DOE Princeton Plasma Physics Laboratory

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PPPL news

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

Twenty-Year DOE Plan Announced

International Fusion Project Tops List

ITER, a major international magnetic fusion research project, tops the list of priorities for the Department of Energy's (DOE's) Office of Science 20-year science facility plan. The project is an international collaboration to build a magnetic fusion device capable of producing a self-heated or burning plasma. The fusion power produced by ITER will be 10 times greater than the external power added to the plasma. The U.S. is one of the international partners.

During a November 10 speech at the National Press Club, U.S. Energy Secretary Spencer Abraham outlined the plan, a roadmap for future scientific facilities to support the Department's basic science and research missions. The plan prioritizes new, major scientific facilities and upgrades to current facilities. Secretary Abraham listed 28 facilities, which cover the range of science supported by the DOE's Office of Science, including fusion energy, materials science, biological and environmental science, high energy physics, nuclear physics, and advanced scientific computation.

"This plan will be the cornerstone for the future of critical fields of science in America. These facilities will revolutionize science — and society," said Abraham. "With this plan our goal is to keep the United States at the scientific forefront."

PPPL Director Rob Goldston described the DOE's plan for future facilities as "visionary," noting that the Department is the primary steward for many areas of science, in particular, plasma physics and fusion energy research, which is conducted at PPPL.

"The recently completed DOE strategic plan, and this 20-year facilities plan, together define an exciting future path for the fusion research community to perform

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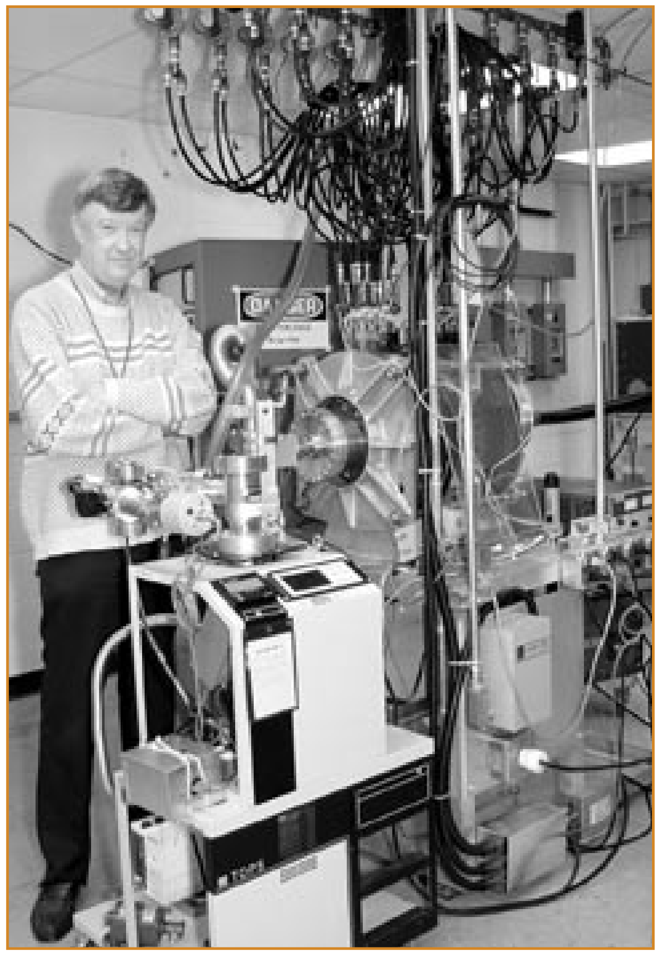
PPPL Researchers Study Plasma Sterilization



John Schmidt

Hundreds of billions of plastic food and beverage containers are manufactured each year in the U.S. All of these packages must undergo sterilization, which at present is done using high temperatures or chemicals. Both of these methods have drawbacks. Chemicals often leave a residue that can affect the safety and taste of the product, and produce undesirable waste. Heat is effective

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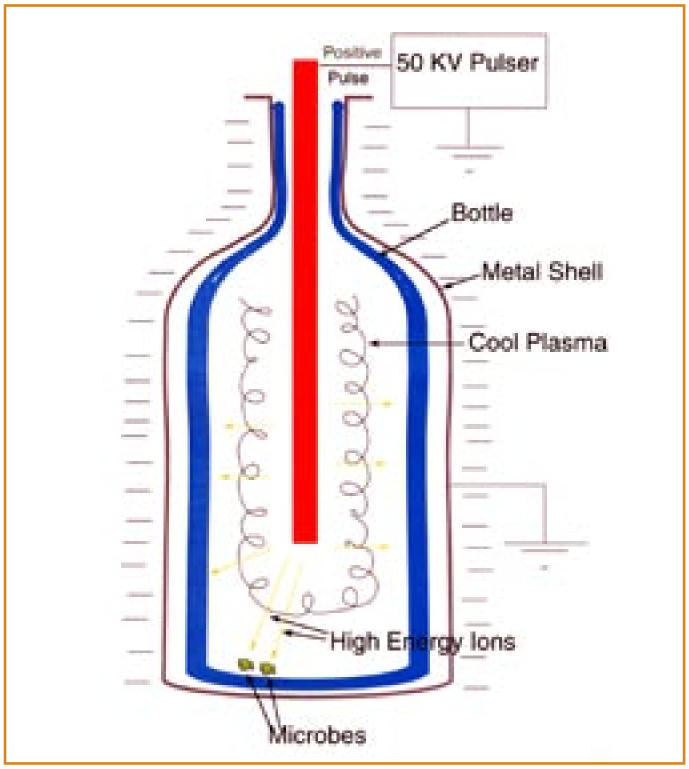
Above at the plasma sterilization experiment are, from left, Gary D'Amico, Nevell Greenough (kneeling and looking into sterilization apparatus) and Lewis Meixler. The experiment is on the first floor of the L-wing. Below is a sketch of the Plasma Sterilization apparatus.



Sterilization

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and sufficiently rapid, but necessitates the use of costly heat-resistant plastics that can withstand sterilization temperatures. What if a new method could be found that eliminated the need for chemicals or heat-resistant plastics?

Plasma just might be the answer. At PPPL, a team is conducting a small-scale research project studying plasma sterilization. This method, if successful, could be used to sterilize food and beverage containers, leading to an enormous savings — potentially hundreds of millions of dollars annually for a large soft drink manufacturer.

New Plasma Approach

"We have experiments indicating it is possible to kill microbes using a new plasma approach," noted John Schmidt, lead scientist of PPPL's Plasma Sterilization project. Schmidt cautioned, however, that the research is preliminary. "These experiments need to be published, peer reviewed, and repeated by other researchers to assure reliability. Physics research will be followed by considerable development work to arrive at a practical system for assembly line use," said Schmidt, who has been awarded a patent for a plasma sterilization system [see apparatus shown in sketch at left]. Working with Schmidt are PPPL Technology Transfer Head Lewis Meixler, physicist Doug Darrow, engineer Nevell Greenough, and technicians Gary D'Amico and Jim Taylor.

The PPPL Experiment

To get started, PPPL researchers modified old equipment that had once been used to study radio-frequency (RF) waves for fusion applications. It consisted of a vacuum chamber equipped with an RF source. A metal sphere measuring one inch in diameter was mounted at the center of the chamber. In preparation for experiments, the sphere is removed and sent to a commercial biological testing laboratory in Hightstown where a known number

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PPPL NEWS

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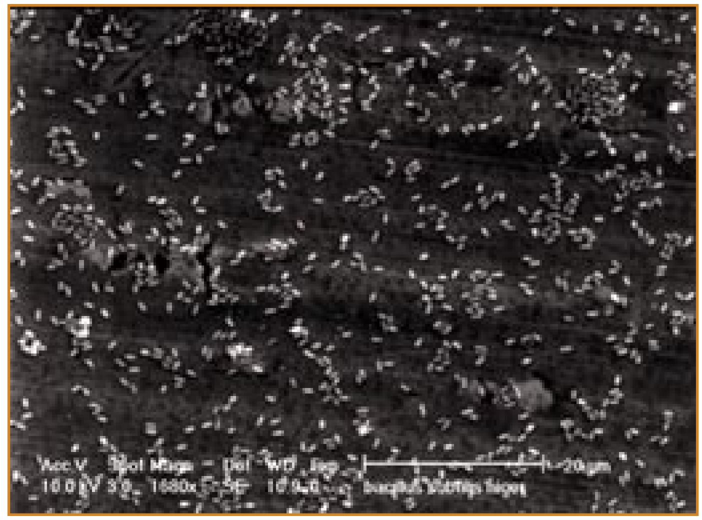
of spores of bacillus subtilis, a non-toxic microbe commonly used as a standard in lab testing, are placed on its surface. Following an experiment, the sphere is returned to Hightstown where technicians determine the number of spores killed in the process.

Fusion experiments at PPPL have generated plasmas with temperatures in the hundreds of millions of degrees centigrade. For killing spores, the PPPL researchers start with "low-temperature" hydrogen plasmas in the range of 50,000 degrees centigrade. At that temperature, the hydrogen ions are moving much too slowly to kill spores quickly. Rapidly pulsing a 50-kilovolt potential between the sphere and the vacuum chamber solves the problem. The sphere is charged negatively and the vessel is at ground. Under these circumstances, the positively charged hydrogen ions accelerate toward the sphere in pulses energetic enough for the ions to pierce the hard outer shell and soft inner core of the spore. Recent experiments employed 4,000 10-microsecond pulses, which reduced the population of live spores by a factor of 100-1000 — the kill ratio.



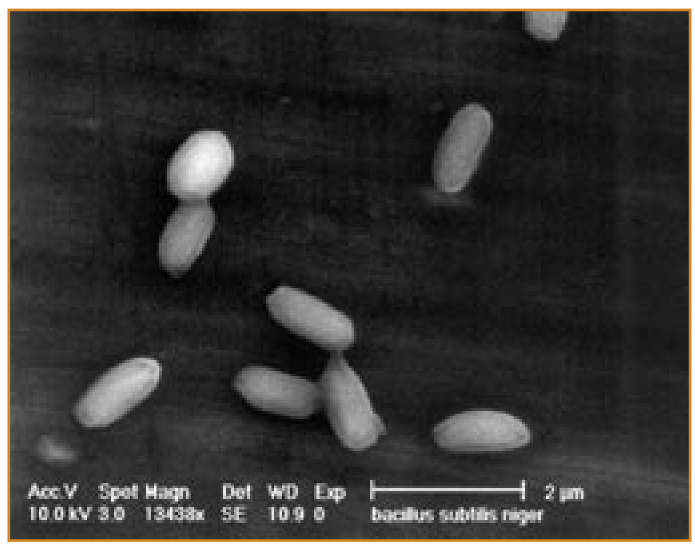
Shown is an example of the spores used in the plasma sterilization experiment. The image, made by a scanning electron microscope, is of bacillus subtilis var Niger spores magnified approximately 1,700 times. It illustrates the typical spore density on the surface of the brass sphere that is inserted into the sterilization apparatus, and shows that the spores are fairly evenly distributed over the surface to be sterilized.

In the Real World

In the real world, equipment and processes suitable for the assembly line of a packaging plant would be needed. In such a situation, sterilization time is precious. RF generates a low-temperature hydrogen plasma inside the evacuated container, which is held in place by a surrounding conducting shell. An electrode is inserted into the container. The plasma is then subjected to a pulsed differential of 50 kilovolts, with the electrode pulsed positively and the conducting shell grounded. This causes energetic pulses of hydrogen ions to accelerate away from the electrode toward the conducting shell. On the way, they collide with spores present on the inner surface of the container. The hydrogen ions are energetic enough to penetrate the durable proteinaceous outer cover of the spores.

"These high-energy hydrogen ions stop very quickly and consequently deposit all their energy over a very small distance, a few microns, which, as it turns out, is the size of the spores. So relatively modest currents of energetic hydrogen ions can do a large amount of damage inside the spores by messing up their DNA," said Schmidt. He estimates that a sufficient kill ratio could be attained by 10-microsecond pulses every millisecond for a few seconds. Further experimentation is needed to confirm the number of 10-microsecond pulses necessary to reach the required kill ratio. A few seconds' processing time per container would make the system feasible for the assembly line.

The effectiveness of the hydrogen ions can be compared with that of gamma rays or X-rays used to sterilize bulk materials. Gamma and X-rays have long penetration depths, so they don't do as much damage per unit length as the hydrogen ions. "Textbooks contain the radiation damage coefficients that are required to kill the relevant microbes. I am confident that we will be able to attain these," said Schmidt.



Shown is a scanning electron microscope image of a small group of bacillus subtilis var Niger spores magnified approximately 13,500 times. The image shows that the spores are approximately 1 µM long and approximately 0.5 µm in diameter.

A small business has been started to do the development work leading to a potential commercial application. ●

— By Anthony DeMeo

DOE's Orbach Attends PPPL On-site Review

In September, Department of Energy Office of Science Director Ray Orbach attended the PPPL On-site Review, which focused on the Laboratory's vision for the next decade. This vision encompasses the National Compact Stellarator Experiment completing construction and coming into operation at PPPL in 2007; the National Spherical Torus Experiment completing its mission by this time, with the Lab possibly moving on to a Next Step Spherical Torus in the former Tokamak Fusion Test Reactor Test Cell; and the construction in the next few years of a West Wing Addition to the Lyman Spitzer Building. The addition would be proposed to house both the U.S. ITER Project Office and a joint PPPL-Geophysical Fluid Dynamics Laboratory-Princeton University computer center.

Facing the camera, from left, are Orbach, Toni Joseph, Director, Office of Laboratory Policy for the DOE Office of Science, and PPPL Director Rob Goldston (standing). At far right with his back to the camera is PPPL Chief Scientist Bill Tang. ●

Plan

Continued from page 1

the scientific research needed to bring a new, clean, and abundant energy source to humankind," said Goldston.

Negotiations are ongoing for the location of ITER, which will be either in France or Japan. PPPL is among the contenders to host the U.S. ITER Home Office.

The Office of Science priority list for new facilities will help the Department plan its potential future scientific investments. Twelve facilities are identified as near-term priorities. Behind the first priority (ITER) is an UltraScale Scientific Computing Capability that would increase by a factor of 100 the computing capability available to support open scientific research. It would be located at multiple sites. The plan further identifies eight facilities as midterm priorities and eight as far-term priorities.

DOE's Office of Science prepared the list over the last year with input from the scientific community, DOE laboratories, and advisory committees.

A document describing all 28 facilities and the prioritization process, Facilities for the Future of Science: A Twenty-Year Outlook, is available at www.sc.doe.gov

Anderson Chairs National Council

PPPL's Jack Anderson is the new Chair of the Department of Energy's (DOE's) National Laboratories Improvement Council. Anderson, head of PPPL's ES&H and Infrastructure Support Department, assumed the one-year post during the summer.

Jack Anderson

The Council's goal is to hold meetings regularly for members to address common issues and share lessons learned, as well as to act on opportunities for improvement in administration and operations.

The Council includes senior representatives from DOE laboratories and programs. ●

PPPL — On Course with Top Crew

Director Goldston Delivers State-of-the-Lab Address

PPPL Director Rob Goldston (large photo) delivers the State-of-the-Lab talk. At top left are (from left), Steve Sabbagh, Adriana Popescu, and Charles Skinner in the Lobby; at top right (from left) are John Schmidt, Greg Schmidt, and Rich Hawryluk, and at bottom right is Alex Ilic.

Dressed in a Hawaiian shirt and surrounded by staff and friends wearing leis, PPPL Director Rob Goldston delivered his annual State-of-the-Lab talk on November 24. His message to the overflow crowd in the Melvin B. Gottlieb Auditorium: PPPL has a "top crew" and is "on course."

"We have great people, an exciting program, and remarkable prospects," said Goldston.

Under the "great people" category, the Director talked about the Lab's "top crew," safety on the job, and risk management. While giving details about the Lab's "exciting program," he discussed the National Spherical Torus Experiment, National Compact Stellarator Experiment, Off-site Research, Plasma Science and Technology, and Theory. Under "remarkable prospects," Goldston focused on the community fusion development path, as well as the support of Congress and the U.S. Administration for fusion. He also discussed the possibility of locating the U.S. ITER Project Office at PPPL and of building the West Wing addition to the Lyman Spitzer Building.

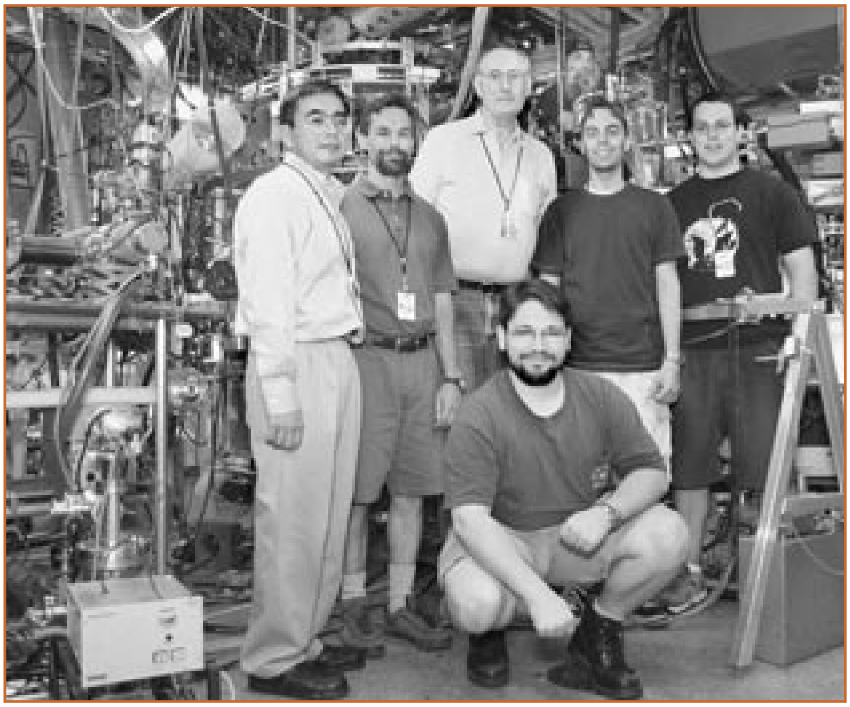
The event had an island theme and concluded with the presentation of awards in the Auditorium and a reception in the Lobby. ●

DOE Pulse

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/.

Successful Liquid Lithium Experiments Continue on CDX-U

Potential for Fusion Reactors Looks Promising



At left at CDX-U are members of the team. From left are Project Co-heads Bob Kaita and Dick Majeski, PPPL engineer John Timberlake, Princeton University graduate student Jef Spaleta (kneeling), PPPL technician James Taylor (back in hat), Drexel University student Douglas Rodgers, and Princeton University graduate student Timothy Gray. At right, the pool of liquid lithium is shown in the toroidal tray that encircles the bottom of the CDX-U vacuum vessel. The tip of the liquid-lithium injector, which is removed before plasma operations, is reflected on the shiny surface of the liquid lithium.

Recent experiments on PPPL's Current Drive Experiment-Upgrade (CDX-U) have demonstrated the effectiveness of liquid-lithium limiters for plasma particle and impurity control. Results are a key step toward the use of free-flowing liquid-lithium walls in a fusion power plant, according to Bob Kaita, who co-heads the project with Dick Majeski.

In May, PPPL staff and their collaborators at the University of California-San Diego (UCSD) achieved a near complete fill of CDX-U's toroidal-tray limiter by injecting liquid lithium onto the two halves of the tray under an argon atmosphere.

"All of the elements were brought together successfully. This is not trivial, because we needed to prepare the tray surface correctly and prepare the injectors so the lithium would remain liquefied and flowing. If the surface of the tray is not clean enough, and not at the right temperature, the lithium will bead up," noted Kaita. The argon atmosphere acts as a buffer to prevent the lithium from evaporating rapidly and coating surfaces inside the vacuum vessel. Plasma discharges were initiated within hours after the tray was filled.

Limiters are metal surfaces that are specially designed to protrude from the vacuum vessel wall toward the edge of the plasma. Their job is to prevent the plasma from striking the vacuum chamber and sputtering impurities, especially heavy metals, into the plasma. Metal atoms soak up energy and radiate it away, causing the plasma temperature to drop. Plasma particles (deuterium ions) striking the limiter plates are neutralized and return to the plasma where they again become ionized. This process, called "recycling," tends to cool the plasma edge, and it limits the ability to achieve beneficial plasma confinement modes that require a hot plasma edge. Liquid lithium may be the solution because of its capability for absorbing plasma particles, thereby reducing recycling.

Initial experiments on CDX-U in FY00-01 employed a rail limiter consisting of a cylindrical stainless-steel mesh soaked with liquid lithium. Only 20 cm^2 of the lithium was actually in contact with the plasma. With the toroidal-tray limiter, a 360-degree annular metal belt running below the entire plasma, the area of interaction increases to as much as 1900 cm^2.

New Results Are Dramatic

Following pump down in any magnetic fusion device, it is necessary to run a series of conditioning plasma shots, until all of the loosely bound water, oxygen, and carbon in the vacuum vessel walls is removed from the chamber. These materials pollute the plasma, preventing the required energy confinement time needed for experiments. In CDX-U, plasma currents are limited to 20 or 30 kA, until vessel surfaces are cleaned. This can take up to a day of conditioning. However, when CDX-U plasmas are started in the presence of lithium, full plasma currents of 70 to 80 kA can be produced after only a few shots — a dramatic demonstration of the ability of lithium to absorb impurities.

Physicists are never satisfied unless they can measure things, and the CDX-U team is no exception. "It's difficult to quantify these (edge) effects. However, we do have an optical diagnostic that can look for oxygen emission lines typically found at the plasma edge. This spectrometer looks directly at the tray through a port in the vacuum chamber. With no lithium, oxygen emission lines are quite measurable. With lithium in the tray, the measurable level of oxygen goes to zero — a dramatic effect," said Kaita.

Experiments such as Princeton's Tokamak Fusion Test Reactor (TFTR) and the DIII-D at General Atomics, Inc., have demonstrated that even modest recycling reductions can significantly improve plasma performance. These results, and recent experiments with liquid lithium at PPPL, UCSD, and other laboratories, suggest it is time to assemble an experiment in which the entire plasma is surrounded with liquid lithium. Consequently, the CDX-U folks have submitted a proposal for the reincarnation of CDX-U as the Lithium Tokamak Experiment (LTX) in FY06.

The LTX would incorporate a shell, just inside the vacuum chamber walls, onto which a thin layer of liquid lithium, about 1000 Angstroms, would be coated evaporatively. The shell would be maintained at a temperature that would keep the lithium in the liquid state. The coating will be sufficiently thick to absorb and retain plasma particles, preventing recycling, and trapping impurities so that they do not re-enter the plasma from the vacuum vessel walls.

"The idea is to put in a fresh coating of lithium after each shot. Conceptually the process is similar to the gettering done between shots on earlier tokamaks, where titanium was sublimated onto vacuum vessel components to reduce impurities. The difference is that we would make a thin liquid coating instead of a solid one," Kaita said. He envisions that such a system is an important step toward a fast flowing, thin liquid-lithium wall in a fusion reactor.

In parallel with the proposed operation of LTX will be a series of prototype studies on the National Spherical Torus Experiment (NSTX) beginning in FY04. The first experiments will involve a small area coated with liquid lithium. The longer-term goal for NSTX would be the design, installation, and operation of a flowing liquid-lithium divertor in FY08. In FY05-06, CDX-U would be used for preliminary tests of lithium coating technology in preparation for its conversion to LTX.

Divertor coils, located inside the vacuum chamber, modify the magnetic field at the plasma edge to divert plasma particles and impurities to a region within the vacuum chamber, where they collide with a specially coated surface, are absorbed, and are prevented from entering the plasma. Divertors eliminate the need for limiters, greatly reducing recycling, resulting in a hotter plasma edge and better confinement. Kaita asked, "If divertors are more effective than limiters for particle control, why not go ahead and use lithium-coated surfaces in them as well?" The divertor envisaged for NSTX would employ a static thin film of liquid lithium first, and then a flowing lithium system.

The jury is still out on the role of divertors and/or limiters in a commercial fusion reactor. This depends on the practicality and effectiveness of the flowing liquid-lithium wall in controlling recycling and impurities. If successful, can such a wall also be used to remove the excess tritium that gets embedded in a fusion reactor wall?

Deuterium and tritium, both isotopes of hydrogen, will be used as fuel in a fusion power plant. During its operation, a substantial quantity of tritium, which is radioactive, can accumulate in the power plant walls. Depending on how long the tritium is retained in the lithium, a flowing liquid-lithium wall could avoid this by moving the tritium out of the vacuum vessel — a major advantage over solid reactor walls.

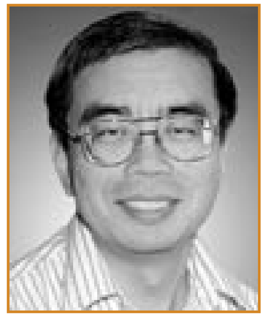
With the exciting, innovative liquid-lithium experiments planned for the next several years on CDX-U, NSTX and LTX, Princeton is positioned to make vital contributions to technological developments that are essential for practical fusion power in the 21st Century. ●

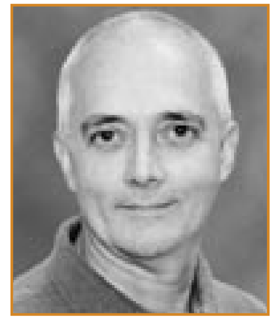
Awards • Awards • Awards • Awards

Nathaniel Fisch, PPPL Associate Director for Academic Affairs, recently received the outstanding Mentor award from the DOE Office of Science. The plaque, signed by Energy Secretary Spencer Abraham, recognizes Fisch for his "dedication as a mentor and for his willingness to share knowledge and to inspire and instill solutions, and immersing inquisitive minds in the world of science." The award, issued this year, honors Fisch for his mentoring efforts in 2002.

PPPL's **Marc Cohen** recently received the Outstanding Co-operative Education Partner Award from the Drexel University Alumni Association. Cohen was recognized for being an outstanding student in his role as a co-op. He was a Drexel University co-op student at PPPL last year and now is a Help Desk technician at PPPL.

In October, PPPL physicist **Dennis Mueller** received the MacMurray College "Distinguished Career Award 2003" from the college's Alumni Association. The award recognizes Mueller for the impact he has made scientifically, academically, and professionally since he received a bachelor's degree in physics from MacMurray in 1968. The college is in Jacksonville, Ill.





PPPL physicists **Robert Kaita** (above, left) and **Neil Pomphrey** (above, right), were elected Fellows of the American Physical Society in October. Kaita and Pomphrey received the lifetime appointments in recognition of their contributions to the field of plasma physics.

PPPL's **Alex Nagy,** coordinator of the Scientist-in-the-Classroom Program at General Atomics (GA) in San Diego, recently received a "Community Science Educator of the Year" award for 2003 from the San Diego Science Education Association. The association specifically honored Nagy, who is on long-term assignment at GA, for his high-quality presentations on plasma science to students in classrooms throughout San Diego County.

PPPL honored its inventors in June at the twenty-first annual Patent Awareness Program Recognition Dinner at Princeton University's Prospect House. The event honored those who received patents and disclosed inventions during Fiscal Year 2002. Those recognized include **George Ascione, Jun Gyo Bak, Manfred L. Bitter, Andrew Carpe, Lloyd Ciebiera, John D. Desandro, Ilya Y. Dodin, Philip Efthimion, Eliot Feibush, Nathaniel J. Fisch, Charles A. Gentile, Geoff Gettelfinger, Kenneth W. Hill, Stephen C. Jardin, Scott Klasky, Stephen Langish, Sang Gon Lee, Dennis Mansfield, Michael Miller, Hideo Okuda, John Parker, Robert F. Parsells, Erik Perry, Steve Raftopoulos, Yevgeny Raitses, Keith Rule, Gennady Shvets, John Schmidt, Charles H. Skinner, David Staack, Brentley Stratton, Robert Woolley, and Irving Zatz.**

In November, PPPL and Princeton University officials presented the PPPL Distinguished Engineering Fellow Award to **Arthur Brooks** and the Kaul Prize for Excellence in Plasma Physics Research and Technology Development to **Masaaki Yamada and Hantao Ji**. From left are Princeton University's Will Happer with PPPL's Masaaki Yamada, Hantao Ji, Art Brooks, and PPPL Director Rob Goldston.