

# PPPL NEWS

The Princeton Plasma Physics Laboratory is a United States Department of Energy Facility

## Hall Thruster Experiments Begin



*In large photo at left, standing next to the Hall Thruster, are, from left (back row), Kai-Mei Fu, PPPL technical associate Dick Yager, PPPL physicist Yevgeny Raitses, visitor Amnon Fruchtman, and Project Head Nathaniel Fisch; (front row) Adam Edwards, Eugenio Ortiz, and Princeton University graduate student Andrei Litvak. In small photo above are Fu (left) and Fisch inside the Hall Thruster. Fu, Edwards, and Ortiz are Energy Research Undergraduate Laboratory Fellowship students who were at the Lab for 10 weeks during the summer.*

**T**o establish the Hall Thruster experiment at the Princeton Plasma Physics Laboratory (PPPL), “all the planets had to be aligned.”

So noted Principal Investigator Nathaniel Fisch as he unfolded how each item — or “planet” — fell into place during the past year to make the project a reality. A Hall thruster is a plasma-based propulsion system for space vehicles.

First, ideas generated in collaborative theoretical research with Professor Amnon Fruchtman of the Center for Technological Education in Holon, Israel, indicated that certain improvements might be made in Hall thrusters. The theoretical effort was funded by the U.S. Air Force, and the theoretical results suggested an interesting experimental campaign.

Second, with the Tokamak Fusion Test Reactor (TFTR) closed down at PPPL, the time was ripe for PPPL to expand nonfusion experimental efforts.

Third, the TFTR remote manipulator tank was available and could serve as the vacuum chamber for the thruster.

Fourth, the area that had housed the S-1 Spheromak at the Laboratory was available and it looked as if the tank would just fit.

Fifth — and probably most importantly — the perfect person to assume a key staff position for the project, Dr. Yevgeny Raitses, was looking for a post-doctoral position. “Yevgeny knew how to build a thruster. He had built one in Russia and then another one in Soreq, Israel for his thesis,” said Fisch, a professor of astrophysical sciences at Princeton University. “Professor Fruchtman and I had been collaborating with the Soreq thruster project, when I noticed a truly exceptional graduate student. Quite frankly, I would not have embarked on the project if we could not have attracted Yevgeny. Fortunately, Yevgeny

**Continued on page 2**

## Thruster

Continued from page 1

was intrigued by the opportunity at PPPL. He has been absolutely key to the project — in designing the laboratory for the Hall Thruster experiment, in figuring out how to build the vacuum system, and in designing and building the prototype thruster and basic diagnostics.”

One of the first obstacles in building the experimental facility was moving the 15-ton, 28-foot by 8-foot manipulator tank. The scientists needed a tank of that size to have a state-of-the-art facility that would be competitive with other thruster facilities. “At first,” recalled Fisch, “people said it couldn’t be done because it was too heavy and would be too costly to move. Also, there was the matter of removing the remote manipulator arm. It was determined that it was possible to move it if some flanges were removed. There was a clearance of what seemed like an inch on both sides; but there was a truck driver who really knew how to park. The crew managed to hoist the tank using a 15-ton crane at the former S-1 site.”

Fisch said there was dedicated support from all corners of the Lab to get the project underway — from checking out possible sites, to ensuring safety, to moving the tank, to getting the facility operational. “There was not a great deal of funding for the project, but everybody seemed to want this to succeed,” said Fisch.

The facility is now host to several student projects, including building a movable probe diagnostic and doing theoretical work on crossed electric and magnetic fields that will be tested on the facility. Also, the U.S. Air Force is now funding experiments in extrapolating the thruster ideas to the microthrust regime. One goal of the research is to improve plasma Hall thrusters, which can be used on

satellites. For example, communications satellites are programmed to remain over one precise geographic location. However, such geosynchronous satellites drift out of place. Hall thrusters could be employed to push a geosynchronous satellite back into its correct position. Other satellites in low-earth orbit are slowed by friction in the upper atmosphere. Hall thrusters could generate the force to compensate for this drag. Presently there are approximately 600 operational satellites in low-earth orbit and over 300 in geosynchronous orbit that could, in principle, employ Hall thrusters. Gradually, these satellites will have to be replaced; consequently, a market may exist for the more efficient Hall thrusters.

Fisch described the potential benefits of plasma-based thrusters over other types of thrusters. “A Hall thruster is a plasma-based propulsion system for space vehicles such as satellites. The amount of fuel that must be carried by a satellite depends on the speed with which it can be ejected by the thruster. Chemical rockets have very limited fuel exhaust speed, but plasmas can be ejected at much higher speeds. Therefore, much less fuel needs to be carried on board,” he said.

Less than \$200,000 was spent to assemble PPPL’s thruster facility and build the first prototype thruster. Fisch takes great pride in this fact and is quick to note that another U.S. facility comparable to PPPL’s reportedly came with a pricetag of \$6 million.

“Our budget was enough to hire Yevgeny, clear out the S-1 space, and move the TFTR manipulator tank. Somehow we also managed on this budget to build a state-of-the-art prototype thruster with basic diagnostics...All the planets were aligned to get this thing to work. We now have a fantastic state-of-the-art thruster facility,” said Fisch. ●

## PPPL NEWS

**Information Services Head:** Anthony R. DeMeo

**Editor:** Patti Wieser

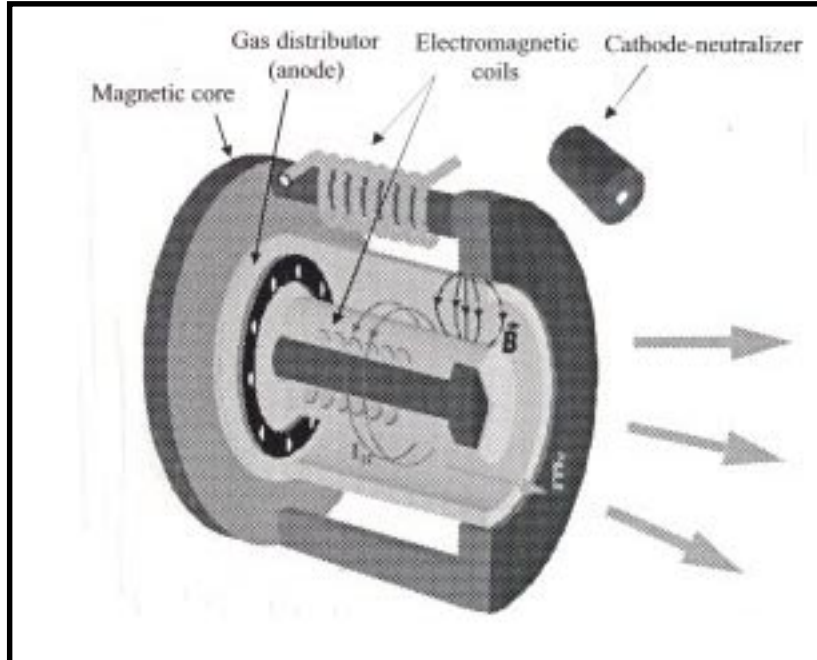
**Photographer:** Elle Starkman

**Layout and Graphics:** Gregory J. Czechowicz,  
Elle Starkman, and Patti Wieser

The **PPPL NEWS** is issued by the Princeton Plasma Physics Laboratory, a research facility supported by the United States Department of Energy and managed by Princeton University. Correspondence and requests to reprint material should be directed to: Information Services, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08543; telephone 609-243-2750; fax 609-243-2751; e-mail [info@pppl.gov](mailto:info@pppl.gov).

# What is a Hall Thruster?

A Hall thruster is a plasma-based propulsion system for space vehicles. 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 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. Together, the magnetic field and a trapped electron cloud serve as a virtual cathode. The ions, too heavy to be affected by the field, continue their journey through the vir-

tual 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. ●

## PPPL Receives Two State Awards



The Laboratory recently received two New Jersey Governor's Occupational Safety and Health Department Recognition Awards. Above right, National Spherical Torus Experiment (NSTX) Project Director Masa Ono (left) and Program Director Martin Peng pose by NSTX after receiving one plaque on behalf of NSTX employees. Above left, Environment, Safety, and Health Division Head Jerry Levine displays the award received on behalf of all PPPL employees. Congratulations, staff!



# PPPL Wins Two “Small Business” Awards

## The Lab Garners the Dwight D. Eisenhower Award and the DOE Small Business Award

**P** PPL recently received the Dwight D. Eisenhower Award from the U.S. Small Business Administration (SBA), as well as the U.S. Department of Energy’s (DOE) Corporate Small Business Award. The awards recognize the Laboratory’s outstanding record in subcontracting to small businesses.

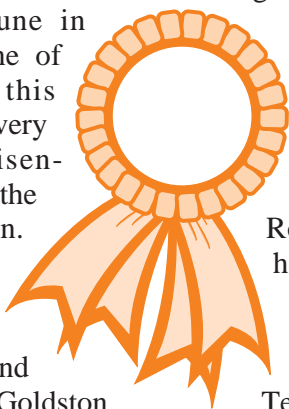
### Eisenhower Award

SBA officials presented the Eisenhower award to PPPL Director Rob Goldston during a procurement conference in June in Washington, D.C. PPPL was one of three to receive the citation this year.

“We are very pleased to receive the Eisenhower Award this year from the Administration. Arlene White and I have been outstanding in their win-win opportunities for our research and businesses,” said Goldston.

Rod Templon is PPPL’s Procurement Head and White is PPPL’s Small Business Liaison. They joined Goldston in accepting the award on behalf of the Laboratory.

Created in 1991, the Eisenhower Award is presented each year to large businesses that operate as federal prime contractors. The award honors those that have excelled in



their use of small businesses as suppliers and subcontractors. Small businesses include small disadvantaged and women-owned firms. PPPL subcontracted nearly \$8.6 million in Fiscal Year 1998 and provided smaller firms with almost \$5.6 million of that total.

PPPL was judged to be the most outstanding of all “research and development” companies nominated from the Small Business Administration’s portfolio of 2,500 large contractors. SBA Commercial Market Representative Andrew Zuber nominated the Laboratory for the award. The Eisenhower Award for 1999 also was awarded in the manufacturing category to Bell Helicopter Textron, Inc., of Forth Worth, Texas, and in the services category to Computer Sciences Corp., of Falls Church, Virginia.

### DOE Corporate Small Business Award

Also in June, PPPL received the DOE Corporate Small Business Award. The award cites the Laboratory for its “outstanding achievement in providing substantial contracting opportunities to small business” during Fiscal Year 1998. DOE Deputy Secretary T.J. Glauthier presented the citation to PPPL Deputy Director Richard Hawryluk during a ceremony in Washington, D.C. PPPL, the DOE Chicago Operations Office, and Brookhaven National Laboratory each received the award this year.

**“We were honored to receive this award from our sponsor, the Department of Energy. It recognizes a great deal of hard work by the Procurement staff in the areas of small business outreach, supplier selection, and contract administration.”**

**—Rod Templon**



From left are Rod Templon, Rob Goldston (holding the Eisenhower Award), and Arlene White.

“We were honored to receive this award from our sponsor, the Department of Energy. It recognizes a great deal of hard work by the Procurement staff in the areas of small business outreach, supplier selection, and contract administration,” said Templon. ●

# Furth Honored at Scientific Symposium



**H**arold P. Furth, former Director of PPPL and one of the “giants” of fusion, was honored during a day-long scientific symposium on June 7 at PPPL. More than 100 people, some from the national and international fusion community, as well as from the Department of Energy and Princeton University, came to the Laboratory to celebrate the life and scientific achievements of Furth. Furth retired on July 1 and became Professor Emeritus of Astrophysical Sciences at Princeton University.

Symposium speakers shared their remembrances of Furth and heralded his contributions to fusion research during the past five decades. Furth, who served as Director of PPPL from 1981 to 1990, launched the record-setting Tokamak Fusion Test Reactor project, which operated for 14 years before closing down in 1997.

A native of Vienna, Furth received a Ph.D. in physics from Harvard in 1960 and worked on controlled magnetic fusion research at the Lawrence Radiation Laboratory (now the Lawrence Livermore National Laboratory) in California prior to joining PPPL in 1967 and being appointed Professor of Astrophysical Sciences at Princeton University. He co-headed the Experimental Division at the Laboratory from 1967 to 1978, when he was appointed Associate Director and Head of the Research Department.

He became Program Director in 1980 and Director of the Lab the following year. Furth holds 20 patents, primarily in the areas of controlled magnetic fusion technology and metal forming with pulsed magnetic fields, and has published more than 200 technical papers. ●



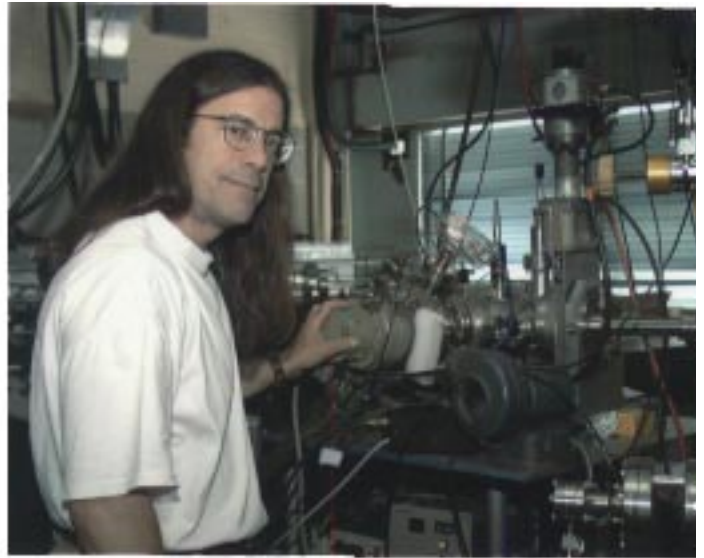
# Teachers Operate Fusion Machine at PPPL

**T**his summer, teachers participating in PPPL's "Plasma Camp" conducted experiments on a small fusion machine at the Laboratory. Three of the 14 teachers enrolled in this year's Plasma Camp, officially called the Plasma Science and Fusion Energy Institute, studied plasma behavior in the Current Drive Experiment-Upgrade (CDX-U).

Working with scientists at the Laboratory, one teacher operated the hydrogen-fueled machine, the second evaluated the temperature and density of the plasma, and the third analyzed impurities in the plasma recorded with a soft X-ray pinhole camera taking pictures inside the machine. The experiments involved changing the magnetic field level to gauge the effect on the plasma.

"This is the first time that I know of where teachers actually ran an experimental fusion device and conducted research the same way our scientists do," said PPPL's Andrew Post Zwicker, a Senior Program Leader in the Laboratory's Science Education Program. Post Zwicker designed and led the program.

The Institute is an intensive two-week summer program of lectures, lab work, and curriculum design for high



*Marc Sabb, a Plasma Camp participant who teaches at Canyon del Oro High School in Tucson, Arizona, stands next to an X-ray spectrometer, which takes a spectrum of multiple emission lines from the plasma.*

school physics teachers who were selected nationwide. This is the second summer the Laboratory hosted the



*The teachers who participated in this year's Plasma Camp and the leaders of the workshop are, from left, Michael Liebl, of Nebraska, Peter Gaudiano, of Louisiana, David Taylor, of Alabama, Sophia Gershman, of New Jersey, Tony Romanello, of Utah, Miguel Villanueva, of Massachusetts, Stephanie Connors, of Louisiana, Nick Guilbert (co-leader of the workshop), of New Jersey, Marc Sabb, of Arizona, Fran Leary, of New York, Randy Brown, of Vermont, Andrew Post Zwicker (co-leader and designer of the workshop), Violeta Grigorescu, of New Jersey, Dwight Johnston, of Pennsylvania, Steve Brehmer, of Minnesota, and Fred Oswald, of California.*

program. The three who did the CDX-U experiments participated in last year's program and returned this year to assist with the workshop. The returning teachers include Sophia Gershman of New Jersey, the Rev. Michael Liebl of Nebraska, and Marc Sabb of Arizona. The program concluded on July 30. The Institute's goal is to help teachers develop curricular materials for introductory physics teaching, making the subject of plasma and fusion accessible to high school pupils. Gershman noted that PPPL's program treats physics teachers as colleagues.

"At the Plasma Institute, they teach us on a graduate level and create a stimulating atmosphere where we can develop curriculum materials appropriate for our students," she said. ●

# Princeton Large Torus Removed and Scrap Sold

**D**uring the summer, an independent wrecking crew came to PPPL and lugged away 212 tons of metal from the Princeton Large Torus (PLT) test cell — and paid for the privilege.

## Removing the Device

Mercer Wrecking and Recycling Corporation won the bid for the removal of PLT and spent 12 weeks breaking apart PLT and hauling it away for scrap metal. The PLT tokamak was made of copper poloidal field and toroidal field coils, insulating compound, and stainless steel. The project entailed removing the device and its supporting platform down to the concrete floor.

Prior to the removal, PPPL staff disconnected all electrical and mechanical systems from the PLT tokamak, which was not contaminated. The PLT operated at PPPL from December of 1975 until December of 1986.

The removal of PLT clears the facility for future projects at the Laboratory. ●



*PPPL'ers take one last look at PLT before it is taken apart and sold for scrap. From left are Alex Ilic, Joel Hosea, and Masa Ono.*

## PPPL's Towner Awarded for Emergency Services Work



**P**PPPL's Harry Towner recently received the Stark & Stark EMS Recognition Award. Towner is an emergency medical technician with the Plainsboro Rescue Squad. He was honored by Stark & Stark, a law firm, for 20 years of tireless work and service for the squad and the residents of Plainsboro. ●





# More Than Just a Summer Job



*Undergraduate students who participated in PPPL summer programs this year are, from left, (kneeling) Sabrina Turner, David Schuster, Jesse Hwang, Damon Tuney, Kai-Mei Fu, Amaria George; (middle) Jonathan Nazemi, Vyacheslav Lukin, Geoffrey Brumfiel, Shinya Kurebayashi, Tim Miller, Anthony Mrozcowski, Mike Mulligan, Karl Leuenroth, Adam Edwards; (back row) Brian Pierce, Eugenio Ortiz, Remik Ziemlinski, Jeff Nine, Steve Little, David Hannum, Brian Kirby, Thawatchai Onjun, and Warren Welch.*

In an effort to prepare the next generation of scientists and engineers, PPPL staff served as mentors to 16 undergraduate and graduate college students this summer. The mentors and students came together through three summer programs organized by PPPL's Science Education Program. The programs include the National Undergraduate Fellowship (NUF), the Energy Research Undergraduate Laboratory Fellowship (ERULF), and a newly implemented collaboration among PPPL, Florida A&M University, and Fisk University aimed at students in Master's degree physics programs.

PPPL Senior Program Leader Pamela Lucas said, "These undergraduate and Master's research programs are designed to prepare future scientists by providing outstanding students with an opportunity to conduct research in the disciplines that comprise the plasma sciences, in general, and fusion research, in particular. It also provides our researchers with capable summer assistants." Lucas oversaw the summer student programs.

## NUF

Through the NUF program, established in 1992, fifteen undergraduate students were selected to participate in the nationwide program this year. A committee with representatives from PPPL, General Atomics, and other institutions made the selections. Six worked on projects at PPPL, while the remaining nine went to various institutions for internships.

PPPL physicist Martha Redi served as a mentor to NUF participant Ahmed Diallo, a University of Montana student who is originally from Burkina-Faso in Africa.

"I've been fortunate to have three NUF students work with me during the last few years," said Redi. "Each opportunity has been enjoyable and worthwhile, both personally and professionally."

Redi characterized the students as "able and energetic and pleasant to work with" and noted that they often make such a contribution to the project that they are included as authors on the project's papers. For instance, Diallo is one of the authors of the "Robustness and Flexibility in the "NCSX: Global Ideal MHD [magnetohydrodynamics] Stability and Energetic Particle Transport" paper that was presented at the 12th International Stellarator Workshop in September in Madison, Wisconsin. NCSX is the proposed National Compact Stellarator Experiment.

"Ahmed has made a great contribution. Without him, I would only have been able to do a fraction of the work," said Redi.

Diallo joined the stellarator team, attending meetings and participating in teleconferences. Redi and Diallo ironed out computing problems that involved moving programs across platforms, which required some program conversion. "What works well is to bring the student into the project I'm actually working on, giving that student the same things to do that I'm doing," said Redi.

Diallo, who was given computer and desk space in the Lab and spent many hours consulting with Redi, said the work was intensive. He often spent evenings at the library on Princeton's main campus continuing his research. Said Diallo, "Working with Dr. Redi has been great. She has taught me a lot, especially about how to organize. I was really challenged by the project." He added that one of his



biggest discoveries was how a research team designs a machine such as a stellarator — through intensive and occasionally heated discussion.

## ERULF

ERULF is a national program offered by the Office of Science at the U.S. Department of Energy (DOE). PPPL, one of 10 laboratories across the U.S. participating, hosted eight undergraduate students this year. PPPL's Ronald Hatcher was a mentor for two ERULF students, helping them with computer and engineering projects.

Pittsburg State University senior Brian Kirby worked on converting an old code for tokamak equilibria for use on a UNIX workstation. University of Texas senior Michael Mulligan assisted in the design of high-power fast switching diode arrays for a Magnetic Reconnection Experiment power system upgrade, which involved some analytical and simulation work.

Said Hatcher of his role as mentor, "It is satisfying in that hopefully you help these students move from academic work where they can find answers to problems in textbooks to something more involved where they are finding solutions and solving problems on their own."

Kirby, a physics major at the Pittsburg, Kansas university, said, "This was a great learning experience and a lot of fun." Mulligan agreed and noted that the projects benefit students other than those enrolled in plasma physics programs. "This was a very good experience for me because the work supports experiments at the Laboratory, but it was not strictly plasma physics research," said Mulligan, an electrical engineering student.

Kirby and Mulligan presented their work, "Porting and Benchmarking the PPPL FQ Equilibrium Code" at the Faculty and Student Undergraduate Research Educa-



From left are PPPL's Ron Hatcher (pointing), and students Brian Kirby (sitting), and Michael Mulligan.



Student Ahmed Diallo (left) works with physicist Martha Redi.

tional conference at Argonne National Laboratory this summer. Hatcher also attended the conference.

## Collaboration

Through a collaboration with Florida A&M and Fisk Universities, PPPL is working with faculty and students from the two institutions whose highest physics degree is a Master's. As part of the collaboration, Kyrion Williams and Erick May, two graduate students under Professor Joseph Johnson at the Center for Nonlinear and Nonequilibrium Aerospace at Florida A&M University, spent three weeks at PPPL this summer. They were involved in setting up a laser-induced fluorescence diagnostic on PPPL's Current Drive Experiment-Upgrade (CDX-U). Florida A&M provided the laser, optics, and detector for the diagnostic, and PPPL provided the data collection electronics as well as on-site coordination and physics support. Physicist Andrew Post Zwicker and CDX-U Co-head Robert Kaita served as the PPPL mentors. "In a relatively short time, the hardware was made operational and the data archiving was set up to enable offsite access," said Kaita. "We look forward to continuing our fruitful collaboration as our colleagues at Florida A&M and Fisk are able to analyze their data remotely in the months ahead."

Both the NUF and ERULF programs are funded and sponsored by the DOE, while the collaboration project is internally sponsored. Other projects the students were involved in for the summer programs ranged from working on the Hall Thruster diagnostics and modeling to computer modeling and computer programming. And while it benefitted students, it was a real bonus for mentors. "Having a summer student work with me increases the work done by a factor of about three, and it's also more fun," said Redi. ●

# The Troops Rally for Safety ...and Ice Cream



*Clockwise, from bottom left, students and staff mingle during the ice cream social; David Gates (left) orders the Rocky Road flavor from PPPL Director Rob Goldston (in hat) while Deputy Director Rich Hawryluk watches; Sabrina Turner (left), an Energy Research Undergraduate Laboratory Fellowship student, and Joe Franchino sample the toppings; Erik Perry (right) dishes up a bowlful of ice cream for Jon Menard. — Photo collage by Elle Starkman*

On one of the hottest days of the summer, the Laboratory celebrated its safety success by breaking out tubs of ice cream in the Lobby.

“The ISM [Integrated Safety Management] review in June was very successful and we owe much of our success to J.W. Anderson and to his group. We passed the review with absolute flying colors,” said PPPL Director Rob Goldston, who had taken a break from scooping to address the troops during the July 28 party. The party was provided by the Laboratory to thank employees for their hard work and commitment to ISM.

During the employee bash, Goldston also acknowledged the following awards: the Small Business Administration Dwight D. Eisenhower Award for Excellence for

Exemplary Utilization of Small Business, presented to Rod Templon and Arlene White; the New Jersey Governor’s Occupational Safety and Health Department Recognition Award, presented to Martin Peng and Masa Ono on behalf of NSTX employees; and the New Jersey Governor’s Occupational Safety and Health Recognition Award presented to J.W. Anderson on behalf of all PPPL employees.

Goldston also noted that the 1999 Fusion Summer Study meeting in Snowmass, Colorado, was an “amazing accomplishment,” thanks to the efforts of Rich Hawryluk and John DeLooper. “It’s a good time to eat ice cream, beat the heat, and realize that fusion is important and people seem to be recognizing this fact,” said Goldston.



# DACW Takes Up Collection for Womanspace

**D**uring the spring, the Laboratory's Director's Advisory Committee on Women (DACW) organized a collection for Womanspace, an area shelter for abused women. On June 7, Committee Chairperson Molly Tompkins and DACW member Mary Ann Brown presented the items to Womanspace Executive Director Pat Hart and Womanspace Residential Manager Peggy Weimer. The DACW collected clothing, toys, and household items. The collection filled a van brought by the Womanspace officials. Also given was a monetary donation. Brown organized the effort at the Laboratory. At far right, Tompkins hands a box of donations to DACW member Phyllis Roney (back to camera). At right, Mary Ann Brown (left), Hart (middle), and Weimer take a break from loading the van. ●

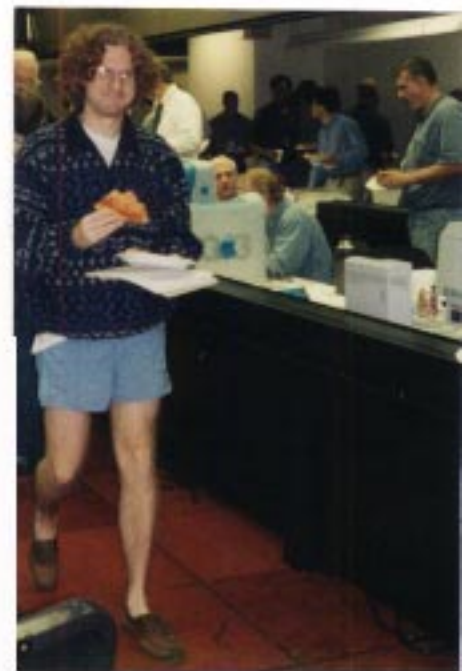


The U. S. Department of Energy's (DOE's) National Laboratories house world-class facilities where more than 30,000 scientists and engineers perform cutting-edge research spanning DOE's science, energy, national security, and environmental quality missions.

Interested in the latest achievements of the National Laboratories? Then visit the DOE Pulse at: <http://www.ornl.gov/news/pulse/>.

DOE Pulse is distributed twice each month. Each issue includes research highlights, updates on collaborations among laboratories, and profiles of individual researchers.

# NSTX Experimental Operations Underway



The National Spherical Torus Experiment (NSTX) and Engineering and Technical Infrastructure Departments hosted a pizza party for all staff in the Control Room on September 16 to celebrate the successful completion of the NSTX construction tasks and the restart of plasma operations. At left everyone enjoys the pizza. At right, graduate student Sean Strasberg gets a slice during the lunch-time celebration. At top left, some members of the NSTX Operations team pose by the project display in the Lobby. From left are Mike Anderson, Bill Blanchard, Glenn Pearson, Ray Camp, Joe Winston, Colin McFarlane, Tom Czeizinger, Jerry Gething, and Bob Herskowitz. At top right is the interior of the NSTX during a plasma shot on September 20. The NSTX experimental campaign is underway! ●

