plasma, which was achieved in the extractor region plasmas in these ion sources, and how this is connected to the wider field of electronegative plasmas in the semiconductor processing field, as well as to a better understanding of how it is possible to extract negative ion beams from weakly electronegative plasmas such as hydrogen, contrary to what would be expected from the positive potential well created by ambipolar diffusion.

The Princeton Plasma Physics Laboratory has proposed a way to extend the ion-ion plasma state into the warm dense matter regime by heating a thin (of order a micron thick) halogen foil of iodine or bromine with an intense, brief burst of energy from an ion beam. If the foil thickness and beam energy are chosen such that the beam enters at the upper edge of the dE/dX peak, and exits the foil at the low-energy edge of the top of the peak, then nearly uniform heating with the maximum power density deposition can be achieved simultaneously. Planning continued this year on how to carry out these experiments with the diagnostics that are expected to be available.

Diagnostic Development

Electron-Bernstein Wave Emission Diagnostic

In spherical torus experiments, such as the National Spherical Torus Experiment (NSTX), the plasma is "over-dense," that is the electron plasma frequency is much higher than the frequency of the lower harmonics of the electron cyclotron resonance, making conventional measurements of electron temperature profile $T_e(R)$ via electron cyclotron emission, and electron cyclotron heating and current drive impossible. An alternative in this situation is to use electron-Bernstein wave (EBW) emission to measure the electron temperature profile and to use electron-Bernstein waves for local heating and current drive. Electron-Bernstein waves do not propagate in vacuum and must be coupled to and from the plasma by mode conversion to electromagnetic waves. To further develop these applications, studies of the physics of EBW coupling are being conducted on NSTX. Recent work has focused on understanding why the EBW coupling falls dramatically when the plasma transitions from the low-confinement mode to the high-confinement mode (L- to H-mode).

Significant increases in thermal EBW emission were recently measured with the NSTX electron-Bernstein wave radiometer diagnostic during H-mode discharges conditioned with evaporated lithium. The EBW coupling efficiency was maintained, or even increased, as the plasma transitioned from the L-mode to the H-mode phase and throughout the H-mode phase. Coupling of fundamental 18-GHz EBW emission from the H-mode plasma core was measured to increase from just 5–10% without lithium conditioning to more than 55–70% with 19 mg per minute of lithium evaporation. Similarly, coupling of second harmonic 28-GHz EBW core emission was measured to increase from just 5–10% to 50% with the addition of lithium conditioning.

The EBW antennas on the EBW diagnostic were remotely steered during a sequence of similar H-mode discharges in order to map the EBW transmission efficiency as a function of the antenna poloidal and toroidal pointing direction. Comparison between the measured and predicted EBW transmission efficiency shows the peak EBW transmission is within a few degrees of where it is theoretically expected to be (Figure 17). Furthermore the absolute value of the measured EBW transmission efficiency agrees with results from an EBW emission simulation when EBW collisional damping near the mode-conversion layer is included in the simulation. Without lithium conditioning, the EBW mode-conversion layer for fundamental and second harmonic EBW emission is located in the plasma scrape-off where the electron temperature is less than 10 eV and there is significant EBW collisional damping prior to mode conversion. With the addition of lithium evaporation, the mode-conversion layer moves towards the last closed flux surface where the electron temperature is approximately 20–30 eV

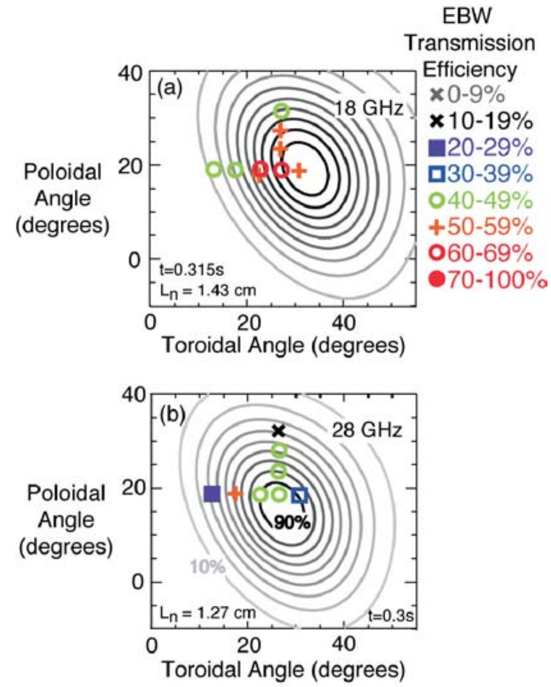


Figure 17. Dependence of the measured (symbols) and predicted (contours) electron-Bernstein wave (EBW) transmission efficiency as a function of EBW antenna pointing angle during an H-mode plasma conditioned with 19 mg per minute of evaporated lithium: (a) for 18-GHz fundamental and (b) 28-GHz second harmonic emission from near the plasma axis.

and, consequently, significantly less EBW damping is needed prior to mode conversion.

3-D Microwave Imaging Diagnostic

Plasma fluctuations continued to be studied on the TEXTOR tokamak (at the Institute for Energy Research, Jülich Forschungszentrum, Germany) using unique 3-D microwave imaging diagnostics developed in a collaboration between PPPL, the University of California at Davis, and the FOM Institut voor Plasmafysica "Rijinhuizen" in the Netherlands. Electron cyclotron emission Imaging (ECEI) and microwave imaging reflectometry (MIR) diagnostics were used to make high spatial and temporal resolution measurements of the electron density and temperature.

The proof-of-principle 128-channel ECEI system installed on TEXTOR produced exciting results in the areas of magnetic reconnection, electron cyclotron heating suppression of magnetic islands, and imaging of meso-scale structures. Figure 18 shows an example data set from TEXTOR of a sawtoothing plasma that demonstrates a collective "breakthrough" of hot plasma through the q = 1 surface and subsequent re-

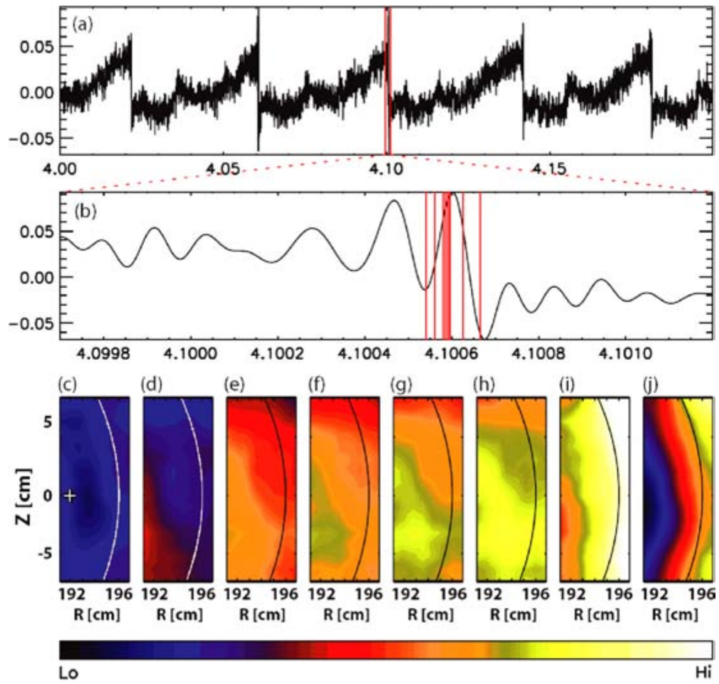


Figure 18. Sawtooth waveform of the repeating growth and crash cycle (a), zoom of single crash event (b), and sequence of 2-D electron cyclotron emission images of the temperature fluctuations corresponding to indicated time points [(c) to (j)]. The color scale runs from +10% to -7% of the time average. The arc in the images (c) to (j) indicates the safety factor q = 1 surface. Waveforms (a) and (b) correspond to the location indicated by the cross in image (c).

equilibration of the smooth flux surfaces after the sawtooth crash. In addition to these studies, the ECEI system was upgraded in February 2007 with new wideband radio-frequency and intermediate frequency electronics. The new electronics offer increased plasma coverage, reduced noise, and enhanced operating controls.

A new optical alignment technique was also developed for the MIR diagnostic. Work in FY08 will focus on using both the ECEI and MIR diagnostics for further fluctuation studies on TEXTOR.

In a new collaboration started with the Pohang University of Science and Technology (POSTECH) in South Korea, the ECEI and MIR diagnostics will be reconfigured for use on the DIII-D tokamak at GA in California. In 2008, the MIR diagnostic will be moved to Pohang University and the performance of the system will be studied and compared with code simulations to provide input to the redesign of the system. The reconfigured ECEI and MIR diagnostics will be deployed on DIII-D in 2009.

Imaging X-ray Crystal Spectrometer

An imaging X-ray crystal spectrometer (XCS) was successfully deployed and operated on the Alcator C-Mod tokamak in FY07. This represents the culmination of an effort to successfully develop such a spectrometer. This diagnostic measures spectra of Ar^{16+} and Ar^{17+} in the 3.1-keV region with good time and spatial resolution. Profiles of the plasma ion temperature and rotation velocity in the toroidal direction are derived by inverting moments of the spectra obtained by line fitting. In contrast to charge-exchange recombination spectroscopy, neutral-beam injection is not required for imaging XCS measurements. This diagnostic is therefore well-suited to radio-frequency heating and current drive studies and other experiments in which perturbation of the plasma due to a neutral beam is undesirable.

The C-Mod imaging XCS design was finalized and the instrument was built, assembled, aligned, installed, and integrated into the C-Mod data control and acquisition system in FY07. A diagram of the imaging XCS is shown on the left side of Figure 19. The key component of the system is four PILATUS II detectors. These are large-area silicon detectors with a large number of pixels. Each pixel has its own readout electronics capable of single-photon counting rates up to 1 MHz, allowing 10-ms time resolution with good statistics. The instrument was operated and provided ion-temperature and rotation-velocity profiles for virtually all C-Mod discharges beginning April 2007. Software was developed to do both quick analysis of the chordally integrated spectra and to provide local ion temperature and velocity profiles from Abel inversion of the chordally integrated radial profiles. An example of the time evolution of the ion temperature profile in a C-Mod discharge is shown in the right side of Figure 19.

Results from the imaging XCS on C-Mod were presented in an invited paper at the International Conference on Burning Plasma Diagnostics (Varenna, Italy, 24–28 September 2007). An imaging XCS system is planned for ITER. The Princeton Plasma Physics Laboratory PPPL has made a comprehensive cost estimate for design, construction, and implementation of the imaging XCS on ITER, which was accepted and approved by the ITER Diagnostic Working Group.

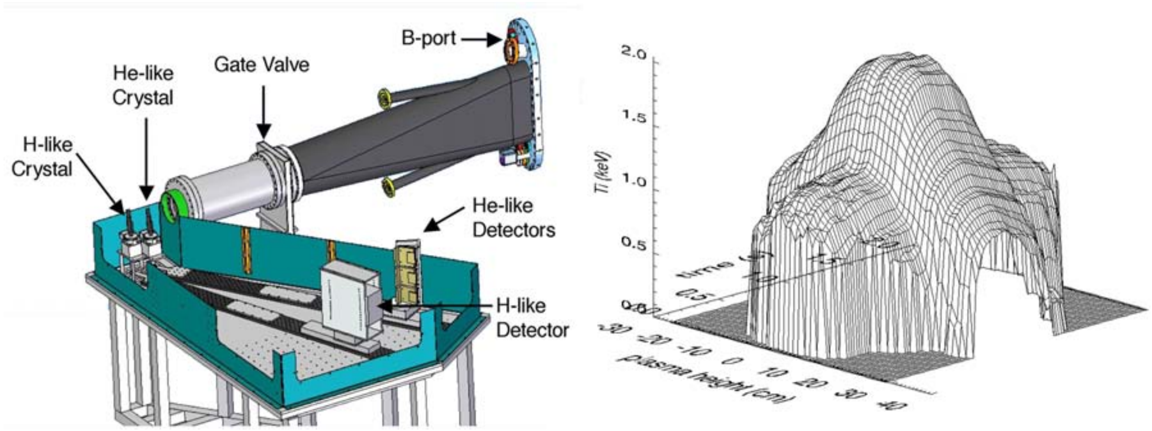


Figure 19. Imaging X-ray crystal spectrometer on Alcator C-Mod (left) and measured time evolution of ion temperature profile (right) in a C-mod discharge. (Do you have an original file for this figure. I'd like to remove the blue background. It is hard to see the images underneath.)

Return to Table of Contents

Engineering and Technical Infrastructure

The Engineering and Technical Infrastructure Department at the Princeton Plasma Physics Laboratory (PPPL) is responsible for managing the Laboratory's engineering resources. This includes a staff of engineers, technicians, and support personnel organized functionally (Mechanical; Electrical; Computer; and Fabrication, Operations, and Maintenance Divisions) to support the Laboratory's research, design, and development endeavors. The Department is responsible for the technological infrastructure of the Laboratory's experiments as well as the maintenance and operation of the major C- and D-site experimental facilities.

National Compact Stellarator Experiment

During FY07, work on the National Compact Stellarator Experiment (NCSX) vacuum vessel subassemblies was completed, the last of the modular coil winding forms was delivered in June, the first pair of toroidal-field coils was delivered, and modular coil manufacturing continued smoothly, with the 14th coil being completed by the fiscal year's end. As the list of completed key components grew and resources became available, the focus of the engineering activities on NCSX moved toward machine assembly.

NCSX Assembly Overview

The basic building block of NCSX is the field-period assembly. Since NCSX is an m = 3 stellarator, it has three identical 120° field periods, each consisting of six modular coils (two each of the three modular coil types), a 120° segment of the vacuum vessel, six identical toroidal-field (TF) coils, external trim coils, and associated structural components. Figure 1 shows the sequence of assembly operations. Station 1 work has been completed (see Figures 2 and 3), Station 2 work is underway, and tooling is being designed and fabricated for Stations 5 and 6. (Note: There is no Station 4 because the activities of Stations 4 and 5 have been combined into Station 5.)

Stellarators are very sensitive to magnetic field errors; consequently, NCSX must be assembled with the current centers of the modular coils located to a tolerance of ±1.5 mm (0.060 inch). During field-period assembly, the current centers must be located to a tolerance of ±0.75 mm (0.030 inch).

Modular Coil Interface Design

The toroidal assembly of the 18 modular coil winding form (MCWF) castings is the structural backbone of NCSX; it supports the modular coils, vacuum vessel, toroidal-field coils, poloidal-field coils, and trim coils. Consequently, the 18 interfaces between the modular coils are one of the most critical elements of NCSX machine, since the structural stiffness of the completed modular coil assembly and the maintenance of accurate coil alignments are directly dependent upon them. The interface designs are difficult due to the complex geometry, space constraints, and the multiple functions they must perform: They must react the electromagnetic forces acting on the coils, provide for accurate positioning of the modular coils during assembly, assure that alignment between the coils is maintained throughout the life of the machine, and provide adequate electrical isolation between the winding forms to allow for field penetration. Peak compressive loads are approximately 10,000 pounds per inch of flange circumference and peak shearing forces are approximately 6,000 pounds per inch of flange circumference.

In the original concept, shown in Figure 4, electrically insulated shims were fitted between the modular coils to properly position them and then they were joined together by bolts in the outboard regions of the coils. Space constraints generally prohibited using bolts in the inner legs, but based on analyses performed at the time, it appeared that they were not needed and simple compressive shims would suffice. Subsequently, more advanced analyses, coupled with a greater understanding of the practical issues of meeting NCSX's ±0.75-mm assembly tolerance

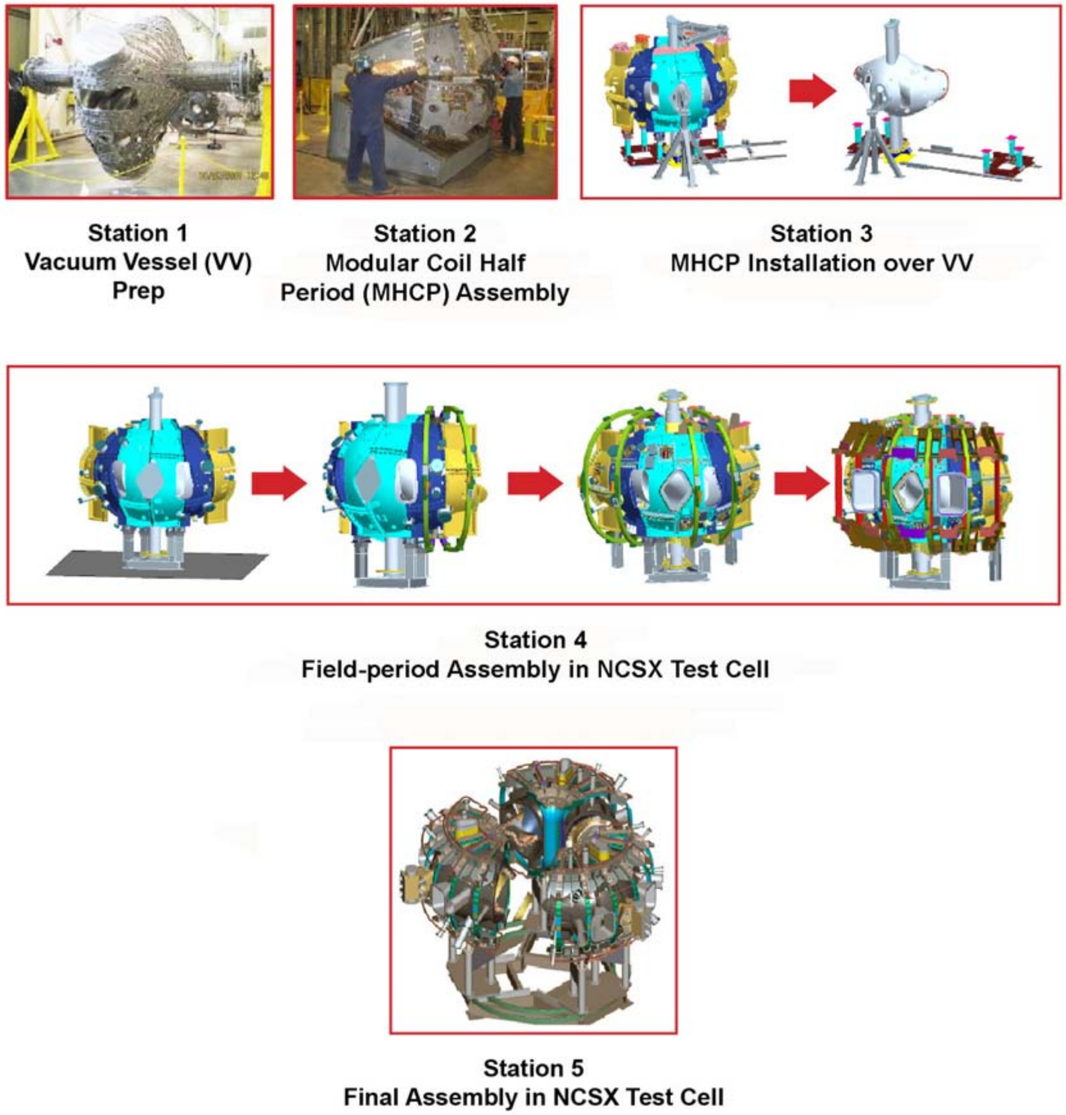


Figure 1. The National Compact Stellarator Experiment assembly sequence.

Figure 2. Installation of magnetic flux loops on a NCSX vacuum vessel segment.

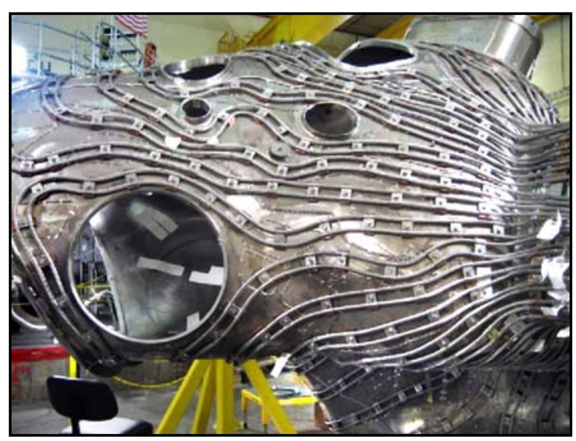


Figure 3. Installation of heating and cooling lines on a NCSX vacuum vessel segment.

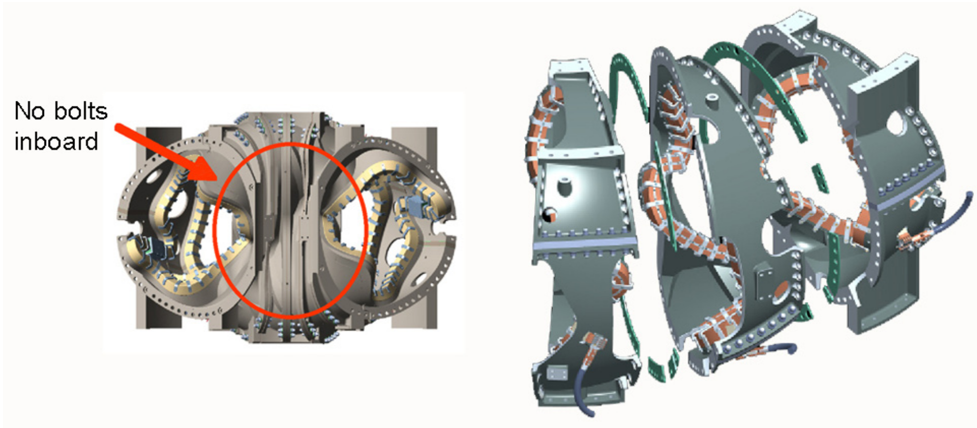


Figure 4. The initial modular coil design configuration.

for the field period, indicated the need to reduce bolt stresses, reduce inner leg deflections, and that shim design changes would be necessary to meet alignment requirements to provide confidence that coil alignment would be maintained throughout NCSX's operational lifetime.

These issues had to be resolved before assembly operations could begin: consequently, a task force of PPPL and Oak Ridge National Laboratory (ORNL) engineers was formed to carefully review a wide range of options before choosing the final design. By the end of FY07, a robust design concept was developed, a number of confirmatory tests were performed on components, and preparations for Final Design Reviews were underway.

In the new interface concept, alumina shims are used in all of the originally provided flange bolt locations. The alumina both increases friction to inhibit motion and provides electrical isolation. Two distinctly different types of interfaces are used on the inner legs, as shown in Figure 5.

Type I, used for connections between modules intra-field period, employs welded connections. This connection and the weld procedures were carefully

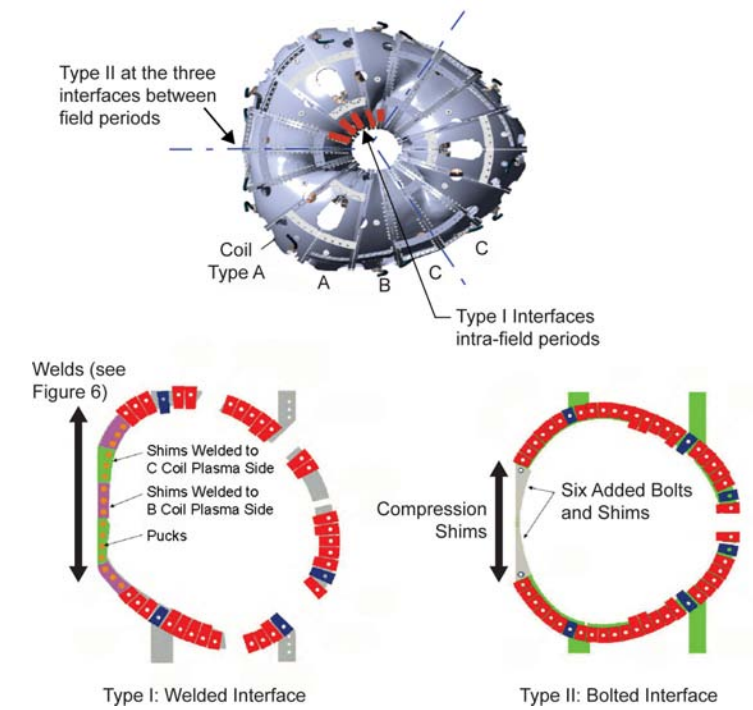


Figure 5. Types of modular coil interfaces.

designed to minimize weld distortions and were developed with the assistance of the ORNL, the European Organization for Nuclear Research (CERN), Wendelstein 7-X (W7X), and the Edison Welding Institute. The partial electrical isolation between modules is adequate for field penetration.

Type II, used in the interfaces between field periods, utilizes bolts and alumina coated shims. This is possible because of the greater modular coil flange width in these locations. Maintaining bolted interfaces at these locations is also favored because it facilitates machine assembly. Details of the interface and current status are shown in Figures 6 and 7 and are enumerated below:

- Plasma-sprayed, alumina-coated, segmented, stainless steel shims are used in all outboard regions. Alumina provides electrical insulation and approximately doubles the coefficient of friction (compared to stainless steel) to resist motion. Shim segmentation facilitates accurate coil positioning. The thickness of each shim is carefully chosen to properly locate the winding forms.
- High-strength bolts are tensioned by "Supernuts®" to ensure adequate clamping to provide the required shim frictional forces. Tests to demonstrate the stability of bolted-joint tension under cryogenic conditions and cold or warm cycling are underway at the Princeton Plasma Physics Laboratory and the Oak Ridge National Laboratory.
- Tight fitting insulating bushings are used around the bolts to provide redundant locking and locating features.
- Metrology techniques have been developed which are compatible with the accuracy requirements and assembly techniques. NCSX has an array of four multi-link portable component measuring machines and two laser trackers to support these activities. NCSX engineers recently visited CERN and W7X, where they discussed the use of photogrammetry to assemble large, complex components. This process can supplement NCSX's existing metrology tools and has the potential to reduce measurement time during assembly; consequently, plans are underway to procure a photogrammetry system.
- Handling methods, assembly fixtures, and procedures have been developed through Station 3 and are being developed for Stations 5 and 6.

Summary

Given the good progress on NCSX component manufacturing and completion of the Station 1 (vacuum vessel segment preparation) efforts, the focus of NCSX engineering shifted to machine assembly. In

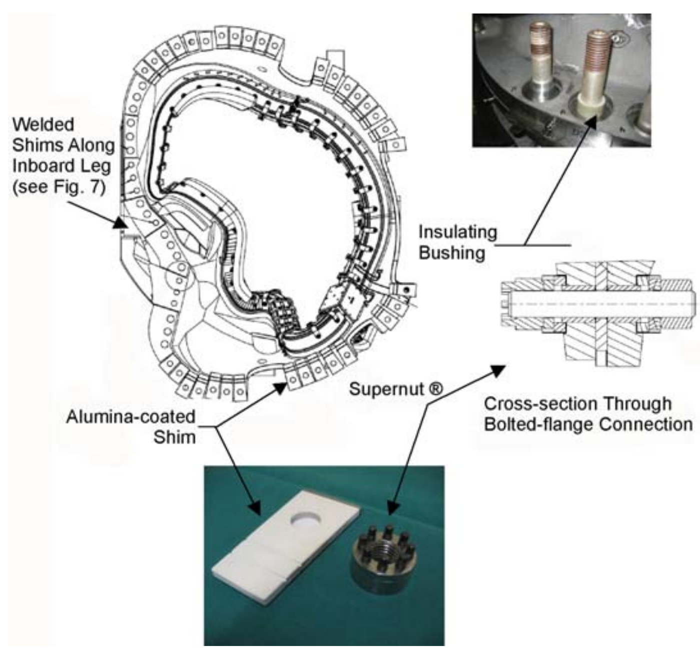


Figure 6. Modular coil interface details. Type I interface is shown, but both Type I and Type II interfaces are similar in regions beyond the inner leg.

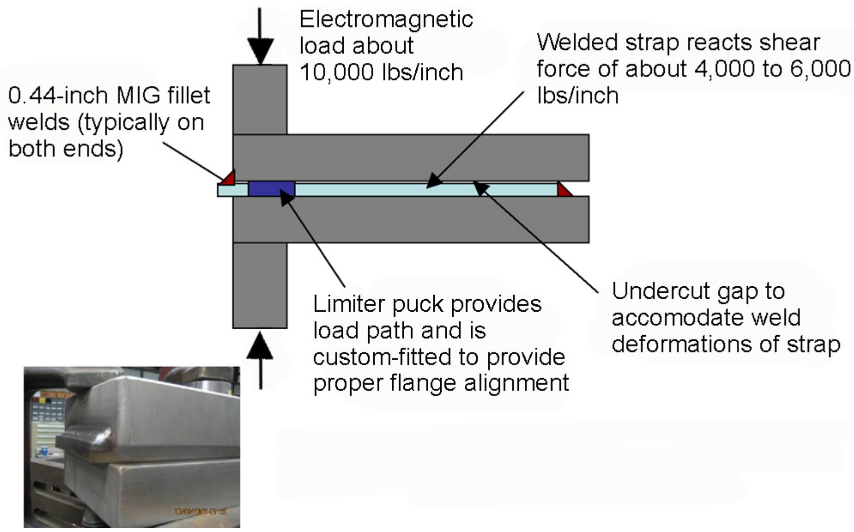


Figure 7. NCSX welded interface design concept. This welding concept minimizes weld shrinkage forces between the flanges and provides a load path as near as possible to the shell-to-shell interface.

concert with this focus, engineers spent a great deal of effort on finalizing and improving the design of the interfaces between the modular coils. By the end of FY07, a robust interface design was developed that gives confidence that NCSX can be assembled to the precision required, with interface engineering margins and design features incorporated to ensure maintenance of alignment during operation. These accomplishments provide a good foundation for machine assembly operations to proceed in FY08.

Figure 8. U.S.-ITER tube mill (at the top of the photo, between two MG sets).

PPPL Support for ITER

The tube mill (see Figure 8) required to compact the outer stainless steel jacket of the ITER toroidal-field superconductor was received, installed, and by the end of FY07 was being readied for safety review in preparation for R&D trials in early FY08. During the production of a toroidal-field superconductor, cabled superconductor is inserted into an oversized 1.875-inch outside diameter, 0.060-inch wall stainless steel tube. It is then processed in a tube mill to compact the tubing around the cable to support it and maintain cable strains due to electromagnetic forces within allowable limits during operation. The final outside diameter of the tube is 1.720 inch. A cross section of the superconductor is shown in Figure 9.

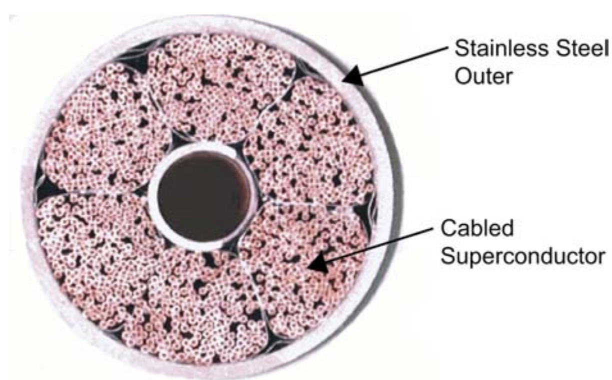


Figure 9. An ITER toroidal-field superconductor cross section after compaction.

NSTX Engineering Operations

The FY07 National Spherical Torus Experiment (NSTX) experimental run period began in mid February 2007, completing 12.63 run weeks by the end of June. During this period there were 505 hours of high-power operations with technical subsystems operating at an average availability of 92.7%. There were 2,078 plasma attempts, resulting in 1,879 plasmas.

NSTX operations this year included extensive use of the lithium evaporator (LITER), routine toroidal-field operations to 5.5 kG, and coaxial helicity injection operations to 1.75 kV. The Multi-pulse Thomson Scattering diagnostic was expanded to 30-channel operation and a new control computer to replace the SKY-based plasma real time control system was installed and commissioned.

The design of a new ohmic-heating coil was completed. The PPPL has entered into a collaboration agreement with the Institute of Plasma Physics, Chinese Academy of Sciences, for collaborative work on NSTX and the Experimental Advanced Superconducting Tokamak (EAST), including the construction of the new ohmic-heating coil.

PPPL Power Systems

PPPL implemented control upgrades to the 2,600-kW standby diesel generator to allow synchronization of the set for seamless transfers. Upon conclusion of the NSTX experimental run period, and during the peak electrical demand period of the summer months, the Lab's electrical distribution system was reconfigured to be able to power-down two 138-kV to 13.8-kV transformers, two 138-kV to 4.16-kV transformers, one 13.8-kV to 4.16-kV transformer, and several 4.16-kV to 480-V transformers, by combining loads on other transformers. This reduced normal summertime electrical load by about 1 MW or 25%.

High-average Laser Program

PPPL's Work-for-Others agreement with the High-average Laser Program continued through FY07. During this time the PPPL Engineering and Technical Infrastructure Department worked on advancing the conceptual design(s) of a closed-loop fuel-reprocessing system, a mechanical vacuum pumping system, and a magnetic intervention system for the purpose of deflecting ions from the first wall of a inertial fusion energy reactor. PPPL possesses unique engineering capabilities in the area of fusion reactor design and subsystem engineering. These capabilities are being employed in support of the conceptual design of the first U.S. inertial fusion energy power reactor.

Miniature Integrated Nuclear Detection System

During FY07 work continued on the development of the Miniature Integrated Nuclear Detection System (MINDS) under a Work-for-Others contract with InSitech, a private corporation. During this time, the first patent for the MINDS technology was issued by the U.S. Trademark and Patent Office, and several more patents were filed and are pending. MINDS installations during FY07 included a regional detection network employed for homeland security purposes, a major commuter rail station in the northeastern United States, and a container ship off/loading facility at the port of Oakland in California.

Computing

Cyber Security

Cyber Security at PPPL continues to be a very important and highly visible issue. During FY07 the rewriting of PPPL's Certification and Accreditation package including the Cyber Security Program Plan, Risk Assessment, Threat Assessment, and Contingency Plan was completed to comply with the Federal Information System Management Act and the National Institute of Standards and Technology requirements. A significant effort, spanning 18 months, was made to produce the policies, procedures, and documentation required and to implement the new processes. In May 2007, PPPL successfully passed a Security Test and Evaluation (ST&E) by On Point Consulting. The successful ST&E completed the Certification and Accreditation process and led to a three-year Authorization to Operate in June 2007.

In FY06, PPPL introduced Virtual Local Area Networks (VLAN's) to segment the former flat network. Segmentation of the network provides greater security in that a compromise of one segment may be contained and restricted from spreading to another segment. In FY07, the use of VLAN's was expanded to include all segments of the Laboratory. Dual internal firewalls monitor and control inter-VLAN access.

The wireless network, redesigned in FY06 to incorporate the use of VLAN's and deploy detection of rogue (unauthorized) access points, was further enhanced in FY07 with the deployment of WPA (Wi-Fi Protected Access) encryption and is compliant with wireless networking standards (802.11X).

The effort to keep worms, viruses, trojan horses, spyware, and other malicious software off PPPL networks continues to be significant. Much effort in the cyber security area has been targeted at addressing cyber security alerts, installing the latest patches, and ensuring that all users have the latest virus protection. So that future vulnerabilities can be patched more efficiently, almost all Windows systems now have basic security and patch updates managed by the PPPL domain. Enforcement of a new Laboratory policy, which requires all Windows systems at PPPL to be managed by the PPPL domain unless specifically exempted by Computing Division management, is increasing. Redhat Linux clusters now boot from a central server allowing for uniform cyber security policy and simple patching. MacOS systems are managed via Apple Remote Desktop (ARD). A MAC Domain is being implemented to augment the capabilities of ARD and further enforce and define configuration requirements similar to management of the Windows computers.

Business and Financial Computing

The business systems are housed on three Dell servers: a production SQL Server database server, a Windows IIS web server, and a test and development server running both SQL and IIS. The client software runs on Windows XP SP2 and is not compatible with Microsoft's new Vista operating system. Microsoft will discontinue support for SQL 2000 in April 2013 and for the Windows XP operating system in April 2014.

A replacement for the main database server was purchased and is expected to go into service in early FY08. A replacement for the business applications web server is budgeted in FY08. The replacement or upgrade of the business systems will be budgeted beginning FY10.

Scientific and Engineering Computing

During FY06, funds were authorized to rebuild PPPL's aging computational cluster. The rebuild project took six months to complete with the new cluster becoming fully operational at the start of FY07.

In FY07 there were about 150 users of the new cluster, up from approximately 70 users in FY05 (prior to the rebuild of the cluster), a more than doubling of the user base.

The PPPL Linux cluster is uniquely important to our mission since it provides computing for single CPU and small parallel jobs that are not favored at the larger supercomputing sites at NERSC (National Energy Research Supercomputing Center) and ORNL. Those sites attach the highest priority to jobs of greater than 256 CPU's and the lowest priority to jobs of less than 64 CPU's. Approximately 90% of the jobs run on the PPPL cluster use less than 16 CPU's.

Computing capabilities unique to PPPL, such as the FusionGrid TRANSP run production service used by researchers worldwide, have been expanded. TRANSP is serviced by the SWIFT cluster of 12 nodes/24 CPU's. TRANSP use continues to grow steadily with usage up 300% since FY05; it is becoming especially important for ITER and NSTX research.

Computing Infrastructure

Upgrading of the second- and third-generation hardware in the wiring closets with a commercial off-the-shelf (COTS) configuration of new switches easily deployed to all closets continued in FY07. Upgrade work of the two closets in the LSB started in FY07 will be completed in FY08. Once the LSB closet upgrades are done, work will begin on the Theory, L-Wing, DAS, and New Engineering wiring closets. This work is expected to continue throughout FY08 and FY09. When this phase of the wiring upgrades is finished, 95% of the most active network ports will have up-to-date switching equipment. The remaining closets will be upgraded as time and budget permits.

The migration of critical data servers and desktops to megabit ports continued. Several server class machines, responsible for PPPL backups, mail serving, and disk serving, were moved to gigabit ports.

A new fiber connection was run between PPPL and Princeton University in FY07. The new connection increased the bandwidth to the University from 100 MB to 1 GB (10 times the speed) allowing for the retirement of the microwave link that had operational issues under certain weather conditions and providing a possible path to higher bandwidth connections to ESnet.

In fiscal year 2004, a Storage Area Network (SAN) was proposed to provide efficient and increased storage capability. Initial SAN storage capacity was 3.5 TB; it was predicted that storage needs would increase by approximately 3 to 4 TB per year. However, due to several changes in data storage requirements at the Lab, it became clear that a substantial increased in storage capacity was needed:

- The NSTX experimental program, using new camera-based diagnostics, started producing gigabytes of data per plasma discharge and began to use the SAN for data storage.

- The Magnetic Reconnection Experiment and other small Laboratory experiments that were storing their data locally started using the SAN for data storage.
- Upgrade of the PPPL Linux cluster set in FY06 increased cluster usage from 10,000 jobs in FY04 to 100,000 jobs in FY07, creating large data sets (especially for the GX2, GYRO, and PIES codes) requiring significant amounts of online data storage.
- Procedures were changed to back up the desktops to disk prior to transferring the data to tape using the fiber.

Because of the significant increase in online storage needs, the SAN was augmented in FY07 with 61 TB of storage; it is estimated that 100 TB of storage capacity will be need by 2009.

Return to Table of Contents

Environment, Safety, and Health

Princeton University and the Princeton Plasma Physics Laboratory (PPPL) enthusiastically support the U.S. Department of Energy's (DOE) commitment to worker safety at the DOE Laboratories. The safety of every student, faculty, staff, and guest is taken very seriously. It is believed that safe operation is of paramount importance, and PPPL continually works to improve the Lab's safety performance. The Laboratory supports the challenging goals that the DOE Office of Science has established, and continues to implement strategies to accomplish them.

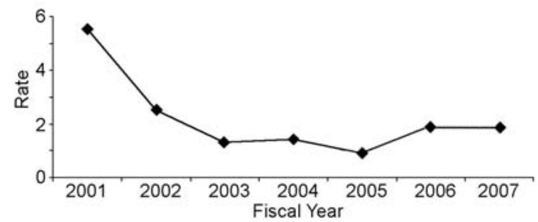


Figure 1. Recordable injury cases per 100 employees per fiscal year.

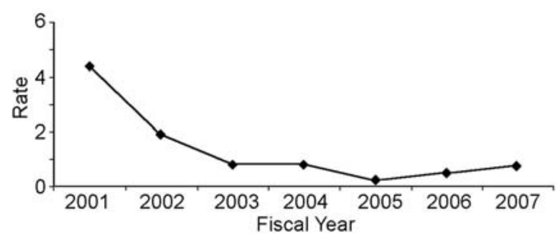


Figure 2. DART (Days Away, Restricted or Transferred) injury cases per 100 employees per fiscal year.

Worker Safety and Health

The Laboratory's Total Recordable Case (TRC) and Days Away Restricted or Transferred (DART) case rate metrics in FY07 featured stronger performance in the final three quarters of the year. During the first quarter of FY07 (October through December, 2006), PPPL experienced three Occupational Safety and Health Administration (OSHA) recordable injury cases, two of which required the workers to be placed on restricted duty. There was improvement in the TRC and DART case rates during the ensuing nine months of the fiscal year with a total of five Occupational Safety and Health Administration (OSHA) recordable injury cases, one of which was classified as a DART case. This period included almost eight consecutive months worked without a DART case.

PPPL endeavors to learn from accidents and incidents that have occurred here and elsewhere, both within and outside the DOE complex. Reports on these cases are published on the PPPL Lessons Learned web site for viewing by all Lab employees, and are automatically emailed to all PPPL supervisors. The trend of recordable injuries is depicted in Figure 1 and the subset of DART injuries is shown in Figure 2.

In March 2007, the Laboratory was informed that it had earned the following safety awards from the State of New Jersey for performance in calendar year 2006 (which included part of FY07):

- PPPL — *Recognition Award* for having a low incidence of away-from-work lost-time injury and illness cases.
- NCSX Project — *Division of Public Safety Award* for working two consecutive years with no away-from-work lost-time injury and illness cases.
- NSTX Project — *Commissioner's Continued Excellence Award* for having gone **six consecutive years** without an away-from-work lost-time injury and illness case.
- PS&T Department — *Citation of Merit Award* for working throughout the year with no away-from-work lost-time injury and illness cases.

In addition to current efforts, ongoing or planned PPPL initiatives to further reduce injury cases include: (1) improving hazards analysis implementation by training supervisors to be safety observers and advisors, and by integrating human performance improvement tools and techniques into critical procedures and practices; (2) enhancing safety education and training, e.g., retraining all personnel that use personal protective equipment; (3) improving line supervisor engagement in coaching employees on safe behaviors and practices; and (4) increasing safety promotion and awareness.

PPPL followed up on last year's very favorable DOE review of its Integrated Safety Management System by addressing and taking advantage of all the opportunities for improvement that arose from this review.

Work proceeded and was completed on a Worker Safety and Health Program for PPPL and to have it approved by DOE as required by the new DOE Worker Safety and Health rule, 10CFR851. Formal submittal of the Worker Safety and Health Program document took place more than two weeks ahead of the submittal deadline. Several comments from DOE were resolved, and DOE approved PPPL's Worker Safety and Health Program on May 1, 2007, twenty-four days ahead of the mandated approval deadline.

Safety Training

PPPL continued to present its Hazard Awareness Training Course to Laboratory staff (including all levels of management, up to and including the Laboratory Director), graduate students, and collaborators. The goal is to teach employees to identify and mitigate hazards using classroom training and field exercises. The course is built around the PPPL Job Hazard Analysis procedure, and includes an exercise that requires participants to collaboratively complete a Job Hazard Analysis in a machine shop or welding shop, on a simulated work task.

By the end of FY07, essentially all of PPPL's staff had received training and new staff members were participating in the training course as soon as practical following their arrival. In addition, Hazard Awareness training had been given to members of the DOE-Princeton Site Office (including the Site Office Manager), a representative of DOE Office of Science senior management, Oak Ridge National Laboratory employees who are working on the National Compact Stellarator Experiment (NCSX) being built at PPPL, and several groups of undergraduate summer students working at the Laboratory.

In March 2007, PPPL initiated a major program of "Human Performance Improvement" training to about 30% of the Laboratory staff. A well-known and respected consultant with expertise in this area provided specialized training, which consisted of modules addressing the following topics and audiences: eight-hour Human Performance Improvement Fundamentals (about 130 people), three-hour Human Performance Improvement for Senior Managers (about 20 people), and four-hour Human Performance Improvement for Safety and Health Professionals (about 20 people). The course is based upon materials originally prepared by the Institute of Nuclear Power Operations and endorsed by the National Academy for Nuclear Training. The subject material addressed the management of human performance incorporating research conducted by the Electric Power Research Institute and the Nuclear Energy Institute, and the Institute of Nuclear Power Operations benchmarking activities.

PPPL also provides an annual class on Environment, Safety, and Health issues in the workplace to newly arrived first-year graduate students. This year's daylong class was given to eight new graduate students in September 2007. The training is designed to help prepare them for the hazards they will encounter in their careers as researchers, scientists, and leaders. The focus is to provide first-hand explanations and tours that demonstrate the specific hazards and controls associated with projects, experiments, and facilities. In addition, the participants meet and interact with the people running the projects. Students provide feedback that helps us improve the class for future groups.

Return to Table of Contents

Applications Research and Technology Transfer

The transfer of technology to private industry, academic institutions, and other federal laboratories is one of the missions of the Princeton Plasma Physics Laboratory (PPPL). The Laboratory is presently working with a number of partners in scientific research and technology development. These collaborations are Cooperative Research and Development Agreements (CRADAs) or Work for Others (WFOs) projects and primarily involve applications of science and technology developed for PPPL's fusion program. In addition to CRADAs and WFOs, the Laboratory also uses Licensing Agreements, Personnel Exchanges, and Technology Maturation Projects to promote the transfer of PPPL technology.

A CRADA, which is a contractual agreement between a federal laboratory and one or more industrial partners, enables industry and PPPL researchers to work on programs of mutual interest. Costs and project results are generally shared between PPPL and the partner. WFO arrangements may involve either federal or non-federal partners. The partners pay for the work performed at PPPL. In the Personnel Exchange Program, researchers from industry assume a work assignment at the Laboratory, or PPPL staff may visit the industrial setting. In a Technology Maturation Project, a Laboratory researcher may work on technologies of interest to industry, where further development is required before a formal collaboration can begin. In addition to the above technology transfer mechanisms, the PPPL Technology Transfer Office encourages the development of technologies that are potentially relevant to commercial interests. These projects are funded by PPPL as Laboratory Program Development Activities.

The PPPL Technology Transfer Office works closely with the Laboratory's Budget Office and with the Princeton University Office of Research and Project Administration (ORPA). PPPL technology is licensed through ORPA, and PPPL inventions are processed through ORPA. The Laboratory works closely with the University for the patenting and protection of PPPL intellectual property.

CRADA

Plasma Treatment of Electrodes or Intelligent Materials

In FY07, PPPL initiated a new CRADA with Ras Labs, LLC, a woman-owned small business. Ras Labs, LLC, is committed to producing electro-responsive material actuators for the design of novel robotics and realistic prosthetics in terms of appearance, range of motion, and strength.

Smart materials, also called intelligent materials, respond by a change to external electrical stimuli. These materials can act, in effect, as artificial muscle. One major challenge is the interface between the embedded electrical lead, the electrode, and the electro-responsive material because of detachment caused by the differential movement between the electrode and the electro-responsive material. Through the CRADA, PPPL's equipment is used to plasma treat a variety of metal samples to modify the surface for

PPPL's Lew Meixler and Lenore Rasmussen of Ras Labs, LLC, prepare a metal wire sample for plasma treatment.

improved bonding to the electro-responsive materials. Different ions are being studied to find an optimum metal and plasma combination that solves the detachment problem.

During FY07, tests conducted at PPPL resulted in improved bond strengths. Stainless steel and titanium, metals suitable for use within the body, were treated with plasma comprised of ions of nitrogen, helium, or hydrogen. Oxygen ions derived from synthetic air (for safety) were also used. Ions were driven onto the surface of a 0.5-inch by 1.5-inch metal foil by a 40-volt electric potential for 12 hours.

Following a typical treatment, an electro-responsive polymer is sandwiched between two pieces of treated foil. The composite is evaluated by an external testing laboratory capable of performing adhesion tests on the small samples that fit into PPPL's apparatus. Standardized testing apparatus controls the speed and strain with which the composite is peeled apart. Initial tests show that a nitrogen plasma seems to have the most beneficial effect.

In addition to identifying a suitable plasma treatment and metals, the tests at PPPL provide insight into the mechanism responsible for improved adhesion of the polymer. Preliminary studies have shown that the plasma ions rough up the metal surface on a molecular scale and make the surface super clean by removing any oils that might be present. Work is planned to continue in FY08.

Work-for-Others Projects

Title: Micro-aviation Vehicle Project

Sponsor: Naval Research Laboratory

Scope: The Micro-aviation Vehicle (MAV) Program involves fundamental research and development of aerodynamics and airframes for novel concepts in unconventional miniature aircraft designs. MAVs generally have a wingspan of less than two feet and weigh less than a pound. These aircraft are expected to perform useful surveillance missions.

Fiscal year 2007 efforts continued last year's work on the Samara hybrid aircraft concept. The Samara is a stop rotor aircraft that combines the vertical ascent/descent capabilities of a helicopter with the speed and aerodynamic efficiencies of a fixed-wing airplane. New enhanced performance of this type of aircraft was explored with Samara II. The improvements included controlled hover ability, simplified stability controls, and a more compact geometry. Fixed-winged versions that were built by Naval Research Laboratory were flown and modifications were made to enhance stability. Rotary winged versions also built by Naval Research Laboratory were tested and are having electronic stabilization added.

In FY07, efforts also continued on the development of a more robust, controllable, and reliable versions of the Biplane Insectoid Travel Engine (BITE-Wing). New prototypes were built based on the success of the pivoting wing control system demonstrated in earlier models, and now have complete three axes control.

The Samara, BITE-Wing and other new vehicle development efforts are part NRL's ongoing Survivable Autonomous Mobile Platform, Long Endurance (SAMPLE) project. These vehicles are expected to be able to move in two or more of the following modes of locomotion: flight, crawling, hopping and swimming. They are also expected to carry out extended missions in a variety of environments.

Title: Nano-air Vehicle Project

Sponsor: Defense Advanced Research Projects Agency

Scope: The objective of the Nano-air Vehicle (NAV) Project is to design and develop flying devices that have a maximum weight of 10 grams; wingspans of less than 7.5 centimeters; a maximum forward speed from 5 to 10 meters per second; the ability to hover in place for greater than 60 seconds; and the ability to navigate to a specific location, drop a payload, and return to the operator. PPPL is part of a team working on the aerodynamic design concepts for NAV. The Laboratory is responsible for aeromechanical component design and model building for computational and empirical aerodynamic evaluation. Also, methods of manufacture have been explored. PPPL is also involved with the team in the areas of propulsion and power, navigation, guidance, communications, and command and control, and the preliminary integrated system design.

Title: Miniature Integrated Nuclear Detection System

Sponsor: InSitech, Inc.

Scope: The Miniature Integrated Nuclear Detection System (MINDS) is designed to detect and identify specific radionuclides for homeland security applications. The MINDS is configured to detect potential nuclear threats from radioactive dispersion devices (RDDs), such as a "dirty bomb." The original MINDS development was funded by the U.S. Army's Picatinny Arsenal and has applications for use by police, the National Guard, the Coast Guard, and other agencies involved in homeland security, homeland defense, as well as transportation rule compliance.

In March 2005 Princeton University and InSitech, a small business located in Dover, NJ, signed a licensing agreement for the commercialization of MINDS. During FY07, the MINDS underwent field evaluations for detecting radioactive dispersion devices inside of shipping containers at a major mass transit station at the Port of Oakland, CA, and for entrance monitoring at a Federal installation. The MINDS received Department of Homeland Security Safety Act Certification for Research, Testing and Evaluation and was the recipient of an award from the Federal Laboratory Consortium Northeast Region for Excellence in Technology Transfer. Other milestones for the MINDS Project included the first royalty income from the Project, and a U.S. Patent was issued on the MINDS invention.

Title: Mobile Operation of the Miniature Integrated Nuclear Detection System

Sponser: U.S. Army's Picatinny Arsenal

Scope: The Miniature Nuclear Detection System (MINDS) is being designed to detect the presence of suspect nuclear material and identify the specific radionuclide or radionuclides in mixed ionizing radiation fields. The system is configured to detect nuclear material entering a site, passing through a tollbooth, placed inside of a shipping container, or hidden in other ways, under realistic conditions. The full system, which employs many off-the-shelf components, will be capable of detecting X-ray, soft gamma, gamma, and neutrons. The objective of this effort is to package the PPPL MINDS for mobile operation and demonstrate such use from a police vehicle or similar mobile unit.

Title: Sterilization of Liquid Foods

Sponser: U.S. Department of Agriculture

Scope: The purpose of this project is to develop new pasteurization methods that use radio-frequency waves and microwave heating. These heating techniques, also used to warm plasma in a fusion device, are being tested for pasteurizing raw liquid foods such as eggs, fruit juices, and milk.

Radio-frequency waves offer advantages over the traditional pasteurization method of directly heating raw liquid foods. The direct method often heats foods unevenly, possibly resulting in incomplete pasteurization in lower temperature regions and in denaturing foods in overheated regions. Using radio frequency waves in the appropriate wavelength may allow pasteurization without heating liquid foods to temperatures that cause food deterioration.

Title: Magnetic Reconnection Experiment

Sponser: National Aeronautics and Space Administration

Scope: A basic plasma physics research facility, the Magnetic Reconnection Experiment (MRX) is used to study the physics of magnetic reconnection — the topological breaking and reconnection of magnetic field lines in plasmas. Scientists hope to understand the governing principles of this important plasma physics process and gain a basic understanding of how it affects plasma characteristics such as confinement and heating. The results of these experiments will have relevance to solar physics, astrophysics, magnetospheric physics, and fusion energy research.

Title: Korean Superconducting Tokamak Advanced Research, Phase II

Sponser: Korean Basic Science Institute

Scope: The Princeton Plasma Physics Laboratory is coordinating a U.S. team in support of the design of the Korean Superconducting Tokamak Advanced Research (KSTAR) device. KSTAR is the flagship project of the Korean National Fusion Program that was launched officially in January 1996. The KSTAR, at the National Fusion Research and Development Center, Korean Basic Science Institute, Taejon, Republic of Korea, completed construction in 2007 and an official ceremony marking its completion was held 12–13 September 2007.

Title: Novel Materials for Electra's "Hibachi" Electron Beam Windows

Sponser: Naval Research Laboratory

Scope: This Work-for-Others project is for the study, design, and production of thin "hibachi" windows fabricated from silicon or other novel materials for the Electra KrF laser system and perform a systems engineering study for Electra.

Title: Raman Pulse Compression of Intense Lasers

Sponser: Defense Advanced Research Projects Agency

U.S. participants standing in front of the KSTAR device.

Scope: A moderately intense, but long, laser pulse can be scattered into short very intense counter-propagating pulses in plasma through a variety of related mechanisms. The simplest and most efficient method is the well-studied stimulated Raman backscatter effect. In principle, fluences tens of thousands of times higher can be handled in plasma, making feasible significantly more intense lasers. In a collaboration involving the University of California, Berkeley, and Princeton University, scientists at the PPPL are assessing the practical realization of the plasma-based pulse compression schemes. Preliminary experimental results show apparent amplification of the counter-propagating wave.

Title: Energy Transport and Dissipation of Electromagnetic Ion Cyclotron Waves in Magnetosphere/Ionosphere

Sponsor: National Aeronautics and Space Administration

Scope: Electromagnetic ion cyclotron waves in plasmas are generated by electron-beam-driven instabilities. These waves play an important role in magnetosphere-ionosphere coupling. They are thought to be responsible for heating ionospheric ions, modulating auroral electron precipitation, populating the magnetosphere with energetic heavy ions during substorms, as well as producing parallel electric fields and electrostatic shock signatures. This program involves the development of solutions to full-wave equations for electromagnetic ion cyclotron waves using a non-local theory which includes kinetic effects and ionospheric collisions. The solutions can provide specific predictions of global electromagnetic ion cyclotron wave structure, wave polarization, and Poynting fluxes, which are observables that can be compared directly with spacecraft measurements.

Title: Self-consistent Model for Regions of Downward Auroral Current

Sponsor: National Science Foundation

Scope: The objective of this program is to develop a self-consistent understanding of the plasma and field properties of downward auroral currents.

Title: Vacuum Ceramic Multi-window in Titanium Flange

Sponsor: Institute for Plasma Research (Gujarat, India)

Scope: The Institute for Plasma Research (IPR) is enhancing its capability on the SST1 Tokamak in Gujarat, India and has contracted PPPL to fabricate and supply two multi-channel, ceramic vacuum windows for them. PPPL staff are working with the staff at the Institute for Plasma Research to design, fabricate, and the test the ceramic window assemblies at the Laboratory before shipment to Institute for Plasma Research.

Title: Testing of the Detritiation of the JET Tiles by Heating with the Oxy-Gas Burner

Sponsor: United Kingdom Atomic Energy Authority

Scope: The United Kingdom Atomic Energy Authority wants to investigate the removal of co-deposited tritium from the Joint European Torus (JET) graphite tiles employing localized heating. In general, the tile samples will first be characterized for tritium content and tritium depth profile. After such analysis, the tile sample will be subjected to direct heat from a burner to liberate the co-deposited tritium from the tile. After the application of localized heat, the tile will be reanalyzed to determine the effectiveness of the techniques employed.

Title: Kinetic Ballooning Instability as a Mechanism for Substorm Onset in the Near Earth Plasma Sheet

Sponsor: National Aeronautics and Space Administration

Scope: The objective of the project is to study the onset mechanism of substorms which occur in the near-Earth plasma sheet region of the magnetosphere. Theoretical predictions are being compared with satellite observations to clarify unresolved physics issues.

Title: Pre-eruption Coronal Magnetic Fields and Coronal Mass Ejections

Sponsor: National Aeronautics and Space Administration

Scope: A typical manifestation of coronal mass ejection (CME) consists of formation and expansion of a coronal mass ejection loop and eventual opening up of the magnetic field lines. Since the field opening is a spontaneous energy-releasing process, the energy of the pre-eruption field of a closed configuration must be greater than the open field energy. The objective of this effort is to investigate the energetics and dynamics of the magnetic fields involved. This study will not only provide an understanding of coronal mass ejection physics, but also information about the observable conditions associated with coronal mass ejections.

Title: Current Sheet Structure in Near-earth Plasma Sheet during Substorm Growth Phase

Sponsor: National Aeronautics and Space Administration

Scope: The purpose of this effort is to study the three-dimensional current sheet structure in the near-Earth plasma sheet region during the substorm growth phase by combining the three-dimensional modeling with observations of magnetic field and plasma pressure from the POLAR satellite.

Title: Accretion onto Massive Black Holes in Low-luminosity Galactic Nuclei

Sponsor: National Aeronautics and Space Administration

Scope: Most galaxies in the universe contain supermassive black holes at their centers; and yet most galactic nuclei emit very little radiation indicative of active accretion. The purpose of this work is to investigate this issue using low-radiative efficiency accretion flow models including advection-dominated and convection-dominated accretion flows.

Title: Low-power Cylindrical Hall Thruster

Sponsor: Air Force Scientific Office of Research

Scope: This project focuses on studying Hall thrusters of cylindrical, rather than annular design, with new features such as emissive, segmented electrodes and central localizing of the cathode neutralizer. The key cylindrical thruster concepts were invented and tested at Princeton, but the physics remains far from sufficiently understood. Many phenomena key to the operation of this thruster concept, and incidentally of general importance to the science of insulating plasma flows, are simply not understood at all. In a cylindrical geometry Hall thruster, including a cusp magnetic field, any optimization requires an understanding of electron transport, ionization, electric potential distribution, waves and instabilities, and discharge stability.

Title: Electromagnetic Full Particle Simulations of the Structure and Stability of the Magnetopause with Velocity Shear

Sponsor: National Aeronautics and Space Administration

Scope: Two-dimensional, electromagnetic particle simulations of the Earth's magnetopause are being performed to study the formation and stability of the magnetopause current layer in regions where there is substantial flow along the magnetopause interface (on the dayside and tail flanks). In particular, geometries considered unstable to the Kelvin-Helmholtz instability are being considered. The results obtained from the simulation model will be compared with space observations in order to improve understanding of the formation and stability of the magnetopause and its boundary layers.

Title: Laboratory Study of Magnetorotational Instability in a Gallium Disk

Sponsor: National Aeronautics and Space Administration

Scope: The importance of magnetic fields has been widely recognized in a class of astrophysical objects called accretion disks. An accretion disk consists of gas, dust, and plasmas rotating around and slowly accreting onto a central point-like object, which can be a star in formation, collapsed stars in binary systems, or supermassive black holes in active galactic nuclei. Rapid angular momentum transport in accretion disks has been an outstanding problem in astrophysics for more than three decades. The magnetorotational instability has been identified as a powerful mechanism to transport angular momentum. The objective of this project is to demonstrate and study this instability in the laboratory for the first time. This work is being performed in close collaboration with the Princeton University Department of Astrophysical Sciences.

Title: Developing the Procedure and Initial Code for Charge-changing Ion-atom Collisions.

Sponsor: Tech-X Corporation

Scope: This project involves the development of the code structure and the procedure for evaluating charge-changing ion-atom collisions based on the Classical Trajectory Monte Carlo method.

Title: Schlumberger Analyses

Sponsor: Schlumberger

Scope: The Princeton Plasma Physics Laboratory is providing chemical and trace tritium analyses services.

Return to Table of Contents

Patents and Invention Disclosures

Patents Issued

A New Method for a Simultaneous Measurement of the Integrated X-ray Reflectivity of a Crystal for Different Orders of Reflection
— *Sang Gon Lee, Jun Gyo Bak, and Manfred L. Bitter*

Miniature Nuclear Detection System (MINDS)
— *Charles A. Gentile, Andrew F. Carpe, and Stephen W. Langish*

Invention Disclosures

An Electro-optical Tunable Birefringent Filter
— *Fred M. Levinton*

Controlling Charge and Current Neutralization of an Ion Beam Pulse in a Background Plasma by Application of a Small Solenoidal Magnetic Field
— *Igor D. Kaganovich, Edward A. Startsev, Adam B. Sefkow, and Ronald C. Davidson*

Convertible Aerial Vehicle with Contra-rotating Wing/Rotors and Twin Tilting Wing and Propeller Units
— *David Cylinder and James C. Kellogg (NRL)*

Direct Drive Electric Generator Pump
— *W.T. Reiersen*

Fusion Reactor First Wall with Pumping, Cooling, and MHD Stabilization using a Lithium "Thick Film" First Wall and Closed-channel Lithium Flow
— *Richard Majeski*

Inductive Field-Reversed Configuration Formation utilizing a Spheromak and an Ohmic Solenoid
— *Stefan Gerhardt, Masaaki Yamada, Hantao Ji, and Elena Belova*

Magnetic Field Coils for Stabilizing the Vertical Mode in Tokamak Plasmas and in other Toroidal Magnetic Confinement Devices
— *Allan Harold Reiman*

Microelectronic Dust Transporter System
— *Charles H. Skinner*

Programmable Coil Array with Optimized Currents for Transcranial Magnetic Stimulation
— *H.E. Mynick, N. Pomphrey, and A.H. Boozer*

Target Positioning Arm
— *John DeSandro, Scott Gifford, Doug Lebrie, and Craig Priniski*

Return to Table of Contents

Graduate Education

Program in Plasma Physics graduate students.

Graduate Education at the Princeton Plasma Physics Laboratory (PPPL) is supported through the Program in Plasma Physics and the Program in Plasma Science and Technology. Students in these programs receive advanced degrees from Princeton University. In the Program in Plasma Physics, Doctoral (Ph.D.) degrees are given through the Department of Astrophysical Sciences, while in the Program in Plasma Science and Technology, Masters (M.S.E.) or Doctoral (Ph.D.) degrees are given through the departments of Astrophysical Sciences, Chemical Engineering, Chemistry, Civil Engineering, Computer Science, Electrical Engineering, Mechanical and Aerospace Engineering, and Physics.

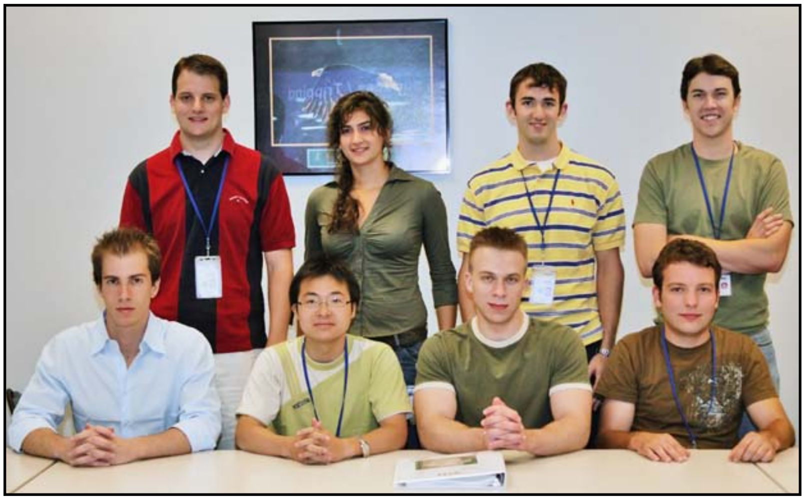
Program in Plasma Physics

With more than 235 graduates since 1959, the Program in Plasma Physics has had a significant impact on the field of plasma physics, providing many of today's leaders in the field of plasma research and technology in academic, industrial, and government institutions.

Both basic physics and applications are emphasized in the Program. There are opportunities for research projects in the physics of the very hot plasmas necessary for controlled fusion, as well as for projects in solar, magnetospheric and ionospheric physics, plasma processing, plasma thrusters, plasma devices, nonneutral plasmas, lasers, materials research, and in other important and challenging areas of plasma physics.

In FY07 there were 40 graduate students in residence in the Program in Plasma Physics, holding between them three U.S. Department of Energy Fusion Energy Sciences Fellowships, one U.S. Department of Energy Science Stewardship Graduate Fellowship, one National Science Fellowship, one National Defense Science and Engineering Graduate Fellowship, one Fulbright International Science and Technology Award, and one Princeton University Charlotte Elizabeth Proctor Honorific Award.

Eight new students were admitted in FY07, five from the United States, one from Lebanon, one from China, and one from Italy. Three students graduated in FY07, accepting positions at The University of Wisconsin at Madison and Sandia National Laboratory.



First-year grduate students. Standing: Clayton Myers, Katy Ghantous, John Rhoads, and Martin Griswold. Sitting: Filippo Scotti, Hua Wang, Paul Schmit, and Anton Stepanov.

Program in Plasma Science and Technology

Applications of plasma science and technology meld several traditional scientific and engineering specialties. The Program in Plasma Science and Technology (PPST) provides strong interdisciplinary support and training for graduate students working in these areas. The scope of interest includes fundamental studies of plasmas, plasma interaction with surfaces and surroundings, and the techniques associated with plasma applications. Plasmas are essential to many high-technology applications, such as gaseous lasers, in which the lasing medium is plasma. X-ray and high-power laser research are prominent in the PPST. Another example is fusion energy for which the fuel is a high-temperature plasma. Lower temperature plasmas are used for critical materials fabrication processes including the etching of complex patterns for micro- and macro-electronic and optical components and the deposition of tribological, magnetic, optical, conducting, insulating, polymeric, and catalytic thin-films. Plasmas are also important for illumination, microwave generation, destruction of toxic wastes, chemical synthesis, spacecraft propulsion, control-system theory and experiment, and advanced-design particle accelerators.

The PPST provides support for Ph.D. students who concentrate on a specific research topic within the field of plasma science and technology while acquiring a broad background in relevant engineering and scientific disciplines. In FY07, twelve graduate students received support from the PPST during the academic year and/or summer. They co-authored more than a dozen refereed publications. Two received Ph.D. degrees from their respective departments.

To enhance a strong research environment, increased efforts were made to develop appreciation for plasma physics in Princeton undergraduates through a summer internship program, including a new international student exchange program initiated with the Department of Physics, Imperial College, London. In FY07, seven Princeton undergraduates worked with PPST and the Woodrow Wilson School of Public and International Affairs faculty on plasma science and technology projects such as plasma manufacture of deformable electrodes, the manipulation of chemical reactions by laser light, intense X-ray sources, and possible impacts of fusion energy on global politics and economics.

Professor Chandrasekar Joshi (University of California at Los Angeles, UCLA) was the distinguished speaker at the PPST public lecture series held to inform the Princeton community of contributions made by plasma science and technology to our society. In a talk entitled, “Surfing Plasma Waves: A New Paradigm for Particle Accelerators,” Dr. Joshi, winner of the American Physical Society’s James Clerk Maxwell Prize, Director of Center for High Frequency Electronics and of the Neptune Laboratory for Advanced Accelerator Research at UCLA, described entirely new plasma-based concepts for charged-particle acceleration. In these experiments, electrons and positrons were accelerated to multi-GeV energies by “surfing” on waves in plasmas produced by intense laser pulses or electron beams.

Table 1. Students Admitted to the Plasma Physics Program in Fiscal Year 2007.

Student	Undergraduate Institution	Major Field
Katy Ghantous	American University of Beirut, Lebanon	Physics
Martin Griswold	University of California at Los Angeles	Physics
Clayton Myers	Cornell University	Physics
John Rhoads	Texas Christian University	Physics
Paul Schmit	Arizona State University	Physics
Filippo Scotti	Politenico di Milano, Italy	Physics
Anton Stepanov	University of California at Los Angeles	Physics
Hua Wang	University of Science & Technology of China	Physics

Table 2. Recipients of Doctoral Degress in Fiscal Year 2007.

Jenkins, Thomas

Thesis: Fluctuations, Noise and Numerical Methods in Gyrokinetic Particle-in-Cell Simulations

Advisor: Wei-li Lee

Employer: University of Wisconsin at Madison

Ren, Yang

Thesis: Studies of non-MHD Effects during Magnetic Reconnection in a Laboratory Plasma

Advisor: Masaaki Yamada

Employer: University of Wisconsin at Madison

Sefkow, Adam

Thesis: Current Density Compression of Intense Ion Beams

Advisors: Ronald C. Davidson

Return to Table of Contents

Science Education

The goal of the Science Education Program (SEP) at the Princeton Plasma Physics Laboratory (PPPL) is to combine the core research activities of PPPL with science education programs to create a center of excellence for students and teachers. To achieve its goals, the SEP strives to: (1) contribute to the training of the next generation of scientists and engineers, (2) collaborate with K–12 teachers on ways to improve science teaching using an inquiry-based approach to learning, and (3) improve the scientific literacy of the community at large. These initiatives, led by SEP staff in conjunction with PPPL volunteers, master teachers, and local education experts, create significant learning opportunities for undergraduate college students and K–12 teachers and students.

The center of all SEP activities is the Plasma Science Education Laboratory (PSEL), a 3,000-square-feet unique space dedicated to professional development workshops for K–12 teachers, enrichment programs for students, and high-quality plasma physics research. A fusion of research between education and plasma science, the facility includes a teaching laboratory/classroom, two research labs, and student offices/storage/prep room.

High school research intern Lauren Chilton calibrating a visible spectrometer for her project: Temperature Measurements of an Electron Cyclotron Resonant Source via Visible Spectroscopy.

The research performed in the PSEL is centered upon dusty plasmas and plasma processing and is primarily student-centered. Undergraduate and advanced high school students plan all work, formulate research goals, assemble all apparatus, collaborate with scientists and engineers, critique and evaluate each other's work, write papers, and make oral and poster presentations. Simultaneously, the PSEL's open layout for educational workshops fosters communication between participants, master teachers, and student researchers to create a unique learning environment for teachers and students of all abilities.

Individual Accomplishments

James Morgan, SEP Program Administrator, continued his study of what attracts students to science and engineering and published, "Teaching Information Evaluation and Critical Thinking Skills in the Physics Classroom" with Princeton University Librarian Adriana Popescu in the journal "The Physics Teacher."

Michael Hvasta, a junior physics major from The College of New Jersey was selected to present his summer research in the Plasma Science Education Laboratory at the annual meeting of the American Association for the Advancement of Science (AAAS). His paper, "UV Induced Motion of a Fluorescent Dust Cloud in an Argon DC Glow Discharge Plasma" was the only one selected from PPPL by the Office of Workforce Development within the Department of Energy (DOE).

Science Education Head Andrew Zwicker gave an invited talk at the Workshop on Nuclear Science Education and Outreach at Brookhaven National Laboratory. His talk, "Plasma Camp: Creating Stars in the Classroom Since 1998" outlined the goals and details of the workshop as well as the measured success of how its teachers "institutionalize" their plasma-based curricula by teaching it yearly in their classrooms and through dissemination to other teachers. He also attended the joint meeting of the American Association of Physics Teachers and the American Astronomical Association in Seattle, WA, and gave a talk on "Teaching Energy in the 21st Century to K–12 Teachers and Students." Finally, he was named Chair-elect of the American Physical Society Forum on Physics and Society. Formed in 1972, the Forum concentrates on the interrelation of physics, physicists, and society. The Forum on Physics and Society is the oldest of the American Physical Society Forums and the second largest unit of the American Physical Society.

Undergraduate Research Programs

PPPL staff continued the tradition of training the next generation of scientists and engineers as 38 students participated in PPPL's undergraduate research programs during FY07. Sixteen students from the National Undergraduate Fellowship (NUF) program and 12 students from the Science Undergraduate Laboratory Internship (SULI) program completed their summer research at PPPL, other DOE Laboratories, and universities including: General Atomics, Los Alamos National Laboratory, University of California-Irvine, University of Colorado-Boulder, and the Massachusetts Institute of Technology (MIT). The ten-week summer research experience includes a one-week introductory course in plasma physics held at PPPL. Princeton Plasma Physics Laboratory senior researchers, Princeton University faculty and professors from other institutions teach the course. Professor Nathaniel Fisch, Director of Princeton University's graduate program in Plasma Physics who serves as the program's Academic Director, leads it.

Three NUF students were recognized for their poster and research at the 2006 American Physical Society Division of Plasma Physics Meeting in Philadelphia, PA: Manuel Aldan of Rensselaer Polytechnic Institute did his research with Dr. Michael Schaffer at General Atomics. His poster was titled, "Exploratory Study of Novel Magnetic Perturbation Coils for the DIII-D Tokamak." Jon Hillesheim of The University of Wisconsin-Madison did his research with Dr. E. Foley of Nova Photonics, Inc. His poster was titled, "Motional Stark Effect with Laser-induced Fluorescence Diagnostic Development." Paul Schmidt of Arizona State University did his research with Dr. S. Wukitch at MIT. His paper was titled, "Investigation of Coaxial Multipactor in the Presence of a Magnetic Field."

In September 2007, ten out of the 16 NUF students that graduated college in 2006 entered graduate school. Of these students, three are in plasma physics and two of these are female. The other seven students (six male, one female) are in physics programs at schools with a strong plasma physics program, but have not chosen a field of study. They are attending the University of Wisconsin; Princeton University; University of California, Los Angeles; University of California, Irvine; University of California, Berkeley; Stanford University; University of Washington; and the University of Maryland.

Pre-college Activities

Each year opportunities exist for motivated high school students to perform independent laboratory work in plasma physics. This year talented students from the Princeton area worked on a variety of research topics with a number of mentors:

Maria Aristova: *Comparative Study to Determine an Optimal Material for Tritium Production in a Direct Drive IFE Reactor* (Charles Gentile)

Ali Burstein: *Process Model of the Fuel Recovery System in an IFE Reactor* (Charles Gentile)

Lauren Chilton: *Electron Temperature Measurement of an Electron Cyclotron Resonant Source via Visible Spectroscopy* (Andrew Zwicker)

Ruslan Fridman: *Development of Fluorescent Spheres for the Dusty Plasma Experiment* (Andrew Zwicker)

Syed Haider: *Narrow-band Tunable Optical Filters* (Jill Foley)

Jenna Kefeli: *Improving Diagnostics and Analyzing Data for Plasma MRI* (Hantao Ji)

David Ku: *Perturbing Ekman Circulation in Couette Flow* (Hantao Ji)

Logan Maingi: *Software Development for an IR Camera for NSTX* (Mike Zarnstorf)

Benjamin Phillips: *Enhancements to ElVis Scientific Graphics Software-I* (Elliot Feibush)

Tarun Pondicherry: *Enhancements to ElVis Scientific Graphics Software-II* (Elliot Feibush)

Kurt Snieckus: *Calibration of an IR camera for NSTX-I* (Rajesh Maingi)

Jonathan Surany: *Calibration of an IR Camera for NSTX-II* (Rajesh Maingi)

Liberty Science Center Partnership

Liberty Science Center celebrated its grand reopening in summer 2007 after a 22-month, $109 million upgrade of its exhibition, program, and theater experiences. The purpose of the redesigned Science Center, now 295,000 square feet, is to be a unique and engaging resource about the science and technology that surround living, learning, and working in the New Jersey-New York City region. PPPL's Science Education Program is partnering with the Liberty Science Center in a variety of innovative ways including: (1) the creation of a new "Live from PPPL" program that uses video conferencing to bring real-time fusion energy research to students and teachers, (2) a new plasma demonstration focusing on fusion for the main floor of the Science Center in the "Energy Quest" exhibit, and (3) workshops on plasma and fusion energy for Liberty Science Center educators and teachers.

Live from PPPL. Sixty physics students from Bergen Academy in Teterboro, NJ participated in a "Virtual Field Trip" to the National Spherical Torus Experiment (NSTX) control room via a video conference link between the school and PPPL. Students had a chance to watch NSTX operations live as part of their study of fusion energy. Graduate students Dave Smith, Stephanie Diem, and Patrick Ross, NSTX physicist Steve Paul, NSTX engineer Tim Stevenson, and Science Education Head Andrew Zwicker answered questions from the students that ranged from plasma physics, to heating a fusion-grade plasma, to NSTX operations, to the experiment occurring that day, to careers in plasma physics and fusion energy research. Feedback from the students was extremely enthusiastic and the 60-minute program was expanded to 90 minutes due to the volume of questions asked by the students.

Energy Quest Exhibit. Visitors are taken on a journey through the five major sources of Earth's energy where they learn about the many methods that humans have used to explore and harness these energy sources at five hands-on stations, including one on plasma and fusion built by PPPL.

Educator Workshop. Twenty-seven Science Educators and other staff from The Liberty Science Center spent the day at PPPL in the Plasma Science Education Laboratory as part of their professional development activities. The staff completed laboratory exercises with plasma balls, half-coated fluorescent light bulbs, and DC glow discharge tubes. The work was the first step in training the staff at the Liberty Science Center in plasma physics education in preparation for the reopening of the science museum and the addition of a new exhibit on plasmas and fusion energy.

Science Bowl

High School Science Bowl. PPPL hosted 27 teams, from 17 high schools, from across the state as participants in the New Jersey Regional Competition of the National Science Bowl® on Saturday, February 24, 2007. More than 40 volunteers from PPPL, Princeton University, Merck, Sarnoff Corporation, Bristol-Myers Squibb, and local school districts helped facilitate the competition. The winner, East Brunswick High School, won an all expense paid trip to Washington, D.C. in early May to compete against 72 teams from around the country in the National Science Bowl®. The New Jersey team placed in the top 16 teams overall, for the fourth year in a row.

Middle School Science Bowl. In FY04, PPPL sponsored the first Middle School Science Bowl for Trenton students. In FY06, the program was expanded to include a second "special needs" district, the Burlington School District. In FY07, the program was expanded to include all NJ school districts and the competition was held on April 14. The rules are similar to the high school competition, but teams also are judged on the results of a race with a hydrogen fuel cell-powered model car. The FY07 results were:

Academic Competition: Thomas Grover Middle School, West Windsor Plainsboro School District

Hydrogen Fuel Cell Model Car Competition: Fisher Middle School, Ewing School District

Civility Award: Burlington City Middle School, Burlington City School District

Fisher Middle School was the winning team based on the best overall results in both competitions. The team went to Denver, Colorado, for the National Middle School Science Bowl Competition.

Andy Carpe with a prototype of the plasma source built by PPPL for the Liberty Science Center's "Energy Quest Exhibit."

"Graduate student Stephanie Diem in the NSTX Control Room talking to students via a video conference link with the Bergen Academy in Teterboro, NJ, as part of the "Live from PPPL" program with the Liberty Science Center.

Plasma Camp

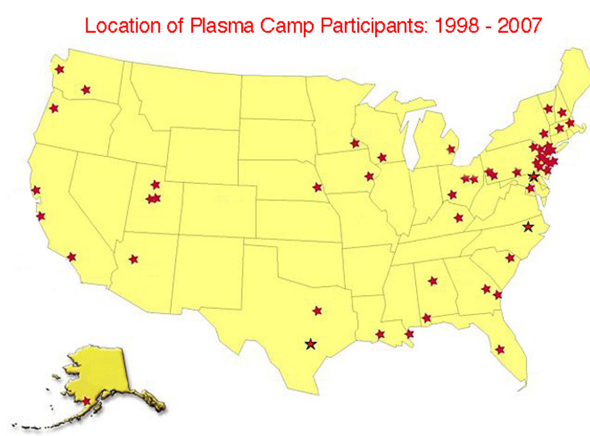
Since 1998, the Plasma Science and Fusion Energy Institute ("Plasma Camp") has brought secondary school teachers from around the country to PPPL for an intensive workshop of plasma physics, fusion energy, and curriculum writing. Plasmas are ideal to illustrate many concepts in physics and physical science curricula including light, waves, atoms, nuclear reactions, relativity, electricity and magnetism. An integral part of the Institute is the development of new plasma-based lesson plans, student-led investigations and demonstrations.

The goals of Plasma Camp are: increase knowledge of plasma physics and fusion energy among secondary-school teachers; develop new plasma-based curricula, laboratories, and demonstration; develop an awareness of the richness and complexity of plasmas through experimentation and exploration of their basic properties; understand some of the social and technological issues addressed by the use of plasma; understand some of the possibilities and constraints in the development of fusion energy; create a network for collaboration and discussion between participants after the conclusion of the Institute and; enhance awareness of the physics of plasmas and fusion within the physics-education community.

In FY07, nine teachers from around the country came to PPPL for the workshop. States represented New Jersey, Virginia, New York, North Carolina, Texas, and Alaska.

Plasma Academy

Each year since 2003, approximately 25 students from the Bergen Academy High School for Math Science and Technology in Hackensack, NJ spend a week in August at PPPL to participate in an intensive, hands-on workshop, "Energy in the 21st Century: Fusion, Solar, Hydrogen Fuel Cells." The agenda includes laboratory work, lecture, and a tour of PPPL.



Plasma Camp, an intensive workshop centered on plasma physics, fusion energy, and curriculum writing, draws participants from around the country.

The Lewis School Collaboration

The Lewis School of Princeton and PPPL have a unique collaboration intended to combine the science of learning and the learning of science to the benefit of students with learning differences and with the long-range goal of attracting new creative talent to basic science. The partnership extends the opportunity for high quality science education to a population of students that is often overlooked by the general education system.

Currently, The Lewis School of Princeton does not have any science laboratory facilities in the building and at the present time does not have any room for installing such facilities. This dramatically limits the opportunities for experimentation and hands-on learning experiences that the school can provide for the students. Thus, students are brought to the Plasma Science Education Laboratory at PPPL during the school year for a series of laboratories centered upon energy. In FY07, two middle school classes completed the energy curriculum.

Science on Saturday

Now in its twenty-third year, Science on Saturday is a winter lecture series geared toward high school students, but open to everyone. Scientists and other professionals who are leaders in their respected fields give the talks. The program currently draws more than 350 students, teachers, parents, and community members each Saturday. The FY07 lectures included:

Where's Waldo? – The Science and Application of GPS, Professor Edward Groth, Department of Physics, Princeton University, Princeton, NJ

Everything's Relative and Other Fables from Science and Technology, or Don't Believe Everything Your Teacher Told You, Dr. Tony Rothman, Department of Physics, Princeton University, Princeton, NJ

On the Road to Petascale Computing, Dr. Scott A. Klasky, Scientific Computing Group: End-to-End Task Lead, Oak Ridge National Laboratory, Oak Ridge, TN

Exploration of Frozen Fire and Volcanoes of the Deep Sea, Professor Peter A. Rona, Institute of Marine and Coastal Sciences and Department of Geological Sciences, Rutgers University, New Brunswick, NJ

Real-Time Radionuclide in Dynamic Urban Environments, Charles A. Gentile, Head, Tritium Systems, Princeton Plasma Physics Laboratory, Princeton, NJ

Teaching Engineering with Antiques, Professor Michael Littman, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ

ITER: The International Path to the Study of Burning Plasmas, Dr. Ned R. Sauthoff, Director, U.S. ITER Project Office, Oak Ridge National Laboratory, Oak Ridge, TN

Young Women's Conference

The Young Women's Conference in Science, Math and Technology was held on March 16, 2007. The conference has been in existence since 2001. The audience is geared toward young women in grades 8–12 with students coming from schools throughout the State of New Jersey and the metropolitan area (New York and Pennsylvania) with a yearly attendance of approximately 200 attendees. The conference goals are: (1) to increase interest in science and mathematics; (2) to provide students an opportunity to meet women working in traditional and nontraditional scientific fields and; (3) to foster an awareness of varied career opportunities for women. Speakers in FY07 included: Dr. Elizabeth Jill Foley, Princeton Plasma Physics Laboratory, Professor Georgia Kalvais, Fashion Institute of Technology, Dr. Carmen Raventos-Suarez, Bristol Meyers Squibb, Dr. Anita Russell, Bristol Meyers Squibb and Dr. Marian Westley, Geophysical Fluid Dynamics Laboratory (GFDL).

Scientist-in-Residence Program

The Scientist-in-Residence program brings a PPPL scientist into an elementary school for an extended period of time. Working with teachers and administrators, a program tailored to the specific needs of the school that adheres to the New Jersey State Science Standards is designed. In FY07, for a second consecutive year, PPPL scientists worked with the Princeton Junior School to create a month-long exploration of solar energy.

Classroom Visits

In FY07, PPPL staff made forty K–12 classroom visits to about 1,760 students. Both the research and engineering staff participated and made one-hour presentations on energy, fusion, plasmas, and cryogenics.

Return to Table of Contents

Awards and Honors

In recognition of PPPL's successful transfer of the Miniature Integrated Nuclear Detection System (MINDS), the Federal Laboratory Consortium (FLC) Northeast Region presented PPPL with the Excellence in Technology Transfer Award. An anti-terrorism technology, MINDS was developed for detection of the radiation emitted from a nuclear threat, such as a dirty bomb or from dangerous nuclear material. This technology employs a conventional off-the-shelf hardware approach to detecting the nuclear radiation spectrum coupled with an innovative detection scheme. The MINDS team includes (from left, seated) Bill Davis, Dana Mastrovito, and Andy Carpe; (standing) Steve Langish, Lewis Meixler, Charles Gentile, and Kenny Silber.

Individual Honors

Erik Granstedt
Thomas H. Stix ′54 Plasma Physics Prize
Princeton University

Taik Soo Hahm
PPPL Distinguished Research Fellow
Princeton Plasma Physics Laboratory

Philip Heitzenroeder
Kaul Prize for Excellence
in Plasma Physics Research and Technology Development
Princeton University

Russell Hulse
Notable People in Physics and Physics Education
American Association of Physics Teachers

Charles Kessel
PPPL Distinguished Engineering Fellow
Princeton Plasma Physics Laboratory

Jon Menard
Kaul Prize for Excellence
in Plasma Physics Research and Technology Development
Princeton University

Andrew Zwicker
Notable People in Physics and Physics Education
American Association of Physics Teachers

Laboratory Honors

2007 Achievement of Excellence in Procurement Award
National Purchasing Institute

Recognition Award
New Jersey Governor's Occupational Safety and Health Awards Program
for PPPL having a Low Incidence of Away-from-Work Lost Time Injury and Illness Cases

Citation of Merit Award
New Jersey Governor's Occupational Safety and Health Awards Program
for the Plasma Science and Technology Department for Working Throughout the Year with
No Away-from-Work Lost Time Injury and Illness Cases

Commissioner's Continued Excellence Award
New Jersey Governor's Occupational Safety and Health Awards Program
for the National Spherical Torus Experiment Project for Working Six Consecutive Years
without an Away-from-Work Lost Time Injury and Illness Case

Division of Public Safety Award
New Jersey Governor's Occupational Safety and Health Awards Program
for the National Compact Stellarator Experiment Project for Working Two Consecutive Years
with No Away-from-Work Lost Time Injury and Illness Cases

Excellence in Technology Transfer Award
for the Successful Transfer of the Miniature Integrated Nuclear Detection System (MINDS)
Federal Laboratory Consortium Northeast Region

Princeton Plasma Physics Laboratory's Procurement Division received the 2007 Achievement of Excellence in Procurement Award from the National Purchasing Institute. PPPL Deputy Director Rich Hawryluk congratulates the Lab's Procurement staff on receiving the Award. From left are Procurement Head Rodney Templon, Hawryluk, Sharon Warkala, Arlene White, Joanna Santoro, Kevin Ranahan, and Larry Sutton.

Return to Table of Contents

The Year in Pictures

Energy Secretary Samuel W. Bodman toured PPPL, addressed staff, and held a press briefing on November 21, describing the Laboratory as "the most advanced center for fusion energy research in the U.S."

PPPL Director Rob Goldston drew a standing-room-only crowd in the Auditorium while presenting his annual State-of-the-Lab address to the staff on November 20.

Fabrication of the National Compact Stellarator Experiment (NCSX) modular field coils was underway in the former Tokamak Fusion Test Reactor Test Cell at PPPL. Hats were off to the engineers and technicians involved in the design and fabrication of these complex, innovative electromagnetic modular field coils. Pictured is the NCSX Coils Group at PPPL.

Model car racing circled the track around science and math on April 14 at PPPL, the site of the New Jersey Regional Competition of the National Middle School Science Bowl®. Sixteen teams from 11 local schools signed up for the bowl that included two competitions — a model hydrogen fuel-cell car competition and an academic, fast-paced question-and-answer contest in which students answered questions about earth, physical, life, and general sciences, and math. Each team was made up of four students, a student alternate, and a teacher who served as an advisor and coach.

PPPL engineers Ray Camp and John Lacenere spent several weeks during the winter helping a team of students from West Windsor-Plainsboro High School North complete a project for the FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition. The competition is "a unique varsity sport of the mind designed to help high-school-aged young people discover how interesting and rewarding the life of engineers and researchers can be. The FIRST Robotics Competition challenges teams of young people and their mentors to solve a common problem in a six-week time frame using a standard 'kit of parts' and a common set of rules. Teams built robots from the parts and entered them in a series of competitions," according to the FIRST web site (http://www.usfirst.org/).

This was the second year Camp and Lacenere teamed up to mentor West Windsor-Plainsboro students. Lacenere (kneeling near door) and Camp (tan shirt) worked with the West Windsor-Plainsboro High School North students on the FIRST robot.

On April 28, PPPL participated in Communiversity, a town-gown community arts festival in downtown Princeton that drew several thousand people. PPPL physicist Michael Zarnstorff (blue shirt) discussed fusion with folks who stopped by the PPPL exhibit.

Without leaving their school in Teterboro, 60 Bergen County Technical High School physics students took a field trip to PPPL's National Spherical Torus Experiment (NSTX) Control Room on May 31. The students participated in "Live From … PPPL," a program created by PPPL Science Education Head Andrew Zwicker in partnership with the Liberty Science Center. The students took a virtual field trip to the Control Room through the innovative program. Using video-conference technology, Liberty Science staff connected the students with scientists, engineers, and support staff in the Control Room while fusion experiments were being performed. Students spoke directly to those involved in fusion research. A TV monitor in the Control Room showed PPPL participants the students in the school's auditorium while the students viewed the Control Room from a large screen in the school's auditorium. Those speaking from either end used a hand-held microphone.

Colleagues, friends, and family from near and far came to PPPL June 11 and 12 to honor Princeton University Professor and former PPPL Director Ronald C. Davidson. The Laboratory hosted the "Symposium on Recent Advances in Plasma Physics" in honor of Davidson's 40 years of plasma physics research and graduate education. The program included scientific talks by researchers from many laboratories, institutions, and universities. During the opening, Representative Rush Holt offered congratulatory remarks to Davidson and Princeton University Dean of the Faculty David Dobkin presented the welcome. The event included two days of technical talks and a banquet. Davidson (right) with U.S. Representative Rush Holt.

PPPL physicist Jon Menard was named the new Program Director for the National Spherical Torus Experiment (NSTX). In this post, he helps define the scientific research program for NSTX, working closely with NSTX Project Director Masa Ono and PPPL's Stan Kaye, who was appointed as the NSTX Deputy Program Director. Menard replaced ORNL's Martin Peng, who took broader responsibility for the coordination of U.S. and international spherical torus activities.

They began as ideas — things that would have significance to stellarators and tokamaks, and for national security. Through creativity and development, they became inventions. On June 21 at the Patent Recognition Dinner, the Laboratory honored those responsible — 27 inventors — for inventions at PPPL during Fiscal Year 2006. Above are the honorees at the dinner, held at Princeton University's Prospect House.

The Lab's staff gathered on the front lawn on September 10 for the "Pirates of PPPL Picnic" for employees. The USS Plasma crew and friends enjoyed food and buccaneer games, and had boatloads of fun.

Return to Table of Contents

PPPL Financial Summary

(Costs Incurred by Fiscal Year in Thousands of Dollars)

	FY2003	FY2004	FY2005	FY2006	FY2007
Operating Costs					
Fusion Energy Sciences					
NSTX	$25,604	$27,203	$27,944	$26,588	$27, 949
NCSX	3,109	621	368	405	671
Theory and Computation	6,749	6,993	7,086	7,024	6,688
Off-site Research	9,121	7,656	7,474	7,000	6,963
CDX-U/LTX	743	865	230	205	231
MRX/MRX Frontier Science Center	673	885	867	882	826
Heavy Ion Fusion	1,410	1,307	1,211	1,083	1,035
Plasma Science and Technology	2,139	2,347	2,466	2,466	2,276
ITER Preparations	705	647	2,606	1,623	(12)
ITER*	–	–	–	186	576
Science Education Programs	667	685	641	498	553
TFTR	717	–	–	–	–
Other Fusion	969	1,408	1,572	1,061	886
Total Fusion Energy Sciences	$52,606	$50,617	$52,465	$49,021	$48,642
Advanced Scientific Computing Research	$437	$231	$536	$1,016	$1,284
High Energy Physics	181	354	182	192	249
Basic Energy Sciences	79	–	–	–	–
Safeguards and Security	1,623	1,907	1,875	1,708	2,038
Science Laboratories Infrastructure	679	1,237	420	93	–
Other DOE	87	86	141	263	127
Total DOE Operating	$55,692	$54,432	$55,619	$52,293	$52,340
Work for Others					
Federal Sponsors	$1,958	$1,661	$1,394	$1,194	$1,105
Nonfederal Sponsors	170	523	598	472	436
Other DOE Facilities	103	51	386	73	–
Total Operating Costs	$57,923	$56,667	$57,997	$54,032	$53,881
Capital Equipment Costs					
NSTX	$976	$2,365	$2,168	$1,326	$852
NCSX	4,796	11,392	16,410	17,296	13,318
Off-site Research	1,817	740	1,291	859	905
LTX	–	75	817	633	1,019
ITER*	–	–	–	2,214	4,416
All Other Fusion	200	850	439	707	743
All Other DOE	–	68	57	–	–
Total Capital Equipment Costs	$7,789	$15,490	$21,182	$23,035	$21,253
Construction Costs					
General Plant Projects - Fusion	$738	$1,696	$2,129	$2,311	$2,211
General Plant Projects - S&S	49	1,265	237	44	–
Other DOE Construction	28	47	258	83	48
Total Construction Costs	$815	$3,008	$2,624	$2,438	$2,259
TOTAL PPPL	$66,527	$75,165	$81,803	$79,505	$77,393

*ITER funded through the U.S. ITER Project Office at the Oak Ridge National Laboratory.

Return to Table of Contents

PPPL Organization and Staffing

PPPL Organization

Directorate

Robert J. Goldston
Director

Richard J. Hawryluk
Deputy Director

William M. Tang
Chief Scientist

Nathaniel J. Fisch
Associate Director for Academic Affairs

John W. DeLooper
Associate Director for External Affairs

Susan E. Murphy-LaMarche
Head, Human Resources

S. Baumgartner
Chief Information Officer

Director's Cabinet

Robert J. Goldston
Director

Richard J. Hawryluk
Deputy Director

William M. Tang
Chief Scientist

A.J. Stewart Smith
Dean for Research
Princeton University

Departments

National Compact Stellarator Experiment
J.L. Anderson,* Project Manager
J.F. Lyon,** Deputy Project Manager

Off-site Research
J.R. Wilson, Head
R. Nazikian, Deputy

ITER Project Contributions
D.W. Johnson, Head

Plasma Science and Technology
Philip C. Efthimion, Head

National Spherical Torus Experiment
Masayuki Ono, Project Director
Jonathan E. Menard, Program Director
Stanley M. Kaye, Deputy Project Director

Theory
J. Manickam, Head
Ronald C. Davidson, Deputy

Experiment
Joel C. Hosea, Head

Engineering and Technical Infrastructure
Michael D. Williams, Head

Business Operations and Chief Financial Officer
Edward H. Winkler

Environment, Safety, and Health and Infrastructure Support
John W. Anderson, Head

**From Los Alamos National Laboratory. **From Oak Ridge National Laboratory, residing at PPPL.*

PPPL Staffing by Fiscal Year.*

	FY03	FY04	FY05	FY06	FY07
Faculty	3	3	3	3	3
Physicists	94	90	83	80	79
Engineers	77	78	73	76	78
Technicians	157	170	161	170	174
Administrative	73	69	73	75	77
Office and Clerical Support	16	17	14	16	16
Total	420	427	407	420	427

**As of September 30 of each year.*

Return to Table of Contents

PPPL Advisory Council

The Princeton Plasma Physics Laboratory Advisory Council advises Princeton University on the plans and priorities of the Laboratory. Members of the Advisory Council are appointed by the Board of Trustees and are chosen from other universities and organizations, and from the Board of Trustees. The Council meets biannually and reports to the University President through the Provost. Members listed below served in fiscal year 2007.

Dr. Norman R. Augustine
Lockheed Martin Corporation

Dr. Jonathan M. Dorfan
Stanford Linear Accelerator Center

Dr. Edward A. Frieman (Chair)
Scripps Institution of Oceanography

Mr. Robert I. Hanfling

Professor Richard D. Hazeltine
University of Texas at Austin

Professor Thomas R. Jarboe
University of Washington, Seattle

Dr. Steve Koonin
British Petroleum

Dr. William Kruer
Lawrence Livermore National Laboratory

Dr. Ants Leetmaa
NOAA's Geophysical Fluid Dynamics Laboratory

Professor Sir Chris Llewellyn-Smith
United Kingdom Atomic Energy Agency
Culham Division

Mr. Bruce Mehlman
Computer Systems Policy Project
Mehlman Strategies

Dr. Richard A. Meserve
Carnegie Institute

Dr. Barrett Ripin
Research Applied

Professor Michael S. Turner
University of Chicago

Professor Friedrich Wagner
Max-Planck-Institut für Plasmaphysik

Professor Ellen G. Zweibel
University of Wisconsin-Madison

Return to Table of Contents

Publications

*Agostini, M., Zweben, S.J., Cavazzana, R., Scarin, P., Serianni, G., Maqueda, R.J., and Stotler, D.P., "Comparison of L-mode and H-mode Edge Turbulence in NSTX with the GPI Diagnostic," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.040. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*§Agostini, M., Zweben, S.J., Cavazzana, R., Scarin, P., Serianni, G., Maqueda, R.J., and Stotler, D.P., "Study of Statistical Properties of Edge Turbulence in the National Spherical Torus Experiment with Gas Puff Imaging, Phys. Plasmas **14**:10 (October 2007) Article No. 102305 (9 pages).

*Allen, S.L., Petty, C.C., Politzer, P.A., and 12 additional co-authors including Nazikian, R. from PPPL, and the DIII-D Experimental Team, "ITER Hybrid Scenario Research on DIII-D," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-5.131. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Alonso, J.A., Zweben, S.J., Carvalho, P., and 10 additional co-authors and the TJ-II Team, "Impact of Different Confinement Regimes on the Two-dimensional Structure of Edge Turbulence," Special Issue Plasma Phys. Cont. Fusion **48**:12B (December 2006) B465–B473; Invited paper at the *33rd European Physical Society Conference on Plasma Physics* (19–23 June 2006, Rome, Italy).

*Atanasiu, C.V., Günter, S., Moraru, A., and Zakharov, L.E., "Resistive Wall Modes Stabilization in the Presence of 3D Wall Structures," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-4.086. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Austin, M.E., Burrell, K.H., Waltz, R.E., and 15 additional co-authors including Nazikian, R. from PPPL, "Transport Improvement Near Low Order Rational q Surfaces in DIII-D," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P3-1. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Bae, Y.S., Cho, M.H., Namkung, W., Bernabei, S., Ellis, R., Wilson, J., Hosea, J., and Park, H., "Launcher Study for KSTAR 5 GHz LHCD System," J. Korean Phys. Soc. **49**, Suppl. 1 (December 2006) S314–S319.

*Bae, Y.S., Na, Y.S., Oh, Y.K., and 13 additional co-authors including Ellis, R.A. and Park, H. from PPPL, "Status of KSTAR Electron Cyclotron Heating System," Fusion Sci. Techn. **52**:2 (August 2007) 321–333.

*†Barnard, J.J., Armijo, J., More, R.M., Friedman, A., Kaganovich, I., Logan, B.G., Marinak, M.M., Penn, G.E., Sefkow, A.B., Santhanam, P., Stoltz, P., Veitzer, S., and Wurtele, J.S., "Theory and Simulation

*First author is from another institution. PPPL co-authors are underlined.
†Paper presented at a conference in fiscal year 2007; published in fiscal year 2008.
§Submitted for publication in fiscal year 2007; published in fiscal year 2008.

of Warm Dense Matter Targets," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 275–283; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*Basse, N.P., Dominguez, A., Edlund, E.M., and 29 additional co-authors including Kramer, G.J., Schilling, G. Scott, S.D., and Zweben, S.J. from PPPL, "Diagnostics Systems on Alcator C-Mod," Special Issue (on Alcator C-Mod) Fusion Sci. Technol. **51**:3 (April 2007) 476–507.

*Batchelor, D.A., Beck, M., Becoulet, A., and 26 co-authors including Budny, R.V., Fu, G.Y., Hahm, T.S., Manickam, J., and Tang, W.M. from PPPL, "Simulation of Fusion Plasmas: Current Status and Future Direction," Plasma Sci. Technol. **9**:3 (June 2007) 312–387.

*†Beiersdorfer, P., Bitter, M., Roquemore, L., Lepson, J., and Gu, M.F., "Grazing-incidence Spectrometer for Soft X-ray and Extreme Ultraviolet Spectroscopy on the National Spherical Torus Experiment," Rev. Sci. Instrum. **77**:10 (October 2006) 10F306 (5 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*†Bekrisa, N., Coad, J.P., Skinner, C.H., Gentile, C.A., Damm, E., and Nägele, W., "Thermal Release Rate of Tritium Trapped in Bulk and Plasma Exposed Surfaces of Carbon Specimens Obtained from JET Divertor," J. Nucl. Mater. **367-370**, Part 2 (1 August 2007) 1254–1259; *Proceedings of the Twelfth International Conference on Fusion Reactor Materials* (7–12 December 2005, Santa Barbara, California), edited by Roger E. Stoller, F.W. (Bill) Wiffen, Peter F. Tortorelli, and Hiroyasu Tanigawa.

†Bell, Ronald E., "Carbon Ion Plume Emission Produced by Charge Exchange with Neutral Beams on NSTX," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E902 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, VA). Princeton Plasma Physics Laboratory Report PPPL-4167 (June 2006) 12 pp.

Belova, E.V., Davidson, R.C., Ji, H., Yamada, M., and Gerhardt, S.P., "Effects of Energetic Beam Ions on Stability Properties of Field Reversed Configuration," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P3-16. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008); Princeton University Plasma Physics Laboratory Report PPPL-4201 (December 2006) 6 pp.

*Berk, H.L., Boswell, C.J., Borba, D., and 13 additional co-authors including Frederickson, E.D., Gorelenkov, N.N., and Medley, S.S. from PPPL, "Interpretation of Mode Frequency Sweeping in JET and NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P3-1. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Berkery, J.W., Pedersen, T.S., Kremer, and 9 co-authors including Mynick, H.E., Pomphrey, N., Reiersen, W., and Dahlgreen, F. [stet] from PPPL, "First Studies of Pure Electron Plasmas in the Columbia Non-neutral Torus," AIP Conference Proceedings **862** (18 October 2006) 62–70; *Proceedings of the Workshop on Non-Neutral Plasmas VI* (25–29 June 2006, Aarhus, Demark).

*Berry, L.A., Batchelor, D.B., Bonoli, P.T., and 11 co-authors including Okuda, H., Phillips, C.K., and Valeo, E.J., from PPPL, "Analysis of Ion Cyclotron Heating Issues for ITER," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-8. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Biewer, T.M., Andrew, Y., Bell, R.E., 8 additional co-authors, and the JET EFDA Contributors, "Charge Exchange Recombination Spectroscopy

Measurements from Multiple Ion Species on the Joint European Torus," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-5.112. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

Bitter, M.L., Broennimann, Ch., Eikenberry, E.F., Hill, K.W., Ince-Cushman, A., Lee, S.G., Rice, J., and Scott, S., "Application of PILATUS II Detector Modules for High Resolution X-ray Imaging Crystal Spectrometers on the Alcator C-Mod Tokamak," in the *Proceedings of the IEEE 2006 Nuclear Science Symposium and Medical Imaging Conference (2006 NSS/MIC)* (29 October – 4 November 2006, San Diego, CA); proceedings published on CD-ROM, 2006 Nuclear Science Symposium Conference Record, IEEE Catalog No. 06CH37832. Princeton University Plasma Physics Laboratory Report PPPL-4259 (August 2007) 3 pp.

*Boedo, J.A., Maqueda, R.J., Rudakov, D.L., and 19 additional co-authors including Kugel, H., Menard, J., Zweben, S.J., and Roquemore, L.A., from PPPL, "Particle and Energy Transport in the SOL of D-III and NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P4-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Bonoli, P.T., Batchelor, D.B., Berry, L.A., and 13 co-authors including Phillips, C.K. and Valeo, E. from PPPL, "Physics Research in the SCiDAC Center for Wave-Plasma Interactions," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 435–442; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*Bonoli, P.T., Harvey, R.W., Kessel, C., and 14 additional co-authors, "Benchmarking of Lower Hybrid Current Drive Codes with Application to ITER-relevant Regimes," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IT/P1-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Bonoli, P.T., Parker, R., Wukitch, S.J. and 48 additional co-authors including Bernabei, S., Ellis, R., Greenough, N., Hosea, J., Kung, C.C., Loesser, G.E., Rushinski, J., Schilling, G., Phillips, C.K., and Wilson, J.R. from PPPL, and the Alcator C-Mod Team, "Wave-Particle Studies in the Ion Cyclotron and Lower Hybrid Ranges of Frequencies in Alcator C-Mod," Special Issue (on Alcator C-Mod) Fusion Sci. Technol. **51**:3 (April 2007) 401–436.

*Borba, D., Nazikian, R., Alper, B., and 20 additional co-authors including Budny, R.V., Gorelenkov, N.N., Kramer, G.J., Mazzucato, E., and Solomon, W.M., and the JET EFDA Contributors ƒx, "Excitation of Alfvén Eigenmodes with sub-Alfvénic Neutral Beam Ions in JET and DIII-D Plasmas," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper PD-1. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Breslau, J.A., Jardin, S.C., and Park, W., "Three-dimensional Modeling of the Sawtooth Instability in a Small tokamak," Phys. Plasmas **14**:5 (May 2007) Article No. 056105 (7 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton Plasma Physics Laboratory Report PPPL-4220 (February 2007) 16 pp.

*§Brizard, A.J. and Hahm, T.S., "Foundations of Nonlinear Gyrokinetic Theory," Reviews of Modern Physics **79**:2 (2 April 2007) 421–468; Princeton Plasma Physics Laboratory Report PPPL-4153 (February 2006) 50 pp.

*§Brown, M.R., Cothran, C.D., Fung, J., Chang, M., Horwitz, J., Schaffer, M.J., Leuer, J., and Belova, E.V., "Dipole Trapped Spheromak in a Prolate Flux

Conserver," Phys. Plasmas **13**:10 (October 2006) Article No. 102503 (7 pp).

*†Brown, M.R., Cothran, C.D., Fung, J., Schaffer, M.J., and Belova, E., "Novel Dipole Trapped Spheromak Configuration," J. Fusion Energy **26**:1–2 (June 2007) 31–35; *Proceedings of the 2006 Innovative Confinement Concepts Workshop* (13–16 February 2006, Austin, Texas).

*†Brown, M.R., Cothran, C.D., Fung, J., Schaffer, M.J., and Belova, E.V., "Spectroscopic Flow and Ion Temperature Studies of a Large *s* FRC," J. Fusion Energy **26**:1–2 (June 2007) 37–41; *Proceedings of the 2006 Innovative Confinement Concepts Workshop* (13–16 February 2006, Austin, Texas).

Brunkhorst, C., Berlinger, B., Ferraro, N., and Cohen, S.A., "The Princeton FRC Rotating Magnetic Field Experiment RF System," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337897.

Budny, R.V., Kessel, C.E., Kinsey, J.E., Imbeaux, F., Voitsekhovitch, I., Candy, J., Waltz, R.E., Fujita, T., Greenfield, C.M., Murakami, M., Sips, A.C.C., Houlberg, W.A., Doyle, E.J., and for the ITPA Topical Group on Transport Physics and the ITPA Profile Database Working Groups, "Transport Physics of Hybrid Scenario Plasmas in the International Multi-Tokamak Database and Implications for ITER," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IT/P1-5. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008). Princeton University Plasma Physics Laboratory Report PPPL-4206 (January 2007) 10 pp.

Budny, R.V., Mazzucato, E., Candy, J., Waltz, R.E., Bravenec, R., Fonseca, A., the TFTR Team, and the JET EFDA Contributors, "Gyrokinetic Simulations of Electron Density Fluctuations and Comparisons with Measurements," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-4.046. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

Burin, M., Schartman, E., and Ji, H., "Local Measurements of Angular Momentum Transport in Taylor-Couette Flow," to be submitted to Phys. Rev. E.

*Bush, C.E., Stratton, B.C., Robinson, J., Zakharov, L.E., Fredrickson, E., Stutman, D., and Tritz, K., "Investigation of MHD Phenomena in NSTX using a Fast Soft X-Ray Imaging Camera," Princeton University Plasma Physics Laboratory Report PPPL-4204 (December 2006) 4 pp; presented at the *17th ANS Topical Meeting on the Technology of Fusion Energy* (12–16 November 2006, Albuquerque, New Mexico).

*Callen, J.D., Anderson, J.K., Arlen, T.C., and 23 additional co-authors including Budny, R.V. and Kaye, S.M. from PPPL, "Experimental Tests of Paleoclassical Transport," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P3-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Casper, T.A., Jayakumar, R.J., Allen, S.L., and 11 additional co-authors including Kessel, C.E., from PPPL, "Evidence for Anomalous Effects on the Current Evolution in Tokamak Operating Scenarios," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P6-4. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Challis, C.D., Joffrin, E., Luce, T., and 19 additional co-authors including Menard, J. from PPPL, and the JET EFDA Contributors, "High β_N JET H-modes for Steady-state Application," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed

Papers Vol. **31F** (ECA 2007) P-5.124. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Chan, Vincent S. and Davison, Ronald C., "Foreword: Papers from the 48th Annual Meeting of the APS Division of Plasma Physics, Philadelphia, Pennsylvania, 2006," Phys. Plasma **14**:5 (May 2007) Article No. 055301 (1 page).

*Chang, C.S., Ku, S., Adams, M., and 18 additional co-authors including Ethier, S., Hahm, T.S., Lee, W.W., Samtaney, R., and Stotler, D., from PPPL and the CPES Team, "Integrated Particle Simulation of Neoclassical and Turbulence Physics in the Tokamak Pedestal/Edge Region using XGC," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-14. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Chapman, I.T., Pinches, S.D., Graves, J.P., and 18 additional co-authors including Budny, R. from PPPL and the MAST and TEXTOR Teams and the JET EFDA Contributors, "The Physics of Sawtooth Stabilization," Special Issue Plasma Phys. Control. Fusion **49**:12B (December 2007) B385–B394; Invited paper at the *34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland).

Chrzanowski, J.H., Fogarty, P.J., Heitzenroeder, P.J., Meighan, T., Nelson, B., Raftopoulos, S., and Williamson, D., "A Conceptual Design for the Magnets in an IFE Magnetic Intervention Chamber," presented at the *22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp.

Chrzanowski, J.H.; Meighan, T.; Raftopoulos, S.; Fogarty, P.J.; Heitzenroeder, P.J.; Nelson, B.; Williamson, D., "NCSX Modular Coil Fabrication," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337903.

*Chu, M.S., Brennan, D.P., Chan, V.S., and 9 additional co-authors including Nazikian, R., and White, R., from PPPL, "Maintaining the Quasi-Steady State Central Current Density Profile in Hybrid Discharges," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/1-5. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Chu, M.S., Brennan, D.P., Chan, V.S., Choi, M., Jayakumar, R.J., Lao, L.L., Nazikian, R., Politzer, P.A., St. John, H.E., Turnbull, A.D., Van Zeeland, M.A., and White, R., "Maintaining the Quasi-steady-state Central Current Density Profile in Hybrid Discharges," Nucl. Fusion **47**:5 (May 2007) 434–442.

Chung, M., Gilson, E.P., Davidson, R.C., Efthimion, P.C., and Majeski, R., "Initial Density Profile Measurements using a Laser-induced Fluorescence Diagnostic in the Paul Trap Simulator Experiment," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Chung, M., Gilson, E.P., Dorf, M., Davidson, R.C., Efthimion, P.C., and Majeski, R., "Experiments on Transverse Compression of a Long Charge Bunch in a Linear Paul Trap," Phys. Rev. ST AB **10** (June 2007) Article No. 064202 (10 pages).

Chung, M, Gilson, E.P., Dorf, M., Davidson, R.C., Efthimion, P.C., and Majeski, R., "Ion Injection Optimization for a Linear Paul Trap to Study Intense Beam Propagation," Phys. Rev. ST AB **10** (26 January 2007) Article No. 014202 (7 pages).

*Classen, I.G.J., Westerhof, E., Domier, C.W., Donne, A.J.H., Jaspers, R.J.E., Luhmann, N.C., Park, H.K., van de Pol, M.J., Spakman, G.W., Jakubowski, M.W., and the TEXTOR Team, "Effect of Heating on the Suppression of Tearing modes in Tokamaks," Phys. Rev. Lett. **98**:3 (19 January 2007) Article No. 035001.

*†Coad, J.P., Andrew, P., Erents, S.K., Hole, D.E., Likonen, J., Mayer, M., Pitts, R., Rubel, M, Strachan,

J.D., Vainonen-Ahlgren, E., Widdowson, A., and JET-EFDA Contributors, “Erosion and Deposition in the JET MkII-SRP Divertor,” J. Nucl. Mater. **363-365** (15 June 2007) 287–293 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

*Cohen, R.H., LaBombard, B., LoDestro, L.L., and 6 additional co-authors including Zweben, S.Z. from PPPL, “Fluid Simulations and Theory of Boundary Plasma Fluctuations,” in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People’s Republic of China) paper TH/P6-25. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Cohen R.H., LaBombard, B., Ryutov, D.D., Terry, J.L., Umansky, M.V., Xu, X.Q., and Zweben, S.J., “Theory and Fluid Simulations of Boundary-plasma Fluctuations,” Nucl. Fusion **47**:7 (July 2007) 621–625.

Cohen, S.A., Berlinger, B., Brunkhorst, C., Brooks, A., Ferraro, N., Lundberg, D.P., Roach, A., and Glasser, A.H., “Formation of Collisionless High-beta Plasmas by Odd-parity Rotating Magnetic Fields,” Phys. Rev. Lett. **98**:14 (6 April 2007) 145002; Princeton University Plasma Physics Laboratory Report PPPL-4229 (March 2007) 21 pp.

Cohen, S.A., Landsman, A.S., and Glasser, A.H., “Stochastic Ion Heating in a Field-reversed Configuration Geometry by Rotating Magnetic Fields,” Phys. Plasmas **14**:7 (July 2007) 072508 (12 pages); Princeton University Plasma Physics Laboratory Report PPPL-4245 (June 2007) 26 pp.

*Connor, J.W., Angioni, C., Diamond, P.H., Hammett, G.W., Hidalgo, C., Loarte, A., and Mantica, P., “11th EU-US Transport Task Force Workshop on Transport in Fusion Plasmas,” Nucl. Fusion **47**:4 (April 2007) 361–369.

*†Craig, D., Goldston, R., Jarboe, T.R., Nelson, B.A., Sovinec, C.R., Woodruff, S., and Wurden, G., “Chair Summaries from the 2006 Innovative Confinement Concepts (ICC) Workshop,” J. Fusion Energy **26**:1–2 (June 2007) 3–15; *Proceedings of the 2006 Innovative Confinement Concepts Workshop* (13–16 February 2006, Austin, Texas).

Dahlgren, F., Dodson, T., Zatz, I., Gentile, C., Priniski, C., Kozub, T., Gettelfinger, G., Sethian, J., and Robson, A.E., “A Conceptual Magnet Design for Magnetic Intervention in the HAPL Reactor,” presented at MT-20: *20th Biennial Conference on Magnet Technology* (27–31 August 2007, Philadelphia, Pennsylvania). Proceedings to be published in IEEE Transactions on Applied Superconductivity.

Darrow, D.S., “Scintillator Based Energetic Ion Loss Diagnostic for the National Spherical Torus Experiment, Princeton University Plasma Physics Laboratory Report PPPL-4248 (July 2007) 14 pp; submitted to Rev. Sci. Instrum.

†Darrow, Doug; Baeumel, Stefan; Cecil, Ed; Ellis, Bob; Fullard, Keith; Hill, Ken; Horton, Alan; Kiptily, Vasily; Pedrick, Les; Reich, Matthias; and Werner, Andreas, “Initial Results from the Lost Alpha Diagnostics on Joint European Torus,” Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E701 (5 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia). Princeton University Plasma Physics Laboratory Report PPPL-4246 (June 2007) 7 pp.

Davidson, R.C., Startsev, E.A., and Qin, H., “Kinetic Description of Nonlinear Wave and Soliton Excitations in Coasting Charged Particle Beams,” in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Davidson, Ronald C., “Editorial: Announcement of Editorial Policy Statement on Verification and Validation,” Phys. Plasma **14**:5 (May 2007) Article No. 050401 (1 page).

†Davidson, Ronald C.; Kaganovich, Igor D.; Startsev, Edward. A.; Qin, Hong; Dorf, Mikhail; Sefkow, Adam B.; Welch, Dale R.; Rose, David D.; and Lund, Steven M., “Multspecies Weibel Instability for Intense Charged Particle Beam Propagation through Background Plasma,” Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and

Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 70–78; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

†Davis, W.M., Mastrovito, D., Roney, P.G., and Sichta, P., "A Software Event Summation System for MDSplus," Fusion Eng. Design **83**:2–3 (April 2008) 326–329; *Proceedings of the 6th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research* (4–8 June 2007, Inuyama, Japan), edited by Shigeru Sudo.

*deGrassie, J.S., Rice. J.E., Burrell, K.H., Groebner, R.J., and Solomon, W.M., "Intrinsic Rotation in DIII-D," Phys. Plasmas **14**:5 (May 2007) Article No. 056115 (15 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

*Delgado-Aparicio, L.F., Stutman, D., Tritz, K. and 9 additional co-authors including Bell, R., Gates, D., Kaita, R., and LeBlanc, B., from PPPL, "A 'Multi-colour' SXR Diagnostic for Time and Space-resolved Measurements of Electron Temperature, MHD Activity and Particle Transport in MCF Plasmas," Plasma Phys. Control. Fusion **49**:8 (August 2007) 1245–1259.

*§Delgado-Aparicio, L.F., Stutman, D., Tritz, K., Finkenthal, M., Bell, R., Hosea, J., Kaita, R., LeBlanc, B., Roquemore, L., and Wilson, J.R., "Fast Electron Temperature Measurements using a 'Multicolor' Optical Soft X-ray Array," J. Appl. Phys. **102**:7 (12 October 2007) Article No. 073304.

*Delgado-Aparicio, L.F., Stutman, D., Tritz, K., Finkenthal, M., and 8 additional co-authors including Bell, R.E., Kaita, R., Kaye, S., LeBlanc, B.P., Paul, S., and Roquemore, L. from PPPL, "Impurity Transport Studies in NSTX Beam Heated H-mode Plasmas," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.050. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Delgado-Aparicio, L.F., Stutman, D., Tritz, K., Vero, R., Finkenthal, M., Suliman, G., Kaita, R., Majeski, R., Stratton, B., Roquemore, L., and Tarrio, C., "High-efficiency Fast Scintillators for 'Optical' Soft X-ray Arrays for Laboratory Plasma Diagnostics," Appl. Opt. **46**:24 (20 August 2007) 6069–6075.

*Diamant, K.D., Pollard, J.E., Cohen, R.B., Raitses, Y., and Fisch, N.J., "Segmented Electrode Hall Thruster," J. Propulsion and Power **22**:6 (November-December 2006) 1396–1401.

Diem, S.J., Taylor, G., Caughman, J.B., Bigelow, T., Garstka, G.D., Harvey, R.W., LeBlanc, B.P., Preinhaelter, J., Sabbagh, S.A., Urban, J., and Wilgen, J.B., "Electron Bernstein Wave Research on NSTX and PEGASUS," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 331–338; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

†Diem, S., Taylor, G., Efthimion, P.C., LeBlanc, B.P., Carter, M., Caughman, J., Wilgen, J.B., Harvey, R.W., Preinhaelter, J., and Urban, J., "Te(R,t) Measurements using Electron Bernstein Wave Thermal Emission on NSTX," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E919 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia). Princeton Plasma Physics Laboratory Report PPPL-4244 (June 2007) 4 pp.

*Dimits, A.M., Nevis, W.M., Shumaker, D.E. and 8 additional co-authors including Hammet, G.W. from PPPL, "Gyrokinetic Simulations of ETG and ITG Turbulence," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P2-3. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Dimits, A.M., Nevis, W.M., Shumaker, D.E. and 10 additional co-authors including Hammet, G.W. from PPPL, "Gyrokinetic Simulations of ETG and ITG Turbulence," Nucl. Fusion **47**:8 (August 2007) 817–824.

*Dodin, I.Y. and Fisch, N.J., "Correction to the Alfvén-Lawson Criterion for the Stability of Relativistic Electron Beams," Phys. Plasma **13**:10 (October 2006) Article No. 103104 (7 pages).

*Dodin, I.Y. and Fisch, N.J., "Nonadiabatic Tunneling in Ponderomotive Barriers," Phys. Rev. E **74**:5 (November 2006) Article No. 056404 (8 pages).

*Dodin, I.Y. and Fisch, N.J., "Particle Manipulation with Nonadiabatic Ponderomotive Forces," Phys. Plasma **14**:5 (May 2007) Article No. 055901 (6 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

*Dodin, I.Y. and Fisch, N.J., "Particle Manipulation with Nonadiabatic Ponderomotive Forces," AIP Conference Proceedings **926** (September 2007) edited by John D. Gillaspy, John J. Curry, and Wolfgang L. Wiese, pages 149–151; *Proceedings of the 15th International Conference on Atomic Processes in Plasmas* (19–22 March 2007, Gaithersburg, Maryland).

*Dodin, I.Y. and Fisch, N.J., "Stochastic Extraction of Periodic Attosecond Bunches from Relativistic Electron Beams," Phys. Rev. Letters **98**:23 (8 June2007) Article No. 234801.

Dodson, T., Dahlgren, F., Zatza, I., Gentile, C., Priniski, C., Kozub, T., Gettelfinger, G., Sethian, J., and Robson, A.E., "A Conceptual Design for the Magnets in an IFE Magnetic Intervention Chamber," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 3 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337877.

*Donné, A.J.H., Costley, A.E., Barnsley, R., and 30 additional co-authors including Johnson D. and Young K. from PPPL, and the ITPA Topical Group on Diagnostics, "Progress in the ITER Basics Chapter 7: Diagnostics," Nucl. Fusion **47**:6 (June 2007) S337–S384 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

Dorf, M., Davidson, R.C., and Startsev, E.A., "Particle-in-Cell Simulations of Halo Particle Production in Intense Charged Particle Beams Propagating through a Quadrupole Focusing Field with Varying Lattice Amplitude," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

†Dorfman, Seth; Ji, Hantao; Yamada, Masaaki; Ren, Yang; Gerhardt, Stefan; Kulsrud, Russell; McGeehan, Brendan; and Wang, Yansong, "Electromagnetic Perturbations in the Reconnecting Current Sheet in MRX," AIP Conf. Proc. **871** (30 November 2006) edited by Olivier Sauther, pages 306–311; *Proceedings of the Joint Varenna-Lausanne International Workshop on Theory of Fusion Plasmas* (28 August – 1 September 2006, Varenna, Italy).

*†Doyle, E.J., Garofalo, A.M., Greenfield, C.M., and 23 additional co-authors including Kaye, S.M., Menard, J.E., Bell, R.E., Gates, D.A., LeBlanc, B.P., and Okabayashi, M., from PPPL, "Progress on Advanced Tokamak and Steady-state Scenario Development on DIII-D and NSTX," Special Issue Plasma Phys. Control. Fusion **48**:12B (December 2006) B39-B52; Invited paper at the *33rd European Physical Society Conference on Plasma Physics* (19–23 June 2006, Roma, Italy).

*Doyle, E.J., Houlberg, W.A., Kamada, Y., and 36 additional co-authors including Hahm, T.S. from PPPL, and the ITPA Transport Physics Topical Group, the ITPA Confinement Database and Modelling Topical Group, and the ITPA Pedestal and Edge Topical Group, "Chapter 2: Plasma Confinement and Transport," Nucl. Fusion **47**:6 (June 2007) S18–S127 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

Dudek, L., Chrzanowski, J., Viola, M, Heitzenroeder, P., Meighan, T., Raftopoulos, S., and., "NCSX Component Fabrication Challenges," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337863.

Efthimion, P.C., Gilson, E.P., Davidson, R.C., Grisham, L., Logan, B.G., Seidl, P.A., Waldron, W., and Yu, S.S., "Meter-Long Plasma Source for Heavy Ion Beam Space-Charge Neutralization," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New

Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

†Efthimion, Philip C.; Gilson, Erik P.; Davidson, Ronald C.; Grisham, Larry; Logan, B.Grant; Seidl, Peter A.; Waldron, William, and Yu, Simon S., "Ferroelectric Plasma Source for Heavy Ion Beam Charge Neutralization," Nucl. Instrum. Methods Phys. Res. A: Accelerators, Spectrometers, Detectors and Associated Equipment **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 203–206; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

Ellis, R., Brooks, A., Brown, T., Reiersen, W., Raftopoulos, S., and Stratton, B., "Dimensional Control for the National Compact Stellarator Experiment," presented at the *22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp.

*Fasoli, A., Gormenzano, C., Berk, H.L., and 16 additional co-authors including Darrow, D.S., Gorelenkov, N., and Nazikian, R. from PPPL, "Chapter 5: Physics of Energetic Ions," Nucl. Fusion **47**:6 (June 2007) S264–S284 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

Feder, R., Youssef, M., Davis, I., Failla, G., and Wareing, T., "ITER Neutronics Analysis for the Design of Diagnostics and Port Plugs using ATTILA Discrete Ordinates Software," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337859.

Ferraro, Nathaniel M., "Finite Larmor Radius Effects on the Magnetorotational Instability," Astrophys. J. **662**:1 (10 June 2007) 512–516; Princeton University Plasma Physics Laboratory Report PPPL-4231 (April 2007) 10 pp.

§Fisch, N.J., "Alpha Channeling in Mirror Machines," Phys. Rev. Lett. **97**:22 (1 December 2006) Article No. 225001; Princeton Plasma Physics Laboratory Report PPPL-4123 (October 2005) 4 pp.

†Fisch, Nathaniel, J., "Alpha Channeling in Mirror Machines and in Tokamaks," Fusion Sci. Technol. **51**:2T (February 2007) 1–6; presented at the *Sixth International Conference on Open Magnetic Systems for Plasma Confinement — OS2006* (17–21 July 2006, Tsukuba Science City, Japan).

*Fischalek,T. and White, R., "The use of Kruskal-Newton Diagrams for Differential Equations," submitted to Proceedings of the Royal Society.

*Frassinetti, L., Predebon, I., Koguchi, H., Yagi, Y.,Hirano, Y., Sakakita, H., Spizzo, G., and White, R.B., "Improved Particle Confinement in Transition from Multiple-helicity to Quasi-single-helicity Regimes of a Reversed-field Pinch," Phys. Rev. Lett. **97**:17 (27 October 2006) Article No. 175001.

Fredrickson, E.D., Crocker, N.A., Gorelenkov, N.N., Heidbrink, W.W., Kubota, S., Levinton, F.M., Yuh, H., Menard, J.E., and Bell, R.E., "β Suppression of Alfvén Cascade Modes in NSTX," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-1.106. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008); Princeton University Plasma Physics Laboratory Report PPPL-4253 (July 2007) 4 pp.

†Fredrickson, E.D., Crocker, N.A., Gorelenkov, N.N., Heidbrink, W.W., Kubota, S., Levinton, F.M., Yuh, H., Menard, J.E., and Bell, R.E., "β-Suppression of Alfvén Cascade Modes in the National Spherical Torus Experiment," Phys. Plasmas **14**:10 (October 2007) Article No. 102510 (6 pages).

†Fredrickson, E.D., Gorelenkov, N.N., Bell, R.E., Menard, J.E., Roquemore, A.L., Kubota, S., Crocker, N.A., and Peebles, W., "Fast Ion Loss in a 'sea-of-TAE'," Special Issue Nucl. Fusion **46**:10 (October 2006) S926–S932; presented at *9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems* (9–11 November 2005, Takayama, Japan). Princeton Plasma Physics Laboratory Report PPPL-4184 (July 2006) 20 pp.

Fredrickson, E.D., Phillips, C.K., Hosea, J., Wilson, J.R., Bonoli, P., Gorelenkov, N.N., Wright, J., and Valeo, E., "Stochastic RF Heating of Thermal Ions," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages

111–114; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

†Fredrickson, E.D., Zarnstorff, M.C., and Lazarus, E.A., "Tearing Mode Stability of Model Plasmas in the National Compact Stellarator Experiment," Trans. Fusion Sci. Technol. **51**:2 (February 2007) 232–237; Princeton Plasma Physics Laboratory Report PPPL-4216 (February 2007) 20 pp.

Fu, G.Y., Breslau, J.A., Park, W., Jardin, S.C, and Chen, J., "Nonlinear Simulations of Fishbone Instability and Sawteeth in Tokamaks and Spherical Torus," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/7-4Rb. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

†Fu, G.-Y., Isaev, M., Ku, L.-P., Mikhailov, M., Redi, M.H., Sanchez, R., Subbotin, A., Cooper, W.A., Hirshman, S.P., Monticello, D.A., Reiman, A., and Zarnstorff, M., "Ideal Magnetohydrodynamic Stability of the NCSX," Trans. Fusion Sci. Technol. **51**:2 (February 2007) 218–231.

*Gao, Q.D., Budny, R.V., Jiao, Y.M., and Indireshkumar, K., "Current Profile Control and Optimization under Dominant Electron Heating in HL-2A," Nucl. Fusion **47**:9 (September 2007) 1318–1325.

*Gao, Q.D., Long, Y.X., Budny, R.V., Jiao, Y.M., Ding, X.T., Pan, Y.D., and Indireshkumar, K., "Control and Optimization of Current Profile under Dominant Electron Heating in HL-2A," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P1-17. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Gao, Zhe; Fisch, Nathaniel J.; and Qin, Hong, "Nonlinear Ponderomotive Force by Low Frequency Waves and Nonresonant Current Drive," Phys. Plasma **13**:11 (November 2006) Article No. 112307 (6 pages); Princeton Plasma Physics Laboratory Report PPPL-4219 (January 2007) 8 pp.

*Gao, Zhe; Fisch, Nathaniel J.; Qin, Hong; and Myra, J.R., "Nonlinear Nonresonant Forces by Radio-frequency Waves in Plasmas," Phys. Plasmas **14**:8 (August 2007) Article No. 084502 (4 pages).

*Garofalo, A.M., Jackson, G.L., La Haye, R.J., and 18 additional co-authors including Okabayashi, M., Solomon, W.M., and Takahashi, H. from PPPL and the DIII-D Team, "Active Control of Resistive Wall Modes in High Beta, Low Rotation DIII-D Plasmas," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/7-1Ra. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Garofalo, A.M., Jackson, G.L., La Haye, R.J., and 13 additional co-authors including Okabayashi, M., Solomon, W.M., and Takahashi, H. from PPPL and the DIII-D Team, "Stability and Control of Resistive Wall Modes in High Beta, Low Rotation DIII-D Plasmas," Nucl. Fusion **47**:9 (September 2007) 1121–1130.

*Garrigues, L., Hagelaar, G., Boeuf, J-P, Raitses, Y., Smirnov, A., and Fisch, N.J., "Two dimensional Hybrid Model of a Miniaturized Cylindrical Hall Thruster," in the *Proceedings of the 30th International Electric Propulsion Conference* (17–20 September 2007, Florence, Italy) IEPC-2007-157.

Gates, D.A., Menard, J., Maingi, R., and 18 additional co-authors, "Progress on NSTX towards a Stable Steady State at Low Aspect Ratio," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P1-3. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Gates, D.A., Menard, J., Maingi, R., and 19 additional co-authors and the NSTX Research Team, "Progress Towards Steady State at Low-aspect Ratio on the

National Spherical Torus Experiment (NSTX)," Nucl. Fusion **47**:9 (September 2007) 1376–1382.

Gentile, C.A., Langish, S.W., Kozub, T., Priniski, C., Dodson, T., Gettelfinger, G., Paul, B., Ciebiera, L., Wermer, J., Nobile, A., Sessions, K., Sethian, J., and Robson, A.E., "Conceptual Design of a Plasma Exhaust and Fuel Recovery System for an Inertial Fusion Energy (IFE) Power Reactor," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337904.

Gerhardt, S.P., Belova, E., Inomoto, M., Yamada, M., Ji, H., Ren, Y., and Kuritsyn, A., "Equilibrium and Stability Studies of Oblate Field-reversed Configurations in the Magnetic Reconnection Experiment," Phys. Plasmas **13**:11 (November 2006) Article No. 112508 (18 pages).

§Gerhardt, S.P., Belova, E.V., Yamada, M., Ji, H., Inomoto, M., Jacobson, C.M., Maqueda, R., MCGeehan, B., and Ren, Y., "Inductive Sustainment of Oblate Field-reversed Configurations with the Assistance of Magnetic Diffusion, Shaping, and Finite–Larmor Radius Stabilization, Phys. Plasmas **15**:2 (February 2007) Article No. 022503 (16 pages).

Gerhardt, S.P., Belova, E.V., Yamada, M., Ji, H., Inomoto, M., Ren, Y., and McGeehan, B., "Inductive Sustainment of a Field-reversed Configuration Stabilized by Shaping, Magnetic Diffusion, and Finite-Larmour-radius Effects," submitted to Phys. Rev. Lett, **99**:24 (14 December 2007) Article No. 245003.

§Gerhardt, S.P., Belova, E.V., Yamada, M., Ji, H., Inomoto, M., Ren, Y.; and McGeehan, B., "New Method for Inductively forming an Oblate Field-reversed Configuration from a Spheromak," Nucl. Fusion **48**:3 (March 2008) Article No. 032001 (Letter) (5 pp).

Gerhardt, S.P., Inomoto, M., Belova, E.V., Yamada, M., Ji, H., and Ren, Y., "Studies of Free-Boundary Field Reversed Configurations with Improved Stability in the Magnetic Reconnection Experiment," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IC/P7-13. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Gilson, E.P., Chung, M., Davidson, R.C., Dorf, M., Efthimion, P.C., Majeski, R.J., and Startsev, E.A., "Experiments on Transverse Bunch Compression on the Princeton Paul Trap Simulator Experiment," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

†Gilson, Erik P.; Chung, Moses; Davidson, Ronald C.; Dorf, Mikhail; Grote, David P.; Efthimion, Philip C.; Majeski, Richard; and Startsev, Edeward A., "Conditions for Minimization of Halo Particle Production During Transverse Compression of Intense Ion Charge Bunches in the Paul Trap Simulator Experiment (PTSX)," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 117–124; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

†Gilson, Erik P.; Chung, Moses; Davidson, Ronald C.; Efthimion, Philip C.; and Majeski, Richard, "Transverse Beam Compression on the Paul Trap Simulator Experiment," PAC07 Special Edition Phys. Rev. ST AB **10** (December 2007) Article No. 124201 (8 pages); *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico).

*Gobbin, M., Martin, P., Marrelli, L., and 7 additional co-authors including White, R.B. from PPPL, and the AUG Team, "Numerical Study of Fast Ion Transport Induced by MHD Instabilities in the Tokamak," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-4.073. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Gobbin, M., Marrelli, L., Bonomo, F., Franz, P., Martin, P., and White, R.B., "Implementation in the ORBIT Code Radial Perturbations in the RFX-mod Toroidal Geometry," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-1.107. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Godyak, V., Raitses, Y., and Fisch, N.J., "RF Plasma Cathode-neutralizer for Space Applications, in the *Proceedings of the 30th International Electric Propulsion Conference* (17–20 September 2007, Florence, Italy) IEPC-2007-266.

Goldston, R.J., Goldenberg, D.H., Goldston, J.S., Grisham, L.R., and Linton, J.D., "Is Fusion Research Worth It?," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper SE/P2-1. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

†Gorelenkov, N.N., Berk, H.L., Crocker, N.A., and 11 additional co-authors and the NSTX Team and the JET EFDA Contributors, "Predictions and Observations of Global Beta-induced Alfvén Acoustic Modes in JET and NSTX," Special Issue Plasma Phys. Control. Fusion **49**:12B (December 2007) B371–B383; Invited paper at the *34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland).

§Gorelenkov, N.N., Berk, H.L., Fredrickson, E.D., Sharapov, S.E., and JET EFDA Contributors, "Predictions and Observations of Low-shear Beta-induced Shear Alfvén-acoustic Eigenmodes in Toroidal Plasmas," Phys. Lett. A **370**:1 (8 October 2007) 70–77; Princeton Plasma Physics Laboratory Report PPPL-4249 (July 2007) 6 pp.

Gorelenkov, N.N., Cheng, C.Z., Crocker, N.A., Fredrickson, E.D., Heidbrink, W.W., Kubota, S., Phillips, C.K., Peebles, W.A., and Wang, G., "Phase Space Gradient Driven Discrete Compressional Alfvén Eigenmodes in Tokamaks: Simulations and Observations," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-1. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Gorelenkov, N.N., Fredrickson, E.D., Heidbrink, W.W., Crocker, N.A., Kubota, S., and Peebles, W.A., "Discrete Compressional Alfvén Eigenmode Spectrum in Tokamaks," Special Issue Nucl. Fusion **46**:10 (October 2006) S933–S941; presented at *9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems* (9–11 November 2005, Takayama, Japan). Princeton Plasma Physics Laboratory Report PPPL-4210 (January 2007) 9 pp.

*Gormezano, C, Sips, A.C.C., Luce, T.C., and 28 additional co-authors including Phillips, C.K., Bundy, R., and Kessel, C. from PPPL, "Chapter 6: Steady State Operation," Nucl. Fusion **47**:6 (June 2007) S285–S336 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

†Gray, T., Kaita, R., Majesk, R., Spaleta, J., and Timberlake, J., "Fast Gas Injection as a Diagnostic Technique for Particle Confinement Time Measurements," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E901 (3 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia). Princeton Plasma Physics Laboratory Report PPPL-4166 (June 2006) 8 pp.

*Greenfield, C.M, Murakami, M., Garofalo, A.M., and 23 additional co-authors including Kessel, C.E., and Okabayashi, M. from PPPL "Progress Toward High Performance Steady-State Ioeratuib ub /dIII-D," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/1-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Greenfield, C.M, Murakami, M., Garofalo, A.M., and 48 additional co-authors including Kessel, C.E., Okabayashi, M., and Solomon, W.M. from PPPL, and the DIII-Team, "Progress towards High-performance Steady-state Operation on DIII-D," Fusion Eng. Design **81**:23–24 (November 2006) 2807–2815; *Proceedings of the Fifteenth International Toki Conference on Fusion and Advanced Technology, ITC-15* (6–9 December 2005, Toki-city, Japan), edited by A. Sagara, S. Imagawa, T. Mito, T. Hamajima, and F. Najmabadi.

Greenough, N., Fredd, E., Hosea, J., Pinsker, R., Baity, F.W, Barber, G., and Horton, A., "Upgrading the General Atomics Radio-Frequency Sources for High Power," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337891.

*Greenwald, M., Basse, N., Bonoli, P., and 26 co-authors including Mikkelsen, D. and Scott, S. from PPPL, "Confinement and Transport Research in Alcator C-Mod," Fusion Sci. Techn. **51**:3 (April 2007) 266–287.

§Grisham, L.R., "Lithium Jet Neutralizer to Improve Negative Hydrogen Neutral Beam Systems," Phys. Plasmas **14**:10 (October 2007) Article No. 102509 (8 pages).

†Grisham, L.R., Kwan, J.W., and Westenskow, G., "Halogens for Negative Ion Beams and Ion-Ion Plasmas," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 267–274; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*Grulke, O., Terry, J.L., LaBombard, B., and Zweben, S.J., "Radial Propagation of Eruptive Turbulent Transport Events in the Scrape-Off Layer of Alcator C-Mod," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P4-7. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Gryanznevich, M.P., Hender, T.C., Howell, D.F., and 17 additional co-authors including Menard, J. from PPPL, and the JET-EFDA Contributors, "Experimental Identification of the Beta Limit in JET," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-5.145. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*†Gürcan, Ö.D., Diamond, P.H., and Hahm, T.S., "Spatial and Spectral Evolution of Turbulence Spectra," AIP Conf. Proc. **871** (30 November 2006) edited by Olivier Sauther, pages 112–123; *Proceedings of the Joint Varenna-Lausanne International Workshop on Theory of Fusion Plasmas* (28 August – 1 September 2006, Varenna, Italy).

*Gürcan, Ö.D., Diamond, P.H., and Hahm, T.S., "Spatial and Spectral Evolution of Turbulence," Phys. Plasmas **14**:5 (May 2007) 055902 (6 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

*Gürcan, Ö.D., Diamond, P.H., Hahm, T.S., and Singh, R., "Intrinsic Rotation and Electric Field Shear," Phys. Plasmas **14**:4 (April 2007) Article No. 042306.

*Hacquin, S., Sharapov, S.E., Alper, B., and 7 co-author including Mazzucato, E. from PPPL, and the JET EFDA Contributors, "Localized X-mode Reflectometry Measurements of Alfvén Eigenmodes on the JET Tokamak," Plasma Phys. Control. Fusion **49**:9 (September 2007) 1371–1390.

Hahm, T.S., Diamond, P.H., Gurcan, O.D., and Rewoldt, G., "Nonlinear Gyrokinetic Theory of Toroidal Momentum Pinch," Phys. Plasma **14**:7 (July 2007) Article No. 072302 (22 pages); Princeton University Plasma Physics Laboratory Report PPPL-4230 (April 2007) 48 pp.

Hahm, T.S., Wang, W.X., Rewoldt, G., Manickam, J., and Tang, W.M., "Gyrokinetic Studies of Nonlocal Properties of Turbulence-driven and Neoclassical Transport," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/2-6Ra. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Hanada, M., Ikeda, Y., Kamada, M., Kikuchi, K., Komata, M., Mogaki, K., Umeda, N., Usui, K., Grisham, L.R., and Kobayashi, S., "Correlation between Voltage Holding Capability and Light Emission in a 500 keV Electrostatic Accelerator Utilized for Fusion Application," Special Issue IEEE Transactions on Dielectrics and Electrical Insulation **14**:3 (June 2007) 572–576; presented at the *XXII IEEE International Symposium on Discharge and Electrical Insulation in Vacuum (ISDEV)* (25–29 September 2006, Matsue, Japan).

*Harvey, R.W., Cary, J.R., Taylor, G., and 26 additional co-authors including Diem, S., Efthimion, P.C., Ellis, R.A., Fredd, E., Hosea, J., LeBlanc, B., Phillips, C.K., and Wilson, J.R. from PPPL, "Electron Bernstein Wave Studies: Current Drive; Emission and Absorption with Nonthermal Distributions; Delta-f Particle-in-Cell Simulations," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-11. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Heidbrink, W.W., Bell, R.E., Luo, Y., and Solomon, W., "A Fast-ion D-alpha Diagnostic for NSTX," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10F120 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*§Heidbrink, W.W., Gorelenkov, N.N., Luo, Y., and 8 additional co-authors including White, R.B., Kramer, G.L., and Nazikian, R. from PPPL and the DIII-D Team, "Anomalous Flattening of the Fast-Ion Profile during Alfvén-Eigenmode Activity," Phys. Rev. Lett. **99**:24 (14 December 2007) Article No. 245002.

*Heidbrink, W.W., Kramer, G.J., Nazikian, R., Van Zeelan, M.A., Austin, M.E., Berk, H.L., Burrell, K.H., Gorelenkov, N.N., Luo, Y., McKee, G.R., Rhodes, T.L., Wang, G., and the DIII-D Team, "Alfvén Instabilities in DIII-D: Fluctuation Profiles, Thermal-Ion Excitation, and Fast-Ion Transport," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/6-3. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Hender, T.C., Reimerdes, H., Chu, M.S., and 9 additional co-authors including Okabayashi, M. from PPPL, the DIII-D Team, and the JET EFDA Contributors, "Prediction of Rotation Stabilisation Resistive Wall Modes in ITER," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P8-18. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Hender, T.C., Wesley, J.C., Bialek, J., and 54 additional co-authors including Jardin, S.C., Kessel, C., Manickam, J. and Okabayashi, M. from PPPL, and the ITPA MHD, Disruption and Magnetic Control Topical Group, "Chapter 3: MHD Stability, Operational Limits and Disruptions," Nucl. Fusion **47**:6 (June 2007) S128–S202 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

*Hender, T.C., Wesley, J.C., deVries, P.C., and 16 additional co-authors including Fredrickson, E.D., Gates, D.A., and Menard, J.E. from PPPL, " Disruption Database Studies for ITER," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-5.133. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Hidalgo, C., Alonso, J.A., Carvalho, P., and 17 co-authors including Zweben, S. from PPPL, and the TJ-II Team, "On the Link Between Edge Momentum Redistribution and Turbulence in the TJ-II Stellarator," in the *Proceedings of the 21st Fusion*

Energy Conference (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P7-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

†Hill, K.W., Bitter, M.L., Broennimann, Ch., Eikenberry, E.F., Ince-Cushman, A., Lee, S.G., Rice, J.E., Scott, S., and Barnsley, R., "Development of a High Resolution X-ray Imaging Crystal Spectrometer for Measurements of Ion-Temperature and Rotation-Velocity Profiles in Fusion Energy Research Plasmas," Plasma and Fusion Research **2** (20 November 2007) Article No. S1067; Special Issue: Papers from the *16th International Toki Conference on Advanced Imaging and Plasma Diagnostics* (5–8 December 2006, Ceratopia Toki, Gifu, Japan).

*Hole, M.J., Dewar, R.L., and Hudson, S.R., "Equilibria and Stability in Partially Relaxed Plasma-Vacuum Systems," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P3-4. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Hole, M.J., Hudson, S.R., and Dewar, R.L., "Equilibria and Stability in Partially Relaxed Plasma-vacuum Systems," Nucl. Fusion **47**:8 (August 2007) 746–753.

*Hole, M.J., Hudson, S.R., and Dewar, R.L., "Stepped Pressure Profile Equilibria in Cylindrical Plasmas via Partial Taylor Relaxation," J. Plasma Phys. **72**:6 (December 2006) 1167–1171.

Hosea, J., Bell, R., Bernabei, S., Delgado-Aparicio, L., LeBlanc, B., Phillips, C.K., Ryan, P., Sabbagh, S., Tritz, K., Wilgen, J., Wilson, J.R., and Yuh, H., "HHFW Heating Efficiency on NSTX versus B_Φ and Antenna $k_{||}$," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 107–110; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*Hu, B., Betti, R., and Manickam, J., "Kinetic Stability of the Internal Kink Mode in ITER, Phys. Plasmas **13**:11 (November 2006) Article No. 112505 (9 pages).

Hudson, S.R., "Calculation of Cantori for Hamiltonian Flows," Phys. Rev. E **74**:5 (November 2006) Article No. 056203 (6 pages).

Hudson, S.R., Hole, M.J., and Dewar, R.L., "Eigenvalue Problems for Beltrami Fields Arising in a 3-D Toroidal MHD Equilibrium Problem," Phys. Plasmas, **14**:5 (May 2007) Article No. 052505 (12 pages); Princeton University Plasma Physics Laboratory Report PPPL-4226 (February 2007) 32 pages.

*Ince-Cushman, A., Rice, J.E., Lee, S.G., Bitter, M., Reinke, M., and Podpaly, Y., "Preliminary Results from the soft X-ray Crystal Spectrometer on Alcator C-Mod," Rev. Sci. Instrum. **77**:10 (October 2006) 10F321 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*Ishikawa, M., Takechi, M., Shinohara, K., and 12 co-authors including Gorelenkov, N.N., Kramer, G.J., and Nazikian, R. from PPPL, and the JT-60 Team, "Observation of Confinement Degradation of Energetic Ions due to Alfvén Eigenmodes in JT-60U Weak Shear Plasmas," Special Issue Nucl. Fusion **46**:10 (October 2006) S898–S903; presented at *9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems* (9–11 November 2005, Takayama, Japan).

*Isobe, M., Goto, K., Toi, K., and 10 additional co-authors including Darrow, D.S. from PPPL, and the CHS Team, "Design and Initial Operation of Lost Fast-ion Probe Based on thin Faraday Films in CHS," Rev. Sci. Instrum. **77**:10 (October 2006) 10F508 (3 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*Isobe, M., Toi, K., Matsushita, H., and 18 co-authors including Darrow, D.S. from PPPL, and the CHS Team, "Studies of Fast-ion Transport Induced by Energetic Particle Modes using Fast-particle diagnostics with High Time Resolution in CHS," Special Issue Nucl. Fusion **46**:10 (October 2006) S918–S925; presented at *9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems* (9–11 November 2005, Takayama, Japan).

*Jaeger, E.F., Berry, L.A., Harvey, R.W., and 11 co-authors including Phillips, C.K. and Valeo, E.J. from PPPL, "Quasilinear Evolution of Multiple Non-thermal Ion Distributions in ICRF Heating," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 443–446; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

Jardin, S., "Two-fluid Extended-MHD Calculations of Toroidal Equilibrium and Collisionless Reconnection in Magnetized Plasmas," to appear in J. Computational Physics (?).

Jardin, S.C., Bateman, G., Hammett, G.W., and Ku, L.P., "On 1D Diffusion Problems with a Gradient-dependent Diffusion Coefficient," Princeton University Plasma Physics Laboratory Report PPPL-4234 (April 2007) 8 pages, submitted to J. Computational Physics.

§Jardin, S.C., Breslau, J., and Ferraro, N., A High-order Implicit Finite Element Method for Integrating the Extended-magneto-hydrodynamic Equations in Two Dimensions," J. Computational Phys. **226**:12 (1 October 2007) 2146–2174; Princeton University Plasma Physics Laboratory Report PPPL-4209 (January 2007) 40 pages.

Jardin, S.C., Ferraro, N., Breslau, J., Bauer, A., Jansen, K., Shephard, M., and the M3D Team, "Two-fluid Extended-MHD Calculations of Collisionless Reconnection in Magnetized Plasmas and Toroidal Equilibrium," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-4.076. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Jaspers, R.J.E., Hogeweij, G.M.D., Park, H.K., 13 additional co-authors, and the TEXTOR-Team, "Imaging and Manipulation of Sawteeth and Tearing Modes in TEXTOR," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P8-17. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Jenkins, Thomas G. and Lee, W.W., "Fluctuations and Discrete Particle Noise in Gyrokinetic Simulation of Drift Waves," Phys. Plasmas **14**:3 (March 2007) Article No. 032307 (10 pages).

†Ji, H., Belova, E., Gerhardt, S.P., and Yamada, M., "Recent Advances in the SPIRIT (Self-organized Plasma with Induction, Reconnection, and Injection Techniques) Concept," J. Fusion Energy **26**:1–2 (June 2007) 93–97; *Proceedings of the 2006 Innovative Confinement Concepts Workshop* (13–16 February 2006, Austin, Texas).

§Ji, Hantao; Burin, Michael; Schartman, Ethan; and Goodman Jeremy, "Hydrodynamic Turbulence cannot Transport Angular Momentum Effectively in Astrophysical Disks," Nature **444**:7117 (16 November 2006) 343–346 (Letter section); Princeton University Plasma Physics Laboratory Report PPPL-4215 (January 2007) 6 pages.

§Johnson, D.W. and Costley, A.E., "Editorial Perspectives-Chapter 13: Challenges in Fusion Diagnostic Development: A Virtual Tour of ITER," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 751–759.

Kaganovich, I., Raitses, Y., Sydorenko, D., and Smolyakov, A., "Kinetic Effects and Beam-related Instabilities in Hall Thrusters," in the *Proceedings of the 43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit* (8–11 July 2007, Cincinnati, Ohio) AIAA-2007:5206.

†Kaganovich, I.D., Pennington, J.S., Sefkow, A.B., Startsev, E.A., and Davidson, R.C., "Charge and Current Neutralization of an Ion Beam Pulse by Background Plasma in the Presence of an Applied Magnetic Field and Gas Ionization," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Kaganovich, I.D., Raitses, Y., Sydorenko, D., and Smolyakov, A., "Kinetic Effects in a Hall Thruster Discharge," Phys. Plasmas **14**:5 (May 2007) Article

No. 057104 (11 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton Plasma Physics Laboratory Report PPPL-4217 (February 2007) 36 pages.

†Kaganovich, I.D., Shnidman, A, and Davidson, R.C., "Calculation of the Charge-Changing Cross Sections of Ions or Atoms Colliding with Fast Ions using the Classical Trajectory Method," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

§Kaganovich, I.D., Startsev, E.A., Sefkow, A.B., and Davidson, R.C., "Charge and Current Neutralization of an Ion-Beam Pulse Propagating in a Background Plasma along a Solenoidal Magnetic Field," Phys. Rev. Lett **99**:23 (6 December 2007) Article No. 235002.

Kaganovich, I.D., Startsev, E.A., Sefkow, A.B., and Davidson, R.C., "Controlling Charge and Current Neutralization of an Ion Beam Pulse in a Background Plasma by Application of a Small Solenoidal Magnetic Field," Princeton Plasma Physics Laboratory Report PPPL-4258 (August 2007) 29 pages.

†Kaganovich, Igor D.; Sefkow, Adam B.; Startsev, Edward A.; Davidson, Ronald C.; and Welch, Dale R., "Effects of Finite Pulse Length, Magnetic Field, and Gas Ionization on Ion Beam Pulse Neutralization by Background Plasma," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 93–102; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France); Princeton University Plasma Physics Laboratory Report PPPL-4223 (February 2007) 15 pages.

§Kaganovich, Igor D.; Startsev, Edward; and Davidson, Ronald C., "Scaling and Formulary of Cross Sections for Ion-Atom Impact Ionization," New J Phys. **8** (November 2006) Article No. 278.

†Kaita, R., Majeski, R., Doerner, R., Gray, T., Kugel, H., Lynch, T., Maingi, R., Mansfield, D., Soukhanovskii, V., Spaleta, J., Timberlake, J., and Zakharov, L., "Extremely Low Recycling and High Power Density Handling in CDX-U Lithium Experiments," J. Nucl. Mater. **363-365** (15 June 2007) 1231–1235 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China). Princeton University Plasma Physics Laboratory Report PPPL-4225 (February 2007) 8 pp.

Kaita, R., Majeski, R., Gray, T., Kugel, H., Mansfield, D., Spaleta, J., Timberlake, J., Zakharov, L., Doerner, R., Lynch, T., Maingi, R., and Soukhanovskii, V., "Low Recycling and High Power Density Handling Physics in the Current Drive Experiment-Upgrade with Lithium Plasma-facing Components," Phys. Plasmas **14**:5 (May 2007) Article No. 056111 (8 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory Report PPPL-4233 (April 2007) 20 pages.

Kalish, M., Chrzanowski, J., Neumeyer, C., Paul, B., Woolley, R., and Jun, C., "NSTX OH Coil Design Improvements," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337876.

Kallman, Joshua B. and Zakharov, Leonid E., "Bishop-Taylor Equilibrium and Equilibrium Reconstruction Codes," Phys. Plasmas **14**:7 (July 2007) Article No. 072504 (6 pages); Princeton University Plasma Physics Laboratory Report PPPL-4222 (February 2007) 8 pp.

§Kaye, S.M., Bell, M.G., Bell, R.E., Fredrickson, E.D., LeBlanc, B.P., Lee, K.C., Lynch, S., and Sabbagh, S.A., "Energy Confinement Scaling in the Low Aspect Ratio National Spherical Torus Experiment (NSTX)," Nucl, Fusion **46**:10 (October 2006) 848–857; Princeton University Plasma Physics Laboratory Report PPPL-4208 (January 2007) 8 pp.

Kaye, SM., Bell, R.E., Gates, D., LeBlanc, B.P., Levinton, F.M., Menard, J.E., Mueller, D., Rewoldt, G., Sabbagh, S.A., Wang, W., and Yuh, H., "The Scaling of Electron and Ion Transport in the High-power Spherical Torus NSTX," Phys. Rev. Lett.

98:17 (27 April 2007) Article No. 175002; Princeton University Plasma Physics Laboratory Report PPPL-4237 (May 2007) 12 pp.

Kaye, S.M., Bell, R.E., LeBlanc, B.P., Levinton, F., Mikkelsen, D., Rewoldt, G., Solomon, W., Wang, W., Wong, K.L., and Yuh, H., "Confinement, Transport and Turbulence Properties of NSTX Plasmas," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.064. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

Kaye, S.M., Levinton, F.M., Stutman, D., and 16 additional co-authors, "Confinement and Local Transport in the National Spherical Torus Experiment (NSTX)," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/8-6. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Kaye, S.M., Levinton, F.M., Stutman, D., Tritz, K., Yuh, H., Bell, M.G., Bell, R.E., Domier, C.W., Gates, D., Horton, W., Kim, J., LeBlanc, B.P., Luhmann Jr., N.C., Maingi, R., Mazzucato, E., Menard, J.E., Mikkelsen, D., Mueller, D., Park, H., Rewoldt, G., Sabbagh, S.A., Smith, D.R., and Wang, W., "Confinement and Local Transport in the National Spherical Torus Experiment (NSTX)," Nucl. Fusion **47**:7 (July 2007) 499–509; Princeton University Plasma Physics Laboratory Report PPPL-4238 (May 2007) 32 pp.

Kessel, C.E, Giruzzi, G., Sips, A.C.C., and 17 additional co-authors, "Simulation of the Hybrid and Steady State Advanced Operating Modes in ITER," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IT/P1-7. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008). Princeton University Plasma Physics Laboratory Report PPPL-4192 (November 2006) 8 pp.

Kessel, C.E, Giruzzi, G., Sips, A.C.C., and 17 additional co-authors, "Simulation of the Hybrid and Steady State Advanced Operating Modes in ITER," Nucl. Fusion **47**:9 (September 2007) 1274–1284.

*§Kirkwood, R.K., Dewald, E., Niemann, C., Meezan, N., Wilks, S.C., Price, D.W., Landen, O.L., Wurtele, J., Charman, A.E., Lindberg, R., Fisch, N.J., Malkin, V.M., and Valeo, E.O., "Amplification of an Ultrashort Pulse Laser by Stimulated Raman Scattering of a 1 ns Pulse in a Low Density Plasmas," Phys. Plasmas **14**:11 (November 2007) Article No. 113109 (7 pages).

*Kirschner, A., Philipps, V., Balden, M., 18 additional co-authors including Strachan, J.D.from PPPL, and the JET-EFDA Contributors, "Material Erosion and Redeposition during the JET MkIIGB-SRP Divertor Campaign," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/3-5. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*§Kislyakov, A.I., Donné, A.J.H., Krupnik, L.I., Medley, S.S., and Petrov, M.P., "Chapter 8: Particle Diagnostics," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 577–603.

*Kolesnichenko, Ya.I., Lutsenko, V.V., Marchenko, V.S., and White, R.B., "Stabilization of the Quasi-interchange Mode in Tokamaks by Circulating Energetic Ions," Phys. Plasmas **14**:1 (January 2007) Article No. 012504; Princeton University Plasma Physics Laboratory Report PPPL-4197 (December 2006) 14 pp.

*Kolesnichenko, Ya.I., White, R.B., and Yakovenko, Yu.V., "High Frequency Shear Alfvén Instability driven by Circulating Energetic Ions in NSTX," Phys. Plasmas **13**:12 (December 2006) Article No. 122503 (3 pages); Princeton University Plasma Physics Laboratory Report PPPL-4189 (October 2006) 6 pp.

Kolesnikov, R.A., Lee, W.W., Qin, H., and Startsev, E., "High Frequency Gyrokinetic Particle Simulation," Phys. Plasmas **14**:7 (July 2007) Article No. 072506 (8 pages); Princeton University Plasma Physics Laboratory Report PPPL-4186 (October 2006) 4 pp.

Kolesnikov, Roman A.; Lee, W.W.; Qin, Hong; and Startsev, Ed, "High Frequency Gyrokinetic Particle-in-Cell Simulation: Application to Heating of Magnetically Confined Plasmas," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 475–478; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*Kotschenreuther, M.T., Valanju, P.M., Mahajan, S.M., and 6 additional co-authors including Gates, D. from PPPL, "On Heat Loading, Divertors and Reactors," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IC/P7-12. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Krommes, John A., "Nonequilibrium Gyrokinetic Fluctuation Theory and Sampling Noise in Gyrokinetic Particle-in-cell Simulations," Phys. Plasmas **14**:9 (September 2007) Article No. 090501 (26 pages).

Ku, L.P., Lyon, J.F., and the ARIES Team, "Configuration Optimization and Physics Basis for ARIES-CS," Princeton University Plasma Physics Laboratory Report PPPL-4196 (November 2006) 4 pp; presented at the *Seventeenth ANS Topical Meeting on the Technology of Fusion Energy (TOFE2006)*, (13–15 November 2006, Albuquerque, New Mexico).

*Kubota, N, Ochiai, K., Kutsukake, C., and 10 additional co-authors including Gentile, C.A. and Skinner, C.H. from PPPL, "Surface Analysis for the TFTR Armor Tile Exposed to D-T Plasmas using Nuclear Technique," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P4-12. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

†Kugel, H.W., Bell, M.G., Bell, R., Bush, C., Gates, D., Gray, T., Kaita, R., LeBlanc, B., Maingi, R., Majeski, R., Mansfield, D., Mueller, D., Paul, S., Raman, R., Roquemore, A.L., Sabbagh, S., Skinner, C.H., Soukhanovskii, V., Stevenson, T., and Zakharov, L., "Effect of Lithium PFC Coatings on NSTX Density Control," J. Nucl. Mater. **363-365** (15 June 2007) 791–796 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China). Princeton Plasma Physics Laboratory Report PPPL-4180 (June 2006) 16 pp.

Kugel, H.W., Maingi, R., Bell, M., Blanchard, W., Gates, D., and Gernhardt, R., "Design and Performance of NSTX Movable GDC Probe," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337871.

†Kugel, H.W., Spong, D., Majeski, R., and Zarnstorff, M., "NCSX Plasma Heating Methods," Trans. Fusion Sci. Technol. **51**:2 (February 2007) 203–217.

Kung, C.C., D'Amico, G., Kramer, G.J., Fredd, E., Brunkhorst, C., Scott, S., and Hosea J., "Grounding, DC Supplies, and Controlling Signal Issues for a Tunable Reflectometry System," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337934.

*Kuritsyn, A., Ji, H., Gerhardt, S.P., Ren, Y., and Yamada, M., "Effects of Global Boundary and Local Collisionality on Magnetic Reconnection in a Laboratory Plasma," Geophys. Res. Lett. **34** (25 August 2007) Article No. L16106; Princeton University Plasma Physics Laboratory Report PPPL-4255 (July 2007) 17 pp.

*†Kuritsyn, Alexey; Craig, Darren; Fiksel, Gennady; Miller, Matt; Cylinder, David; and Yamada, Masaaki, "Local Measurements of Plasma Ion Dynamics with Optical Probes," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10F112 (3 pp); *Proceedings of the 16th Topical Conference on High-Temperature*

Plasma Diagnostics (7–11 May 2006, Williamsburg, Virginia).

Labik, G., Brown, T., Johnson, D., Pomphrey, N., Stratton, B., Viola, M., Zarnstorff, M., Duco, M., Edwards, J., Cole, M., and Lazarus, E., "National Compact Stellarator Experiment Vacuum Vessel External Flux Loops Design and Installation," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 3 pp. Available from IEEE on CD-ROM, Digital Object Identifier 10.1109/FUSION.2007.4337935.

*§Lasnier, C.J., Allen, S.L., Boedo, J.A., Groth, M., Brooks, N.H., McLean, A., LaBombard, B., Skinner, C.H., Rudakov, D.L., West, W.P., and Wong, C.P.C., "Chapter 10: First Wall and Operational Diagnostics," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 640–666.

LeBlanc, B.P., Bell, R.E., Bernabei, S., 15 additional co-authors, and the NSTX Team, "HHFW and EBW Research on NSTX," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-4.160. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Lazarus, E.A., Luce, T.C., Austin, M.E., and 20 additional co-authors including Solomon, W.M. from PPPL "Sawtooth Oscillations in Shaped Plasmas," Phys. Plasmas **14**:5 (May 2007) Article No. 055701 (17 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

*Lee, Jeongwoo; Gary, Dale E., and Choe, G.S., "Magnetic Energy Release during the 2002 September 9 Solar Flare," Astrophys. J. **647** (10 August 2006) 638–647; Princeton University Plasma Physics Laboratory Report PPPL-4190 (October 2006) 10 pp.

*†Lee, K.C., Domier, C.W., Johnson, M., Luhmann, Jr., N.C., Park, H., and Soukhanovskii, V.A., "Survey of Diagnostic System for the Study of Gyrocenter Shifts on National Spherical Torus Experiment," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10F505 (3 pages); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*§Lee, S.G., Bak, J.G., and Bitter, M., "Calibration of an Imaging Crystal Spectrometer for Low X-ray Energies," Rev. Sci. Instrum. **79**:1 (January 2008) Article No. 013501 (5 pages).

Lee, W.W., Ethier, S., Jenkins, T.G., Wang, W.X., Lewandowski, J.L.V., Rewoldt, G., Tang, W.M., Parker, S.E., and Chen, Y., "Long Time Simulations of Microturbulence in Fusion Plasmas," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/2-6Rb. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Levinton, F.M., Yuh, H., Bell, M.G., Bell, R.E., Delgado-Aparicio, L., Finkenthal, M., Fredrickson, E.D., Gates, D.A., Kaye, S.M., LeBlanc, B.P., Maingi, R., Menard, J.E., Mikkelsen, D., Mueller, D., Raman, R., Rewoldt, G., Sabbagh, S.A., Stutman, D., Tritz, K., and Wang, W., "Transport with Reversed Shear in the National Spherical Torus Experiment," Phys. Plasmas **14**:5 (May 2007) Article No. 056119 (9 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

*§Lin, Z., Holod, I., Chen, L., Diamond, P.H., Hahm, T.S., and Ethier, S., "Wave-Particle Decorrelation and Transport of Anisotropic Turbulence in Collisionless Plasmas," Phys. Rev. Lett. **99**:26 (27 December 2007) Article No. 265003.

*Lipschultz, B., Bonnin, X., Counsell, G., and 44 additional co-authors including Skinner, C. and Zweben, S. from PPPL, "Plasma-surface Interaction, Scrape-off Layer and Divertor Physics: Implications for ITER," Nucl. Fusion **47**:9 (September 2007) 1189–1205.

*†Liu, D., Heidbrink, W.W., Darrow, D.S., Roquemore, A.L., Medley, S.S., and Shinohara, K., "Performance of the Solid State Neutral Particle Analyzer Array on the National Spherical Torus Experiment," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10F113 (4

pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginis). Princeton Plasma Physics Laboratory Report PPPL-4174 (June 2006) 12 pp.

Liu, Wei; Goodman, Jeremy; and Ji, H., "Traveling Waves in a Magnetized Taylor-Couette Flow," Phys. Rev. E **76**:1 (July 2007) Article No. 016310 (4 pages).

Liu, Wei; Goodman, Jeremy; Herron, Isom; and Ji, Hantao, "Helical Magnetorotational Instability in Magnetized Taylor- Couette Flow," Phys. Rev. E **74**:5 (November 2006) Artilce No. 056302 (8 pages).

*Loarte, A., Lipschultz, B., Kukushkin, A.S., and 33 additional co-authors including Strachan, J. from PPPL, and the ITPA Scrape-off Layer and Divertor Physics Topical Group, "Chapter 4: Power and Particle Control," Nucl. Fusion **47**:6 (June 2007) S203–S263 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

*†Logan, B.G., Bieniosek, F., Celata, C.M., and 30 additional co-authors including Davidson, R.C., Efthimion, P.C., Gilson, E.P., Grisham, L.D., Kaganovich, I.D., Qin, H., Sefkow, A.B., and Startsev, E.A. from PPPL, "Recent U.S. Advances in Ion-beam-driven High Energy Density Physics and Heavy Ion Fusion," Nucl. Instrum. Methods Phys. Res. A: Accelerators, Spectrometers, Detectors and Associated Equipment **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 1–7; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*§Lou, Y., Heidbrink, W.W., Burrell, K.H., Ruskov, E., and Solomon, W.M., "Fast-ion D_α Measurements and Simulations in Quiet Plasmas, Phys. Plasmas **14**:11 (7 November 2007) Article No. 112503.

*Luo, Y., Heidbrink, W.W., Ruskov, E., Burrell, K.H., Pinsker, R.I., and Solomon, W.M., "Summary of the Fast-Ion D_α Measurements in Various Plasma Conditions in DIII-D," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.151. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*§Loureiro, N.F. and Hammett, G.W., "An Iterative Semi-Implicit Scheme with Robust Damping," J. Computational Phys. **227**:9 (20 April 2008) 4518–4542.

*Luce, T.C., Burrell, K.H., Buttery, R.J., and 20 additional co-authors including Okabayashi, M. and Solomon, W.M. from PPPL, "Dependence of Confinement and Stability on Variation of External Torque in the DIII-D Tokamak," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper PD-3. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*§Luhmann, Jr., N.C., Bindslev, H., Park, H., Sánchez, J., Taylor, G., and Yu, C.X., "Chapter 3: Microwave Diagnostics," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 335–396.

*Lund, S.M., Kikuchi, T., and Davidson, R.C., "Generation of Initial Vlasov Distributions for Simulation of Charged Particle Beams with High Space-charge Intensity," submitted to Physical Review Special Topics on Accelerators and Beams, 2007.

*Lyon, J.F., Harris, J.H., Benson, R.D., and 12 additional co-authors including Brooks, A., Heitzenroeder, P.J., and Neilson, G.H. from PPPL, "Status of the Quasi-Poloidal Stellarator," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-1.160. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Maingi, R. and 30 additional co-authors including Bell, M.G., Fredrickson, E.D, Zweben, S.J., Bell, R.E., Gates, D.A., Johnson, D.W., Kaita, R., Kaye, S.M., Kugel, H.W., LeBlanc, B.P., Menard, J.E., Mueller, D., Park, H., Roquemore, A.L., Soukhanovskii, V.A., and Stevenson, T. from PPPL, "Characterization of Small, Type V ELMs in the National Spherical Torus Experiment, Princeton University Plasma Physics Laboratory Report PPPL-4198 (December 2006) 40 pp; presented at the *5th International Conference on Atomic and Molecular Data and Their Applications (ICAMDATA)*, (15–19 October 2006, Meudon, France).

*Maingi, R. and the NSTX Team, "Variation of the Midplane Heat Flux Width with Plasma Current Heating Power in NSTX," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.020. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*†Maingi, R., Bush, C.E., Kaita, R., Kugel, H.W., Roquemore, A.L., Paul, S.F., Soukhanovskii, V.A., and the NSTX Team, "Divertor Heat Flux Scaling with Heating Power and Plasma Current in H-mode Discharges in the National Spherical Torus Experiment," J. Nucl. Mater. **363-365** (15 June 2007) 196–200 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

Majeski, R., Kugel, H., Bell, M.G, and 22 additional co-authors, "Results from the CDX-U Lithium Wall and NSTX Lithium Pellet Experiments," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P4-23. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Malkin, V.M. and Fisch, N.J., "Relic Crystal Lattice Effects on Raman Compression of Powerful X-ray Pulses in Plasmas," Phys. Rev. Lett. **99**:20 (November 2007) Article No. 205001.

*§Malkin, V.M., Fisch, N.J., and Wurtele, J.S., "Compression of Powerful X-ray Pulses to Attosecond Durations by Stimulated Raman Backscattering in Plasmas," Phys. Rev. E **75**:2 (February 2007) Article No. 026404 (5 pages).

*†Maqueda, R.J. Maingi, R., Tritz, K., Lee, K.C., Bush, C.E., Fredrickson, E.D., Menard, J.E., Roquemore, A.L., Sabbagh, S.A., and Zweben, S.J., "Structure of MARFEs and ELMs in the NSTX," J. Nucl. Mater. **363-365** (15 June 2007) 1000–1005 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

*Marmar, E., Lin, Y., Lipschultz, B., and 12 additional co-authors including Scott, S. from PPPL and the Alcator Team, "Operation of Alcator C-Mod with High-Z Plasma Facing Components with and without Boronization," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/3-4. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Mau, T.K., Kaiser, T.B., Lyon, J.F., Maingi, R., Raffray, A.R., Wang, X., Ku, L.P., and Zarnstorff, M., "Divertor Heat Loads from Thermal and Alpha Particles in a Compact Stellarator Reactor," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337872.

§Mazzucato, E., "Detection of Short-scale Turbulence in the Next Generation of Tokamak Burning Plasma Experiments," Plasma Phys. Control. Fusion **48**:12 (December 2006) 1749–1763; Princeton Plasma Physics Laboratory Report PPPL-4181 (June 2006) 14 pp.

*McDonald, D.C., Cordey, J.G., Thomsen, K., and 26 additional co-authors including Kaye, S.M. from PPPL, "Recent Progress on the Development and Analysis of the ITPA Global H-mode Confinement

Database," Nucl. Fusion **47**:3 (March 2007) 147–174.

McGeehan, B., *et al*., "Equilibrium Flow States Between Short Cylinders," submitted to Theoretical and Computational Fluid Dynamics, 2007.

*†McKee, George R.; Fonck, Raymond J.; Gupta, Deepak K.; Schlossberg, David J.; Shafer, Morgan W.; Boivin, Réjean L.; and Solomon, Wayne, "Plasma Turbulence Imaging via Beam Emission Spectroscopy in the Core of the DIII-D Tokamak," Plasma and Fusion Research **2** (20 November 2007) Article No. S1025; Special Issue: Papers from the *16th International Toki Conference on Advanced Imaging and Plasma Diagnostics* (5–8 December 2006, Ceratopia Toki, Gifu, Japan).

Medley, S.S., Andre, R., Bell, R.E., Darrow, D.S., Fredrickson, E.D., Gorelenkov, N.N., Kaye, S.M., Levinton, F.M., LeBlanc, B.P., Menard, J.E., Stutman, D., Roquemore, A.L., Tritz, K., Yuh, H., and the NSTX Team, "Status of Recent Experimental and Analytical Investigation of MHD-induced Energetic Ion Redistribution or Loss in the National Spherical Torus Experiment," Princeton University Plasma Physics Laboratory Report PPPL-4235 (April 2007) 84 pp.

Medley, S.S., Andre, R., Bell, R.E., Darrow, D.S., Fredrickson, E.D., LeBlanc, B.P., Levinton, F.M., Menard, J.E., Stutman, D., Roquemore, A.L., Shinohara, K., Tritz, K., and Yuh, H., "Investigation of Collective Fast Ion Instability-induced Redistribution or Loss in NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P6-13. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Medley, S.S., Donné, A.J.H., Kaita, R., Kislyakov, A.I., Petrov, M.P., and Roquemore, A.L., "Contemporary Instrumentation and Application of Charge Exchange Neutral Particle Diagnostics in Magnetic Fusion Experiments," Rev. Sci. Instrum. **79**:1 (January 2008) Article No. 011101 (16 pages); Princeton University Plasma Physics Laboratory Report PPPL-4250 (July 2007) 61 pp.

§Menard, J.E., Bell, M.G., Bell, R.E., and 146 additional co-authors, "Overview of Recent Physics Results from the National Spherical Torus Experiment (NSTX)," Special Issue Nucl. Fusion **47**:10 (October 2007) S645–S657 [Overview and Summary Reports Based on the 2006 Fusion Energy Conference Contributions (Chengdu, China, 16–21 October 2006)]; Princeton University Plasma Physics Laboratory Report PPPL-4211 (January 2007) 32 pp.

Menard, J.E., Bell, M.G., Bell, R.E., and 45 additional co-authors, and the NSTX Research Team, "Recent Physics Results from NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper OV/2-4. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Menard, J.E., Goldston, R.J., Fu, G.-Y., Gorelenkov, N., Kaye, S.M., Kramer, G., Maingi, R., Neumeyer, C.L., Sabbagh, S.A., Soukhanovskii, V.A., and Woolley, R., "Physics Design of the National High-power Advanced Torus eXperiment," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-1.162. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008). Princeton University Plasma Physics Laboratory Report PPPL-4252 (July 2007) 4 pp.

†Mikkelsen, D.R., Maassberg, H., Zarnstorff, M.C., Beidler, C.D., Houlberg, W.A., Kernbichler, W., Mynick, H., Spong, D.A., Strand, P., and Tribaldos, V., "Assessment of Transport in NCSX," Trans. Fusion Sci. Technol. **51**:2 (February 2007) 166–180; Princeton University Plasma Physics Laboratory Report PPPL-4205 (December 2006) 48 pp.

*†Mioduszewski, P.K., Owen, L.W., Spong, D.A., Fenstermacher, M.E., Koniges, A.E., Rognlien, T.D., Umansky, M.V., Grossman, A., and Kugel, H.W., "Power and Particle Handling and Wall Conditioning in NCSX," Trans. Fusion Sci. Technol. **51**:2 (February 2007) 238–260.

†Mueller, D., Raman, R., Bell, M.G., Jarboe, T.R., LeBlanc, B., Maqueda, R., Sabbagh, S. and Nelson, B.A., "NSTX Plasma Start-up using Transient Coaxial Helicity Injection," Fusion Sci. Technol. **52**:3 (October 2007) 393–397; *Proceedings of the 17th Topical Meeting on the Technology of Fusion Energy* (12–16 November 2006, Albuquerque, New Mexico).

*Mukhovatov, V., Shimada, M., Lackner, K., and 13 additional co-authors including Goldston, R.J. from PPPL and the ITPA CC Members, the ITPA Topical Group Chairs and Co-Chairs, and the ITER International Team, "Progress in the ITER Basics Chapter 9: ITER Contributions for Demo Plasma Development," Nucl. Fusion **47**:6 (June 2007) S404–S413 (Nuclear Fusion Issue on "Progress in the ITER Physics Basis").

*Munsat, T. and Zweben, S.J., "Derivation of Time-dependent Two-dimensional Velocity Field Maps for Plasma Turbulence Studies," Rev. Sci. Instrum. **77**:10 (October 2006) Article No. 103501 (6 pages).

Mynick, H. and Boozer, A., "Zonal Flows in Toroidal Systems" Phys. Plasmas **14**:7 (July 2007) Article No. 072507 (8 pages); Princeton University Plasma Physics Laboratory Report PPPL-4228 (March 2007) 22 pp.

*Myra, J.R., Boedo, J., Coppi, B., and 9 additional co-authors including LeBlanc, B.P., Stotler, D.P., and Zweben, S.J. from PPPL, "Blob Transport Models, Experiments, and the Accretion Theory of Spontaneous Rotation," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-21. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Nakajima, N., Hudson, S.R., and Hegna, C.C., "Properties of Ballooning Modes in the Planar Axis Heliotron Configurations with a Large Shafranov Shift," Fusion Sci. Techn. **51**:1 (January 2007) 79–91.

Nazikian, R., Austin, M.E., Budny, R.V., Chu, M.S., Heidbrink, W.W., Makowski, M.A., Petty, C.C., Politzer, P.A., Solomon, W.M., Van Zeeland, M.A., and White, R.B., "Fast Ion Redistribution and Implications for the Hybrid Regime," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-1.114. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

Neilson, G., Nelson, B., Pomphrey, N., Reiersen, W., Boozer, A., Brooks, A., Brown, T., Cole, M., Dudek, L., Chrzanowski, J., Fan, H.M., Fogarty, P., Fredrickson, E., Gettelfinger, G., Goranson, P., Heitzenroeder, P., Lazarus, E., Lyon, J., Malinowski, F., Raftopoulos, S., Stratton, B., Simmons, R., Strykowsky, R., Viola, M., Williams, M., Williamson, D.; and Zarnstorff, M., "Progress in the Construction of NCSX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper FT/2-4. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008). Princeton University Plasma Physics Laboratory Report PPPL-4188 (October 2006) 8 pp.

Neilson, G.H., Fredrickson, E., Lyon, J., Maingi, R., Pomphrey, N., Stratton, B., Strykowski, R., Williams, M., and Zarnstorff, M., "Preparations for NCSX Research," presented at the *22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp.

*Nelson, B.E., Lyon, J.F., Fogarty, P.J., and 11 additional co-authors including Heitzenroeder, P.J. and Neilson, G.H. from PPPL, "Innovation in Design and Fabrication of Compact Stellarators," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper FT/P5-6. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Neumeyer, C., Gentile, C., Ramakrishnan, S., Stevenson, T., Woolley, R., and Zatz, I., "Engineering Assessment of a National High-power Advanced

Torus Experiment (NHTX)," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337901.

*Nevins, W.M., Candy, J., Cowley, S., Dannert, T., Dimits, A., Dorland, W., Estrada-Mila, C., Hammett, G.W., Jenko, F., Pueschel, M.J., and Shumaker, D.E., "Characterizing Electron Temperature Gradient Turbulence via Numerical Simulation," Phys. Plasmas **13**:12 (December 2006) Article No. 122306 (13 pages).

*Nevins, W.M., Parker, S.E., Chen, Y., Candy, J., Dimits, A., Dorland, W., Hammett, G.W., and Jenko, F., "Verification of Gyrokinetic δf Simulations of Electron Temperature Gradient Turbulence," Phys. Plasmas **14**:8 (August 2007) Article No. 084501 (4 pages); UCRL-JRNL-230864, 17 pp.

*†Nieto, M., Allain, J.P., Hassanein, A., Titov, V., Hendricks, M., Gray, T., Kaita, R., Kugel, H., Majeski, R., Mansfield, D., Spaleta, J., and Timberlake, J., "Plasma-material Interaction Studies on Lithium and Lithiated Substrates during Compact Tokamak Operation," AIP Conference Proceedings **875** (December 2006) 78–82; *Proceedings of the 16th IAEA Technical Meeting on Research using Small Fusion Devices and XI Latin American Workshop on Plasma Physics* (30 November – 9 December 2005, Mexico City, Mexico) edited by J. Julio and E. Herrera Velázquez.

*Nishimura, Y., Lin, Z., and Wang, W.X., "Electromagnetic Global Gyrokinetic Simulation of Shear Alfvén Wave Dynamics in Tokamak Plasmas," Phys. Plasmas **14**:4 (April 2007) Article No. 042306 (10 pages).

*Nührenberg, C., Hudson, S.R., and Boozer, A.H., "Verification of the CAS3D-perturbed Equilibrium Code in the Cylindrical Limit," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-4.065. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*O'Dell, J.S., Majeski, R., and Timberlake, J., "Engineered Surfaces for the Lithium Tokamak Experiment (LTX)," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337875.

*Oikawa, T., Shimada, M., Polevoi, A.R., Naito, O., Bonoli, P.T., Hayashi, N., Kessel, C.E., and Ozeki, T., "Study on Current Drive Capability of Lower Hybrid Waves and Neutral Beam in an ITER Steady State Scenario," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IT/P1-4. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Pan, Yudong; Jardin, S.C.; and Kessel, C., "The Discharge Design of HL-2M with the Tokamak Simulation Code (TSC)," Princeton University Plasma Physics Laboratory Report PPL-4257 (October 2007) 42 pp.

Park, H., Luhmann, Jr., N.C., Donné, A.J.H., Glassen, I.G.J., Dornier, C.W., Mazzucato, E., Munsat, T., Van de Pol, M.J., Xia, Z., and the TEXTOR Team, "New Paradigm for the m/n=1/1 Mode ("Sawtooth Oscillation") Based on High Resolution 2-D Images of Te Fluctuations and Comparisons with Theoretical Models," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper PD/P6-1. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

†Park, H.K., Luhmann, Jr., N.C., Donné, A.J.H., Domier, C.W., Munsat, T., Van de Pol, M.J., and the TEXTOR Team, "New Insights to the Sawtooth Oscillation ("m/n=1/1mode") in Hot Plasmas Based on High Resolution 2-D Images of T_e Fluctuations," Plasma and Fusion Research **2** (20 November 2007) Article No. S1002; Special Issue: Papers from the *16th International Toki Conference on Advanced*

Imaging and Plasma Diagnostics (5–8 December 2006, Ceratopia Toki, Gifu, Japan).

Park, Jong-Kyu; Boozer, Allen H.; and Glasser, Alan H., "Computation of Three-dimensional Tokamak and Spherical Torus Equilibria," Phys. Plasmas **14**:5 (May 2006) Article No. 052110 (9 pages); Princeton University Plasma Physics Laboratory PPPL-4239 (May 2007) 10 pp.

*§Park, Jong-kyu; Schaffer, Michael J.; Menard, Jonathan E.; and Boozer, Allen H., "Control of Asymmetric Magnetic Perturbations in Tokamaks," Phys. Rev. Lett. **99**:19 (9 November 2007) Article No. 195003.

*†Parker, C.V., Skinner, C.H., and Roquemore, A.L., "Controlling Surface Dust in a Tokamak," J. Nucl. Mater. **363-365** (15 June 2007) 1461–1465 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

*Parker, R.R., Wilson, J.R., Bonoli, P.T., Harvey, R.W., Hubbard, A.E., Porkolab, M., Schmidt, A.E., and Wallace, G.M., "Lower Hybrid Current Drive Experiments in Alcator C-Mod," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-5.067. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*†Parker, S.E., Kohut, J.J., Chen, Y., Lin, Z., Hinton, F.L. and Lee, W.W., "Fine-scale Zonal Flow Suppression of Electron Temperature Gradient Turbulence," AIP Conf. Proc. **871** (30 November 2006) edited by Olivier Sauther, pages 193–203; *Proceedings of the Joint Varenna-Lausanne International Workshop on Theory of Fusion Plasmas* (28 August – 1 September 2006, Varenna, Italy).

*†Penaflor, B.G., Ferron, J.R., Walker, M.L., and 7 co-authors including Gates, D.A., from PPPL, "Worldwide Collaborative Efforts in Plasma Control Software Development," Fusion Eng. Design **83**:2–3 (April 2008) 176–180; *Proceedings of the 6th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research* (4–8 June 2007, Inuyama, Japan), edited by Shigeru Sudo.

*†Pennington, J.S., Kaganovich, I.D., Sefkow, A.B., Startsev, E.A., and Davidson, R.C., "Charge and Current Neutralization of an Ion Beam Pulse by Background Plasma in the Presence of an Applied Magnetic Field and Gas Ionization," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Phillips, C.K, Bonoli, P.T., Hosea, J.C., Lin, Y., Porkolab, M., Valeo, E.J., Wilson, J.R., Wright, J.C., and Wukitch, S.J., "ICRF Heating with $\omega < \omega_{ci}$ in Alcator C-Mod," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 91–94; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*Pinches, S.D., Kiptily, V.G., Sharapov, S.E., Darrow, D.S., and 6 additional co-authors and the ASDEX Upgrade Team and JET-EFDA Contributors, "Observation and Modelling of Fast Ion Loss in JET and ASDEX Upgrade," Special Issue Nucl. Fusion **46**:10 (October 2006) S904–S910; presented at *9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems* (9–11 November 2005, Takayama, Japan).

*Polomarov, Oleg; Sefkow, Adam B.; Kaganovich, Igor; and Shvets, Gennady, "Computationally Efficient Description of Relativistic Electron Beam Transport in Collisionless Plasma," Phys. Plasmas **14**:4 (April 2007) Article No. 043103 (10 pages).

*Polzin, K.A., Markusic, T.E., Stanojev, B.J., Dehoyos, A., Raitses, Y., Smirnov, A., and Fisch, N.J., "Performance of a Low-Power Cylindrical Hall Thruster," J. Propulsion and Power **23**:4 (July–August 2007) 886–888.

†Pomphrey, N., Boozer, A., Brooks, A., and Hudson, S.R., "NCSX Magnetic Configuration Flexibility and Robustness," Trans. Fusion Sci. Technol. **51**:2 (February 2007) 181–202.

Pomphrey, N., Lazarus, E., Zarnstorff, M., Boozer, A., and Brooks, A., "Novel Design Methods for

Magnetic Flux Loops in the National Compact Stellarator Experiment," Phys. Plasmas **14**:5 (May 2007) Article No. 056103 (12 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory PPPL-4203 (December 2006) 30 pp.

*§Popescu, A. and Morgan, J., "Teaching Information Evaluation and Critical Skills in the Physics Classroom," The Physics Teacher **45**:B (November 2007) 507–510.

*Porkolab, M., Edlund, E., Lin, L., Parker, R., Rost, C., Sears, J., Snipes, J., Wukitch, S.J., Breizman, B., Gorelenkov, N., Kramer, G.J., Fasoli, A., and Smith, H., "Experimental Studies and Analysis of Alfvén Eigenmodes in Alcator C-Mod," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P6-16. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Preinhaelter, Josef; Urban, Jakub; Pavlo, Pavol; Taylor, Gary; Diem, Steffi; Vahala, Linda; and Vahala, George, "Electron Bernstein Wave Simulations and Comparison to Prelliminary NSTX Emission Data," Rev. Sci. Instrum. **77**:10 (October 2006) Article No 10F524 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7-11 May 2006, Williamsburg, Virginia).

Princeton Plasma Physics Laboratory FY2006 Annual Highlights, edited by A.R. DeMeo and C.A. Phillips, 160 pp. Report is available in PDF format at http://www.pppl.gov/pub_report/2007/reports-2007.html (active as of 1 July 2008) or contact PPPL Reports and Publications for a copy on CD-ROM.

Qin, H., Cohen, R.H., Nevins, W.M., and Xu, X.Q., "Geometric Gyrokinetic Theory for Edge Plasmas," Phys. Plasmas **14**:5 (May 2007) Article No. 056110 (11 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory Report PPPL-4224 (February 2007) 29 pp.

Qin, H., Davidson, R.C., and Startsev, E.A., "Kinetic Equilibrium and Stability Properties of 3D High-Intensity Charged Particle Bunches," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Qin, H., Davidson, R.C., and Startsev, E.A., "Nonlinear δf Particle Simulations of Energy-Anisotropy Instabilities in High-Intensity Charge Bunches," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

†Qin, Hong; Davidson, Rondald C.; and Startsev, Edward A., "Nonlinear δf Particle Simulations of Collective Effects in High-Intensity Bunched Beams," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 86–92; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

Qin, Hong; Davidson, Ronald C.; and Startsev, Edward A., "Nonlinear δf Particle Simulations of Collective Excitations and Energy Anisotropy-Driven Instabilities in High-Intensity Bunched Beams," Phys. Rev. ST AB **10** (6 June 2007) Article No. 064201 (10 pages).

Qin, Hong; Phillips, Cynthia K.; and Davidson, Ronald C., "A New Derivation of the Plasma Susceptibility Tensor for a Hot Magnetized Plasma Without Infinite Sums of Products of Bessel Functions," Phys. Plasmas **14**:9 (September 2007) Article No. 092103 (8 pages).

Qin, Hong; Phillips, Cynthia K.; Kolesnikov, Roman A.; Lee, W. Wei-li; Valeo, Ernest J.; and Smithe, David N., "Gyrocenter Gauge Theory and Algorithm for Nonlinear Particle Simulations of Radio-Frequency Waves in Plasmas," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 471–474; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*Raffray, A.R., Dahlgren, F., Gentile, C., Priniski, C., Robson, A.E., Rose, D., Sawan, M.E., Sethian,

J., Snead, L., Sviatoslavsky, G., and Wang, X.R., "Conceptual Study of Integrated Chamber Core for Laser Fusion with Magnetic Intervention," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 5 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 0.1109/FUSION.2007.4337951.

Raftopoulos, S., Brooks, A., Brown, T., Duco, M., Ellis, R., and Stratton, B., "Metrology for the NCSX Project," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337862.

§Raitses, Y., Skinner, C.H., Jiang, F., and Duffy, T.S., "Raman Spectroscopy of Carbon Dust Samples from NSTX," J. Nucl. Mater. **375**:2 (30 April 2008) 365–369.

Raitses, Y., Smirnov, A., and Fisch, N.J., "Enhanced Performance of Cylindrical Hall Thrusters," Appl. Phys. Lett. **90**:22 (28 May 2007) Article No. 221502 (3 pages); Princeton University Plasma Physics Laboratory Report PPPL-4240 (May 2007) 15 pp.

Raitses, Yegeny; Smirnov, Artem; Granstedt, Erik; and Fisch, Nathaniel J., "Optimization of Cylindrical Hall Thrusters," Princeton University Plasma Physics Laboratory Report PPPL-4256 (June 2007) 10 pp. Presented at the *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit* (8–11 July 2007, Cincinnati, Ohio) and submitted to the Journal of Propulsion and Power.

Raitses, Y., Smirnov, A., Granstedt, E., and Fisch, N.J., "Overrun Discharge Current Operation of Low Power Cylindrical Hall Thrusters," presented at the *30th International Electric Propulsion Conference (IEPC-2007)* (17–20 September 2007, Florence, Italy) 222.

*Raman, R., Jarboe, T.R., Mueller, D., Nelson, B.A., Bell, M.G., Ono, M., Bigelow, T., Kaita, R., LeBlanc, B., Maqueda, R., Menard, J., Paul, S., and Roquemore, L., "Plasma Startup in the NSTX using Transient Coaxial Helicity Injection," Phys. Plasmas **14**:5 (May 2007) Article No. 056106 (7 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory Report PPPL-4207 (January 2007) 23 pp.

*Raman, R., Jarboe, T.R., Mueller, D., Nelson, B.A., Bell, M.G., Ono, M., Bigelow, T., Kaita, R., LeBlanc, B., Maqueda, R., Menard, J., Paul, S., and Roquemore, L., "Solenoid-free Plasma Start-up in NSTX using Transient CHI," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P8-16. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Raman, R., Jarboe, T.R., Nelson, B.A., Bell, M.G., and Mueller, D., "Solenoid-free Plasma Start-up in HIT-II and NSTX using Transient CHI," J. Fusion Energy **26**:1–2 (June 2007) 159–162; *Proceedings of the 2006 Innovative Confinement Concepts Workshop* (13–16 February 2006, Austin, Texas).

*Raman, R., Mueller, D., Jarboe, T.R., Nelson, B.A., Bell, M.G., Ono, M., Bigelow, T., Kaita, R., LeBlanc, B., Lee, K.C., Maqueda, R., Menard, J., Paul, S., and Roquemore, L., "Non-inductive Solenoid-less Plasma Current Start-up in NSTX using Transient CHI," Nucl. Fusion **47**:8 (August 2007) 792–799; Princeton University Plasma Physics Laboratory Report PPPL-4243 (May 2007) 26 pp.

*Raman, R., Nelson, B.A., Bell, M.G., Jarboe, T.R., Mueller, D., Bigelow, T., LeBlanc, B., Maqueda, R., Menard, J., Ono, M., and Wilson, R., "Efficient Generation of Closed Magnetic Flux Surfaces in a Large Spherical Tokamak using Coaxial Helicity Injection," Phys. Rev. Lett. **97**:17 (27 October 2006) Article No. 175002; Princeton University Plasma Physics Laboratory Report PPPL-4212 (January 2007) 4 pp.

*Rax, J.M., Robiche, J., and Fisch, N.J., "Autoresonant Ion-cyclotron Isotope Separation," Phys. Plasma **14**:4 (April 2007) Article No. 043102 (8 pages).

*Razdobarin, G.T., Walsh, M.J., Hatae, T., Murkhin, E.E., Narihara, K., Vayakis, G., Johnson, D., Carlstrom, T., and the ITPA Specialists Working Group on Thomson Scattering, "Progress in Development of Thomson Scattering Systems for ITER," in the *Proceedings of the 21st Fusion Energy Conference*

(FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IT/P1-25. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Reiersen, W., Nelson, B., Heitzenroeder, P., Brooks, A., Brown, T., Cole, M., Chrzanowski, J., Dudek, L., Fan, H.-M., Fogarty, P.; Gettelfinger, G.; Goranson, P., Kalish, M., Labik, G.; Lyon, J.,; Neilson, G.H., Raftopoulos, S., Stratton, B., Strykowsky, R., Viola, M., Williams, M., Williamson, D., and Zarnstorff, M., "Progress in NCSX Construction," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier210.1109/FUSION.2007.4337915.

Reiman, A., "Stabilization of the Vertical Mode in Tokamaks by Localized Nonaxisymmetric Fields," Phys. Rev. Lett. **99**:13 (28 September 2007) Article No. 135007.

†Reiman, A., Hirshman, S., Hudson, S., Monticello, D., Rutherford, P., Boozer, A., Brooks, A., Hatcher, R., Ku, L., Lazarus, E.A., Neilson, H., Strickler, D., White, R., and Zarnstorff, M., "Equilibrium and Flux Surface Issues in the Design of NCSX," Fusion Sci. Technol. **51**:2 (February 2007) 145–165; Princeton University Plasma Physics Laboratory Report PPPL-4214 (January 2007) 20 pp.

Reiman, A., Zarnstorff, M., Monticello, D., Weller, A., Geiger, J., and the W7-AS Team, "Localized Breaking of Flux Surfaces and the Equilibrium Beta Limit in the W7AS Stellarator" in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P7-3. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Reiman, A., Zarnstorff, M., Monticello, D., Weller, A., Geiger, J., and the W7-AS Team, "Pressure-induced Breaking of Equilibrium Flux Surfaces in the W7AS stellarator," Nucl. Fusion **47**:7 (July 2007) 572–578; Princeton University Plasma Physics Laboratory Report PPPL-4241 (May 2007) 19 pp.

*†Reimerdes, H., Garofalo, A.M., and 14 additional co-authors including Okabayashi, M., Solomon, W.M., and Takahashi, H. from PPPL and the DIII-D Team, "Resistive Wall Mode Stabilization in Slowly Rotating High Beta Plasmas," Special Issue Plasma Phys. Control. Fusion **49**:12B (December 2007) B349–B358; Invited paper at the *34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland).

*Reimerdes, H., Garofalo, A.M., Jackson, G.L., and 11 additional co-authors including Okabayashi, M., Solomon, W.M., and Takahashi, H. from PPPL, "Reduced Critical Rotation for Resistive-Wall Mode Stabilization in a Near-Axisymmetric Configuration," Phys. Rev. Lett. **98**:05 (2 February 2007) Article No. 055001.

Ren, Yang; Yamada, Masaaki; Ji, Hantao; Gerhardt, Stefan, and Kulsrud, Russell, "Identification of the Electron Diffusion Region in the Reconnection Layer of a Laboratory Plasma," accepted for publication in Phys. Rev. Lett., in press 2008.

§Rewoldt, G., Lin, Z., and Idomura, Y., "Linear Comparison of Gyrokinetic Codes with Trapped Electrons," to be published in Computer Physics Communications **177**:10 (15 November 2007) 775–780; Princeton University Plasma Physics Laboratory Report PPPL-4195 (November 2006) 8 pp.

*Reynolds, D.R., Samtaney, R., and Woodward, C.S., "A Fully Implicit Numerical Method for Single-fluid Resistive Magnetohydrodynamics," J. Computational Phys. **219**:1 (20 November 2006) 144–162.

*†Rhodes, T.L., Peebles, W.A. DeBoo, J.C., and 21 additional co-authors including Solomon, W.M. from PPPL, "Broad Wavenumber Turbulence and Transport during Ohmic and Electron Cyclotron Heating in the DIII-D Tokamak," Special Issue Plasma Phys. Control. Fusion **49**:12B (December 2007) B183–B193; Invited paper at the *34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland).

Roquemore, A.L., Boeglin, W., Maqueda, R., Nishino, N., Skinner, C.H., Pigarov, A. Yu., Smirnoff, R.D., and Krasheneninikov, S.I., "3-D Measurements of Dust

Particle Trajectories in the NSTX," presented at the *1st Workshop on the Dust in Fusion Plasmas* (8–10 July 2007, Warsaw Poland); submitted to Nuclear Fusion.

†Roquemore, L.A., Davis, W., Kaita, R., Skinner, C.H., Maqueda, R., and Nishino, N., "Imaging of High-speed Dust Particle Trajectories on NSTX," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E526 (3 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

Roquemore, A.L., Maingi, R., Lasnier, C.J., Nishino, N., Evans, T.E., Fenstermacher, M.E., and Nagy, A., "A Fast Visible Camera Divertor-imaging Diagnostic on DIII-D," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337940.

†Roquemore, L.A., Nishino, N., Skinner, C.H., Bush, C., Kaita, R., Maqueda, R., Davis, W., Pigarov, A.Yu., and Krasheninnikov, S.I., "3D Measurements of Mobile Dust Particle Trajectories in NSTX," J. Nucl. Mater. **363-365** (15 June 2007) 222–226 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

*Rose, D.V., Genoni, T.C., Welch, D.R., Startsev, E.A., and Davidson, R.C., "Two-stream Instability Analysis for Propagating Charged Particle Beams with a Velocity Tilt," Phys. Rev. ST AB **10**:3 (28 March 2007) Article No. 034203 (7 pages).

*†Roy, P. K., Seidl, P.A., Baca, D., Barnard, J.J., Bieniosek, F.M., Coleman, J.E., Davidson, R.C., Efthimion, P., Gilson, E.P., Leitner, M., Logan, B.G., Molvik, A., Sefkow, A.B., Waldron, W.L., and Welch, D.R., "A Solenoid Final Focusing System with Plasma Neutralization for Target Heating Experiments," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

*†Roy, P.K., Yu, S.S., Waldron, W., Anders, A., Baca, D., Bieniosek, F.M., Coleman, J., Davidson, R.C., Efthimion, P.C., Eylon, S., Gilson, E.P., Greenway, W.G., Henestroza, E., Kaganovich, I., Leitner, M., Logan, B.G., Sefkow, A.B., Seidl, P., Thoma, C., and Welch, D.R., "Neutralized Drift Compression Experiments (NDCX) with a High Intensity Ion Beam," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 223–230; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*†Rudakov, D.L., West, W.P., Wong, C.P.C., and 16 co-authors including Solomon, W.M. from PPPL, "Migration of Artificially Introduced Micron-size Carbon Dust in the DIII-D Divertor," J. Nucl. Mater. **363-365** (15 June 2007) 227–232 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

*Sabbagh, S.A., Bell, R.E., Menard, J.E., Gates, D.A., Sontag, A.C., Bialek, J.M., LeBlanc, B.P., Levinton, F.M. Tritz, K., and Yuh, H., "Resistive Wall Mode Active Stabilization in High Beta, Low Rotation Plasmas," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper PD/P6-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Saibene, G., Sartori, R., de Vries, P., 23 additional co-authors including Budny, R. from PPPL, and the JET EFDA Contributors, "Toroidal Field Ripple Effects on H-modes in JET and Implications for ITER," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) O-4.001. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*§Sánchez, J., Acedo, M., Alonso, A., and 109 additional co-authors including Zweben, S.J. from PPPL,

"Overview of TJ-II Experiments," Special Issue Nucl. Fusion **47**:10 (October 2007) S677–S685 [Overview and Summary Reports Based on the 2006 Fusion Energy Conference Contributions (Chengdu, China, 16–21 October 2006)].

*Schekochihin, A.A., Cowley, S.C., Dorland, W., Hammett, G.W., Howes, G.G., Quataert, E., and Tatsuno, T., "Astrophysical Gyrokinetics: Kinetic and Fluid Turbulent Cascades in Magnetized Weakly Collisional Astrophysical Plasmas," submitted to Astrophysical Journal.

*Schmidt, A.E., Bonoli, P.T., Hubbard, A.E., Liptac, J., Parker, R.R., Wallace, G.M., Wilson, J.R., Harvey, R.W., and Smirnov, A.P., "Measurements and Modeling of X-Ray and ECE Spectra During LHCD Experiments on Alcator C-Mod," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 281–284; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

Scott, S., Badner, A., Bakhtiari, M., and 85 additional co-authors, "Overview of Alcator C-Mod Research Program," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper OV/3-2. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

§Scott, S., Bader, A., Bakhtiari, M., and 85 additional co-authors, "Overview of the Alcator C-MOD Research Program," Special Issue Nucl. Fusion **47**:10 (October 2007) S598–S607 [Overview and Summary Reports Based on the 2006 Fusion Energy Conference Contributions (Chengdu, China, 16–21 October 2006)].

Sefkow, A.B., "Current Density Compression of Intense Ion Beams, Ph.D. Thesis, Princeton University (2007).

Sefkow, A.B., Davidson, R.C., Efthimion, P.C., Gilson, E.P., Kaganovich, I.D., Coleman, J.E., Roy, P.K., Seidl, P.A., Barnard, J.J., and Welch, D.R., "Extreme Compression of Heavy-Ion Beam Pulses: Experiments and Modeling," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Sefkow, A.B., Davidson, R.C., and Gilson, E.P., "Advanced Plasma Flow Simulations of Cathodic-Arc and Ferroelectric Plasma Sources for Neutralized Drift Compression," Physical Review Special Topics on Accelerators and Beams, submitted for publication (2007).

†Sefkow, Adam B. and Davidson, Ronald C., "Advanced Numerical Studies of the Neutralized Drift Compression of Intense Ion Beam Pulses," Phys. Rev. ST AB **10** (October 2007) Article No. 100101 (21 pages); *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico).

†Sefkow, Adam B.; Davidson, Ronald C.; Kaganovich, Igor D.; Gilson, Erik P.; Roy, Prabir K.; Seidl, Peter A.; Yu, Simon S.; Welch, Dale R.; Rose, David V.; and Barnard, John J., "Optimized Simultaneous Transverse and Longitudinal Focusing of Intense Ion Beam Pulses for Warm Dense Matter Applications," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 289–297; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*†Seidl, P.A., Armijo, J., Baca, D., and 22 additional co-authors including Sefkow, A.B., Gilson, E.P., Efthimion, P.C., Kaganovich, I., and Davidson, R.C. from PPPL, "Plans for Neutralized Drift Compression Experiments and Initial Results from Solenoid Transport," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 215–222; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*§Sharma, Prateek and Hammett, Gregory W., "Preserving Monotonicity in Anisotropic Diffusion,"

J. Computational Phys. **227**:1 (10 November 2007) 123–142.

*Sharma, P., Quataert, E., Hammett, G.W., and Stone, J.M., "Electron Heating in Hot Accretion Flows," accepted for publication in Astrophysical Journal.

*†Shen, Zuowei; Yang, Lu; Luhman, Jr., N.C.; Domier, C.W.; Ito, N.; Kogi, Y.; Lian, Y.; Mase, A.; Park, H.; Sakata, E.; Tsai, W.; Xia, Z.G.; and Zhang, P., "Advanced Microwave/Millimeter-Wave Imaging Technology," Plasma and Fusion Research **2** (20 November 2007) Article No. S1019; Special Issue: Papers from the *16th International Toki Conference on Advanced Imaging and Plasma Diagnostics* (5–8 December 2006, Ceratopia Toki, Gifu, Japan).

*†Shinohara, K., Isobe, M. and Darrow, D.S., "Escaping Ion Measurement with High Time Resolution on CHS," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E521 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*Shnidman, A., Kaganovich, I.D., and Davidson, R.C., "Calculation of the Charge-Changing Cross Sections of Ions or Atoms Colliding with Fast Ions using the Classical Trajectory Method," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

Sichta, P., Lawson, J., Mastrovito, D., Roney, P., and Tindall, K., "Preliminary Design of the NCSX Central Computing and Control," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/ FUSION.2007.4337939.

§Skinner, C.H., "Applications of EBIT to Magnetic Fusion Diagnostics," Canadian Journal of Physics **86**:1 (January 2008) 285–290.

§Skinner, C.H., Hensley, R., and Roquemore, A.L., "Large Aperture Electrostatic Dust Dectector," J. Nucl. Mater. **376**:1 (15 May 2008) 29–32.

†Skinner, C.H., Kugel, H.W., Roquemore, A.L., Maingi, R., and Wampler, W.R., "Pulse-by-pulse Measurements of Dynamic Retention and Deposition in NSTX," J. Nucl. Mater. **363-365** (15 June 2007) 247–251 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China). Princeton Plasma Physics Laboratory Report PPPL-4168 (June 2006) 14 pp.

Smirnov, Artem; Raitses, Yegeny; and Fisch, Nathaniel J., "Experimental and Theoretical Studies of Cylindrical Hall Thrusters," Phys. Plasma **14**:5 (May 2007) Article No. 057106 (12 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory Report PPPL-4199 (December 2006) 40 pp.

*Snipes, J.A., Gorelenkov, N.N., and Sears, J.A., "A Comparison of Measured and Calculated Toroidal Alfvén Eigenmode Damping Rates in Alcator C-mod," Nucl. Fusion **46**:12 (December 2006) 1036–1046.

†Solomon, W.M., Burrell, K.H., deGrassic, J.S., and 13 additional co-authors, "Momentum Confinement at Low Torque," Special Issue Plasma Phys. Control. Fusion **49**:12B (December 2007) B313–B324; Invited paper at the *34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland).

*Sontag, A., Sabbagh, S.A., Zhu, W. and 10 co-authors and Menard, J.E., Bell, R.E., Bell, M.G., Gates, D.A., and LeBlanc, B.P. from PPPL, "Investigation of Resistive Wall Mode Stabilization Physics in High-beta Plasmas using Applied Non-axisymmetric Fields in NSTX," Nucl. Fusion **47**:8 (August 2007) 1005–1011.

*Sontag, A.C., Sabbagh, S.A., Zhu, W., and 10 additional co-authors including Menard, J.E., Bell, R.E., Bell, M.G., Gates, D.A., and LeBlanc, B.P. from PPPL, "Investigation of Resistive Wall Mode Stabilization Physics in High Beta Plasmas Using Applied Non-axisymmetric Fields in NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/7-2Rb. An unedited Conference

Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Soukhanovskii, V.A., Bell, M.G., Blanchard, W.R., Dong, J.K., Gernhardt, R.C., Kaita, R., Kugel, H.W., Provost, T.J., Roquemore, A.L., and Sichta, P., "High Pressure Supersonic Gas Jet Fueling on NSTX," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 4 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337860.

*†Soukhanovskii, V.A., Johnson, D.W., Kaita, R., and Roquemore., A.L., "Electron Density Measurements in the National Spherical Torus Experiment Detached Divertor Region using Stark Broadening of Deuterium Infrared Paschen Emission Lines," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10F127 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*†Soukhanovskii, V.A., Maingi, R., Bush, C.E., Raman, R., Bell, R.E., Kaita, R., Kugel, H.W., Lasnier, C.J., LeBlanc, B.P., Menard, J.E., Paul, S.F., Roquemore, A.L., and the NSTX Research Team, "Divertor Heat Flux Reduction and Detachment Experiments in NSTX," J. Nucl. Mater. **363-365** (15 June 2007) 432–436 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China).

*Soukhanovskii, V.A., Maingi, R., Gates, D.A., Menard, J.E., Raman, R., Bell, R.E., Bush, C.E., Kaita, R., Kugel, H.W., Leblanc, B.P., Paul, S.F., Roquemore, A.L., and the NSTX Team, "Divertor Heat Flux Amelioration in Highly-shaped Plasmas in NSTX," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.023. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Soukhanovskii, V.A., Maingi, R., Raman, R., and 10 additional co-authors including Bell, R.E., Gates, D., Kaita, R., Kugel, H.W., LeBlanc, B.P., Menard, J.E., Paul, S.F., and Roquemore, A.L. from PPPL, and the NSTX Team, "Divertor Heat Flux Reduction and Detachment in NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper EX/P4-28. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Sovinec, C.R., Pankin, A.Y., Kruger, S.E., and 9 additional co-authors including Jardin, S.C. and Breslau, J. from PPPL, "Extended Magnetohydrodynamic Simulations of Edge Localized Modes in Existing and Future Tokamak Devices," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P8-3. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

†Spaleta, J., Zakharov, L., Kaita, R., Majeski, R., and Gray, T., "Magnetic Probe Response Function Calibrations for Plasma Equilibrium Reconstructions of CDX-U," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E305 (3 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*§Spizzo, G., White, R.B., and Cappello, S., "Chaos Generated Pinch Effect in Toroidal Confinement Devices," Phys. Plasmas **14**:10 (October 2007) Article No. 102310 (8 pages).

Startsev, E.A., Davidson, R.C., and Qin, H., "Numerical Studies of the Electromagnetic Weibel Instability in Intense Charged Particle Beams with Large Temperature Anisotropy using the Darwin Delta-f Code BEST," in the *Proceedings of the 2007 Particle Accelerator Conference* (25–29 June 2007, Albuquerque, New Mexico), to be published in Physical Review Special Topics on Accelerators Beams, 2008.

†Startsev, Edward A. and Davidson, Ronald C., "Dynamic Stabilization of the Two-Stream Instability During Longitudinal Compression of Intense Charged Particle Beam Propagation Through Background Plasma," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 79–85; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

Startsev, Edward A., Davidson, Ronald C., and Qin, Hong, "Collective Temperature Anisotropy Instabilities in Intense Charged Particle Beam," Physics of Plasmas **14**:5 (May 2007) 056705 (9 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory Report PPPL-4213 (January 2007) 29 pp.

Stotler, D.P., Bell, R.E., Hill, K.W., Johnson, D.W., and Levinton, F.M., "Atomic Physics in ITER – The Foundation for the Next Step to Fusion Power," AIP Conference Proceedings **901** (April 2007) 95–104; *Proceedings of the 5th International Conference on Atomic and Molecular Data and Their Applications (ICAMDATA)*, (15–19 October 2006, Meudon, France); Princeton University Plasma Physics Laboratory Report PPPL-4194 (November 2006) 11 pp.

†Stotler, D.P., Boedo, J., LeBlanc, B., Maqueda, R.J., and Zweben, S.J., "Progress towards the Validation of Models of the Behavior of Neutral Helium in Gas Puff Imaging Experiments," J. Nucl. Mater. **363-365** (15 June 2007) 686–692 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China). "Details of Neutral Transport in Gas Puff Imaging Experiments," Princeton Plasma Physics Laboratory Report PPPL-4182 (June 2006) 14 pp.

Strachan, J.E., Coad, P., Corrigan, G., 9 additional co-authors, and the JET-EFDA Contributors, "Carbon Migration during JET ^{13}C Experiments," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-1.030. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*§Strait, E.J., Fredrickson, E.D., Moret, J.-M., and Takechi, M., "Chapter 2: Magnetic Diagnostics," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 304–334.

*Strait, E.J., Garofalo, A.M., Jackson, G.L., and 12 additional co-authors including Okabayashi, M., Solomon, W.M., and Takahashi, H. from PPPL and the DIII-D Team, "Resistive Wall Mode Stabilization by Slow Plasma Rotation in DIII-D Tokamak Discharges with Balanced Neutral Beam Injection," Phys. Plasmas **14**:5 (May 2007) Article No. 056101 (9 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

†Stratton, B., Brooks, A., Brown, T., Johnson, D., Labik, G., Lazarus, E., Pomphrey, N., Raftopoulos, S., and Zarnstorff, M., "External Magnetic Diagnostics for the National Compact Stellarator Experiment," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E314 (3 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia). Princeton Plasma Physics Laboratory Report PPPL-4177 (June 2006) 12 pp.

§Stratton, B.C, Bitter, M., Hill, K.W., Hillis, D.L., and Hogan, J.T., "Chapter 5: Passive Spectroscopic Diagnostics for Magnetically Confined Fusion Plasmas," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 431–486; Princeton University Plasma Physics Laboratory Report PPPL-4254 (July 2007) 158 pp.

*Strauss, H.R., Sugiyama, L., Chang, C.S., Park, G.Y., Ku, S., Park, W., Breslau, J., and Jardin, S., "ELM Simulations with M3D," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P8-6. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on

CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Stutman, D., Tritz, K., Delgado, L., Finkenthal, M., Kaye, S., Bell, M., Bell, R., Kugel, H., LeBlanc, B., and Yuh, H., "Dependence of Electron Transport on Heating Power and q-profile in NSTX," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.061. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*†Stutman, D., Tritz, K., Delgado-Aparicio, L., Finkenthal, M., Suliman, G., Roquemore, L., Kaita, R., Kugel, H., Johnson, D., Tamura, N., Sato, K., and Sudo, S., "High Throughput Measurements of Soft X-ray Impurity Emission Using a Multilayer Mirror Telescope," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10F330 (5 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

*Sydorenko, D., Smolyakov, A., Kaganovich, I., and Raitses, Y., "Effects of non-Maxwellian Electron Velocity Distribution Function on Two-stream Instability in Low-pressure Discharges," Phys. Plasmas **14**:1 (January 2007) Article No. 013508 (8 pages). Princeton University Plasma Physics Laboratory Report PPPL-4227 (February 2007) 9 pp.

*Takei, N., Nakamura, Y., Ushigome, M., Suzuki, T., Aiba, N., Takechi, M., Tobita, K., Takase, Y., Fukuyama, A., and Jardin, S.C., "Intermittent β collapse after NBCD Turn-off in JT-60U Fully Non-inductive Reversed Shear Discharges," Plasma Phys. Control. Fusion **49**:3 (March 2007) 335–345.

*†Tala, T., Crombe, K., deVries, P.C., and 21 additional co-authors including Budny, R. from PPPL and the JET-EFDA Contributors, "Toroidal and Poloidal Momentum Transport Studies in Tokamaks," Special Issue Plasma Phys. Control. Fusion **49**:12B (December 2007) B291–B302; Invited paper at the *34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland).

*Tardini, G., Hobirk, J., Igochine, V.G., Maggi, C.F., Martin, P., McCune, D., Peeters, A.G., Sips, A.C.C., Staebler, A., Stober, J., and the ASDEX Upgrade Team, "Thermal Ions Dilution and ITG Suppression in ASDEX Upgrade Ion ITBs," Nucl. Fusion **47**:4 (April 2007) 280–287.

Taylor, G., "Recent Developments in Electron Cyclotron Emission Research on Magnetically Confined Plasmas," Fusion Sci. Techn. **52**:2 (August 2007) 119–133; Princeton University Plasma Physics Laboratory Report PPPL-4202 (December 2006) 50 pp.

Taylor, G., Bigelow, T.S., Caughman, J.B., and 14 additional co-authors, "Plans for Electron Bernstein Wave and Electron Cyclotron Heating in NSTX," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 339–342; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*Terry, D.R., Burke, W., Kanojia, A., MacGibbon, P., Johnson, D., Parker, R.R., Vieira, R.F., Wallace, G., Beck, W., Koert, P., Irby, J., Wilson, J.R., Greenough, N., and Gwinn, D., "Lower Hybrid Current Drive on Alcator C-Mod: System Design, Implementation, Protection, Calibration and Performance," in the *Proceedings of the 22nd IEEE/NPSS Symposium on Fusion Engineering 2007* (17–21 June 2007, Albuquerque, New Mexico) 5 pp. Available from IEEE on CD-ROM, Digital Object Identifier Digital Object Identifier 10.1109/FUSION.2007.4337922.

*Terry, J.L., LaBombard, B., Lipschultz, B., Greenwald, M.J., Rice, J.E., and Zweben, S.J., "The Scrape-off Layer in Alcator C-Mod: Transport, Turbulence, and Flows," Special Issue (on Alcator C-Mod) Fusion Sci. Techn. **51**:3 (April 2007) 342–356.

*Tritz, K., Bell, M., Bell, R., Delgado-Aparicio, L., Finkenthal, M., Kaye, S., LeBlanc, B., Maingi, R., Menard, J., and Stutman, D., "Investigation of the Relationship between ELM Energy Loss and Perturbed Electron Tansport on NSTX," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.048. The conference proceedings is available on CD-ROM. Papers

are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

Valeo, E.J., Phillips, C.K., Bonoli, P.T., Wright, J.C., and Brambilla, M., "Full-wave Simulations of LH Wave Propagation in Toroidal Plasma with Non-Maxwellian Electron Distributions," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 297–300; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida); Princeton University Plasma Physics Laboratory Report PPPL-4247 (June 2007) 4 pp.

Valeo, E.J., Phillips, C.K, Okuda, H., Wright, J.C., Bonoli, P.T., Berry, L.A.,and the RF SciDAC Team, "Full-wave Simulations of ICRF Heating in Toroidal Plasma with Non-Maxwellian Distribution Functions in the FLR Limit," Princeton University Plasma Physics Laboratory Report PPPL-4251 (July 2007) 12 pp., accepted for publication in Physics of Plasma, 2008.

*Van Zeeland, M.A., Austin, M.E., Carlstrom, T.N., and 12 additional co-authors including Kramer, G.J., Nazikian, R., and Solomon, W.M. from PPPL, "Internal Alfvén Eigenmode Observations on DIII-D," Special Issue Nucl. Fusion **46**:10 (October 2006) S880–S887; presented at *9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems* (9–11 November 2005, Takayama, Japan).

*Van Zeeland, M.A., Austin, M.E., Gorelenkov, N.N., Heidbrink, W.W., Kramer, G.J., Makowski, M.A., McKee, G.R., Nazikian, R., Ruskov, E., and Turnbull, A.D., "Coupling of Global Toroidal Alfvén Eigenmodes and Reversed Shear Alfvén Eigenmodes in DIII-D," Phys. Plasmas **14**:5 (May 2007) Article No. 056102 (7 pages); Invited paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA).

*Wallace, G., Bonoli, P., Parisot, A., Parker, R., Schmidt, A., and Wilson, J.R., "Lower Hybrid Coupling Experiments on Alcator C-Mod," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 277–280; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*†Wang, G., Peebles, W.A., Doyle, E.J., Rhodes, T.L., Zeng, L., Nguyen, X., Osborne, T.H., Snyder, P.B., Kramer, G.J., Nazikian, R., Groebner, R.J., Burrell, K.H., Leonard, A.W., Fenstermacher, M.E., and Strait, E., "Initial Results of H-mode Edge Pedestal Turbulence Evolution with Quadrature Reflectometer Measurements on DIII-D," J. Nucl. Mater. **363–365** (15 June 2007) 534–538 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, China).

Wang, W.X, Hahm, T.S., Lee, W.W., Rewoldt, G., Manickam, J., and Tang, W.M., "Non-local Properties of Gyrokinetic Turbulence and Role of ExB Flow Shear," Phys. Plasmas **14**:7 (July 2007) Article No. 072306 (8 pages). Princeton University Plasma Physics Laboratory Report PPPL-4236 (May 2007) 18 pp.

*†Welch, Dale R.; Rose, David V.; Thoma, Carsten; Sefkow, Adam B.; Kaganovich, Igor D.; Seidl, Peter A.; Yu, Simon S.; Roy, Prabir K.; and Barnard, John J., "Integrated Simulation of an Ion-Driven Warm Dense Matter Experiment," Nucl. Instrum. Methods Phys. Res. A (Accelerators, Spectrometers, Detectors and Associated Equipment) **577**:1–2 (1 July 2007) edited by Claude Deutsch, Marie-Madeleine Gombert, Gilles Maynard, Jean-Pierre Didelez, and Eric Sonnendrücker, pages 231–237; *Proceedings of the 16th International Symposium on Heavy Ion Inertial Fusion, HIF06* (9–14 July 2006, Saint-Malo, France).

*Wesley, J.C., Hyatt, A.W., Strait, E.J., and 15 additional co-authors including Fredrickson, E.D., Gates, D.A., and Menard, J. from PPPL, "Disruption Characterization and Database Activities for ITER," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IT/P1-21. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*†Wilgen, J.B., Ryan, P.M., Hanson, G.R., Swain, D.E., Bernabei, S.I., Greenough, N., DePasquale, S., Phillips, C.K., Hosea, J.C., and Wilson, J.R.,

"Reflectometer Sensing of rf Waves in Front of the High Harmonic Fast Wave Antenna on NSTX," Rev. Sci. Instrum **77**:10 (October 2006) Article No 10E933 (4 pp); *Proceedings of the 16th Topical Conference on High-Temperature Plasma Diagnostics* (7–11 May 2006, Williamsburg, Virginia).

Wilson, J.R., Bernabei, S., Bonoli, P., Hubbard, A., Parker, R., Schmidt, A., Wallace, G., Wright, J., and the Alcator C-Mod Team, "Lower Hybrid Current Drive Experiments in Alcator C-Mod," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 269-276; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida). Princeton University Plasma Physics Laboratory Report PPPL-4263 (October 2007) 8 pp.

*Wing, S., Gjerloev, J.W., Johnson, J.R., and Hoffman, R.A., "Substorm Plasma Sheet Ion Pressure Profiles," Geophys. Res. Lett. **34**:16 (29 August 2007) Article No. L16110.

*Wing, S., Johnson, J.R., Fujimoto, M., "Timescale for the Formation of the Cold-dense Plasma Sheet: A Case Study," Geophys. Res. Lett. **33**:23 (9 December 2006) Article No. L23106.

Wong, K.L., Kaye S., Mikkelsen, D.R., Krommes, J.A., Hill, K., Bell, R., LeBlanc, B., "Microtearing Instabilities and Electron Transport in the NSTX Spherical Tokamak," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) P-2.043. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

Wong, K.L., Kaye S., Mikkelsen, D.R., Krommes, J.A., Hill, K., Bell, R., LeBlanc, B., "Microtearing Instabilities and Electron Transport in the NSTX Spherical Tokamak," Phys. Rev. Lett. **99**:13 (26 September 2007) Article No. 135003.

*Wright, J.C., Bonoli, P.T., Brambilla, M., Phillips, C.K., and Valeo, E., "Full-wave Electromagnetic Field Simulations of Lower Hybrid Waves in Tokamaks," AIP Conference Proceedings **933** (28 September 2007) edited by Philip M. Ryan and David Rasmussen, pages 285–288; *Proceedings of the 17th Topical Conference on Radio Frequency Power in Plasmas* (7–9 May 2007, Clearwater, Florida).

*†Xiao, B.J., Humphreys, D.A., Walker, M.L. and 14 co-authors including Mueller, D. from PPPL, "EAST Plasma Control System," Fusion Eng. Design **83**:2–3 (April 2008) 181–187; *Proceedings of the 6th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research* (4–8 June 2007, Inuyama, Japan), edited by Shigeru Sudo.

*Xiao, B.J., Li, J., Luo, J.R., 7 additional co-authors including Mueller, D. from PPPL, the EAST Team, and the DIII-D Plasma Control Team, "The First Diverted Plasma on EAST Tokamak," in the *Proceedings of the 34th European Physical Society Conference on Plasma Physics* (2–6 July 2007, Warsaw, Poland), edited by Pawet Gasior and Jerzy Wotowski, Contributed Papers Vol. **31F** (ECA 2007) O-4.014. The conference proceedings is available on CD-ROM. Papers are available in PDF format at http://epsppd.epfl.ch/Warsaw/start.htm (active as of 13 July 2008).

*Xu, X.Q., Bodi, K., Candy, J., and 13 additional co-authors including Qin, H. from PPPL, "Edge Gyrokinetic Theory and Continuum Simulations," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-23. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Xu, X.Q., Xiong, Z., Dorr, and 13 additional co-authors including Qin, H. from PPPL, "Edge Gyrokinetic Theory and Continuum Simulations," Nucl. Fusion **47**:8 (August 2007) 809–816.

*Yakovenko, Y.V., Kolesnichenko, Ya.I., Lutsenko, V.V., Burdo, O.S., and White, R.B., "Redistribution of Energetic Ions During Reconnection Events in NSTX," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper TH/P6-6. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

Yamada, M., "Progress in Understanding Magnetic Reconnection in Laboratory and Space Astrophysical Plasmas," Phys. Plasmas **14**:5 (May 2007) Article No. 058102 (16 pages); Tutorial paper at the *48th Annual Meeting of the American Physical Society Division of Plasma Physics* (30 October – 3 November 2006, Philadelphia, PA). Princeton University Plasma Physics Laboratory Report PPPL-4242 (May 2007) 16 pp.

Yamada, Masaaki; Ji, Hantao; Gerhardt, Stefan P.; Belova, Elena V.; Davison, Ronald C.; and Mikkelsen, David R., "SPIRIT Concept for Field Reversed Configuration Research," Plasma and Fusion Research **2** (1 March 2007) Article No. 004.

*§Yan, Longwen, Evans, T.E., Kaye, S.M., and Maingi, R., "Modelling of Stochastic Magnetic Perturbation by RWMEF Coils on NSTX," Nucl. Fusion **46**:10 (October 2006) 858–863.

§Young, Kenneth M., "Chapter 1: Plasma Measurements: An Overview of Requirements and Status," Special Issue [on High-temperature Diagnostics on Magnetic Fusion Energy (MFE) Research] Fusion Sci. Techn. **53**:2 (February 2008) 281–303.

*Yu, S.S., Logan, B.G., Barnard, J.J., and 27 additional co-authors including Davidson, R.C., Gilson, E.P., Grisham, L.R., Kaganovich, I.D., Qin, H., Sefkow, A., and Startsev, E.A. from PPPL, "Heavy-Ion-Fusion-Science: Summary of US Progress," in the *Proceedings of the 21st Fusion Energy Conference* (FEC 2006), (16–21 October 2006, Chengdu, People's Republic of China) paper IF/P5-11. An unedited Conference Proceedings (IAEA CN-149) is available in electronic format on CD-ROM and in PDF format on the IAEA Physics Section web site at http://www-naweb.iaea.org/napc/physics/FEC/FEC2006/html/index.htm (active as of 13 July 2008).

*Yu, S.S., Logan, B.G., Barnard, J.J., and 30 additional co-authors including Davidson, R.C., Gilson, E.P., Grisham, L.R., Kaganovich, I.D., Qin, H., Sefkow, A., and Startsev, E.A. from PPPL, "Heavy-ion-fusion-science: Summary of US Progress," Nucl. Fusion **47**:8 (August 2007) 721–727.

†Zakharov, L.E., Blanchard, W., Kaita, R., Kugel, H., Majeski, R., and Timerlake, J., "Low Recycling Regime in ITER and the LiWall Concept for its Divertor," J. Nucl. Mater. **363-365** (15 June 2007) 453–457 (edited by Jiangang Li, Xiang Gao, Junling Chen, Tetsuo Tanabe, Philippe Ghendrih, and Anthony Leonard); *Proceedings of the 17th International Conference on Plasma-Surface Interactions in Controlled Fusion Devices, PSI-17* (22–26 May 2006, Hefei, Anhui, China). Princeton University Plasma Physics Laboratory Report PPPL-4218 (February 2007) 10 pp.

Zakharov, L.E., Kugel, H.W., Roquemore, A.L., and Skinner, C.H., "Reference Lithium Deposition on NSTX Plasma Facing Components by LITER–1 Evaporator," Princeton University Plasma Physics Laboratory Report PPPL-4187 (October 2006) 12 pp.

Zakharov, Leonid E.; Foley, Elizabeth, L.; Levinton, Fred M.; and Howard Y. Yuh, "Reconstruction of q- and p-profiles in ITER using External and Internal Measurements," presented at the *Twelfth All-Russia Conference on High Temperature Plasma Diagnostics* (2–8 June 2007, Zvenigorod, Russia); Princeton University Plasma Physics Laboratory Report PPPL-4260 (August 2007) 21 pp (report is in Russian).

*Zonca, F., Briguglio, S., Chen, L., Fogaccia, G., Hahm, T.S., Milaranov, A.V.,and Vlad, G., "Physics of Burning Plasmas in Toroidal Magnetic Confinement Devices," Special Issue Plasma Phys. Control. Fusion **48**:12B (December 2006) B15–B28; Invited paper at the *33rd European Physical Society Conference on Plasma Physics* (19–23 June 2006, Roma, Italy).

Zweben, S.J., Boedo, J.A., Grulke, O., Hidalgo, C., LaBombard, B., Maqueda, R.J., Scarin, P., and Terry, J.L., "Edge Turbulence Measurements in Toroidal Fusion Devices," Plasma Phys. Control. Fusion **49**:7 (July 2007) S1–S24; from special section containing papers from the *IEA Large Tokamak IA Workshop on Edge Transport in Fusion Plasmas* (11–13 September 2006, Krakow, Poland). Princeton University Plasma Physics Laboratory Report PPPL-4191 (October 2006) 52 pp.

Return to Table of Contents

Abbreviations, Acronyms, and Symbols

1-D	One-dimensional
2-D	Two-dimensional
3-D	Three-dimensional
AAAS	American Association for the Advancement of Science
AAPT	American Association of Physics Teachers
AFOSR	(U.S.) Air Force Office of Scientific Research
Alcator C-Mod	A tokamak at the Plasma Science and Fusion Center at the Massachusetts Institute of Technology
ALPS	(Energy) Advanced Liquid Plasma-facing Surface Program (a U.S. Department of Energy Program)
AMR	Adaptive Mesh Refinement
APD	Avalanche Photodiode Detector
APDEC	Applied Partial Differential Equations Center (a SciDac Center)
APEX	Advanced Power Extraction Program (a U.S. Department of Energy Program)
APS	American Physical Society
ARD	Apple Remote Desk
ARIES	Advanced Reactor Innovation Evaluation Studies
ARSC	Arctic Region Supercomputing Center
AS	Advanced Stellarator
ASDEX	Axially Symmetric Divertor Experiment at the Max-Planck-Institut für Plasmaphysik, Garching, Germany
ASDEX-U	ASDEX-Upgrade (went into operation in 1990)
AT	Advanced Tokamak
ATO	Authorization to Operate
$\mathbf{B_t}$	Toroidal Magnetic Field
BAAE	Beta-induced Alfvén Acoustic Eigenmode
BAE	Beam Alfvén Eigenmode
BES	Beam Emission Spectroscopy
BEST	Beam Equilibrium Stability and Transport Code
BPAC	Burning Plasma Assessment Committee (under the National Research Council)
BPX	Burning Plasma Experiment
CAD	Computer-aided Design
CADD	Computer-aided Design and Drafting
CAE	Compressional Alfvén Eigenmode
CCD	Charge-coupled Device
CD	Current Drive
CD-4	Critical Decision 4
CDR	Conceptual Design Review
CDX-U	Current Drive Experiment-Upgrade at the Princeton Plasma Physics Laboratory now the Lithium Tokamak Experiment

CEMM Center for Extended MHD Modeling (a SciDAC center)
CER Charge-exchange Recombination spectroscopy diagnostic on DIII-D at General Atomics in California
CFC Carbon Fiber Composite
CHE Coaxial Helicity Ejection
CHERS Charge-exchange Recombination Spectrometer
CHI Coaxial Helicity Injection
CIEMAT Centro de Investigaciones Energéticas, Medioamblentales y Tecnológicas in Spain
CIF Collisionally-induced Fluorescence
CIT Compact Ignition Tokamak
CME Coronal Mass Ejection
C-Mod A tokamak in the "Alcator" family at the Plasma Science and Fusion Center at the Massachusetts Institute of Technology
COTS Commercial Off The Shelf
CPES Center for Plasma Edge Simulation (a SciDac Center)
CPPG Computational Plasma Physics Group at the Princeton Plasma Physics Laboratory
CRADAs Cooperative Research and Development Agreements
CSWIM Center for the Simulation of RF Wave Interactions with Magnetohydrodynamics (a SciDac Center)
CTF Component Test Facility
CY Calendar Year

DIII-D A tokamak at the DIII-D National Fusion Facility at General Atomics in San Diego, California
D&D Decontamination and Decommissioning
D-D Deuterium-deuterium
D-T Deuterium-tritium
DARPA Defense Advanced Research Projects Agency
DART Days Away, Restricted, Transferred (case rates)
DBM Drift Ballooning Model
DCRs Design Change Requests
DE Differential Evolution
DMSP Defense Meteorological Satellites Program
DND Double-null Divertor
DOE (United States) Department of Energy
DWC Diamond Wire Cutting

EAEs Ellipticity-induced Alfvén Eigenmodes
EAST Experimental Advanced Superconducting Tokamak (also known as HT-7U) in Hefei, Anhui Province, China
EBE Electron-Bernstein (Wave) Emission
EBW Electron-Bernstein Wave (Heating)
ECCD Electron Cyclotron Current Drive
ECE Electron Cyclotron Emission
ECEI Electron Cyclotron Emission Imaging
ECH Electron Cyclotron Heating
ECR Electron Cyclotron Resonance
ECRH Electron Cyclotron Resonance Heating
EDA Enhanced D_α Mode
EF Error Field
EFC Error Field Correction

EFDA	European Fusion Development Agreement
EFIT	An equilibrium code
EIO	Energy Industries of Ohio, Inc. of Independence, OH. Subcontractor to manurfacture the National Compact Stellarator Experiment modular coil winding forms.
E-LHDI	Electrostatic Lower-hybrid Drift Instability
ELMs	Edge Localized Modes
ELVS	Graphics Program
EMS	Environmental Management System at the Princeton Plasma Physics Laboratory
EPM	Energetic Particle Mode
ER/WM	Environmental Restoration and Waste Management
ERD	Edge Rotation Diagnostic
ES&H	Environment, Safety, and Health
ES&H/IS	Environment, Safety, and Health and Infrastructure Support Department at the Princeton Plasma Physics Laboratory
ESC	Earth Simulator Center in Japan
ESC	Equilibrium and Stability Code
ESnet	Energy Science Network
ET	Experimental Task
ETG	Electron-temperature Gradient (Mode)
ETI	Everson Tesla Incorporated of Nazareth, PA. Subcontractor to manufacture the National Compact Stellarator Experiment toroidal-field coils.
EU	European Union
eV	Electron Volt
FAC	Field-aligned Current
FCC	Fusion Computational Center
FCPC	Field Coil Power Conversion
FEAT	Fusion Energy Advanced Tokamak
FEM	Finite Element Method
FES	Fusion Energy Sciences
FESAC	Fusion Energy Sciences Advisory Committee
FIR	Far-infrared
FIRE	Fusion Ignition Research Experiment (a national design study collaboration)
FIReTIP	Far-infrared Tangential Interferometer and Polarimeter
FIRST	For Inspiration and Recognition of Science and Technology
FISMA	Federal Information Security Management Act
FLC	Federal Laboratory Consortium (for Technology Transfer)
FLR	Field-line Resonance
FPT	Fusion Physics and Technology, Inc.
FRC	Field-reversed Configuration
FREP	Fast Reciprocating Edge Probe
FSP	Fusion Simulation Project (a SciDAC program)
FTP	File Transfer Protocol
FUV	Full Ultraviolet
FW	Fast Wave
FWR	Full Wave Reflectometer
FY	Fiscal Year
GA	General Atomics in San Diego, California
GAE	Global Alfvén Eigenmodes
GAM	Geodesic Acoustic Modes

GDC Glow Discharge Cleaning
GEM Gas Electronic Multiplier
GFDL Gas Fluid Dynamics Laboratory (on Princeton University's James Forrestal Campus)
GPI Gas Puff Imaging
GPSC Gyrokinetic Particle Simulation Center
GTC Gyrokinetic Toroidal Code

HAPL High-average Power Laser (Program), hosted by the Naval Research Laboratory
HCX High Current Experiments at the Lawrence Berkeley National Laboratory
HFS High-field Side
HHFW High-harmonic Fast-waves
HIT-II Helicity Injected Torus II at the University of Washington, Seattle, Washington
H-mode High-confinement Mode
HTX Hall Thruster Experiment at the Princeton Plasma Physics Laboratory
HXR Hard X-Ray
HYM Hybrid and MHD Code

I/O Input/Output
IBW Ion-Bernstein Wave
IBX Integrated Beam Experiment
ICE Ion Cyclotron Emission
ICF Inertial Confinement Fusion
I-coil Radial Field Coil
ICRF Ion Cyclotron Range of Frequencies
ICW Ion-cyclotron Wave
IDSP Ion Dynamic Spectroscopy Probe; an optical probe used to measure local ion temperature and flows during magnetic reconnection
IFE Inertial Fusion Energy
IGNITOR Ignited Torus
IIH Ion-ion Hybrid
IMF Interplanetary Magnetic Field
I_p Plasma Current
IPP Institut für Plasmaphysik, Garching, Germany
IPR Institute for Plasma Research, Gujarat, India
IR Infrared
IRE Integrated Research Experiment at the Princeton Plasma Physics Laboratory
IRE Internal Reconnection Event
ISS International Stellarator Scaling
ITB Internal Transport Barrier
ITER "The Way" in Latin. Formerly interpreted to stand for International Thermonuclear Experimental Reactor, although this usage has been discontinued.
ITG Ion-temperature Gradient (Mode)
ITPA International Tokamak Physics Activity

JAERI Japan Atomic Energy Research Institute
JET Joint European Torus (JET Joint Undertaking) in the United Kingdom
JFT-2M A small Japanese tokamak
JHA Job Hazard Analysis (procedure at the Princeton Plasma Physics Laboratory)
JHU Johns Hopkins University
JT-60U Japanese Tokamak at the Japan Atomic Energy Research Institute

kA	Kiloampere
KAWs	Kinetic Alfvén Waves
keV	Kiloelectron Volt
kG	Kilogauss
KMB	Kinetic Ballooning Mode
KSTAR	Korea Superconducting Tokamak Advanced Research device in Taejon, South Korea
kV	Kilovolt
kW	Kilowatt
L-α	Lyman Alpha
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LDV	Laser Doppler Velocimetry
LFS	Low-field Side
LH	Lower-hybrid
LHCD	Lower-hybrid Current Drive
LHD	Large Helical Device; a stellarator operating in Japan
LHDI	Lower-hybrid Drift Instability
LIF	Laser-induced Fluorescence
LITER-1	Lithium evaporator on NSTX (**LIT**hium **E**vaporato**R**)
LLNL	Lawrence Livermore National Laboratory
L-mode	Low-confinement Mode
LMX	Liquid Metal Experiment at the Princeton Plasma Physics Laboratory
LPDA	Laboratory Program Development Activities at the Princeton Plasma Physics Laboratory
LPI	Lithium Pellet Injector
LSB	Lyman Spitzer Building (at the Princeton Plasma Physics laboratory)
LSN	Lower Single Null
LTOA	Long Torus Opening Activity (on the DIII-D at General Atomics)
LTX	Lithium Tokamak Experiment (formerly the CDX-U) at the Princeton Plasma Physics Laboratory
MA	Megampere
MARFEs	Multi-faceted Axisymmetric Radiation From the Edge
MAST	Mega-Ampere Spherical Tokamak at the Culham Laboratory, United Kingdom
MAV	Micro-air Vehicle
MCWF	Modular Coil Winding Form
MFE	Magnetic Fusion Energy
MHD	Magnetohydrodynamic
MHz	Megahertz
MINDS	Miniature Integrated Nuclear Detector System
MIR	Microwave Imaging Reflectometer
MIT	Massachusetts Institute of Technology in Cambridge, Massachusetts
MLM	Multilayer Mirror
MMRE	Multiscale Mathematics Research and Education (an Office of Advanced Scientific Computation Research initiative)
MNX	Magnetic Nozzle Experiment at the Princeton Plasma Physics Laboratory
MPI	Message Passing Interface
MPP	Massively Parallel Processor
MPTS	Multi-point Thomson Scattering
MRI	Magnetorotational Instability Experiment at the Princeton Plasma Physics Laboratory

MRX	Magnetic Reconnection Experiment at the Princeton Plasma Physics Laboratory
ms, msec	Millisecond
MSE	Motional Stark Effect (Diagnostic)
MST	Madison Symmetric Torus at the University of Wisconsin at Madison
MW	Megawatt
NASA	National Aeronautics and Space Administration
NBCD	Neutral-beam Current Drive
NBI	Neutral Beam Injection (Heating)
NCCS	National Center for Computational Sciences at the Oak Ridge National Laboratory
NCSX	National Compact Stellarator Experiment (a Princeton Plasma Physics Laboratory-Oak Ridge National Laboratory fabrication project)
NDCX	Neutralized Drift Compression Experiment at the Lawrence Berkeley National Laboratory
NEPA	National Energy Policy Act
NERSC	National Energy Research Supercomputer Center
NFRI	(Korean) National Fusion Research Institute
NHTX	High-power advanced Torus Experiment
NIFS	National Institute of Fusion Science (Japan)
NIST	National Institute of Standards and Technology
NJIT	New Jersey Institute of Technology
NJTC	New Jersey Technology Council
NNBI	Negative-ion-based Neutral-beam Injection
NOAA	National Oceanic and Atmospheric Administration
NPA	Neutral Particle Analyzer
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSO	Next-step Option
NSO-PAC	Next-step Option Program Advisory Committee
NSST	Next-step Spherical Torus
NSTX	National Spherical Torus Experiment at the Princeton Plasma Physics Laboratory
NTCC	National Transport Code Collaboration
NTM	Neoclassical Tearing Mode
NTX	Neutralized Transport Experiment at the Lawrence Berkeley National Laboratory
NUF	(DOE) National Undergraduate Fellowship
OASCR	Office of Advanced Scientific Computing Research
OFES	Office of Fusion Energy Sciences (at the U.S. Department of Energy)
OH	Ohmic Heating
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory, Oak Ridge, Tennessee
ORPA	Office of Research and Project Administration at Princeton University
OSHA	Occupational Safety and Health Administration
PAC	Program Advisory Committee
PBX	Princeton Beta Experiment, predecessor to PBX-M at the Princeton Plasma Physics Laboratory (no longer operating)
PBX-M	Princeton Beta Experiment-Modification at the Princeton Plasma Physics Laboratory (no longer operating)
PCHERS	Poloidal CHarge-exchange Recombination Spectroscopy

PDC	Pulse Discharge Cleaning
PDI	Parametric Decay Instabilities
PDR	Preliminary Design Review
PDX	Poloidal Divertor Experiment, predecessor to PBX and PBX-M at the Princeton Plasma Physics Laboratory (no longer operating)
PEGASUS	A toroidal experiment at the University of Wisconsin at Madison
PF	Poloidal Field
PFC	Plasma-facing Component
PFRC	Princeton Field-reversed Configuration (Experiment) at the Princeton Plasma Physics Laboratory
PIC	Particle-in-Cell
PICSciE	Princeton Institute for Computational Science and Engineering
PLT	Princeton Large Torus at the Princeton Plasma Physics Laboratory (no longer operating)
PPPL	Princeton Plasma Physics Laboratory (Princeton University, Princeton, New Jersey)
PPST	Program in Plasma Science and Technology
PSACI	Plasma Science Advanced Scientific Computing Initiative
PSEL	Plasma Science Education Laboratory at the Princeton Plasma Physics Laboratory
PSFC	Plasma Science and Fusion Center at the Massachusetts Institute of Technology in Cambridge, Massachusetts
PTSX	Paul Trap Simulator Experiment at the Princeton Plasma Physics Laboratory
Q	The ratio of the fusion power produced to the power used to heat a plasma
QA	Quality Assurance
QA	Quasi-axisymmetry
QAS	Quasi-axisymmetry Stellarator
QDB	Quiescent Double Barrier
QH-mode	Quiescent High-confinement Mode
RCS	Reconnection Current Sheet
R&D	Research and Development
RDDs	Radioactive Dispersion Devices
REs	Reconnection Event(s)
rf	Radio-frequency (Heating)
RFA	Resonant Field Amplification
RGA	Residual Gas Analyzer
RI	Radiative-improved Confinement Mode
RMF_o	Odd-parity Rotating Magnetic Fields
RMP	Resonant Magnetic Perturbation
RPI	Rensselaer Polytechnic Institute
RSAEs	Reversed-shear Alfvén Eigenmodes
RTAE	Resonant TAE
RWM	Resistive Wall Mode
SAN	Storage Area Network (at the Princeton Plasma Physics Laboratory)
SBIR	Small Business Innovative Research (Program)
SciDAC	(The Department of Energy Office of Science's) Scientific Discovery through Advance Computing Program
SCOREC	Scientific Computational Research Center at the Rensselaer Polytechnic Institute
SEP	Science Education Program at the Princeton Plasma Physics Laboratory
SF	Shaping field
SGI	Supersonic Gas Injector

SLAC Stanford Linear Accelerator Center (in California)
SOL Scrape-off Layer
SSEPN Steady-state Electric Power Network
SST-1 Steady-state Superconducting Tokamak at the Institute for Plasma Research in Gujarat, India
SSX Swarthmore Spheromak Experiment located at the Department of Physics and Astronomy, Swarthmore College, Swarthmore, Pennsylvania
SSX-FRC Swarthmore Spheromak Experiment-Field-reversed Configuration
ST Spherical Torus
ST-DEMO Demonstration Spherical Torus Device
ST&E Security Test and Evaluation
START Small Tight Aspect Ratio Tokamak at Culham, United Kingdom
SULI (DOE) Science Undergraduate Laboratory Internship
SXR Soft X-ray

T Temperature
TAE Toroidicity-induced Alfvén Eigenmode or Toroidal Alfvén Eigenmode
TEM Trapped-electron Mode
TEXTOR Tokamak Experiment for Technologically Oriented Research in Jülich, Germany
TF Toroidal Field
TFC Topical Computing Facility
TFTR Tokamak Fusion Test Reactor (1982–1997), at the Princeton Plasma Physics Laboratory (no longer operating)
TJ-II A “flexible” Heliac (stellarator) located at the CIEMAT Institute in Madrid, Spain
TOPS Towards Optimal Petascale Simulations (a SciDAC Center)
Tore Supra Tokamak at Cadarache, France
TRACE Transition Region and Coronal Explorer (satellite)
TRC Total Recordable Case
TRC Twisted Racetrack Coil
TS Thomson Scattering (Diagnostic)
TSC Transport Simulation Code
TWC Tandem Wing Clapper

UC Davis University of California at Davis
UC Irvine University of California at Irvine
UCLA University of California at Los Angeles
UCSD University of California at San Diego
UKAEA United Kingdom Atomic Energy Agency
ULF Ultra-low Frequency
USBPO U.S. Burning Plasma Organization
USDA United States Department of Agriculture
USDOE United States Department of Energy
USIPO U.S. ITER Project Office (at Oak Ridge National Laboratory)
USXR Ultra-soft X-ray (tomography)
UV Ultraviolet

VLAN Virtual Local Area Networks (at the Princeton Plasma Physics Laboratory)
VPN Virtual Private Network (at the Princeton Plasma Physics Laboratory)
VPP Voluntary Protection Program (An U.S. Department of Energy Program — a reinforcement of Integrated Safety Management which promotes worksite-based safety and health.)
VVSAs Vacuum Vessel Subassemblies

W7-AS Wendelstein-7 Advanced Stellarator, an operating stellarator in Germany
W7-X A stellarator being built in Germany
WBS Work Breakdown Structure (at the Princeton Plasma Physics Laboratory)
WFOs Work For Others
WPA Wi-Fi Protected Access
WSHP Worker Safety and Health Program (at the Princeton Plasma Physics Laboratory)
WVU West Virginia University

XCS X-ray Crystal Spectrometer
XP Experimental Proposal

Y2K Year 2000

September 2008

Editors: Anthony R. DeMeo and Carol A. Phillips

Contributors: S.A. Cohen, R.C. Davidson, A.R. DeMeo, P.C. Efthimion, N.J. Fisch, R.J. Goldston, P. Hampton, R.J. Hawryluk, M.T. Iseicz, S.C. Jardin, H. Ji, D.W. Johnson, J.R. Johnson, I. Kaganovich, R. Kaita, J.D. Levine, R.P. Majeski, J. Manickam, L.D. Meixler, J.E Menard, G.H. Neilson, M. Nornberg, M. Ono, E. Oz, C.A. Phillips, B.A. Sarfaty, B.R. Sobel, B.C. Stratton, M.D. Williams, P.A. Wieser, J.R. Wilson, M. Yamada, and A. Zwicker

Cover Design: Gregory J. Czechowicz

Photography: Elle Starkman

Graphics: Gregory J. Czechowicz

Layout: Carol A. Phillips

The Princeton Plasma Physics Laboratory is funded by the U.S. Department of Energy under contract DE-AC02-76CH03073 and managed by Princeton University.

For additional information contact:

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: (609) 243-2750
Fax: (609) 243-2751

e-mail: pppl_info@pppl.gov

Internet Address: http://www.pppl.gov/