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HOTLINE

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# 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 this summer. The Hall Thruster is in the space that formerly housed the S-1 Spheromak.*

To establish the Hall Thruster experiment at 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 (**see sidebar on page 3**).

First, there were ideas generated in collaborative theoretical research with Professor Amnon Fruchtman of the Center for Technological Education in Holon, Israel, which 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, 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 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

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## Thruster

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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 project was moving the 15-ton, 28-foot by 8-foot manipulator tank. The scientists needed that size tank in order 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. But Victor Garzotto said, 'just slide it out.' 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. "J.W. Anderson and Steve Paul were helpful in figuring out the best site for the project; Ray Camp and Jerry Levine made sure the project was safety compliant; management, in particular Rich Hawryluk, supported the experiment; Dick Yager provided expert technical assistance; Assistant Professor Edgar Choueri of the University's MAE Department provided helpful advice; and Victor Garzotto assisted in getting the tank moved into the former S-1 space. Larry Dudek was enormously helpful in orchestrating the whole move." Fisch also credits his immediate management, Phil Efthimion and Plasma Science and Technology Department Head Stewart Zweben. "Phil and Stewart are a lot of fun to work with and have played key roles in making sure this project succeeded," he said.

Fisch described the project as "a tremendous amount of fun" that has allowed him to get acquainted with so many other PPPL'ers. "Before Yevgeny came, I'd been hiding in the Theory Division for 20 years. Since the project was initiated, I've met more people in the Lab than I did during my first two decades here," he said.

The project is now host to several student projects. First-year graduate student Leonid Dorf built a movable probe diagnostic. Thesis student Andrei Litvak is doing theoretical work on crossed electric and magnetic fields that will be tested on the facility. Princeton University junior, Eugenio Ortiz, helped design the thruster magnetic field for his junior paper. With experiments now underway, the facility is host to several undergraduate summer projects. 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 make improvements in 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.

Less than $200,000 was spent to assemble PPPL's thruster facility and to 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. The assembly of PPPL's device was funded as a Laboratory Program Development Activity. According to Fisch, "This 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. ●


## HOTLINE

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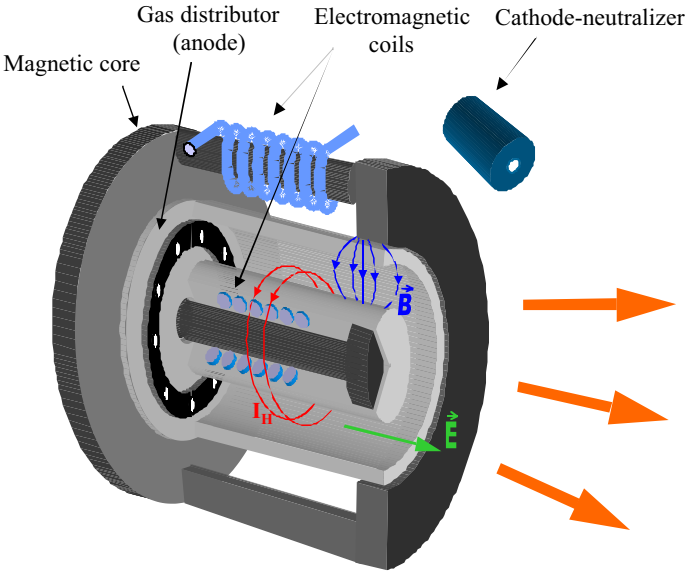
# Hall Thrusters: An Emerging Technology

by Anthony DeMeo

The Hall Thruster is a plasma-based propulsion system for space vehicles that was invented in the late 1950s. It has been developed primarily by the Russians. During the past 20 years, the Russians placed in orbit about 100 Hall Thrusters. However, the vast majority of satellites worldwide have relied on chemical thrusters and, to a lesser extent, ion thrusters.

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 (see figure). The ions, too heavy to be affected by the field, continue their journey through the virtual cathode. The movement of the positive and negative electrical charges through the system results in a net force on the thruster in a direction opposite that of the ion flow.

Generally, thrusters are used to compensate for atmospheric drag on satellites in low-earth orbit, to reposition satellites in geosynchronous orbit, or to raise a satellite from a lower orbit to geosynchronous orbit. As a basic rule of thumb, for each kilogram of satellite mass one or two watts of on-board power are available. PPPL's Hall Thruster consumes several hundred watts of power, making it suitable for a satellite with a mass in the range of a few hundred kilograms. PPPL physicists believe there may be a market for Hall Thrusters operating at 1,000 watts or more, but say predictions are difficult to make. They also speculate about the development of Hall microthrusters with power outputs in the 100-watt range, useful for very small satellites with masses of 50 to 100 kilograms. One could envision a large satellite disbursing hundreds of the smaller ones for the exploration of a planet or as a spaced-based radar array. The Hall Thruster may be too power hungry for this application, but answers to these and other questions may emerge from research now underway at PPPL.

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

Initial results indicate that PPPL's Hall Thruster operating at 900 watts does so with an efficiency that is comparable to state-of-the-art thrusters. Planned upgrades include segmenting the thruster. Each segment would be held at a specific electric potential, enabling researchers to control exactly where the voltage drop occurs along the length of the thruster. PPPL's Hall Thruster was designed with a modular configuration so as to allow multiple thruster geometries that could be diagnosed in detail easily. This includes the ability to measure precisely in three dimensions how the thrust varies with position. This information could be used to arrive at techniques to narrow the plume and obtain more control over the outflow from the thruster, possibly improving its efficiency.

These capabilities may allow PPPL to advance the Hall Thrusters, making them more attractive for commercial and military applications. ●

# Keep on Learning!

**Staff Continue Self Development through Training, Books, and Conferences**

NSTX Administrator Joanne Savino recently completed a 10-week course on Office Management and Technology at Mercer County Community College (MCCC). She learned about business writing, picked up pointers on computer software she uses daily, and discovered more efficient ways of managing an office.

Site Protection Division Training Coordinator Kevin Rhoades finished an MCCC management course, which included 15 workshops that are part of the nationally recognized Zenger-Miller Leadership 2000 management series.

Some PPPL managers have taken on the task of reading the book, *A Force for Change: How Leadership Differs From Management*. In addition, employees have completed computer courses, participated in diversity training, and attended conferences about topics in their fields.

Through these activities, all are continuing their self development.

"Self development is a continuous process that helps to promote a creative environment and encourage innovation and enhancement of work performance of each individual at the Laboratory," said PPPL Director Rob Goldston in a recent memo to staff.

The Lab Director supports participation in professional development. "Everyone is encouraged to examine his or her performance and to take ownership of his or her personal development. Remember to meet with your supervisors to discuss the type of development activity that will boost your individual and your team accomplishments at PPPL," he said.

Self development activities include self education through studying textbooks and professional publications, as well as formal training through seminars, lectures, and courses. According to PPPL policy, exempt staff may dedicate up to 10 percent of their time in developmental and outreach activities and bi-weekly staff may dedicate up to 5 percent.

## Investing in Yourself

"Think about investing in yourself because you are also investing in PPPL," said Human Resources Deputy Head Susan Murphy-LaMarche.

She added that because of Savino's recent accomplishment, the latter is "better off and NSTX is better off." When Savino came to Human Resources to discuss her self development, she wanted to identify what was necessary to do the best job possible for NSTX, said Murphy-LaMarche.

*Joanne Savino*

Savino attended the course at MCCC for one day a week for 10 weeks, and shared much of her newly gained knowledge, such as business writing techniques, with her work group at NSTX. While taking the course, she put in extra effort during her four days a week at work. "I had to work a little harder to catch up — but it was worth it," said Savino, adding that her group was supportive of her self development efforts.

NSTX Project Director Masa Ono said, "With everyday pressure at work and at home, it is not always easy for us to undertake new educational activities. This makes me particularly appreciative of the fact that Joanne has successfully completed the course on the Office Management and Technology at Mercer County Community College. What Joanne brings back in terms of new knowledge through her training will not only benefit her, but all of us working with her directly or indirectly. As I have come to appreciate through working on the NSTX Project, the people resource is what makes PPPL a special place, a premier fusion research institution highly respected worldwide. So Joanne's achievement is a very good reminder for all of us about the importance of professional development."

Rhoades, a captain for the Site Protection Division, continues to profit from the course that he completed in

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## Self Development

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two semesters. "I thought the course was very informative and has helped me immensely as a supervisor. We conducted practice sessions and role playing about the topic of the evening during each class," said Rhoades. "I often review my course notes in preparation for normal administrative and operational duties. I believe I have become a better supervisor since completing this course. I would recommend it to anyone interested in improving their professional development."

**"The important thing is that we keep learning."**
**— Susan Murphy-LaMarche**

Murphy-LaMarche stressed that there are many ways for employees to develop themselves. Examples are single-session or multiple-session training courses, conferences, books, management training, and computer instruction. Since the activities are varied, some may take a longer period of time to complete.

"The important thing is that we keep learning," said Murphy-LaMarche. ●

*For information about self development, please contact Human Resources Deputy Head Susan Murphy-LaMarche at ext. 2224 or e-mail her at smurphy@pppl.gov.*


# PPPL Garners DOE Small Business Award

*From left are PPPL Procurement Head Rodney Templon, PPPL Small Business Liaison Arlene White (holding the DOE Corporate Small Business Award), and PPPL Deputy Director Richard Hawryluk.*

PPPL recently received the U.S. Department of Energy's (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 on June 9 during a ceremony in Washington, D.C. PPPL, the DOE Chicago Operations Office, and Brookhaven National Laboratory each received the award this year.

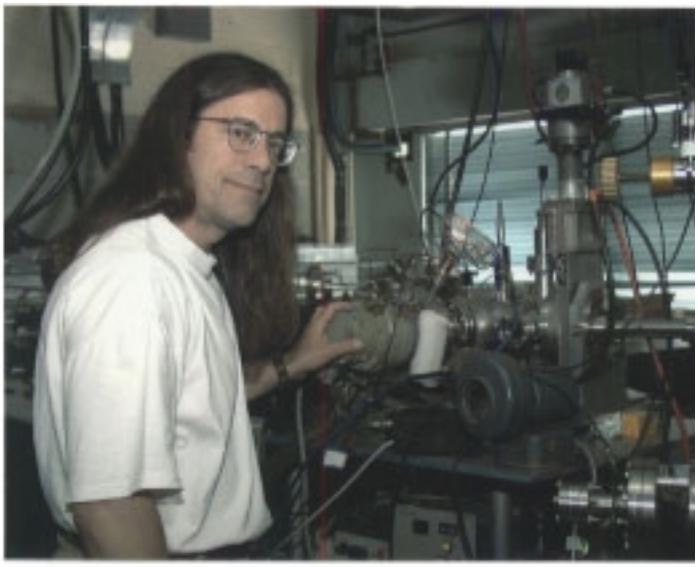
"We were honored to receive this award from our sponsor, the Department of Energy. It recognizes a great deal of hard work by the Procurement staff in the areas of small business outreach, supplier selection, and contract administration," said PPPL Procurement Head Rodney Templon. Templon, Hawryluk, and PPPL Small Business Liaison Arlene White represented the Laboratory during the awards presentation. ●

# Teachers Operate Fusion Machine at PPPL

This 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.



*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.*

The Institute is an intensive two-week summer program of lectures, lab work, and curriculum design for high school physics teachers who were selected nationwide. This is the second summer the Laboratory hosted the 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. ●

*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.*

# Peng Honored by Oak Ridge for Work on NSTX

NSTX Program Director Martin Peng has been selected to receive an Oak Ridge National Laboratory (ORNL) Significant Event Award (SEA). The award recognizes Peng's work on NSTX. His specific contributions were expressed in the nomination as follows:

"Dr. Martin Peng was appointed as the NSTX Program Manager and is on relocation to PPPL in fulfilling that role. As program manager he is responsible for developing the NSTX research program, which involves collaborations with 14 installations. For over ten years he worked tirelessly on both the physics and engineering issues involved in the ST [spherical torus] concept. His personal development of the theories of low aspect ratio equilibrium, internal stability at high beta, and scrape-off layer stability caused interest to be cultivated in the low aspect ratio regime. Although he had very few supporters at first, it did not stop him from working patiently to convince the fusion community of the potential of ST as an attractive, cost-effective fusion reactor and development path for fusion." Peng is an ORNL employee on a long-term assignment at PPPL.

Congratulations, Martin! ●

# Batter Up! PPPL Softball Team Completes Season

*Above, Tony Bleach takes a swing at the ball during one of the games. At right are 1999 PPPL Softball Team members (from left), standing, Tony Bleach, John Wheeler, Colin McFarlane, Sean Strasberg, Troy Carter, Kyle Morrison, Josh Carter, Phil Snyder, and Adam Rosenberg; kneeling, Jef Spaleta and Prentice Bisbal. Not pictured are Dave Cylinder, Jill Foley, Nick Guilbert, Dave Haas, Bob Heeter, Pat Hullfish, Steve Jardin, Jay Johnson, Russell Kulsrud, Cathy Manfredi, Jon Menard, Don Monticello, Hyeon Park, Steve Paul, Andrew Post Zwicker, Ed Synakowski, and Stewart Zweben. The team had four wins out of 13 games this summer before the August playoffs. Go team!*

# 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. ●