Plasma Science and Fusion Center

MIT's Plasma Science and Fusion Center (PSFC) is known internationally as a leading university research center for the study of plasma and fusion science and technology with research activities in five major areas:

1. The science of magnetically confined plasmas in the development of fusion energy, in particular the Alcator C-Mod tokamak project
2. The basic physics of plasmas including magnetic reconnection experiments on the Versatile Toroidal Facility (VTF), plasma-surface interactions, development of novel high-temperature plasma diagnostics, and theoretical plasma physics and fusion science research
3. The physics of high energy density plasmas (HEDP) which includes the center's activity on inertial confinement laser-plasma fusion interactions
4. The physics of waves and beams (gyrotron and high gradient accelerator research, beam theory development, non-neutral plasmas, and coherent wave generation)
5. A broad program in fusion technology and engineering development that addresses problems in several areas (e.g., magnet systems, superconducting materials, and system studies of fusion reactors), and non-fusion related technology development, mostly in the superconducting magnet area.

Administratively, each of these areas constitutes a separate research division. In order of research area above, the PSFC research divisions are the Alcator Project, Physics Research, High Energy Density Plasma Physics, Waves and Beams, and Fusion Technology and Engineering.

PSFC research and development programs are supported principally by the Department of Energy's Office of Fusion Energy Sciences (DOE OFES). There are approximately 250 personnel associated with PSFC research activities. These include 25 faculty and senior academic staff, 59 graduate students, and 10 undergraduates, with participating faculty and students from Aeronautics and Astronautics, Electrical Engineering and Computer Science, Nuclear Science and Engineering, and Physics; 76 research scientists, engineers, postdoctoral associates/fellows and technical staff; 28 visiting scientists, engineers, and research affiliates; 3 visiting students; 24 technical support personnel; and 25 administrative and support staff.

Total PSFC funding for FY2012 is expected to be $36.34 million, a decrease of 9.6% relative to FY2011 funding of $40.19 million. (Note that the FY2011 and FY2012 totals include $0.70 million and $0.67 million, respectively, of stimulus funding from the American Recovery and Reinvestment Act of 2009).

The reduction in the center's total funding in FY2012 relative to FY2011 can be better understood by looking at the FY2012 total relative to the FY2010 total and in particular by looking at the change in funding within the center's Fusion Technology and Engineering (FT&E) Division over that time period. In FY2010, FT&E Division funding was $2.93 million. The division's FY2011 funding increased to $8.34 million due to growth of four programs sponsored by the US Department of Defense Defense Threat Reduction Agency (DTRA), which included nearly $5.0 million of fabricated equipment funds, for hardware. Subsequently, DTRA withdrew its support of these homeland security-related programs in FY2012, causing FT&E funding to drop precipitously to $2.64 million. This funding is only 10.1% less than the division's $2.93 million FY2010 funding.

Similarly, the center's FY2012 total funding ($36.34 million) actually grew relative to FY2010 ($34.60 million). During this time, funding for the PSFC's largest research division, the Alcator Project (which accounts for nearly 70% of the PSFC's research funding), increased by at least $1.0 million each year, or from $22.72 million in FY2010, to $23.72 million in FY2011, and to $24.81 million in FY2012.

FY2012 funding for two other PSFC research divisions, Physics Research and High Energy Density Physics, both grew relative to FY2011. Physics Research funding increased by 12.4% in FY2012 to $4.61 million, up from $4.10 million in FY2011. Funding in the High Energy Density Physics Division grew by 12.9% in FY2012 to $2.48 million, up from $2.20 million in FY2011. Finally, funding dropped slightly (0.9%) for the Waves and Beams Division in FY2012 to $1.72 million, down from $1.74 million in FY2011.

The FY2013 congressional budget process has cast a long shadow over the future of domestic fusion energy program in general and over Alcator C-Mod in particular. In the president's 2013 budget request, the US domestic fusion program would be cut by 16%—from $296 million in FY2012 to $248.3 million in FY2013–in order to free up funds to accommodate a $45 million increase in the US contribution to the International Thermonuclear Experimental Reactor (ITER) Program. Alcator C-Mod is one of the domestic programs affected by these cuts, and language in the Administration's version of the budget calls for the Alcator C-Mod Project to cease operations and shut down in FY2013, with funds provided in FY2013 to be used to complete analysis of data taken in 2012, publish results, and dismantle the experiment. This version of the budget has been adopted by the Senate.

More favorably, the House of Representative's proposed FY2013 budget calls for complete restoration of the Alcator C-Mod budget, and the addition of funds for the ITER Program without necessitating a reduction in the US domestic fusion program ($296.6 million). As of now, the final FY2013 budget outcome is not known.

Throughout this time, the PSFC director and senior scientists have worked closely with MIT's vice president for research, the director of MIT's Washington DC Office, and with senior officers of the labor union representing Alcator technicians to make the case to preserve the Alcator C-Mod Project to the Department of Energy and to our elected officials, including Senator John Kerry (D-MA), Congressman Michael Capuano (D-MA), and Governor Deval Patrick. Senator Kerry and Governor Patrick have recently visited the PSFC, and Senators Kerry and Brown have written the leaders of the Senate Appropriations Committee to restore Alcator C-Mod funding.

Alcator Division

The Alcator C-Mod tokamak is an international fusion experimental facility that is recognized as one of three major US national fusion facilities. Earl Marmar, senior research scientist in the MIT Department of Physics and the Plasma Science and Fusion Center, is the principal investigator and project head.

The C-Mod team consists of an MIT full-time equivalent staff of approximately 50 scientists and engineers, including 10 faculty and senior academic staff, plus 28 graduate students and 25 technicians. Additionally a large number of Alcator collaborators from around the world brings the total complement of scientific facility users to more than 200. The cooperative agreement with DOE's Office of Fusion Energy Sciences, which funds the C-Mod project, was renewed effective November 1, 2008 for a five-year period. Including major collaborators, total FY2012 funding for the project is about $28.8 million ($24.8 million direct funding at MIT).

Research on C-Mod continued during the past year in high-performance, high-magnetic-field plasma confinement. State of the art experiments are being carried out this year in the critical science areas of transport, wave-plasma interactions, edge pedestal, boundary physics, and magnetohydrodynamic stability, as well as in plasma integration areas involving advanced tokamak and burning plasma science. Many of the experiments are in direct support of urgent ITER research needs.

A significant number of facility and diagnostic upgrades have been completed in the last year or are in progress. Highlights include: implementation of a novel, magnetic field-aligned Ion Cyclotron radio frequency (RF) antenna; a correlation electron cyclotron emission imaging system to measure core temperature fluctuations; upgrades to impurity spectroscopy systems; improvements to the polarimeter laser system designed to measure current profile and magnetic fluctuations; first operation of a unique accelerator facility designed to probe in situ surface conditions following plasma discharges for plasma-wall-interaction studies. Design and prototyping of the outer divertor upgrade, which will utilize actively heated (~600^0 C) solid tungsten plasma facing tiles, is progressing well, and its installation in FY2013 and operation in FY2014, would allow the world's first investigations into hot tungsten plasma-facing components, recognized by the Fusion Energy Sciences Advisory Committee as the leading candidate approach for the demonstration fusion reactor (DEMO) and other reactors. Facility operation for research this fiscal year is planned to total 18 weeks. We plan to keep operating through to the end of FY2012.

As one strong indication of C-Mod's continued high scientific productivity, the program committee for the upcoming APS-DPP meeting in November, 2012 has selected nine submissions for invited talks based on C-Mod results: Istvan Cziegler, "Edge/Scrape-Off-Layer turbulence and Transport Studies"; Odd Erik Garcia, "Intermittent SOL fluctuations in C-Mod, Experiment and Theory"; Graham Wright, "Tungsten Nano-tendril Growth in C-Mod and on Linear Simulators"; Steve Wukitch, "Advanced Field-aligned ICRF Antenna Studies on C-Mod"; Geoff Olynyk, "Toroidal Symmetry of Massive Gas Disruption Mitigation Utilizing Multiple Gas Jets on C-Mod"; Jerry Hughes, "Joint C-Mod/DIII-D/NSTX Research on Pedestal Physics"; Darin Ernst, "Trapped Electron Mode Turbulence, Simulation and Experiments"; Matt Reinke, "Poloidal Variation of High-Z Impurity Density due to Hydrogen Minority Heating on Alcator C-Mod"; and Anne White, "Multi-channel/Multi-field Turbulence and Transport in Alcator C-Mod in L-mode and I-mode plasmas". In addition, Dennis Whyte has been selected to give a review talk called "The Role of the Boundary Plasma in Defining the Viability of a Magnetic Fusion Reactor," a topic on which the C-Mod team has been world leading for many years.

Recent Research Highlight

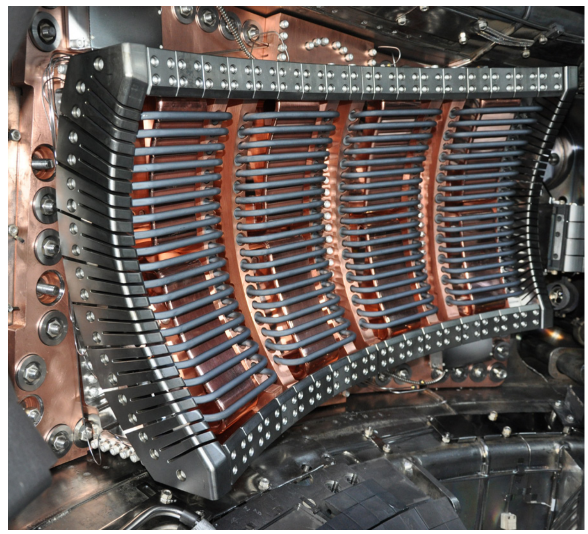

Figure 1. Photograph of field-aligned ion cyclotron range of frequency (ICRF) antenna installed in Alcator C-Mod. The four current straps (visible in the background behind the Faraday shield rods) are slanted about 10 degrees to the vertical in the perpendicular directions of the total magnetic field direction near the plasma edge. This new antenna couples up to 3 MW of radio frequency power to heat the plasma to tens of millions of degrees.

Impurity contamination associated with ion cyclotron range of frequency (ICRF) heating remains a major challenge to ICRF utilization in magnetic confinement devices, particularly with metallic plasma facing components. We have recently begun experimental investigations of a high-power, magnetic field-aligned (FA) antenna (Figure 1), designed to reduce parallel electric (E||) field through symmetry and thereby reduce RF-related impurity contamination. Using the standard non-field aligned antennas (ST) as a reference, the impurity contamination and sources on the antenna are significantly lower for the FA antenna than the ST antennas. In addition, the radiated power is reduced for given injected power for the FA antenna compared to the ST antennas in L- and H-mode discharges. The improved performance is consistent with simulations indicating that the FA antenna has reduced integrated E|| relative to the non-aligned antennas. However, the simulation also predicts that so-called monopole phasing, where antenna strap current has [0,0,0,0] phase, should have the lowest integrated E||. The initial results suggest that monopole phasing has a stronger impact on the plasma potential and higher core impurity contamination and sources at the antenna. Utilizing gas puff imaging, the radial electric field profile in the scrape-off-layer (SOL) is readily measured. For the ST and FA antennas, fine structure (variations of order ~0.5 cm) in the radial electric field is observed and radial penetration of the rectified potential structures is ~10 times greater than the skin depth. This anomalous penetration appears to be consistent with including cross-field RF polarization currents in the sheath model. Further comparisons of the FA and ST antennas are being carried out with an extensive array of boundary plasma diagnostics to characterize the impurity behavior and impact on the SOL transport and SOL density profiles.

Physics Reseach Division

The Physics Research Division, headed by professor Miklos Porkolab, is comprised of a strong basic and applied plasma theory and computational program that focuses on magnetic confinement devices such as tokamaks and stellarators. It also develops novel plasma physics diagnostic experiments and investigates general plasma mechanisms such as reconnection. Its goal is to improve theoretical and experimental understanding of plasma physics and fusion science while training students for careers at universities, in industry, and at laboratories.

Fusion Theory and Simulations

The division's theory effort focuses on basic and applied plasma theory and simulations. It is mainly funded by the US Department of Energy Office of Fusion Energy Sciences and is led by Peter Catto, PSFC assistant director. It supports Alcator C-Mod and other tokamak experiments worldwide, as well as some stellarator research. The PSFC theory effort has been expanded to include assistant professor Felix Parrain the Nuclear Science and Engineering (NSE) Department. Joining him is Michael Barnes, who won a DOE Oak Ridge Institute for Science and Education postdoctoral fellowship. In addition, the impressive group of postdocs includes Matt Landreman, who also won a DOE Oak Ridge Institute for Science and Education postdoctoral fellowship; Antoine Cerfon, who becomes a professor at the Courant Institute at New York University in September 2012; and Bo Li, who was supported by the Science Discovery through Advanced Computing Center for the Study of Plasma Microturbulence and now has joined the faculty of Peking University in Beijing.

Professor Parra won a five-year grant from the DOE Office of Science Early Career Research Program to initiate a research program titled "Spontaneous generation of rotation in tokamak plasmas." In May 2012 Dr. Catto was awarded an honorary doctorate by Chalmers University of Technology in Gothenburg, Sweden.

Tokamak and Stellarator Confinement and Transport

Gyrokinetic and drift kinetic descriptions are used throughout the magnetic fusion program to simulate turbulence and treat collisional transport in tokamaks and stellarators. Gyrokinetics allows gyromotion and magnetic drift departures from constant pressure surfaces to be retained and extends drift kinetic descriptions by retaining arbitrary perpendicular wavelengths effects. Recent work by Professor Parra and Dr. Barnes focuses on implementing and extending the momentum transport description for tokamaks they began during their postdoctoral appointments at Oxford University. Barnes presented this work as an invited talk at the April 2012 American Physical Society (APS) meeting. The axisymmetry of tokamaks makes this a particularly challenging problem for the magnetic fusion community. The analytic and numerical procedures they formulated and are implementing are known to be the only ones capable of obtaining meaningful results as demonstrated in Parra's thesis work with Catto and his subsequent research with Ivan Calvo of the National Fusion Laboratory in Spain. Parra's graduate student Jungpyo Lee is working with Professor Parra and Barnes to use their formulation to gain insight into momentum transport effects observed during lower hybrid current drive on C-Mod. One of the two ways to obtain steady state operation in a tokamak is to drive toroidal current using directional radio frequency waves as in done on C-Mod. Parra's graduate student Justin Ball is exploring new high rotation designs for tokamaks that work as thermal engines, converting the thermal energy in the tokamak into directed energy.

Postdoctoral fellow Matt Landreman is developing a new drift kinetic code retaining the full collision operator in the presence of the strong radial density and temperature gradients associated with the pedestal region at the outer edge of the core plasma during high confinement tokamak operation. This poorly understood region is known to play a key role in tokamak performance. Landreman's new code has demonstrated poloidal variation on pressure surfaces that does not occur in the core.

Landreman summarized his thesis work with Catto in an APS Division of Plasma Physics (DPP) invited talk on transport in optimized or omnigeneous stellarators that, like tokamaks, confine all collisionless orbits in the absence of turbulence. Even though omnigenous stellarators are fully three-dimensional, unlike tokamaks, Landreman was able to derive concise, explicit expressions for the gradient-driven ("bootstrap") current, the ion flow, and the radial electric field in the long-mean-free-path regime, as well as the collisionality-independent, geometry-driven Pfirsch-Schluter current and ion flow. At the same APS meeting, Professor Parra, the winner of the 2011 Marshall N. Rosenbluth Outstanding Doctoral Thesis Award from DPP, summarized his ongoing momentum transport work with Barnes, Calvo, and Catto.

Research scientist Darin Ernst led two C-Mod experiments for the DOE 2012 Joint Research Target, one on "Hidden Variables in Neo-Alcator Scaling" and the other on transport and fluctuations in internal transport barriers with modulated radio frequency heating. The second experiment demonstrated a new technique for separating out-of-phase core and edge fluctuations that enables a more direct comparison of line-integrated measurements of density fluctuations with local gyrokinetic turbulence simulations. Ernst's work was presented in a plenary talk at the US Transport Task Force Workshop, and it has been selected as an APS DPP invited talk in fall 2012.

Bo Li and Darin Ernst are developing new two-dimensional and three-dimensional electromagnetic fluid edge turbulence codes. The codes simulate turbulence in the pedestal and scrape-off-layer regions simultaneously.

Magnetohydrodynamics and Extended MHD Simulations

Principal research scientist Jesus Ramos participates in the DOE Science Discovery through Advanced Computing (SciDAC) Center for Extended MHD Modeling. During the past year he has extended his examination of weakly collisional tokamak plasmas with near Maxwellian distribution function to further develop a theoretical model to analyze slowly growing macroscopic instabilities (such as the neoclassical tearing mode) in a high-temperature, magnetically confined plasma. The ion description and the electron description are now complete. Both feature finite Larmor radius drift-kinetic equations for the non-Maxwellian perturbations to the Maxwellian that guarantee consistency between the fluid particle, momentum and energy conservation equations, and the density, mean velocity, and temperature of the Maxwellians. They recover the neoclassical results in the long-mean-free-path limit, including the ion radial heat flux and the bootstrap current in general magnetic geometry, as needed for a realistic simulation of dynamic, three-dimensional magnetic fields. A new numerical code has been developed in collaboration with Stephen Jardin and Brendan Lyons of Princeton Plasma Physics Laboratory that efficiently evaluates the corresponding, near-stationary neoclassical distribution functions.

Antoine Cerfon and professor Jeffrey Freidberg (NSE), in collaboration with Andras Pataki and professor Leslie Greengard of the Courant Institute at NYU, developed a new, fast high-order accurate numerical solver for the Grad-Shafranov equation that determines plasma equilibria in toroidally axisymmetric magnetic confinement devices such as the tokamak. By combining conformal mapping methods with Fourier and integral equation methods in the unit disk, they showed that spectral accuracy is achieved for the solution and its first and second derivatives. This accuracy is crucial since the stability and transport properties of plasma equilibria are very sensitive to the local magnetic field shear and curvature that depend on these derivatives.

Heating, Current Drive, Advanced Tokamaks, and Nonlinear Dynamics

Abhay Ram, PSFC principal research scientist, along with professor Kyriakos Hizanidis and Yannis Kominis of the National Technical University of Athens, Greece, have been studying the scattering of radio frequency waves by edge density fluctuations in magnetically confined fusion plasmas. The usual studies use the geometric optics approximation to determine the effect of fluctuations, but the approximation applies to small density fluctuations and excludes the domain of large fluctuations that are routinely observed in experiments. Their collaboration has developed a full-wave theory for scattering of RF waves from density blobs that is valid for arbitrary magnitude of the fluctuations. This first-of-a-kind model for these scattering studies includes diffractive scattering and coupling of incident waves to other plasma waves. They find that diffraction broadens the wave vector spectrum of the RF waves. For electron cyclotron waves an externally excited ordinary wave can couple some of its power to the extraordinary wave, thereby affecting the power flowing into the core of a fusing plasma and modifying the current profile. Electron cyclotron waves in ITER will be used for controlling the deleterious neoclassical tearing modes.

Center for Simulation of Wave-Plasma Interactions and Center for Simulation of Wave Interactions with MHD Fusion Simulation Project

The PSFC participates in the Science Discovery through Advanced Computing Center for the Simulation of Wave-Plasma Interactions (CSWPI) and Center for the Simulation of Wave Interactions with MHD by its research program on wave-particle interactions in fusion plasmas in the ion cyclotron range of frequencies (ICRF) and the lower hybrid range of frequencies. Senior research scientist Paul Bonoli serves as the lead principal investigator for the multi-institutional CSWPI. Also involved are research scientist John Wright, professor Ronald Parker (retired), and graduate students Haruhiko Kohno, Jungpyo Lee, and Aaron Bader. Kohno successfully defended his thesis on "Numerical Analysis of Radio-Frequency Sheath-Plasma Interactions in the Ion Cyclotron Range of Frequencies." He showed that the rectified sheath may generate potentials of the order of 100 V near the wall–energies sufficient to yield enhanced sputtering at the wall. Bader also successfully defended his thesis on "Experimental Measurements and Numerical Modeling of Fast-ion Distributions in the Alcator C-Mod Tokamak." He demonstrated that photon counts measured by a Compact Neutral Particle Analyzer associated with the charge exchange of ICRF-generated fast ions can be simulated with a synthetic diagnostic using the fast-ion distribution function from a combined ICRF field solver and Fokker-Planck code (Figure 2). Dr. Wright's work on lower hybrid waves with field solvers has identified the importance of interference effects in lower hybrid range of frequency induced diffusion of electrons and of warm plasma contributions to the wave dispersion. Jungpyo Lee's dissertation work used full-wave lower hybrid simulations to calculate the wave-induced torque on the plasma.

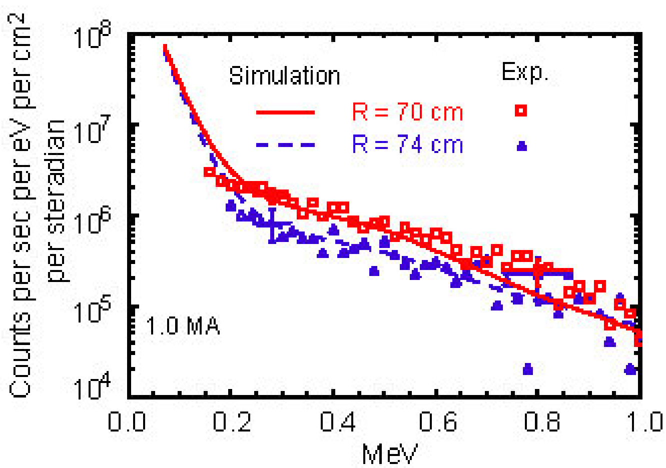

Figure 2. Comparison between simulated and measured Compact Neutral Particle Analyzer (CNPA) spectra for a discharge in Alcator C-Mod. Two of the CNPA sightlines at R = 70 cm (red) and R = 74 cm (blue) are shown. The parameters are f0 = 80 MHz, PIC ≈ 1.75 MW, ne(ave) ≈ 1.3 × 1020 m-3, Ip = 1 MA, and Bϕ = 5.4T.

Experimental Research

Evolution of the Levitated Dipole Experiment

The Levitated Dipole Experiment (LDX), a joint collaborative project with Columbia University, was a basic physics experiment that explored the confinement of plasmas in the magnetic field of a floating dipole ring. Headed by Jay Kesner (MIT) and professor Michael Mauel (Columbia University), LDX was originally conceived as an alternate fusion concept experiment which also had relevance to astrophysics. However, as DOE narrowed its research focus in favor of projects that directly support the international ITER effort, it terminated this experimental effort in 2010.

This past year, the PSFC and Columbia have repositioned LDX as a platform for basic plasma physics research in non-fusion-related areas, and have secured a three-year $1.2 million grant from the National Science Foundation and the DOE OFES to jointly develop and test models of "space weather." Local weather forecasts do not typically include information about what is happening beyond the Earth's ionosphere. Being able to predict "space weather" could be of crucial importance. Understanding geomagnetic storms that are caused by massive plumes of plasma ejected from the sun could be used to plan satellite operations, predict radio outages, and protect the electrical transmission grid.

Experiments will be performed on the superconducting LDX facility at MIT and on the smaller CTX facility at Columbia. The joint research project will explore the physics of high-temperature ionized gas (plasma), trapped by strong magnets resembling the magnetic field of the Earth. The strong magnets in these experiments have confined plasma at very high pressure and with intense energetic electron belts similar to the Earth's radiation belts. With plasma diagnostics spanning from global to small spatial scales and user-controlled experiments, these devices will be used to measure and study important phenomena in space weather such as fast particle excitation and rapid electromagnetic events associated with magnetic storms.

Plasma Science Center on Plasma-Surface Interactions

Professor Dennis Whyte is the director of the multi-institutional Plasma Science Center on Plasma-Surface Interactions (PSI), a collaboration among MIT, University of California/San Diego, University of California/Berkeley, and Sandia National Labs. The Plasma Surface Interactions Science Center, established in 2009, is focused on understanding the response of materials to extreme particle and thermal fluxes anticipated in fusion confinement devices. In addition, it works on basic PSI research to advance other fields, such as understanding material erosion limits in plasma thrusters used for space exploration. The center develops synergistic experimental and modeling tools that treat the truly coupled multi-scale aspect of PSI issues. Computational modeling has demonstrated the importance of sub-surface helium bubble formation on the initial stages of topological instabilities driving the formation of a nanometer-sized fuzz morphology in tungsten, as well as understanding the partitioning of hydrogen to gas bubbles. Experiments performed by the center have definitively shown that the helium saturates at high concentrations below the surface, and that the helium level is constant throughout the fuzz depth. An integrated test of tungsten fuzz growth was carried out collaboratively on Alcator C-Mod (Figure 3), proving not only that fuzz will be expected on ITER and reactors, but that the empirical and model extrapolations from

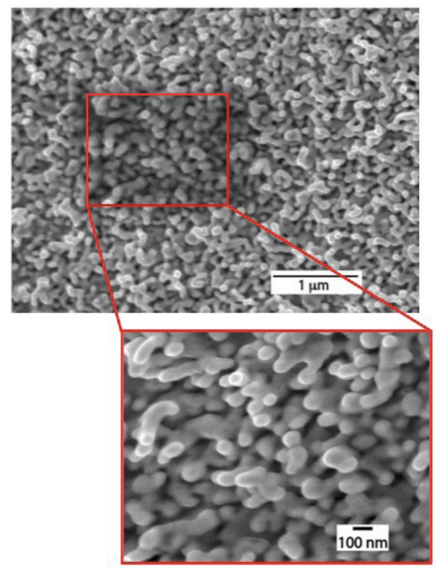

Figure 3. Electron microscope photo of tungsten nano-tendril "fuzz" formed during a Plasma Science Center on Plasma-Surface Interactions-organized run on Alcator C-Mod. These ~micron thick tendrils grew in about 10 seconds of helium plasma exposure in the reactor-like divertor of C-Mod. The key to growing the fuzz was having a surface temperature ~1200 Celsius, with the heat provided by the intense plasma; the fuzz grew despite an incident heat flux of about 40 million watts per square meter (the same heat flux as the surface of the sun). [From G. Wright invited talk at 20th International Conference on Plasma Surface Interactions, Aachen Germany, 2012]

center laboratory research agreed quite well with the tokamak experiment. The center work provides the key physics insight required to extrapolate from laboratory-based studies to confinement devices, and enable the design of plasma facing components to withstand the harsh environment that materials will have to endure in future fusion reactors.

Magnetic Reconnection Experiments on the Versatile Toroidal Facility

Reconnection is the process by which stress in the field of a magnetized plasma is reduced by a topological rearrangement of its magnetic-field lines. The process is often accompanied by an explosive release of magnetic energy and is implicated in a range of astrophysical phenomena. In the Earth's magnetotail, reconnection energizes electrons up to hundreds of keV and solar-flare events can channel up to 50% of the magnetic energy into the electrons, resulting in superthermal populations in the MeV range. Magnetic reconnection has been studied in the Versatile Toroidal Facility (VTF) under the leadership of professor Jan Egedal, who leads the effort of half a dozen undergraduate and graduate students. The experiments on VTF have provided insight into what controls the onset of the explosive magnetic reconnection event observed in nature. Suggestive of events observed on the sun and measurements in fusion devices, the experiments have shown that the onset is a truly three-dimensional phenomenon. It is facilitated by a global mode that breaks the nominal axisymmetry of the experiment and enables a localized reconnection onset followed by the propagation of the reconnection electric field toroidally around the VTF device.

The experimental results in VTF have led to the development of a new fluid model applicable to reconnection. As recently documented in *Nature Physics*, the new theory shows that parallel electric fields develop outside the standard reconnection region, and allow for an efficient acceleration of electrons over larger length scales, and also to much higher energies than previously thought possible. In addition, the new fluid model is now implemented in a numerical code (running on up to 10^4 computational cores at the National Energy Research Scientific Computing Center, NERSC). As a breakthrough on reconnection research, this work demonstrates that the new physics included in the new model is responsible for the elongated current layers that have been routinely observed in kinetic simulations of reconnection but never seen before in fluid simulations. The VTF experiment will be closed down by the end of FY 2013 as professor Egedal relocates away from MIT.

Collaboration on Alfvén Wave Propagation and Instabilities

Professor Miklos Porkolab leads this project from MIT, with significant participation by Paul Woskov, PSFC senior research engineer. This program supports experiments at Joint European Torus (JET), the world's largest tokamak located near the Culham Laboratories, UK, and involves collaboration between PSFC, professor Ambrogio Fasoli of the Center for Plasma Physics Research in Lausanne, Switzerland, and a group headed by professor Ricardo Galvao of the Instituto de Física, University of Sao Paulo, Brazil. In these experiments, Alfvén waves are launched by a specially built antenna array, consisting of eight phase-locked loops, all of which have been installed in JET during the past two years. These studies are expected to lead to an improved understanding of plasma stability and transport that will be important in future burning plasma experiments where the fusion process generates a substantial alpha particle component which may drive Alfvén waves unstable. In 2012 a new hardware approach to upgrade the diagnostics system using eight 4 kW class D amplifiers (one for each antenna) was finalized and hardware fabrication commenced. This is an upgrade from the previous single 5-kW amplifier to a total power of 32 kW. MIT is responsible for the new digital control system that will independently drive each antenna with arbitrary phase and feedback gain control. A new control system has been designed and parts of it have been tested at National Instruments. In the next year the upgrade will be implemented at JET with plans for a plasma campaign with the new system in the summer of 2013.

Phase Contrast Imaging Diagnostic of Waves and Turbulence on DIII-D and C-Mod

Under the leadership of Professor Porkolab, PSFC research scientist Chris Rost (at the DIII-D tokamak in San Diego) and graduate students on DIII-D and C-Mod have upgraded the Phase Contrast Imaging diagnostics to detect short wavelength (cm to sub-cm), high frequency (up to 5 MHz) modes. The shorter wavelength modes (the so-called ion temperature gradient , transverse electromagnetic and electron temperature gradient modes) should play a fundamental role in determining particle and energy transport, one of the frontiers of fusion research. These experiments are providing important new information on short wavelength turbulence related to energy and particle transport. Ongoing comparisons with state-of-the-art gyrokinetic codes (see description in the section of theory research), in particular GYRO, have provided a critical insight into the physics of electron transport which is key to understanding energy transport in ITER-scale burning plasma experiments in the presence of intense alpha particle heating of electrons. In addition, in Alcator C-Mod, mode-converted ion cyclotron waves have been measured during intense ion-cyclotron resistance heating (see the Alcator C-Mod section in this report). A postdoc has been hired on the DIII-D project who will help with the ongoing experiments, including the procurement and installation of a new cryogenically cooled detector array. Physics graduate student Naoto Tsujii defended his thesis on studying mode-converted ion cyclotron waves in Alcator C-Mod, and a comparison with the state-of-the-art full wave codes AORSA (All Orders Spectral Algorithm, developed by scientists at the Oak Ridge National Laboratory) as well as TORIC (developed at the Max Planck Institute in Garching, Germany) was carried out. It was found that while for small-minority concentration the experimentally measured wave intensity agreed with theoretical predictions, in the high-minority concentration regime significant discrepancies were discovered, indicating the need to extend the full wave codes to include nonlinear physics in the mode conversion process. This work was written up and accepted for publication in the APS journal *Physics of Plasmas*. Regarding turbulence studies, a detailed comparison between experiment and theory was carried out in the so-called linear ohmic confinement regime on C-Mod, and the results could only be explained by invoking the importance of deuterium density (majority ion species) depletion due to the importance of oxygen like impurity species. These results were presented in an invited talk by Professor Porkolab at the recent EPS 2012 meeting in Stockholm, Sweden. Two physics graduate students are continuing this research on C-Mod. Finally, since the present grant period will end at the end of this calendar year, a new proposal was scheduled for submission to DOE in early August, 2012 to continue these experiments on DIII-D for the next four years.

Spinoff Research in the Physics Research Division

Applications of Fusion Technology to Engineered Geothermal Systems

Engineered Geothermal Systems (EGS) offer the potential for a sustainable source of baseline energy. However, successful exploitation depends strongly on the availability of a natural or artificially created underground fracture system that does not deteriorate with time for the circulation of a fluid to heat exchangers. The economical and technical feasibility of EGS depends very much on drilling costs to create the wells and the formation of reservoir heat exchangers. At present the well costs can account for 60% or more of the total capital cost. For EGS to be viable, a significant increase in the rock penetration rates over present mechanical rotary drilling technology is needed along with lower cost. Advances in rock penetration systems may now be possible with efficient (less than 50%) high-energy millimeter-wave (MMW) gyrotron sources originally developed for fusion energy research. During FY2012 Woskov worked with professor Herbert Einstein at the MIT Rock Mechanics Laboratory, Civil Engineering Department, and Impact Technologies win a contract from the DOE Golden Field Office for a phase-one effort to better develop the basis for a field test of the proposed new drilling approach. Work is starting on additional laboratory tests with a gyrotron at the PSFC. An upgrade to the gyrotron system has been designed to allow more power on the rock target to more fully explore the thermodynamics of rock melting and vaporization. Modeling heat transfer calculations have also been carried out in the design of new high-power gyrotron components for the rock test. The PSFC is also partnering with Professor Einstein to study the strength of MMW exposed rocks and resulting vitrified forms that could be used as borehole casing.

Thermal Analysis of GEN IV Nuclear Reactor Materials

The development of Generation IV (Gen IV) very-high-temperature nuclear reactor (VHTR) technology depends on the development and characterization of high-temperature materials that can reliably meet the diverse fuel and structural requirements in extreme VHTR environments. During FY2012 Woskov continued experiments funded by the DOE Nuclear Energy University Program on the development and use of novel millimeter-wave (MMW) thermal analysis tools to address VHTR materials needs. An Undergraduate Research Opportunities Program student participated during the summer of 2011. A pair of 137 GHz heterodyne receivers with orthogonal polarization is used in this work to view specimens inside a furnace for high-temperature materials studies. Real-time non-contact observations were carried out of material temperature, emissivity, displacement, and anisotropy. Measurements have been made of graphite and silicon carbide samples to demonstrate the unique thermal analysis capabilities of millimeter waves. In particular, during the past year, anisotropic material behavior was studied using linearly grooved reactor-grade graphite samples. Results show that there is a significant dependence of the thermal emission on polarization of the radiometer views. These studies show that a potential exists for real-time detection of fracture growth in high temperature reactor structural materials. Studies will be completed at the end of FY2012.

High-Energy-Density Plasma Physics Division

The High-Energy-Density Physics (HEDP) Division, led by senior scientist Richard Petrasso, has carried out pioneering and important studies in the areas of inertial confinement fusion (ICF) physics, HEDP, and laboratory astrophysics. The division designs and implements experiments, and performs theoretical calculations, to study and explore the non-linear dynamics and properties of plasmas in inertial fusion, in astrophysics, and under extreme conditions of density (~1000 g/cc, or 50 times the density of gold), pressure (~1000 billion atmospheres, or 5 times the pressure at the center of the sun), and field strength (~1 megagauss, corresponding to 2.5 million times the Earth's magnetic field).

In ICF, the division collaborated extensively with the Lawrence Livermore National Laboratory (LLNL), where the giant National Ignition Facility (NIF) is expected to achieve ignition (self-sustaining burn) by imploding fuel capsules with a 2-MJ, 192-beam laser. MIT scientists, using MIT-developed diagnostic instruments, had substantial impact this year on the understanding of NIF implosions and on the planning of optimized experiments. The MIT instruments include a high-resolution neutron spectrometer, the "Magnetic Recoil Spectrometer" (Figure 4) for measuring fusion yields and inferring plasma temperatures and areal densities for implosions with deuterium-tritium (DT) fuel; compact proton spectrometers for measuring energy and yield of 14.7-MeV D^3He protons, and inferring areal density, during fusion in fuel capsules containing D and ^3He; and a particle time-of-flight detector for measuring the time evolution of fusion product yields. Compact proton spectrometers record two separate proton lines (the first generated when shock waves coalesce at the capsule center, the second at the time of maximum fusion yield) and thus determine areal densities at two different times. In addition, multiple proton spectrometers are utilized simultaneously at different directions around the capsules to provide a measure of the symmetry of capsule compression both at shock coalescence time and at compression bang time. Collectively, these instruments have revealed this year how laser pointing and other parameters affect the compression, symmetry, yields, and burn histories of NIF implosions, and verified record values of areal density, contributing to the understanding and optimization of implosion dynamics as well as the testing of predictive tools.

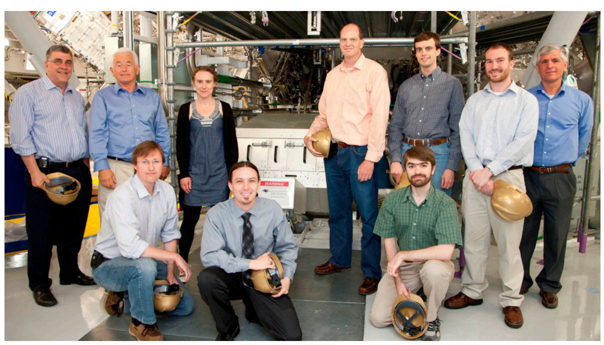

Figure 4. Students and scientists from MIT, Lawrence Livermore National Laboratory (LLNL), and General Atomics (GA) in front of the MIT-developed Magnetic Recoil Spectrometer for neutrons, mounted on the target chamber of the National Ignition Facility (NIF) at LLNL. Back row: Ed Moses, NIF Director; J. Kilkenny, GA; M. Gatu Johnson, MIT postdoc; D. McNabb, LLNL; A. Zylstra and M. Rosenbert, MIT PhD students; J. Larsen, LLNL. Front row: J. Frenje, MIT; D. Casey, recent MIT PhD recipient and soon-to-be LLNL staff member; H. Rinderknecht, MIT PhD student.

The division also collaborated and did its own original research at the Laboratory for Laser Energetics (LLE) at the University of Rochester, where the 30-kJ, 60-beam OMEGA laser and the 4-beam OMEGA-EP laser provide an important test bed for ICF experiments and HEDP experiments. MIT has contributed novel diagnostic instruments and techniques that are used in collaboration with LLE to provide comprehensive diagnostic information about ICF plasmas by making spectral, spatial, and temporal measurements of fusion products. MIT diagnostics and experiments on the OMEGA laser facility support programmatic objectives of both LLE and LLNL, MIT's own scientific goals, and research programs of other external users of the OMEGA laser facility from universities and national laboratories around the world.

MIT goals accomplished at OMEGA this year included the use of proton radiography for studies of the structure and evolution of astrophysically scaled, high-Mach-number plasma jets (including scenarios in which two jets collide); the first observation of Rayleigh-Taylor-instability-induced magnetic fields in laser-driven plasmas; asymmetric magnetic reconnection involving two dissimilar plasma bubbles; and self-generated electromagnetic fields in both direct- and indirect-drive ICF implosions. In addition, MIT and collaborators performed the first basic nuclear physics experiment at an ICF facility by measuring the differential cross section for the elastic neutron-triton (n-^{3}H) and neutron-deuteron (n-^{2}H) scattering at a neutron energy of 14.1 MeV (Figure 5). This work has ushered in a new and exciting field of research, plasma nuclear science, blending the separate disciplines of plasma and nuclear physics, which is now being expanded for studies of nuclear reactions relevant to stellar nucleosynthesis.

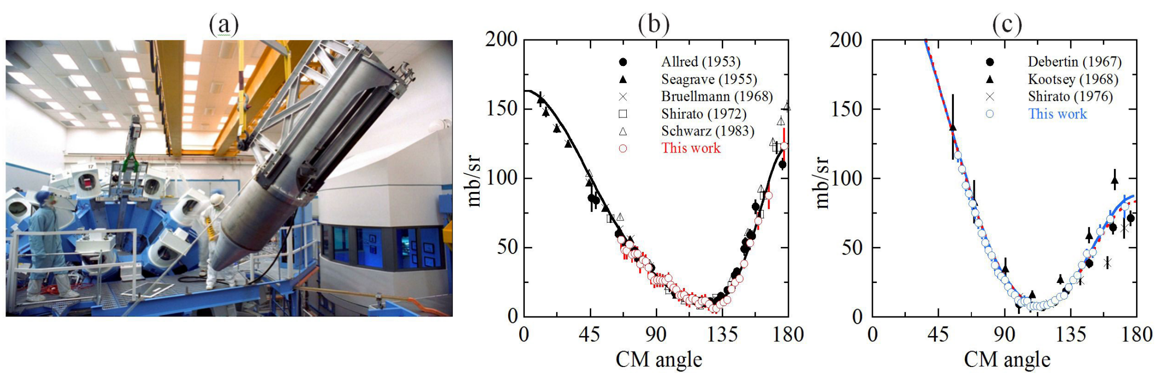

Figure 5. MIT measurements that heralded the beginning of the new field of plasma nuclear science. The MIT-developed charged-particle spectrometer CPS2 (a), shown during installation on the target chamber for the OMEGA laser at the Laboratory for Laser Energetics at the University of Rochester, was used to measure differential cross sections for elastic scattering of 14.1-MeV neutrons with D (b) and T (c) by simultaneously measuring elastically scattered T and D ions from a deuterium-tritium gas-filled inertial confinement fusion capsule implosion. The cross section for n-T scattering was obtained with significantly higher accuracy than achieved in previous accelerator experiments.

MIT also continued its role in plasma physics outreach, organizing all external OMEGA researchers for the fourth time in the annual OMEGA Laser Users' Group Workshop.

This workshop brought together scientists and students from all over the world to discuss current research and to help LLE enhance its facility and procedures for outside scientists.

Beside research results themselves, the HEDP division places equal importance on the training and accomplishments of its seven PhD students and its postdoctoral associate. They are intensely involved in all division projects at LLNL and LLE, and they perform major work on the division's accelerator, where they calibrate MIT-developed diagnostics and do other basic research. One student who finished his PhD this year, Daniel Casey, wrote the first thesis based on NIF experiments and is about to join the NIF staff.

Waves and Beams Division

The Waves and Beams division, headed by Richard Temkin, conducts research on novel sources of electromagnetic radiation and on the generation and acceleration of particle beams. Substantial graduate student involvement is emphasized in all research programs within the Waves and Beams Division.

Gyrotron and Accelerator Research

Gyrotrons are under development for electron cyclotron heating of present day and future plasmas, including the ITER plasma; for high frequency radar; and for spectroscopy. These applications require gyrotron tubes operating at frequencies in the range of 90–500 GHz at power levels up to several megawatts. The Gyrotron Group, headed by research scientist Michael Shapiro, is conducting research aimed at increasing the efficiency of a 1.5-MW, 110-GHz gyrotron with an internal mode converter and a depressed collector. A second goal of this research is to demonstrate operation of the gyrotron at two frequencies, 110 and 124 GHz, to allow greater flexibility in the application of the gyrotron. The gyrotron, a form of electron cyclotron maser operated at high frequency, is used for heating large-scale plasmas in the fusion energy research program. Research on the MIT 1.5-MW power level gyrotron is needed to help plan the upgrade of the heating system of the DIII-D tokamak at General Atomics in San Diego, CA; that system now uses 1-MW power level gyrotrons. In 2011–2012, the group completed an experimental research investigation by measuring the gyrotron cavity modes excited during the start-up, as the voltage increased, of the pulsed gyrotron operating at 96 kV and 42 A. The group found that at the operating point corresponding to the highest output power in the TE22,6 design mode, a high-order axial TE21,6 backward wave mode was excited during start-up and persisted up to a voltage of 70 kV. This surprising result can be explained using new results on the excitation of gyrotron modes obtained using the MAGY code developed by the University. of Maryland and the Naval Research Lab. The researchers have been collaborating with the University of Maryland on the use of their code to explain these unexpected results. These results are being written up for publication. The group is fabricating parts for the next experiment, a two-frequency gyrotron experiment. The gyrotron group is also using the 1.5-MW, 110-GHz power-level pulsed gyrotron to study breakdown in air and in other gases, including the discovery of arrays of filaments in microwave air breakdown. In 2011–2012, the researchers measured the density and temperature of the air-breakdown plasma as a function of pressure and microwave field strength. These results are of great interest in planning future radars.

The group is continuing research on low-loss microwave (170 GHz) transmission lines in collaboration with the US ITER project headquartered at Oak Ridge National Lab. In 2011–2012, the researchers investigated methods for eliminating the unwanted higher-order modes in the transmission line. Theoretical analysis indicates that tilting the mirrors in two miter bends can reduce the power in the unwanted LP11 mode of the transmission line. Elimination of the higher-order modes is needed to properly steer the microwave beams at the exit of the transmission line and to avoid damaging the launching structures. The group also has received two polarizing miter bends for test from General Atomics and initiated measurements of the ohmic and mode conversion loss in these bends.

Research on high-gradient accelerators is focused on high-frequency linear accelerators for application to future multi-TeV electron colliders. The Accelerator Research Group operates the Haimson Research Corporation/MIT 25-MeV, 17-GHz electron accelerator. This is the highest-power accelerator on the MIT campus and the highest-frequency standalone accelerator in the world. The group also participates in a High Gradient Collaboration headed by the Stanford Linear Accelerator (SLAC) National Accelerator Laboratory that includes major labs in the US as well as the European Organization for Nuclear Reserch (CERN) and Institute of Particle and Nuclear Studies (KEK) labs. In 2011–2012, we completed testing of a novel accelerator structure in collaboration with SLAC. We also completed construction of our high-gradient 17-GHz accelerator test facility at MIT. The test facility will be powered by a 17-GHz klystron source currently being modified at Haimson Research. These results are important for planning future accelerators.

Fusion Technology and Engineering Division

The Fusion Technology and Engineering Division, headed by senior research engineer Joseph Minervini, conducts research on conventional and superconducting magnets for fusion devices and other large-scale power and energy systems. The division has broad experience in all aspects of engineering research, design, development, and construction of magnet systems and supporting power and cryogenic systems. The division's major emphasis is on support of the US national fusion program and international collaboration, where the PSFC provides leadership through the Magnets Enabling Technology program.

During the past year, division efforts were focused in three major areas: research and development of very compact, high-field superconducting cyclotron accelerators for detection of strategic nuclear materials, application of high-temperature superconducting materials and systems to fusion magnet systems, and design and analysis of particle detector magnets for high energy and nuclear physics.

A substantial program capability was cultivated during the previous two years with the development of very-high-field, superconducting cyclotrons for medical, security, and research applications. During the past year the division had four active projects funded by the Defense Threat Reduction Agency (DTRA). One was a basic research program called the "Frontier Studies Program" aimed at understanding the physics and technology for sensing fissile materials at long range. This program supports a scientist and two graduate students in fundamental topics applied to this technology. This includes both theoretical and experimental research. The project concludes in July 2012. Among the highlights of this research was the design, fabrication, and testing of a compact superconducting magnet that serves as a prototype for a 10-MeV, weak-focusing cyclotron. The high-current electron cyclotron resonance ion source was also designed, fabricated, and successfully tested during this period. With the conclusion of this three-year program, this research comes to an end because agency funding for this type of research was curtailed under the present national budget situation.

More directed research was supported using DTRA funds through two awards from the Pennsylvania State University Applied Research Laboratory. This work was aimed at developing a new type of inspection system that will result in a rapidly relocatable system for the active interrogation of objects at a distance for concealed strategic nuclear materials. Under these awards two devices were being investigated. The first one was to design and eventually construct and commission a 250-MeV, 1-mA, high-extraction-efficiency, superconducting, isochronous cyclotron proton accelerator. By February 2012, the final design was near completion and approximately $3 million of long-lead components and equipment were ordered and received at MIT in anticipation of starting construction this year. The second MIT contract from the Applied Research Lab was to develop a proof-of-principle device called the Nanotron, a small-scale superconducting cyclotron proton accelerator for portable deployment in various operational scenarios. Unfortunately, DTRA changed research priorities to eliminate both of these remote detection programs. Work was curtailed this spring. The equipment received at MIT for these devices is in storage at the PSFC until DTRA makes a final determination for disposal or reuse.

A third project, also using DTRA source funds, through a contract with Raytheon Integrated Defense Systems, came to a conclusion in September 2011. This program was called the Integrated Standoff Inspection System (ISIS). This is an active-interrogation nuclear radiation detection system that will provide the government with an accurate and reliable inspection system that is fully integrated and automated. Several components designed and built by the PSFC were delivered to Raytheon where they were integrated into the inspection system for initial testing at MIT Bates Laboratory. Components built by the PSFC include the Bremstrahlung beam guidance system and the energy selector system.

Under the fusion magnets base program, we have continued our research efforts on developing magnet technology for devices beyond ITER, and toward the era of a DEMO fusion-based demonstration power plant. Progress has been made in development of very-high-current cables and joints using yttrium and gadolinium-based ceramics second-generation high-temperature superconductors. A cabling design based on twisted-stacked-tapes has been developed and an application for a patent has been made. A conductor was successfully tested up to 10 kA, and low resistance joint designs have been fabricated and twisted. Two graduate students have been conducting thesis research on critical current and alternating current loss measurements of the tapes and conductors and on quick-connect joints.

Other projects concluded this year include design and analysis of superconducting magnets and cryogenic systems for high energy and nuclear physics particle detectors. Under contract to Lawrence Berkeley National Laboratory we carried out studies for the spectrometer solenoid and for the coupling coils for the Muon Ion Cooling Experiment. Further studies were performed for the Thomas Jefferson National Accelerator Facility. One study was to perform a conceptual design for a superconducting detector solenoid for the Hall D experiment (GlueX). Under a second study we performed a finite element structural analysis for the Hall B CLAS 12 detector torus magnets.

A major personnel event occurred this past year when Timothy Antaya, a principal research engineer in the division, retired to start up a company developing compact superconducting cyclotrons for various applications. His company will license several MIT patents developed from funded research programs during the previous eight years.

Educational Outreach Programs

The Plasma Science and Fusion Center's educational outreach program is planned and organized under the direction of Paul Rivenberg, communications and outreach administrator of the PSFC. The program focuses on heightening the interest of K-12 students in scientific and technical subjects by bringing them together with scientists, engineers, and graduate students in laboratory and research environments. This kind of interaction is aimed at encouraging young people to consider science and engineering careers, and feedback has always been extremely positive. Tours of our facilities are also available for the general public.

Outreach days are held twice a year, encouraging high school and middle school students from around Massachusetts to visit the PSFC for hands-on demonstrations and tours. PSFC graduate students who volunteer to assist are key to the success of our tour programs (Figure 6). The experience helps them develop the skill of communicating complex scientific principles to those who do not have advanced science backgrounds.

Figure 6. During Middle School Outreach Day, graduate student Ted Golfinopoulos has a student help him demonstrate plasma properties.

Richard Temkin oversees the PSFC Seminar series, weekly plasma science talks aimed at the MIT community. Graduate students also hold their own weekly seminar series, where they take turns presenting their latest research in a relaxed environment. The PSFC's new associate director, Martin Greenwald, has also helped organize the PSFC's annual Industrial Affiliates Program open house seminars, as well as special visits from dignitaries, including U.S. and Massachusetts lawmakers.

The PSFC has received significant attention from lawmakers this year, facilitated by MIT alumnus Reiner Beeuwkes '67. These included visits by US Senator Sheldon Whitehouse (D-RI), Representative Chris Murphy (D-CT), and Representative Martin Heinrich (D-NM). Governor Patrick, Representative Capuano, and Senator Kerry also visited (Figures 7–8), motivated by the proposed cuts to the domestic fusion program in the 2013 presidential budget. All were guided around the Alcator C-Mod control room and cell to learn more about the benefits of fusion energy.

Figure 7 (left). Massachusetts governor Deval Patrick (right), PSFC director Miklos Porkolab (second from right), and senior officers of the Research, Development, and Technical Employees' Union, at the entrance to the Alcator C-Mod control room.
Figure 8 (right). Senator John Kerry (D-MA) consults with professor Dennis Whyte (front left), as well as research scientists and graduate and undergraduate students in the Alcator C-Mod control room.

Paul Thomas, who retired his in-school Mr. Magnet Program, has not retired his vision of bringing science into elementary school classrooms. He has designed demos that could be easily handled and transported by PSFC personnel. Originally motivated by a desire to bring new demonstrations to his niece's school, Thomas built three tabletop experiments for grades K-4 focused on measuring voltage, building circuits, and testing electromagnets, which have become the foundation of the PSFC's "Portable Elementary Physics (PEP) program." Any PSFC employee or alumni interested in bringing science into the K-4 classroom is welcomed to sign out the equipment (or pieces of it). Thomas provides training, which addresses safety issues involved with bringing MIT equipment into a school.

The PSFC has continued its educational collaboration with the MIT Energy Club, bringing a variety of interactive plasma demonstrations to the MIT energy conference at the Park Plaza Hotel in Boston in March. These events were attended by hundreds of MIT students, as well as business entrepreneurs, who learned about the latest directions of plasma and fusion research.

The PSFC continues to collaborate with other national laboratories on educational events. An annual teacher's say (to educate middle school and high school teachers about plasmas) and Plasma Sciences Expo (to which teachers can bring their students) has become a tradition at each year's APS Division of Plasma Physics meeting. This year Paul Rivenberg has been coordinating educational activities for the Rhode Island meeting in October. Rivenberg is also a member of the Fusion Communications Group, a collaborative of communications professionals from fusion laboratories around the U.S., who meet to discuss ways to best inform the general public about the benefits of fusion energy research.

The PSFC also continues to be involved with educational efforts sponsored by the Coalition for Plasma Science (CPS), an organization formed by members of universities and national laboratories to promote understanding of the field of plasma science (Figure 9). Richard Temkin is working with this group on goals that include requesting support from Congress and funding agencies, strengthening appreciation of the plasma sciences by obtaining endorsements from industries involved in plasma applications, and addressing environmental concerns about plasma science. Like Temkin, Rivenberg is a member of the CPS Steering Committee. He works with CPS on new initiatives, and is editor of the Coalition's *Plasma Page,* which summarizes CPS news and accomplishments of interest to members and the media. Rivenberg also heads a subcommittee that created and maintains a website to help teachers bring the topic of plasma into their classrooms. He also works with the Coalition's Technical Materials subcommittee, to develop material that introduces the layman to different aspects of plasma science.

Figure 9. During a Coalition for Plasma Science congressional presentation about medical uses for plasma, professor David Graves (University of California/Berkeley) engages Chris King (left) of the US House Committee on Science, Space and Technology and Bill Bonvillian (right), director of the MIT Washington DC Office, in a discussion about the value of plasmas for disinfection.

Awards, Appointments, and Promotions

During the past year, a number of PSFC staff have received awards, received appointments, or have been promoted.

Awards

Peter Catto, assistant director and leader of the Theory and Computations research group, received an honorary doctorate from Chalmers University of Technology in a ceremony held in May in Gothenburg, Sweden.

Principal research scientist and group leader Stephen Wolfe was awarded the 2012 Infinite Mile Award by the Office of the Provost, along with the Office of the Vice President for Research and Associate Provost.

At the 2012 International Vacuum Electronics Conference (IVEC) in April 2012, graduate student Emilio Nanni received the 2012 IVEC Best Student Paper Award for "A 250 GHz Photonic Band Gap Traveling Wave Amplifier," co-authored by Michael Shapiro and Richard Temkin.

Graduate student Franco Mangiarotti received the "IEEE CSC Graduate Study Fellowship in Applied Superconductivity," an award given to selected Ph.D. students that do research in applied superconductivity.

Appointments

Alcator Division: Morris Chung was appointed high power systems design engineer; Matthew Reinke was appointed postdoctoral fellow; Christian Theiler and Howard Nathan were appointed postdoctoral associates.

Physics Research Division: Matthew Landreman and Michael Barnes were appointed postdoctoral fellows; Daniel Casey and Ari Li were appointed postdoctoral associates.

Technology and Engineering Division: Craig Miller was appointed senior structural engineer.

Promotions

Alcator Division: Richard Leccacorvi was promoted to mechanical design and fabrication specialist; Thomas Toland was promoted to vacuum shop supervisor.

Graduate Degrees

During the past year, two departments awarded degrees to students with theses in plasma fusion and related areas:

- Nuclear Science and Engineering: Aaron Craig Bader, PhD; Matt Reinke, PhD; Orso Maria Meneghini, PhD; Daniel T. Casey, PhD; Nathan Howard, PhD; Yuri Podpaly, PhD; Joshua Payne, MS; Christian Haakonsen, MS.
- Physics: Zaoto Tsujii, PhD; Ari Le, PhD.

Miklos Porkolab
Director
Professor of Physic