Summer 2013, Issue 1

QUEST

RESEARCH NEWS FROM PPPL

DOUBLE THE POWER...

PPPL Races Ahead with Fusion Research

PPPL PRINCETON PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY

Summer 2013, Issue 1

Stewart Prager,
PPPL Director

LETTER FROM THE DIRECTOR

Welcome to the premiere issue of *Quest*, the annual magazine of the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL). We are pleased to provide this news of our strides in advancing research into fusion energy and plasma science—two topics of vital interest to the United States and the world.

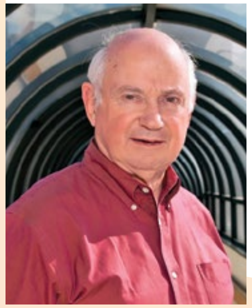
Fusion powers the sun and stars, and harnessing this power on Earth could provide a safe, clean and virtually limitless way to meet global electricity needs.

PPPL is a world leader in this quest. The first sections of this magazine detail our progress in understanding the superhot, electrically charged plasma gas that fuels fusion reactions, and in learning how to control this gas with magnetic fields.

Fusion is the foremost, but far from the only, focus of our research. PPPL's study of plasma, often called the fourth state of matter, ranges from its use in fusion energy to its role in fields as vast as astrophysics and as small as nanotechnology. These pages describe our research in these areas and some of the benefits it could bring, including improved forecasts of disruptive solar storms and new techniques for manufacturing items from golf clubs to microchips.

PPPL shares its knowledge with leading research institutions around the world and provides science education to students, teachers and parents throughout the Northeast and sometimes across the globe. Our collaborations include participation in ITER, an international fusion facility of unprecedented size and power that is under construction in France, and cooperation with other facilities in the United States, Europe and Asia. Here at home, hundreds of lecture-goers, from high school physics students to senior retirees, flock to our weekly Science on Saturday programs during the winter.

All these are part of the stories that we have to tell. We hope that you enjoy reading this premiere issue and discovering the many kinds of work that we do.

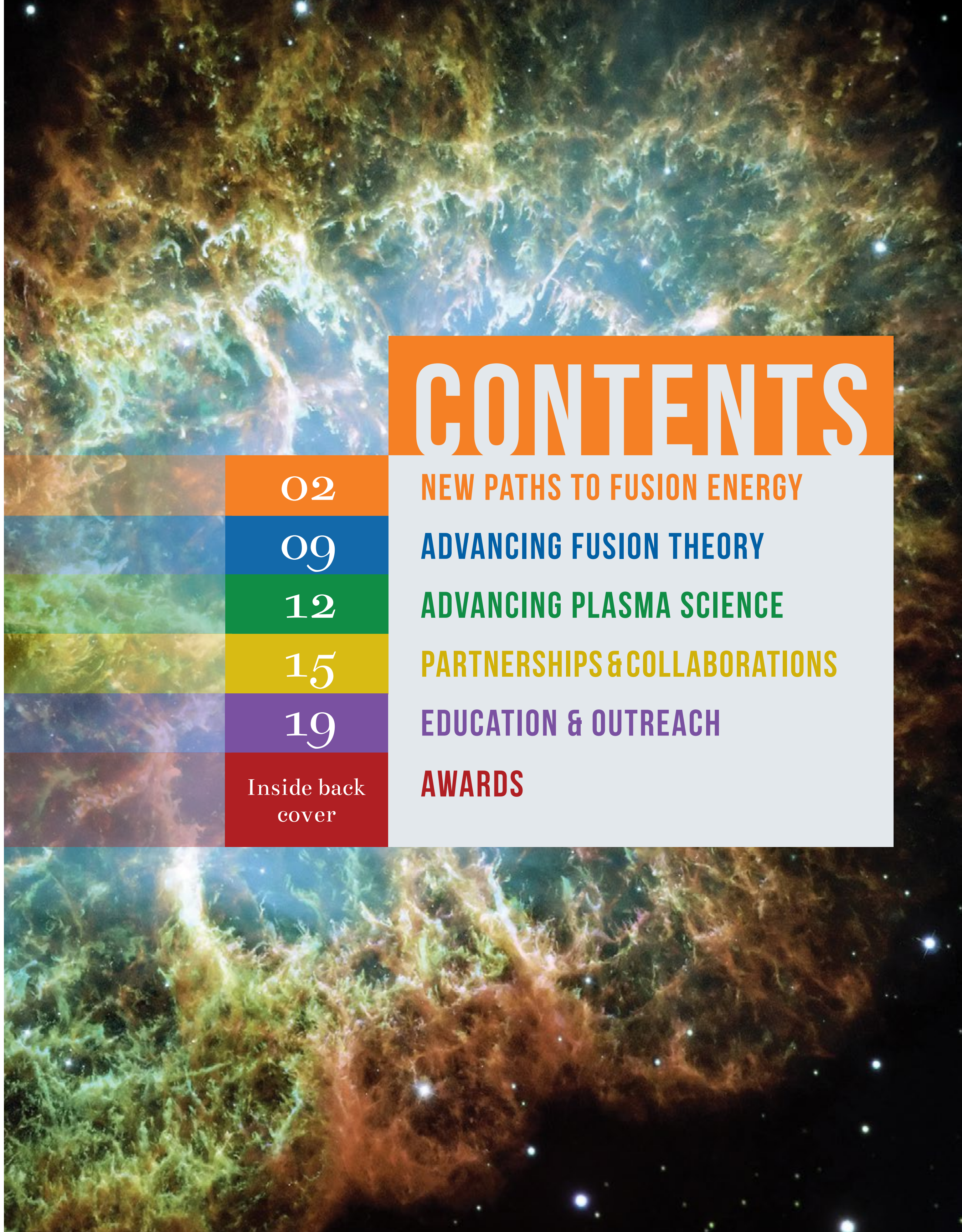


A.J. Stewart Smith,
Princeton University
Vice President for PPPL

ABOUT THE PRINCETON UNIVERSITY VICE PRESIDENT FOR PPPL

A.J. Stewart Smith, who has served as Princeton University's first dean for research since 2006, moves this summer to the newly created position of University vice president for PPPL, which he has overseen as dean. In his new capacity, Smith serves as the University's primary contact with the U.S. Department of Energy (DOE) and will continue to oversee the Laboratory, which the University manages for the DOE.

On the cover: A sample of lithium-coated material under conditions similar to what might be found in a fusion reactor.



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CREATING THE MOST POWERFUL FUSION FACILITY OF ITS KIND ON EARTH

EACH SECOND, THE SUN MAKES 1 MILLION TIMES MORE ENERGY THAN the entire world population consumes in a year. Discovering how to harness the sun's power—fusion—to produce safe, clean and abundant energy for generating electricity is the primary mission of the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL).

To pursue that mission, scientists and engineers at PPPL are completing a $94 million upgrade of the Laboratory's main fusion facility, the three-story tall National Spherical Torus Experiment (NSTX), which is shaped like a cored apple. The upgrade will make the NSTX the most powerful fusion device of its kind in the world when the work is completed in 2014.

The revamped machine will heat charged gases called plasma to as high as 60 million degrees Celsius—six times hotter than the core of the sun—and confine the plasma in substantially strengthened magnetic fields. The extreme heat will create conditions inside the NSTX that are similar to those required for fusion, which occurs when the atomic nuclei in plasma merge inside the sun and stars and release a burst of energy.

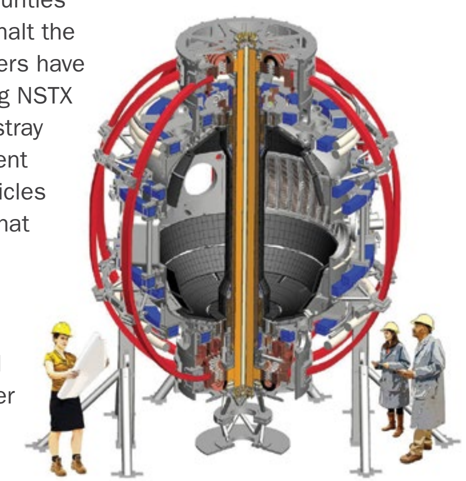
The NSTX has already set records for plasma confinement in terms of a key measure called "beta"—the ratio of the pressure of a plasma to the strength of the magnetic field that confines it.

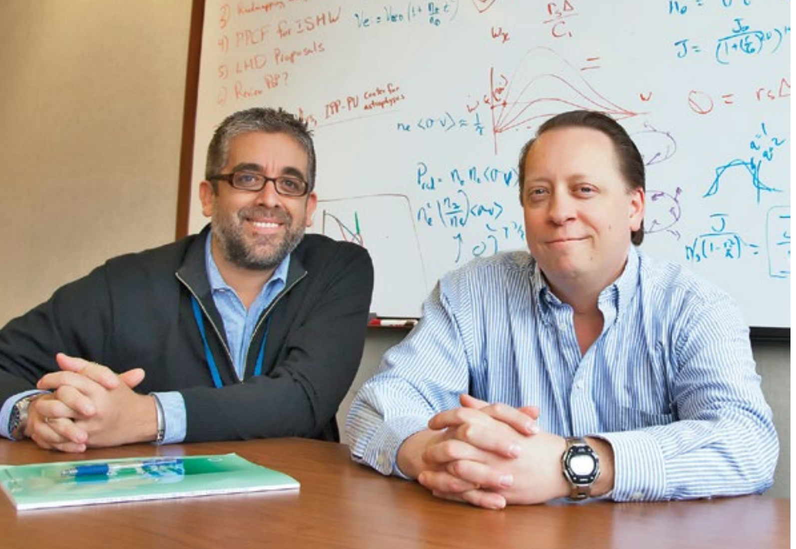
The upgrade will enable PPPL scientists to delve into mysteries that have puzzled them for years. Researchers will focus on these major questions:

- Can the NSTX maintain its record high level of beta as the plasma grows hotter? If so, "that means we could achieve high fusion power in a pretty compact machine, and that could make machines cheaper in the future," said Jonathan Menard, program director for the NSTX.
- Can the researchers start and sustain the electric current that creates the plasma without using a solenoid—a coil that winds around the center stack and delivers the current? Finding ways to eliminate the solenoid will be crucial for future machines since extreme heat could damage the coil. Successful elimination of the part could provide "a very solid basis to design the next-step machine," said Masayuki Ono, who heads the NSTX department at PPPL.
- Can the upgrade tame the hot plasma particles that escape the confinement and can damage interior surfaces, drive impurities back into the plasma and halt the fusion reaction? Researchers have coated parts of the existing NSTX with lithium to sponge up stray particles, and will experiment with lithium to absorb particles in the upgraded machine that are even hotter.

The extensive upgrade will thus serve as a key testing ground for concepts that could prove vital to bringing the power of the sun to Earth.

NSTX: At left, Interior view prior to upgrade. This page, schematic of the upgraded facility.





FOUND: THE POSSIBLE SOURCE OF A KEY BARRIER TO FUSION ENERGY

PHYSICISTS AT PPPL HAVE DISCOVERED A POSSIBLE solution to a mystery that has long baffled researchers working to harness fusion. If confirmed by experiment, the finding could help remove a major impediment to the development of fusion as a clean and abundant source of energy for producing electric power.

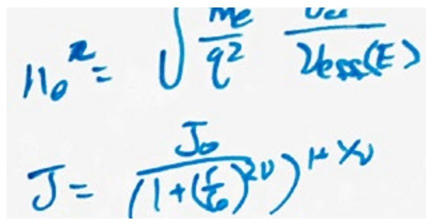
Luis Delgado-Aparicio, left, and David Gates.

The scientists zeroed in on tiny, bubble-like islands that appear in the hot, charged plasma gases during experiments. These islands collect impurities that cool the plasma. And these islands, the scientists reported in the journal *Physical Review Letters*, are at the root of a longstanding problem known as the "density limit" that can prevent fusion reactors from operating at maximum efficiency.

Fusion occurs when plasmas become hot and dense enough for the atomic nuclei contained within the hot gas to combine and release energy. But when the plasmas in experimental reactors called tokamaks reach the mysterious density limit, they can spiral apart into a flash of light.

"The big mystery is why adding more heating power to the plasma doesn't get you to higher density," said David Gates, a principal research physicist at PPPL and co-author of the proposed solution with Luis Delgado-Aparicio, a staff research physicist. "This is critical because density is the key parameter in reaching fusion and people have been puzzling about this for 30 or 40 years."

The scientists hit upon their theory in what Gates called "a 10-minute 'Aha!' moment." Working out equations on a whiteboard in Gates' office, the physicists focused on the islands and the impurities that drive away energy. The impurities stem from particles that the plasma



kicks up from the tokamak wall. "When you hit this magical density limit, the islands grow and coalesce and the plasma ends up in a disruption," said Delgado-Aparicio.

Gates and Delgado-Aparicio hope to test their theory on fusion facilities. Among other things, they intend to see if injecting power directly into the islands will lead to higher density. If so, that could help future tokamaks reach the extreme density and 100-million-degree temperatures that fusion requires.

NEW FORECASTING TECHNIQUE BOOSTS PROSPECTS FOR FUSION POWER

RESEARCHERS HAVE CONFIRMED THE REMARKABLE ACCURACY OF A model developed at PPPL for predicting the size of a key challenge to fusion power. "This allows you to depict the size of the challenge so you can think through what needs to be done to overcome it," said physicist Robert Goldston, the Princeton University professor of astrophysical sciences and former PPPL director who developed the model.

Robert Goldston

Results of the model have been "eerily close" to the data, said Thomas Eich, a senior scientist at the Max Planck Institute for Plasma Physics in Garching, Germany, who has gathered the data from experiments.

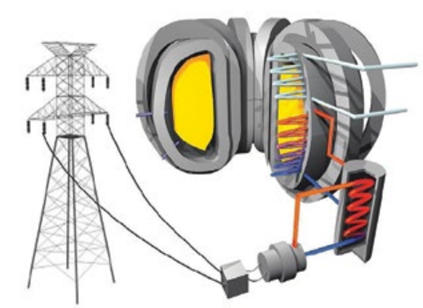
Goldston's model, published in the journal *Nuclear Fusion*, predicts the width of what physicists call the "scrape-off layer" in tokamaks, the most widely used fusion facilities. Such devices confine hot, electrically charged plasma gas in powerful magnetic fields. But heat inevitably flows through the system and becomes separated, or scraped off, from the edge of the plasma and flows into an area called the divertor chamber.

The challenge is to prevent a thin and highly concentrated layer of heat from reaching and damaging the plate that sits at the bottom of the divertor chamber and absorbs the scrape-off flow. Preventing such damage will be vital for future machines like ITER, the major international experiment under construction in France to demonstrate fusion as a source of clean and abundant energy.

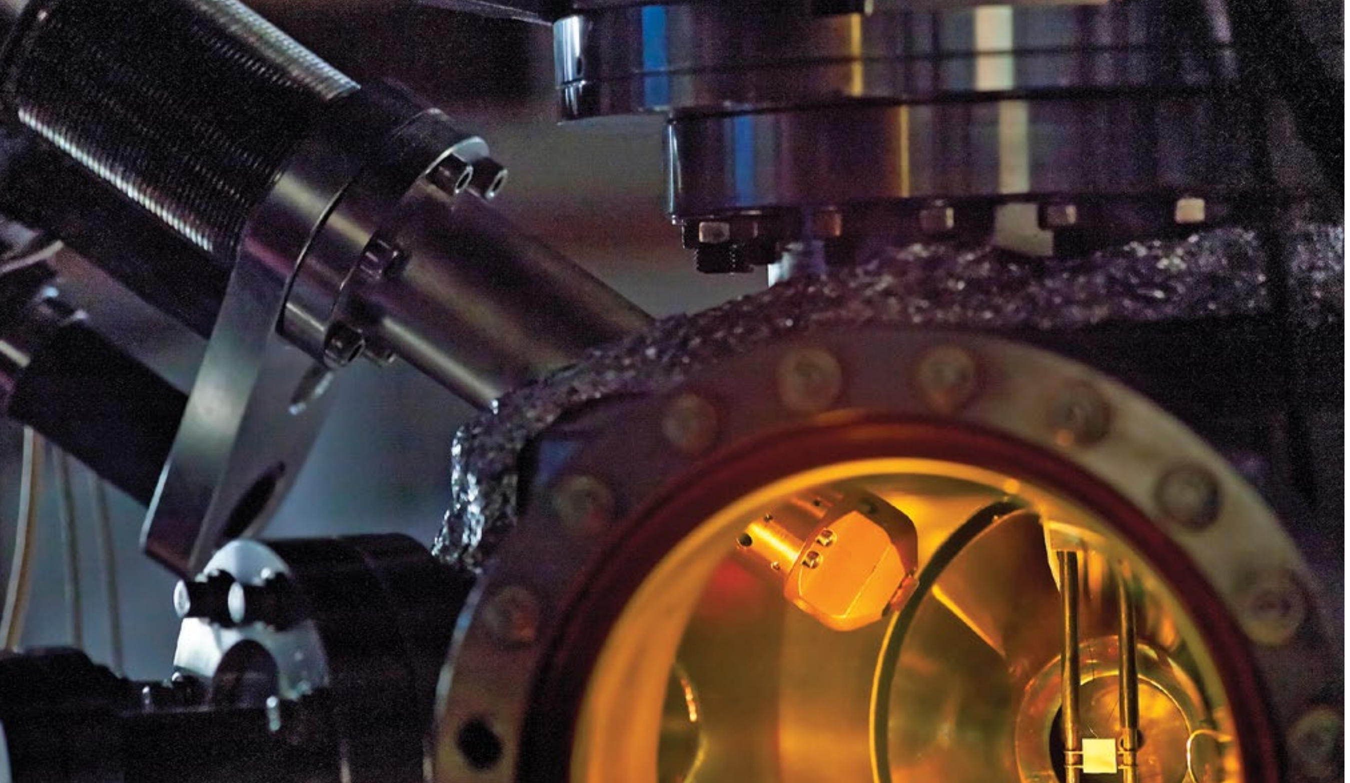
ROADMAPPING THE FUTURE OF FUSION ENERGY

PPPL has played a leading role in global forums to define a roadmap to commercial fusion energy. Such forums bring together participants in the world's major fusion programs to chart pathways to demonstration—or DEMO—fusion power plants that would mark the final step before the construction of commercial fusion plants by mid-century.

PPPL hosted a worldwide gathering of fusion scientists in 2011 that has led to plans for an annual series of roadmapping workshops to be held under the auspices of the International Atomic Energy Commission to address key scientific and technological challenges. The first such workshop took place in October, 2012, at the University of California at Los Angeles, with the next session scheduled for December 2013 in Vienna, Austria.



Artist's conception of the interior of a fusion power plant connected to a power grid. The rendering depicts the plasma in yellow.



KEEPING PLASMA SUPERHOT WITH METAL THAT ACTS LIKE A SPONGE

IN THE LAB DOWN THE HALL FROM BRUCE KOEL'S NEW OFFICE IN the Princeton Plasma Physics Laboratory, the temperature is about to rise above 11 million degrees Centigrade in a hot tub-sized chamber that cradles the energy of a burning star.

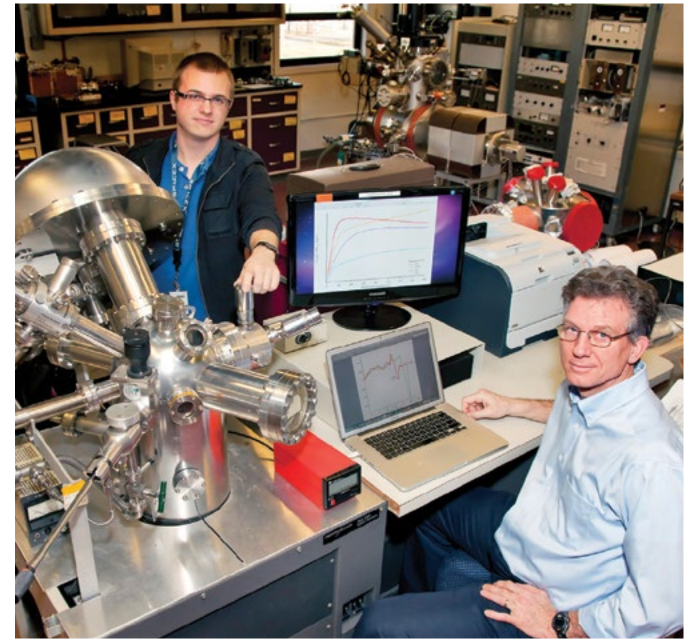
Koel, a professor of chemical and biological engineering at Princeton University, is joining with PPPL scientists to tackle the challenge of capturing the energy of the sun on Earth. His mission at PPPL is to apply the science of surfaces to solving one of the biggest obstacles facing fusion: how to keep the fusion reaction burning for long periods without cooling off.

Amazingly, a thin metal lining, just the width of a human hair, on the inner wall of a fusion reactor, could help to prevent this cooling. The most promising lining is lithium, the lightest metal on Earth.

The electrically charged plasma that fuels fusion reactions is superhot at the core but grows colder toward the edge—a process accelerated by stray plasma particles that strike the reactor's inner walls. "No matter how hot you make the middle, the walls are cold," said physicist Richard Majeski, principal investigator for PPPL's Liquid Tokamak Experiment, which explores lithium as a reactor lining and on which Koel collaborates. "It's sort of like bad insulation in a house,"

The lithium can act like a sponge by turning liquid when struck by stray particles and soaking them up, thereby offsetting their cooling effect. The metal is a challenge to work with, however, because of its tendency to lose its purity by linking up with just about any atom that comes along.

Koel's new laboratory at PPPL explores such issues. "Surface chemists have learned a lot over the past 20 years about lithium, but most of the studies were done with pure lithium," Koel said. "We are moving into new territory by studying how plasma particles react with not just pure lithium but with all the other compounds it makes."



Bruce Koel, right, with Princeton graduate student Ryan Sullenberger. Opposite page: Heating lithium-coated material in Koel's laboratory.

COORDINATING KEY RESEARCH

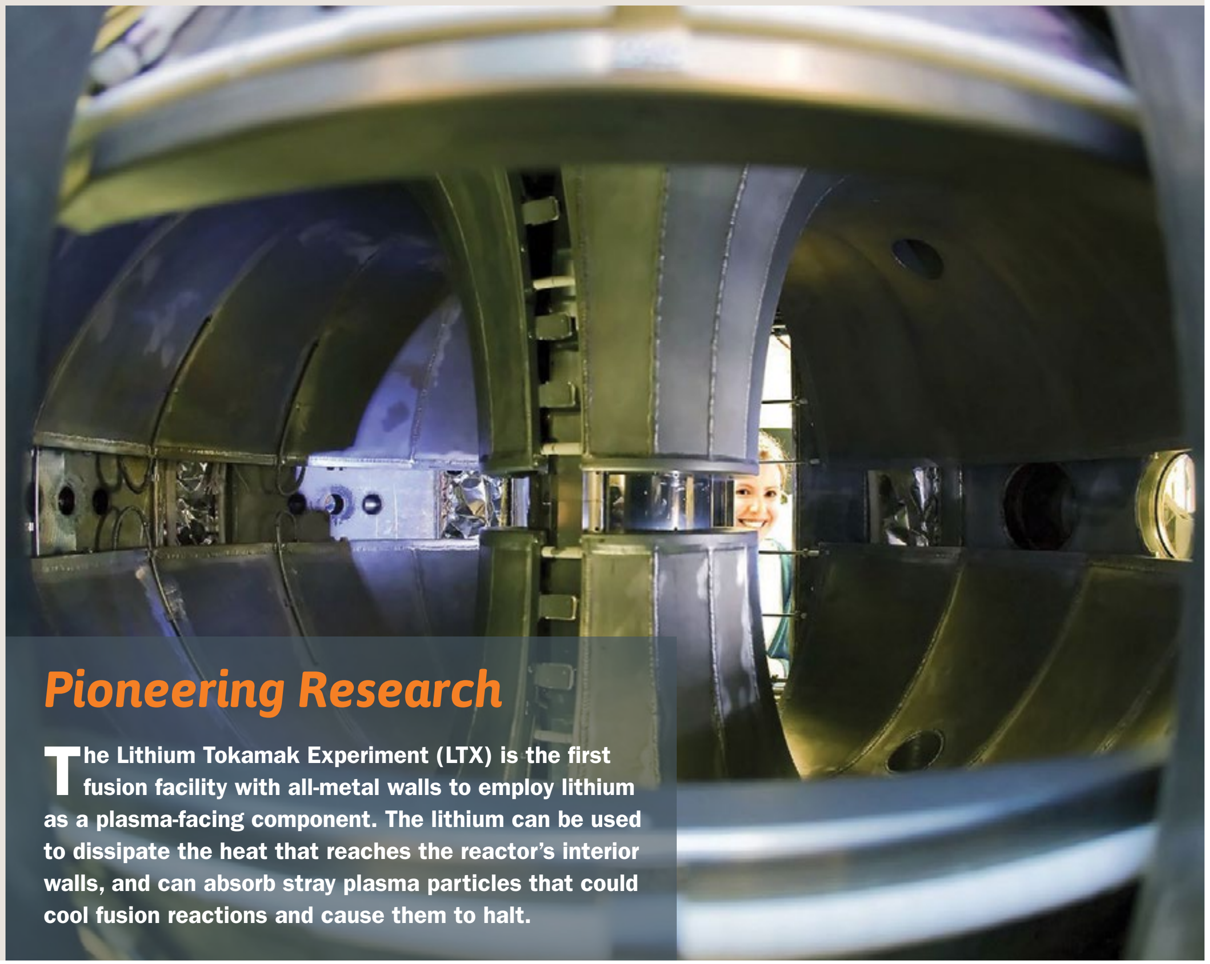
Physicist Rajesh Maingi has assumed the new position of manager of edge physics and plasma-facing components at PPPL. In that role he will coordinate all Laboratory research on the volatile edge and boundary regions of the plasma, which must be carefully controlled for fusion to take place. Maingi had been on long-term assignment from Oak Ridge National Laboratory to the National Spherical Torus Experiment (NSTX), the major fusion facility at PPPL, from 1999 to 2012. He currently is stationed at the DIII-D fusion facility operated by General Atomics in San Diego, and is to return to PPPL full-time when the upgrade of the NSTX is completed in 2014.

Rajesh Maingi

Wonder Weld: Friction Stir Welding

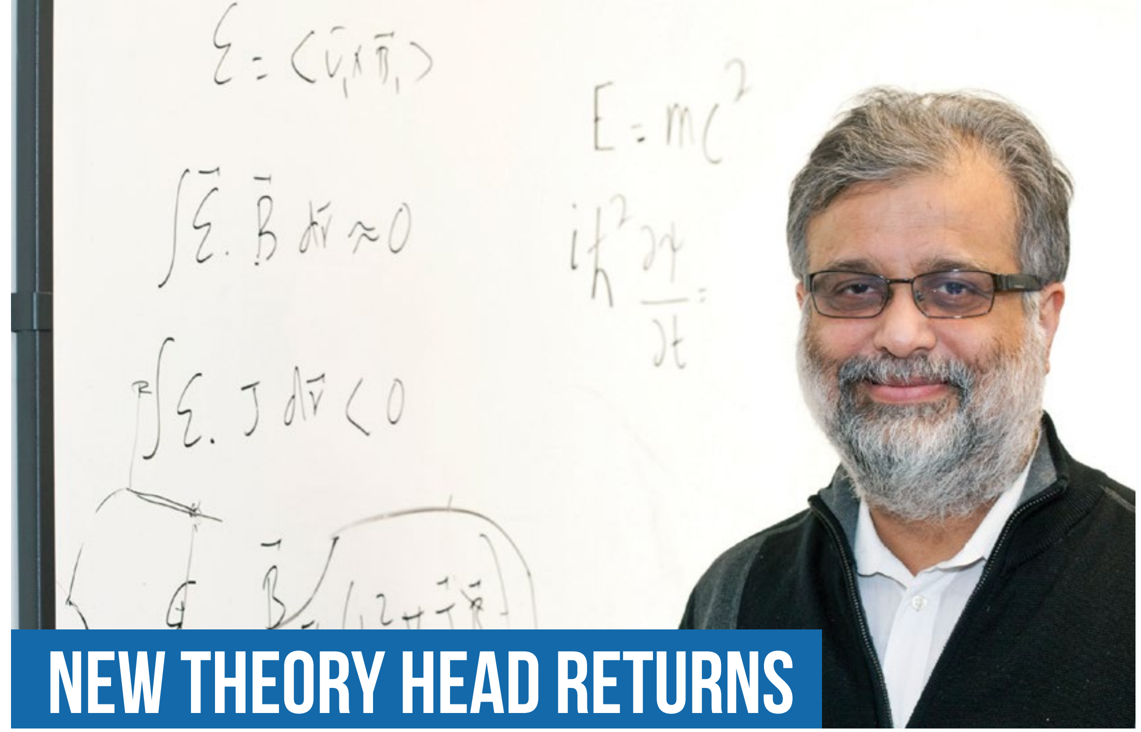
James Chrzanowski

When PPPL engineers needed superstrong bonds for the links between magnetic coils and the new center stack for the NSTX upgrade, they turned to a technique called "friction stir welding." Unlike conventional joining methods, friction stir welding turns two dissimilar materials into a wax-like consistency and fuses them together without compromising the strength of the joint. Engineer James Chrzanowski displays two different types of copper plate that have been fused through friction stir welding.



Pioneering Research

The Lithium Tokamak Experiment (LTX) is the first fusion facility with all-metal walls to employ lithium as a plasma-facing component. The lithium can be used to dissipate the heat that reaches the reactor's interior walls, and can absorb stray plasma particles that could cool fusion reactions and cause them to halt.



Amitava Bhattacharjee

NEW THEORY HEAD RETURNS TO HIS ROOTS

PHYSICIST AMITAVA BHATTACHARJEE HAS COME FULL CIRCLE. THE NEW HEAD OF the Theory Department took up the job more than 30 years after completing his doctoral work at PPPL.

His past came flooding back to Bhattacharjee when he gave a talk at PPPL while interviewing for the job, which includes a full professorship in the Princeton Department of Astrophysical Sciences. "When I looked at the audience and saw my former teachers, friends and even former students, I felt that I had arrived," he said. "That does make this appointment very special to me."

Bhattacharjee arrived from the University of New Hampshire, where he held an endowed professorship in the Department of Physics and ran the Center for Integrated Computation and Analysis of Reconnection and Turbulence, a joint center with Dartmouth College that is supported by the DOE. Along the way he taught at the University of Iowa and Columbia University, and established himself as a leading theoretician in plasma physics disciplines including fusion energy, space and astrophysical plasmas, and dusty plasmas.

Bhattacharjee takes a broad view of his new role. He plans to help develop programs "that continue the PPPL theory group's preeminence in the world in fusion physics and plasma physics more broadly, encompassing space and astrophysical plasmas."

A key goal will be developing software that high-performance supercomputers can use to simulate the behavior of complex dynamics in plasmas and guide fusion experiments. Creating codes for such computer systems, in which hundreds of thousands of microprocessors operate together, represents the next frontier in computing and "the third leg of discovery, in addition to experiment and theory," Bhattacharjee said.

GRANT-WINNING PPPL SCIENTISTS LEAD FUSION TO THE EDGE

C.S. Chang

TO PRODUCE FUSION, SCIENTISTS MUST FIRST LEARN TO CONTROL the dazzlingly complex conditions at the edge of the plasma in magnetic fusion facilities. Now tackling this problem is a center based at PPPL that has won a highly competitive, $12.25 million grant from the U.S. Department of Energy (DOE) to develop computer codes to simulate the turbulent plasma edge.

The five-year grant comes from the Department's Scientific Discovery through Advanced Computing (SciDAC) program supported by the DOE Office of Science.

"The DOE grant is terrific for the Laboratory because it allows us to work in the forefront of the simulation of the edge region of fusion plasmas," PPPL Director Stewart Prager said of the award, which funds the Laboratory-based Center for Edge Physics Simulation (EPSI). "This code could go a long way toward modeling and understanding this pivotal region," Prager said.

The task of successfully confining plasma has many everyday parallels. "If you want to confine soup, the bowl should not leak, wobble or be broken by the heat," said C.S. Chang, a principal research physicist at PPPL who heads EPSI. His nationwide team consists of leading physicists, mathematicians and computer scientists from 11 U.S. research institutions, together with PPPL participants.

This team will work on Titan, a lightning-fast Cray XK6 supercomputer at the DOE's Oak Ridge National Laboratory. Titan has performed more than 17 quadrillion—or million billion—calculations a second, making it the world's fastest supercomputer. It has the power of well over 2 million home computers and the ability to perform in one day what a single desktop device would take more than 5,000 years to complete. The EPSI team also will work on Hopper, a Cray XE6 supercomputer at the DOE's E.O. Lawrence Berkeley National Laboratory.

Titan has performed more than 17 quadrillion—or million billion—calculations a second, making it the world's fastest supercomputer.

EPSI researchers will test their model against data gleaned from actual fusion experiments to see if its predictions are accurate. If so, the model could serve as a guide to developers of next-generation fusion facilities that include ITER, an international project that is under construction in France to produce a sustained fusion reaction—or burning plasma—by the late 2020s.

MODELING THE CAUSES AND IMPACT OF PLASMA DISRUPTIONS

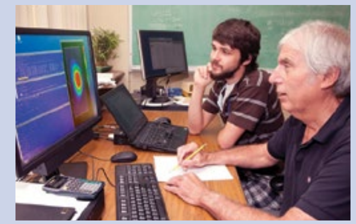
PHYSICIST STEPHEN JARDIN HEADS TWO KEY PROJECTS TO MODEL THE POWERFUL disruptions in plasma that can halt magnetic fusion experiments. Creating computer models that can forecast such disruptions and lead to their control is among the major challenges facing the development of fusion power. "I find it amazing that just from solving these mathematical equations on a computer you can predict reality," said Jardin.

His projects include a three-year PPPL study to forecast the impact of large-scale disruptions on the inner walls of the huge ITER fusion facility, an international experiment under construction in France. Funding for this study comes from a three-year, $333,750 grant that the ITER Organization issued in 2012.

Jardin also directs a PPPL-based center that models the sources of instability in fusion plasmas under a five-year, $5.2 million Scientific Discovery through Advanced Computing (SciDAC) grant that the U.S. Department of Energy awarded in 2011. Joining PPPL in this center are 10 leading U.S. research institutions that include MIT, General Atomics and the University of Wisconsin.

The computer codes that Jardin's projects are developing demand the power of some of the world's fastest supercomputers. Both studies treat the superhot, charged plasma that fuels fusion reactions as if the plasma were an electric current-carrying fluid—a method of analysis known as magnetohydrodynamics (MHD). This method simulates the impact of disruptions on the plasma as a whole and contrasts with the other major form of theoretical analysis, which models the behavior of local regions of the plasma.

While Jardin's two projects are separate, they could be viewed as complementary to each other. His SciDAC-supported Center for



Stephen Jardin, right, with summer intern Andrew Ritchie, an undergraduate at Whitworth University

Extended Magnetohydrodynamic Modeling simulates the dazzlingly complex interaction between the electric and magnetic forces in the plasma that can lead to disruptive instability. And his research for ITER takes MHD analysis a step further by focusing on what a disruption could do to the interior of that facility.

A COMPUTER CODE FOR ALL SEASONS

Scientists around the world employ a PPPL-developed software package to interpret the results of fusion experiments and plan new experimental programs. The software, called Transport Analysis Code (TRANSP), has been adopted as the gold standard for analyzing such experiments at global research centers, many of which have added applications of their own. More than 200 man-years have gone into the development of TRANSP and a recently enhanced version called PTRANSP that strengthens the code's predictive power. In 2012, more than 90,000 TRANSP/PTRANSP runs were recorded worldwide.

LAB LAUNCHES NANO FACILITY AS FUTURE RESOURCE FOR THE WORLD

NANOMATERIALS ARE PRIZED FOR THEIR USE IN EVERYTHING FROM golf clubs and swimwear to microchips, paints and pharmaceutical products. Now researchers at PPPL have launched a nanotechnology laboratory as a step toward research capabilities that could serve as a resource for institutions and industries around the world.

The researchers are applying their knowledge of plasma to optimize the hot, electrically charged gas as a tool for producing nanoparticles. Such particles are measured in billionths of a meter and have exceptional strength and flexibility. Carbon nanotubes, for example, are tens of thousands of times thinner than a human hair, yet are stronger than steel on an ounce-per-ounce basis.

Principal investigator Yevgeny Raitses, right, with Washington University in St. Louis undergraduate Mitchell Eagles in the PPPL nanolaboratory.

The new lab "could be a test bed for new technologies and devices," said PPPL Deputy Director Adam Cohen. Users could include laboratories looking for small amounts of nanomaterial, "or companies interested in using plasmas in large-scale nanomanufacturing, or anyone in between."

PPPL scientists possess decades of experience working with plasmas in fusion experiments and in other areas, ranging from studies of plasmas for particle beams and space-vehicle propulsion to the analysis of astrophysical phenomena.

The production of nanomaterials involves complex transitions between different states of matter when plasma serves as a synthesizing medium. One method vaporizes a substance such as a rod of carbon with a lightning-like electric arc, transforming the carbon from a solid to a plasma. The plasma then condenses back into a solid as nanomaterial. Accompanying these transitions are little-understood chemical, kinetic and electrical interactions that need to be controlled to ensure the quality and purity of the nanomaterial.

PPPL researchers seek to better understand these interactions to conduct controllable synthesis of nanomaterials with precisely prescribed properties. "The question I've always had," said Cohen, "is that if nanoparticles and nanotubes are going to be in everything from car cylinders to medical equipment to nano-robots, who's going to ensure that these materials are made consistently with the highest quality? That seemed like an opportunity for us."

Super separator: The advanced centrifuge under development at PPPL employs independently rotating cylinders to produce a powerful, low-turbulence fluid flow.

A PAIR OF INNOVATIVE PROJECTS FOR ADDRESSING NUCLEAR WASTE

RESEARCHERS AT PPPL ARE APPLYING THEIR KNOWLEDGE OF PLASMA physics and related technologies to address the radioactive waste remaining from U.S. nuclear arms production and development during World War II and the Cold War. More than 50 million gallons of such waste remain in storage, most of it in underground and sometimes leaky tanks at the Hanford Site in Washington State.

PPPL has two projects under way that could help remediate key aspects of this problem. Both concepts would physically separate high-level radioactive components of the waste from low-level ones so that each could be handled separately.

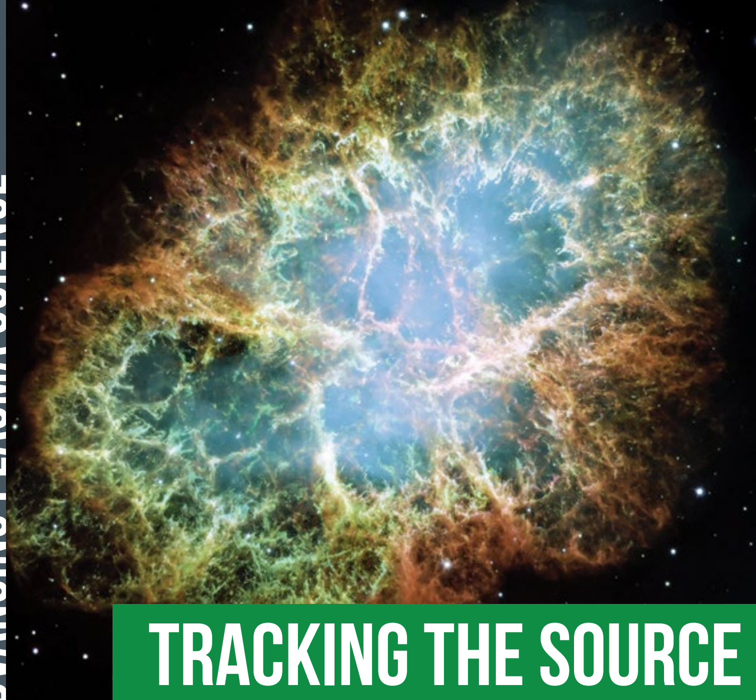
The Two Projects:

Plasma Mass Filter. This concept would ionize the waste stream through a process that turns the material into plasma, and would rotate the plasma in a vacuum chamber that confines the material within magnet fields. High- and low-level radioactive wastes would be separately expelled through different sections of the chamber. Unlike standard chemical methods for separating waste components, this entirely physical process would not increase the overall volume of waste, since no chemicals would be added during processing, and could produce the separation with greater efficiency and a higher throughput.

Advanced Centrifuge. This concept employs large centrifugal forces to separate effluent waste material with high efficiency. Originally developed for astrophysical research, the device does not revolve as a single unit, as standard centrifuges do. Instead, the inner cylinder rotates independently of the outer cylinder, creating a powerful fluid flow with very low turbulence that could deliver faster, more efficient and more economical separation of nuclear wastes than standard centrifuges permit.

Underground nuclear-waste storage tanks under construction at the Hanford Site.

Photo courtesy of Pacific Northwest National Laboratory



TRACKING THE SOURCE OF DISRUPTIVE SOLAR STORMS

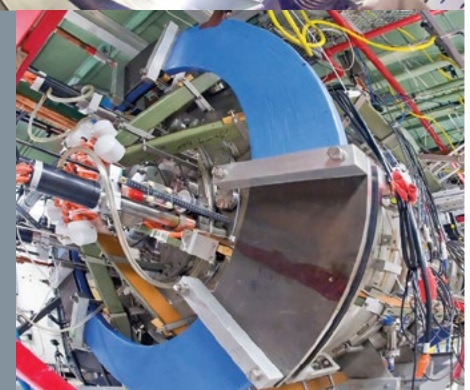
WITH THE CLICK OF A COMPUTER MOUSE, A PPPL SCIENTIST SENDS 10,000 volts of electricity into a chamber filled with hydrogen gas. The charge heats the gas to 100,000 degrees Centigrade. In an instant—one-thousandth of a second, to be precise—a process called "magnetic reconnection" takes place.

This carefully controlled experiment recreates one of the most common but least understood phenomena in the universe—one that gives rise to the northern lights, solar flares and geomagnetic storms that can disrupt cell phone service, black out power grids and damage orbiting satellites. The process also is thought to produce the extraordinary bursts of radiation that emerge from the center of the Crab nebula—the remains of an exploded star—some 6,500 light years from Earth.

Researchers at PPPL have brought this mysterious process down to Earth in miniature so it can be studied under laboratory conditions. "Here we can actually recreate reconnection," said Masaaki Yamada, a PPPL physicist and principal investigator for the Magnetic Reconnection Experiment (MRX), the leading project of its kind in the world.

The project seeks insights whose benefits could range from improved predictions of solar outbursts to greater control of fusion reactions and increased understanding of the formation of stars.

Magnetic reconnection takes place when magnetic lines of force break apart and reconnect with a violent burst of energy that in huge bodies like the sun has the explosive power of millions of tons of TNT. This occurs when super-hot, charged plasma gases converge. PPPL studies of this process will help guide a four-satellite exploration of reconnection that NASA scientists plan to launch in 2014. The spacecraft will sweep through the magnetosphere—the magnetic field that surrounds the Earth—on a multi-year mission to study the regions where reconnection takes place. "We hope to provide a database that will tell (NASA) what kind of data-taking is most efficient," Yamada said.



Cosmic insight in above photos from left: Crab nebula; Princeton graduate student Clayton Myers, left, and technician Robert Cutler adjust interior of MRX; exterior view of MRX.

Princeton, Max Planck Society Launch New Research Center for Plasma Physics

Princeton University and the Max Planck Society of Germany have joined forces in a scientific collaboration that is designed to accelerate progress in cutting-edge research ranging from harnessing fusion to understanding solar storms. The center will be a virtual facility in which researchers will work cooperatively on projects from their current locations.

"This collaboration with Germany's distinguished Max Planck Society is certain to enhance our common excellence in fusion and plasma astrophysical research and, more broadly, to advance the development of clean and abundant energy," Princeton President Shirley M. Tilghman said during the signing ceremony.

Such cooperation is coming at precisely the right time, according to Peter Gruss, president of the Max Planck Society. "It is essential that we pool our strengths and knowledge in the field of fusion research, in particular, so that we can develop nuclear fusion into something the world urgently needs for the years and decades to come: safe, clean, and dependable energy technology," Gruss said.

The new center will combine the research capabilities of Princeton's Department of Astrophysical Sciences and the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) with the Max Planck Society's institutes for plasma physics, astrophysics and solar system research. "There is wonderful synergy between PPPL and the Max Planck Institute for Plasma Physics," said PPPL Director Stewart Prager. "We are very enthused to combine the capabilities of the two labs to make otherwise unattainable advances in key problems in fusion and astrophysics."

Signing the pact: Front row from left: Princeton President Shirley M. Tilghman, Max Planck Society President Peter Gruss. Back row from left: James Van Dam, director of the research division of the U.S. DOE's Office of Fusion Science; Stewart Prager, director of PPPL; James Stone, Princeton professor of astrophysical sciences and applied and computational mathematics; A. J. Stewart Smith, Princeton vice president for PPPL; Busso von Alvensleben, consul general of the Federal Republic of Germany in New York; Sybille Günter, director of the Max Planck Institute for Plasma Physics; and Sami Solanki, director of the Max Planck Institute for Solar System Research.

PPPL PLASMA SOURCE KEEPS BERKELEY LAB BEAM SHARPLY FOCUSED

Pictured from top: A Berkeley Lab technician readies the plasma source for installation on the accelerator; Erik Gilson displays a copper-clad module designed for the source.

WHEN RESEARCHERS AT THE E.O. LAWRENCE BERKELEY NATIONAL Laboratory needed a crucial component for a new particle accelerator, they turned to physicist Erik Gilson at PPPL. Gilson designed a plasma source the size of a hand telescope that keeps a beam of electrically charged particles from flying apart before it can reach its target.

This part completes an accelerator that Berkeley Lab researchers are using to heat a spot of foil to 30,000 degrees Centigrade in less than a billionth of a second. The process creates a state called "warm dense matter" that is rarely seen on Earth but can be found in the molten core of giant planets like Jupiter and in the preliminary stages of fusion. Such matter intrigues physicists studying the cosmos and scientists, including those at PPPL, who seek ways to harness fusion to produce electric power.

The new plasma source marks the third generation of components that Gilson has created for Berkeley Lab projects that are part of the Heavy Ion Fusion Science Virtual National Laboratory—a joint venture of PPPL, Berkeley Lab and Lawrence Livermore National Laboratory. The part consists of modules made from 1.6-inch-long rings of barium titanate ceramic that produce a swarm of atomic nuclei and electrons at its surface when a high-voltage is applied to it. These ions and electrons form a plasma that holds the charged particle beam together as it zips through the modules.

FINE-TUNING A KEY GERMAN EXPERIMENT

ENGINEERS AT PPPL HAVE DESIGNED AND DELIVERED TO GERMANY a set of five barn-door size components for a major device for developing fusion power. The components, called "trim coils," represent one of the largest hardware collaborations that PPPL has conducted with an international partner.

The powerful coils will fine-tune the shape of the superhot plasma gas in the Wendelstein 7-X stellarator that the Max Planck Institute for Plasma Physics is building in Greifswald, Germany. In exchange for the coils, PPPL scientists will be able to lead and carry out experiments on the W7-X when the machine begins operating in 2015.

Stellarators are one of the two major devices that scientists are using to develop fusion as a source of clean and abundant energy. The other device is the tokamak.

Delivery of the first coil over the 4,300-mile sea and land route blazed a challenging path for the others to follow. Workers at Everson Tesla, which built the coils in Nazareth, Pa., had to crate the first one in an upright position since it was too wide to travel on German roads without a police escort. Planners then plotted the overland route the 13-foot-high crate traveled by truck from Antwerp, Belgium, to Greifswald to avoid low highway clearances.

Workers at Everson Tesla shown here with the first of five barn-door size trim coils designed by PPPL.

The coil arrived at the Max Planck Institute for Plasma Physics in Greifswald, Germany after a 4,300-mile journey.

The first coil mounted on the W7-X stellarator, where it will help experiments on the machine run smoothly.

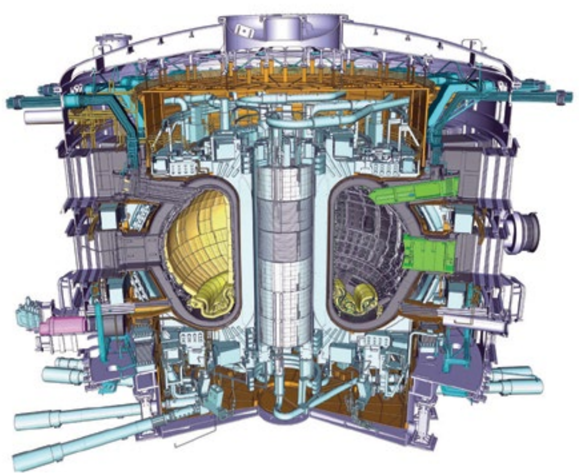
Search for Big Bang Neutrinos

PPPL is collaborating with Princeton University in a laboratory designed to detect neutrinos that appeared just one second after the Big Bang. Detection of these relic neutrinos would significantly enhance scientific understanding of elementary particles and the formation of the universe. Christopher Tully, a Princeton University physics professor who directs the project, is shown here checking a reading in the laboratory, which is housed at PPPL and called the "Princeton Tritium Observatory for Light, Early Universe, Massive Neutrino Yield" (PTOLEMY).

Sharing Their Knowledge

PPPL scientists participate in experiments on the DIII-D tokamak, the largest U.S. fusion facility, which General Atomics operates in San Diego for the U.S. Department of Energy. Eight PPPL researchers are currently assigned full-time to the DIII-D in a collaboration that enables the laboratories to pool their expertise on scientific and technological issues of mutual interest. PPPL staffers pictured from left in front of the DIII-D: Wayne Solomon, Devon Battaglia, Alex Nagy and Rajesh Maingi. Not shown: Brian Grierson, Egemen Kolemen, Raffi Nazikian and Benjamin Tobias.

PPPL Provides Key Components to ITER



A CAD illustration of the ITER tokamak.

The Laboratory is supplying a wide range of equipment to ITER, the huge fusion facility that the United States, the European Union, Japan, China, India, South Korea and Russia are building in France. PPPL is responsible for providing the following major items under contract with the US ITER office at Oak Ridge National Laboratory:

- Four of the 18 port plugs that will house diagnostic equipment to measure the performance of the superhot plasma in ITER
- Seven different types of diagnostic systems that will be used to gauge the temperature, density and other vital signs of the plasma
- Electromagnetic coils to help control the plasma and minimize sudden surges of heat that could destroy the divertor plates that vent the exhaust from fusion reactions
- Components for the AC electric power supplies that will run water-cooling and other critical systems on ITER, along with the building that houses the seven-story machine

Current plans call for the construction of ITER to be completed in 2019. The device is slated to produce a sustained fusion reaction, or burning plasma, in the late 2020s to showcase the feasibility of fusion power.

Science on Saturday

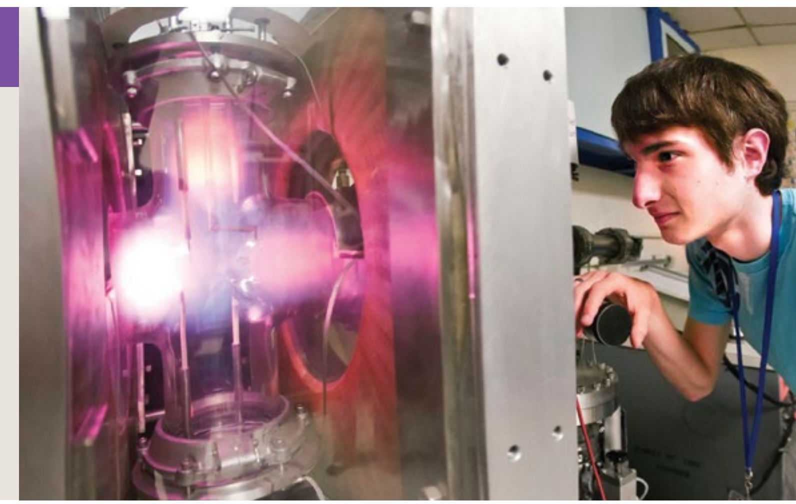
More than 10,000 lecture-goers of all ages have flocked to the weekly Science on Saturday presentations that PPPL hosts during the winter. The nine-week program features talks by leading scientists on a wide range of compelling topics.

Bright New Website

PPPL completely redesigned its website to provide a bright and open look. The new site (www.pppl.gov) weaves news of the Laboratory together with PPPL people and events in a format that features attractive photos and graphics and clearly written articles. The site employs a dynamic content management system that can be rapidly updated and that viewers can readily navigate.

Science Education

Princeton student Alexander Creely learns to take the temperature of plasma during a week-long summer internship in plasma physics for undergraduates. Fully 72 percent of the physics and engineering students who have taken the course have gone on to enter doctoral programs in physics since 2000.



Public Tours

PPPL conducts tours for the general public throughout the year. Physicists, engineers and other staffers guide visitors of all ages through the Laboratory and describe its research and experiments. Tour groups range in size from several persons to several hundred, and in places of origin from local communities to other countries.

Lieutenant Governor at PPPL

Among visitors to the NSTX upgrade site last year was New Jersey Lt. Gov. Kim Guadagno, shown here in the front row at right.

Bipartisan Support

U.S. Reps Rodney Frelinghuysen (R-NJ-11) and Rush Holt (D-NJ-12) visited the NSTX Upgrade site to express support for research into fusion energy. Top photo, from left: Rep. Rodney Frelinghuysen; Princeton President Shirley M. Tilghman; Rep. Rush Holt; Plainsboro Mayor Peter Cantu; PPPL Director Stewart Prager. Bottom photos, from left: Holt and Frelinghuysen addressed Laboratory staffers.

R&D 100 Award

R&D magazine bestowed its prestigious R&D 100 Award on physicists whose theoretical and experimental work developed the innovative snowflake divertor. The device spreads the heat from fusion experiments to keep it from damaging a facility's interior walls and contaminating the plasma. Those sharing the honor included Jon Menard, left, program director for the National Spherical Torus Experiment, and Vlad Soukhanovskii of Lawrence Livermore National Laboratory. Also honored were Egemen Kolemen of PPPL and Joon-Wook Ahn of Oak Ridge National Laboratory. Soukhanovskii and Ahn are on long-term assignments at PPPL. The annual R&D 100 Awards recognize the 100 most significant research and development advances in multiple disciplines.

Curbing Greenhouse Gases

The U.S Department of Energy honored PPPL with a Sustainability Award for reducing overall greenhouse gas emissions 48 percent since 2008—far exceeding the federal government's goal of a 28 percent reduction. Staff members cited for the award included Tim Stevenson, head of project management, shown here checking the level of sulfur hexafluoride in a power-supply tank to help protect against leaks. Also recognized were Bill Gervasi, manager of facilities and operations; Margaret King, grounds and maintenance supervisor; John Lacenere, head of AC Power Engineering; and Matt Lawson of the Material Services Branch.

What Is a Flame?

PPPL received an honorable mention—placing 15th out of 500 entries—for its video response to the Flame Challenge posed by actor Alan Alda. Science Education Head Andrew Zwicker and Aliya Merali, a program leader in science education, answered the Challenge question, "What is a Flame?" by showing that a flame is a plasma. Sponsoring the contest was the Center for Communicating Science at Stony Brook University, part of the State University of New York.

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Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543-0451
GPS: 100 Stellarator Road
Princeton, NJ 08540

www.pppl.gov

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