PPPL PRINCETON PLASMA PHYSICS LABORATORY
A Collaborative National Center for Fusion & Plasma Research
U.S. DEPARTMENT OF ENERGY
WEEKLY
NOVEMBER 18, 2013

SPECIAL APS physics ISSUE

At PPPL THIS WEEK

WEDNESDAY, NOV. 20

PPPL Colloquium
4:15 p.m. ◆ MBG Auditorium
Cybersnooping: Collection and Analysis of Metadata and Content
Edward Felten, Princeton University

THURSDAY, NOV. 21

PPPL United Way Bake Sale
8 a.m. ◆ LSB Lobby

PPPL United Way Presentation
9:30 a.m. ◆ MBG Auditorium

FRIDAY, NOV. 22

Princeton Deconstructed: PPPL
Noon ◆ Princeton University Frist Campus Center, Room 302
Adam Cohen gives an overview of PPPL

Open Enrollment Ends

UPCOMING EVENTS

November 28-29
Lab closed
Thanksgiving Holiday

December 4
PPPL Colloquium
4:15 p.m. ◆ MBG Auditorium
Observing the Deep Sea Globally
Stephen Riser, Univ. of Washington

December 11
PPPL Colloquium
4:15 p.m. ◆ MBG Auditorium
DIII-D Explorations of Fusion Science to Prepare for ITER and FNSF
R. Buttery, General Atomics, DIII-D

December 18
PPPL Colloquium
4:15 p.m. ◆ MBG Auditorium
LTX
Richard Majeski, Princeton University

INSIDE...

PPPL scientists present cutting-edge results at major physics meeting

More than 1,500 researchers, including scientists from PPPL gathered last week in Denver for the 55th Annual Meeting of the American Physical Society's (APS) Division of Plasma Physics (DPP). The five-day conference concluded Nov. 15. While there, they attended nine half-day sessions covering topics ranging from the challenges of producing a fusion reaction to the mysteries of plasma, an ionized gas that composes most of the matter in the universe. Two PPPL scientists, David Gates and Charles Skinner, were inducted as Fellows of the APS, an honor bestowed upon only half of one percent of all APS members each year.

The APS is a non-profit membership organization working to advance knowledge of physics through research journals, scientific meetings, and education, outreach, advocacy and international activities. APS represents over 50,000 members, including physicists in academia, national laboratories and industry in the United States and throughout the world. DPP was established in 1959, with its first elected chair the late Melvin B. Gottlieb, a former director of PPPL.

PPPL scientists presented a host of cutting edge results at the conference from their latest experiments and theoretical advances in fusion and plasma science. These press releases were prepared by the APS with the assistance of the scientists quoted and Science Writer John Greenwald.

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Bring a 50,000-degree Plasma into Your Living Room

An online open-user experiment puts users in control of a real physics laboratory

Paper by: A. Dominguez, A. Zwicker

With the rise of online open course platforms such as Khan Academy, MIT OpenCourseWare and iTunes U, it has never been easier to teach yourself everything from American history to semiconductor manufacturing. These courses enable students to advance at their own pace while accessing the limitless resources available on the Internet for supplemental material.

But there's a glaring exception to this cornucopia of courseware: Online physics classes that enable students to interact with a real physical experiment. While excellent online sites like Phet Interactive Simulations have developed virtual labs that simulate laboratory environments, there's no substitute for actual live experiments.

At PPPL, we've developed software for an experiment that can be observed and controlled from anywhere in the world. This "Remote Glow Discharge Experiment (RGDX)" consists of three main components:

- A live-streaming video that constantly observes an experimental apparatus housed at PPPL.
- A set of online controls.
- Information that explains what the user observes and controls, plus more in-depth resources that explore plasma and its uses.

The RGDX consists of a hollow glass tube with air held under a vacuum. Supplying a voltage of up to 2000V generates a glow discharge within. The user has control of the pressure inside the tube, the voltage supplied to the plasma and of the strength of an electromagnet surrounding the tube. Users are guided through steps that gradually increase their level of engagement and introduce them to new topics.

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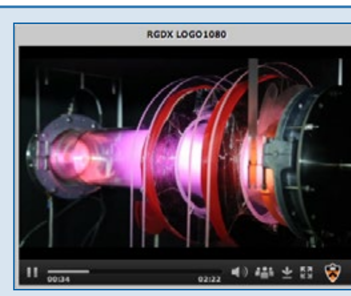
Video captures the wow factor in experimental device



PPPL photographer Elle Starkman and physicist Arturo Dominguez collaborated on a video showing the Remote Glow Discharge Experiment in action. See it at http://www.pppl.gov/news/2013/11/pppl-scientists-present-cutting-edge-results-major-physics-meeting.

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Simple instructions explain how to quickly produce a plasma, for example. If the user is interested in the physics behind the voltages, pressures and magnets, further explanations are given for each topic. Users are questioned about the observed phenomena, such as the color of the light emitted by the plasma, and a deeper explanation of spectroscopy and its uses is provided.

Audiences for the RGDX can range from someone simply interested in controlling a physical apparatus from afar, to an undergraduate or graduate student who wants to study phenomena such as instabilities in a plasma or the physics behind plasma breakdown voltages. The RGDX could serve as an experimental component of either an online or in-class physics course, and the software can be adapted to a wide array of experiments in other fields of physics and, potentially, to experiments in other sciences as well.

The user can operate the experiment with a set of controls, shown on the left side of the screen, and watch the effect on the apparatus at PPPL using the webstream video, shown on the right.

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Using Airport Screening Technology to Visualize Waves in Fusion Plasma

Millimeter-wave imaging helps scientists better understand and manage plasma instabilities

Paper by: B. Tobias, C. M. Muscatello

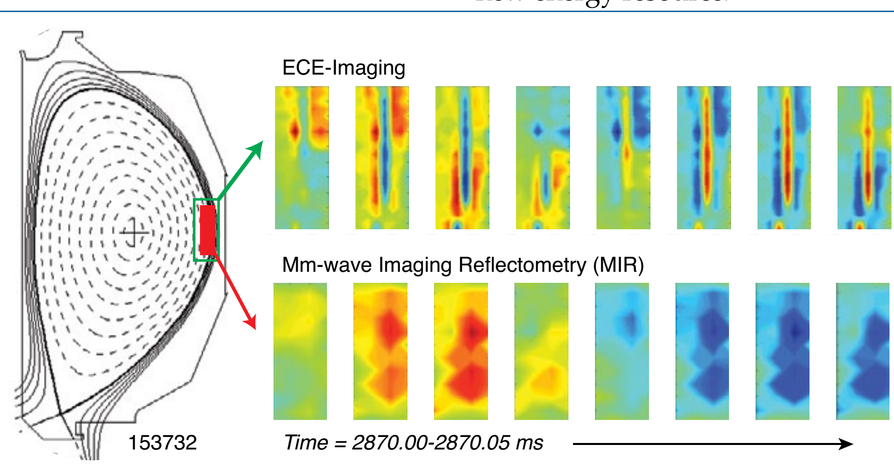
Millimeter-wave imaging technology is widely used in airborne radar, automotive sensors and full-body scanners for passenger screening at airports. A new, quasi-optical radar technique images millimeter-wave radiation reflected from fusion plasmas in 2D, time-resolved images. This novel application enables researchers to image waves in fusion plasmas in startling detail, and provides vital information to devise strategies to avoid instabilities which can reduce fusion power output. This enhanced imaging diagnostic of the tokamak interior was developed by a collaboration of fusion scientists from the University of California at Davis and PPPL.

Fusion experiments burn far hotter than the surface of our sun, too hot even to emit visible light. This renders typical photographic techniques all but useless. However, just as millimeter-waves penetrate the light clothing of passengers screened at airports and reflect from denser, concealed objects, millimeter-wave imaging reflectometry (MIR) illuminates the plasma with radio waves that penetrate the thin outer layers and reflect off small density fluctuations within the plasma interior.

In a plasma, waves can eject particles that ride the waves like surfers to the shore. Or the particles can grow uncontrollably until the entire discharge is lost. On the DIII-D tokamak at General Atomics in San Diego, MIR is paired with an Electron Cyclotron Emission Imaging (ECE-I) camera that radiometrically detects small variations in electron temperature.

In this way, both the density and temperature fluctuations caused by waves can be imaged in the same place and at the same time. Furthermore, because these diagnostics do not rely on an energetic particle beam, they can take 2D pictures continuously during the discharge without perturbing the plasma conditions. The results are images that help scientists understand how and why the waves grow and how to maintain plasma stability.

"The 2D and 3D structure of plasma fluctuations are important components of the magnetohydrodynamic (MHD) theory that allows us to predict the behavior of a future burning plasma fusion power plant," said physicist Benjamin Tobias, who participated in the research. "With this new visualization capability, we can perform the kinds of ambitious experiments that will accelerate our progress toward a viable new energy resource."



ECE-Imaging and the new diagnostic, MIR, sample overlapping regions of the tokamak plasma and produce 2D images of turbulence and fluctuations. ECE-Imaging measures the radiation temperature of electrons orbiting around magnetic field lines, while MIR detects changes in the electron density. In the series of frames shown, an instability associated with the formation of internal magnetic islands can be seen rotating through the diagnostic field of view.

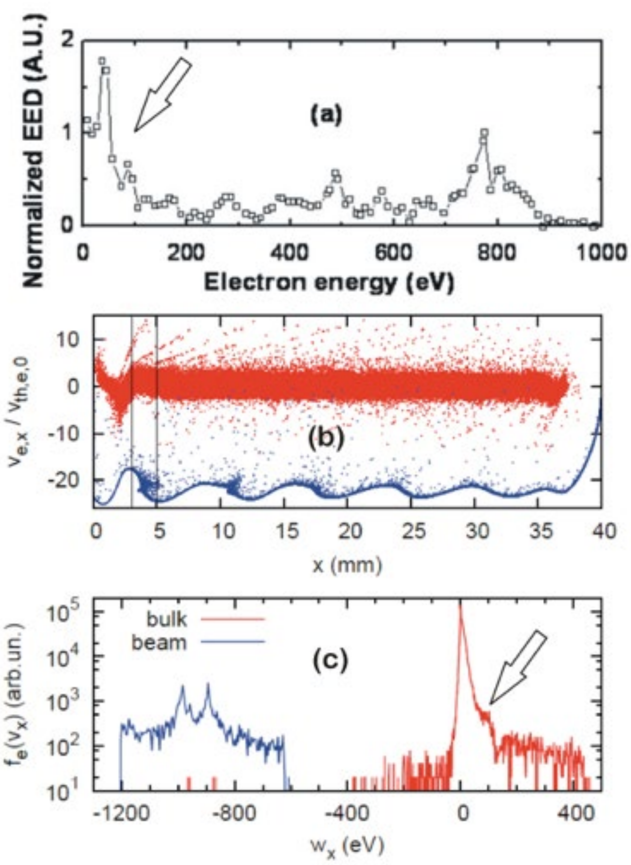
Riding an Electron Wave into the Future of Microchip Fabrication

Computer simulation explores how intense plasma waves generate suprathermal electrons, which are critical to microchip fabrication

Paper by: **I. D. Kaganovich**, **D. Sydorenko**

Advanced plasma-based etching is a key enabler of Moore's Law that observes that the number of transistors on integrated circuits doubles nearly every two years. It is the plasma's ability to reproduce fine patterns on silicon that makes this scaling possible and has made plasma sources ubiquitous in microchip manufacturing.

A recent fabrication technique, based on what is called "a DC-augmented capacitively coupled plasma source," affords chip makers unprecedented control of the plasma. This process enables DC-electrode borne electron beams to reach and harden the surface of the mask that is used for printing the microchip circuits. More importantly, the presence of the beam enables populations of suprathermal electrons to evolve in the plasma, producing the plasma chemistry that is key to protecting the mask.



Electron energy distribution function measured in a rf-dc discharge [from Xu et al., App.Phys.Lett., vol. 93, 261502 (2008)]. Phase plane electron velocity-coordinate (b) and the electron velocity distribution function (c) in a numerical simulation. Arrows in (a) and (c) point to the supra-thermal electrons.

The energy of these electrons is greater than simple thermal heating could produce — hence the name "suprathermal." But how the beam electrons transform themselves into this suprathermal population has been a puzzle.

Now a computer simulation developed at PPPL in collaboration with the University of Alberta has shed light on this transformation. The simulation reveals that the initial DC-electrode borne beam generates intense plasma waves that move through the plasma like ripples in water. And it is this beam-plasma instability that leads to the generation of the crucial suprathermal electrons.

Understanding the role that these instabilities play provides a first step toward still-greater control of the plasma-surface interactions, and toward further increasing the number of transistors on integrated circuits. Insights from both numerical simulations and experiments related to beam-plasma instabilities thus portend the development of new plasma sources and the increasingly advanced chips that they fabricate.

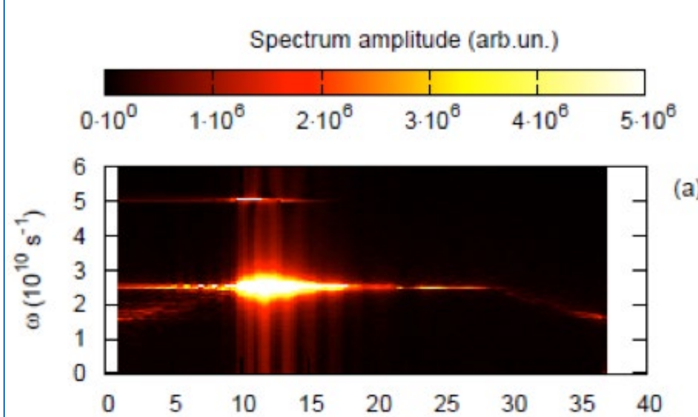


Image of a plasma wave that can give rise to a population of suprathermal electrons.

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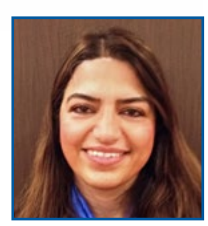
Building a Better Tokamak by Blowing Giant Plasma Bubbles



Research shows how magnetic reconnection — the force behind solar flares — could initiate fusion in a tokamak reactor

Paper by: **F. Ebrahimi**, **R. Raman, E. B. Hooper**

Advanced computer codes are helping scientists reimagine how they might initiate a fusion reaction in the center of a tokamak, a doughnut-shaped experimental vessel. These simulations are also shedding new light on complex phenomena in magnetic fields.

Plasma confinement devices based on the tokamak concept rely on a solenoid that runs through the center of the device to generate the initial current. But solenoids have a limited pulse length and cannot sustain the initial current indefinitely in a steady-state reactor. Finding a way to eliminate the solenoid would thus remove a large component from the center of the tokamak, make the device simpler and less expensive, and allow the freed space in the center to be used to optimize the tokamak and make it more efficient.

Now advanced computer modeling with the NIMROD code — code specifically designed to facilitate these simulations — has begun to describe the mechanism behind a magnetic structure that could replace the solenoid to start the initial current. This modeling simulates an enormous magnetic bubble that carries 300,000 amperes of current, or 1,500 times the amount that flows into a home.

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Researchers at the National Spherical Torus Experiment (NSTX) at PPPL have produced the actual bubble through a method known as transient Coaxial Helicity Injection (CHI). Originally developed on the much smaller HIT-II device at the University of Washington, the method has been improved on the 30-times-larger in volume NSTX spherical tokamak.

CHI uses a process called magnetic reconnection to create the bubble. This process takes place when magnetic field lines break apart and reconnect with a burst of energy. The type of reconnection that occurs during transient CHI experiments in NSTX is similar to the process that produces solar flares—the magnetic strings, or filaments, ejected from the surface of the sun. These experiments also represent the first-ever occurrence of forced magnetic reconnection during an experiment on a large-scale fusion facility.

CHI creates a bubble inside the NSTX by driving currents along magnetic filaments in the plasma. The sequence of camera images in Figure 1a, at right, shows the bubble being generated in the lower part of NSTX and expanding to fill the entire vessel. Figure 1b shows the magnetic structure as modeled using the NIMROD code.

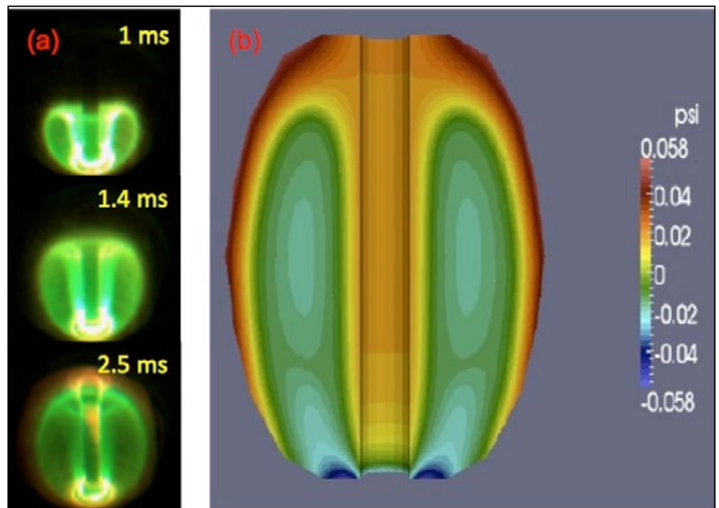

Figure 1: (a) Sequence of visible fast camera images of a CHI discharge inside NSTX. The top image shows the expansion of the CHI discharge one thousands of a second after it is initiated. As shown in the third frame, within three thousands of a second the plasma has fully filled the vessel. (b) Magnetic structure of a bubble in NSTX as simulated by the NIMROD code.

The simulations describe the fundamental processes as follows:

- First, magnetic forces arising from the current on the surface of the filaments overcome the rubber-band-like tension that could reverse the strings' expansion. This allows the strings to expand and fill the vessel.
- Second, when the current is suddenly turned off, the expanded strings seek a stable configuration.
- Third, the simulations show that new forces then take over. These bring the magnetic strings in the lower part of the NSTX vessel closer together until they reconnect and generate a magnetic bubble.
- Finally, the simulations are now starting to identify the different parameters needed to generate a high-quality magnetic structure.

Fusion Foe Lends a Helping Hand

Recent experiments breathe new understanding into oxygen's role in fusion devices

Paper by: C. N. Taylor, J. P. Allain

Although oxygen is required to sustain life, oxygen sucks the life out of fusion by radiating away too much power from the high-temperature plasma. Accordingly, great efforts are expended to reduce the oxygen found in fusion facilities. Surprisingly, recent laboratory experiments and atomistic simulations have found that the oxygen bound by lithium at the walls of fusion devices plays a key role in improving plasma performance.

Researchers at the National Spherical Torus Experiment (NSTX) that is now being upgraded at PPPL have long used lithium wall conditioning as a method for improving plasma performance. These improvements include elimination of otherwise virulent edge plasma instabilities, and an improvement in the energy confinement of the plasma, both of which are correlated with a reduction of neutrals that 'recycled' at the plasma facing components. Until recently, researchers assumed that the lithium was primarily responsible for these benefits, although the precise mechanism remained unknown.

Contributing to the mystery is the fact that the walls of NSTX are made of carbon in the form of graphite tiles. Lithium tends to seep into graphite, so it was unclear why any lithium would be left to capture anything that landed on the surface of the tiles. Instead, it appears that the lithium interacts with both the carbon in the tiles and the oxygen that is naturally embedded in them to create a new plasma-facing wall that contains all three elements.

Recent studies have now shed light on how effectively this special wall surface can improve plasma performance. These studies have demonstrated the strong reaction that takes place when deuterium, the hydrogen isotope used in NSTX plasmas, comes into contact with lithium and oxygen at the plasma-facing wall of the fusion facility. Researchers first used a highly sensitive measurement technique called "X-ray photoelectron spectroscopy," or XPS, to detect the chemistry of the top few nanometers of the lithium-covered graphite tiles in NSTX experiments.

Researchers then used computer simulations, led by P. S. Krstic, to replicate the contact between deuterium and graphite tiles impregnated with lithium and oxygen. Results showed that the lithiated and oxidized graphite captured much of the deuterium, mirroring what occurred in NSTX. (See "Deuterium Uptake in Magnetic-Fusion Devices with Lithium-Conditioned Carbon Walls" by P. S. Krstic et al. in Physical Review Letters 110, 105001 (2013).)

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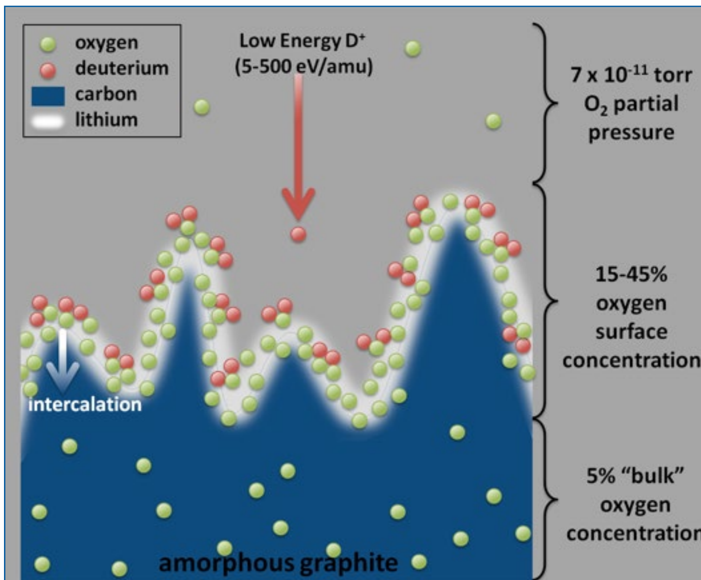
When researchers changed the simulation to eliminate the oxygen, leaving only lithium on the graphite tiles, the deuterium retention was quantitatively lower, and carbon erosion higher. As a computational exercise, the next simulation reversed the scenario to bring the deuterium into contact with a matrix of just graphite and oxygen, which would in practice be difficult to realize because of excessive oxygen contamination of the hot plasma. Surprisingly, the deuterium retention was even higher than in the other two simulations.

"The combination of these simulations and experiments leads to the conclusion that lithium forms the 'glue' that allows the carbon-lithium-oxygen surface layer to very effectively retain deuterium and reduce recycling. Without the lithium, the high levels of oxygen in the surface layers needed to see this beneficial effect would likely contaminate and cool the main plasma," said physicist Chase Taylor, who led the experimental portion of the surface physics research at Purdue University with PI Prof. Jean Paul Allain who recently joined University of Illinois Urbana-Champaign. "Our results show how lithium should be prepared and maintained to yield optimum plasma performance."



The lithium coating on graphite, which appears mountainous in this graphic done at microscopic scale, provides the perfect setting for oxygen to control the hot deuterium plasma. Reference: C.N. Taylor, et al., "The role of oxygen in retaining deuterium in lithiated graphite", J. Appl. Phys., submitted 2013.

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Hot Lithium Vapors Shield Fusion Facility Walls

Coating protects reactor components while preventing plasma contamination

Papers by: M. Jaworski, T. Abrams, R. Kaita

Recent experiments suggest that a novel regime for liquid-metal plasma facing components of fusion facilities can produce a vapor shield for 10 times longer than previously expected. If confirmed by further research, this type of operation could alleviate widespread concerns that liquid-lithium plasma-facing components will rapidly overwhelm the core of the plasma with impurities and abort fusion reactions.

Researchers at PPPL and the Dutch Institute for Fundamental Energy Research (DIFFER) conditioned the target samples with lithium and, in the course of experiments, raised the surface temperature above 900 degrees Celsius. At such high temperatures the lithium rapidly ablates, or wears away, from the target through a combination of evaporation and other erosion processes. The vaporized lithium is expected to serve as a shield that will intercept and mitigate the intense plasma flux before it can impinge upon the rest of the wall.

These experiments demonstrated that such a vapor cloud could be produced and was stable over a wide temperature range. The research found that the regime persisted for three-to-four seconds under the intense plasma bombardment. This indicated that nearly 100 percent of any eroded wall material had been confined to the surface of the sample. Simple estimates had suggested that coatings without such high confinement at the target could last less than half a second under the intense conditions and would fail to keep impurities from drifting into other parts of the machine.

These initial experiments, performed on the Magnum-PSI linear plasma device at the Dutch center, were done in support of a research and development program planned for the National Spherical Torus Experiment-Upgrade (NSTX-U) at PPPL. The Magnum-PSI plasma served as a proxy for the hot plasma exhaust that the divertor region will channel away in the NSTX-U and other current and future fusion facilities. The researchers used a lithium evaporator developed at PPPL to test the novel vapor-shielded regime on different target materials.

This research indicates that modest coatings of lithium on metallic substrates like tungsten can be sufficient for initial experiments of the regime in a tokamak such as NSTX-U. Demonstration of the vapor-shielded regime in the NSTX-U would provide proof-of-principle for using liquid lithium as a divertor target material in a reactor-relevant device.

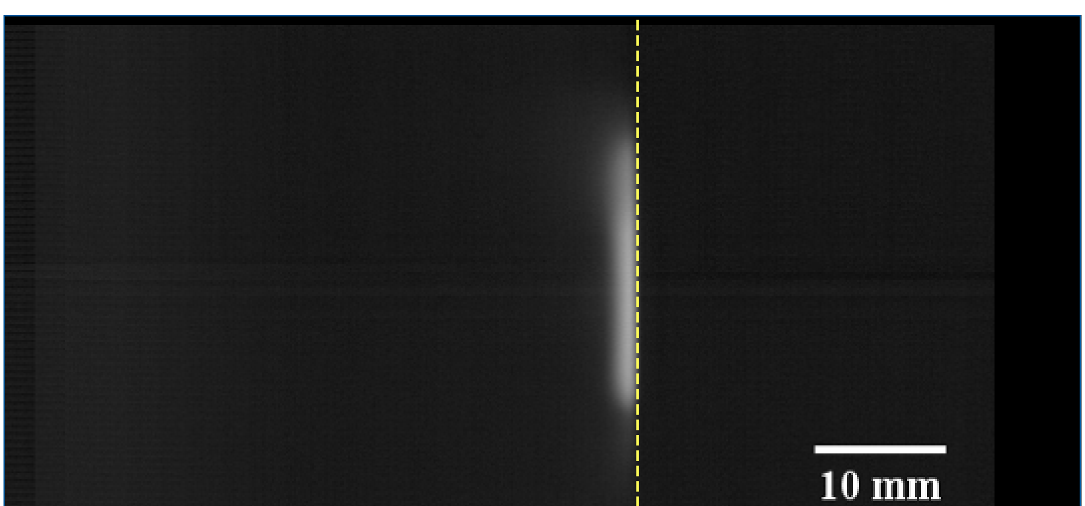

Image of lithium emission during experiments conducted on the Magnum-PSI device. Plasma streams toward the target from the left and impinges the sample indicated by the yellow dashed line. The lithium ablates into the plasma stream and forms a cloud in front of the target.

COLLOQUIUM

Cybersnooping: Collection and Analysis of Metadata and Content

EDWARD FELTEN
Princeton University

Wednesday, Nov. 20

4:15 p.m. (Coffee/Tea at 4 p.m.) • MBG Auditorium

Food Contributions Needed for Local Food Bank

More than 25,000 people in Mercer County depend on food provided by the Mercer Street Friends Food Bank, which serves more than 50 pantries, shelters and soup kitchens.

You can help by bringing your donations of canned or packaged food (no glass please!) to the LSB Lobby from Nov. 25 through Dec. 18 as part of the Princeton University Food Drive.

The most needed items include canned protein such as tuna fish or chicken, Parmalat, cereals, and peanut butter and jelly. The Food Bank also needs personal care products such as soap, shampoo, deodorants, feminine products and laundry soap.

Items needed for the Send Hunger Packing Program, which provides food to school-aged children to get them through the weekend, include: single servings of Parmalat, individual servings of cereal and individual servings of microwaveable food, granola bars and pudding cups.

Contribute to United Way Campaign & Bake Sales

The United Way presentation at PPPL is scheduled for Nov. 21 at 9:30 a.m. in the MBG auditorium with speakers, a parking space raffle, and a bake sale at 8 a.m.

Please come to the presentation to hear about the United Way and enter a raffle to win one of 16 parking spaces for three months. Coffee will be served.

There will be a bake sale in the lobby on Nov. 21 starting at 8 a.m. with baked goods available for $1. Please volunteer by bringing in home-baked goodies for the sale. Contact Kim Mastromarino (kmastrom@pppl.gov) and let her know what you would like to donate.

The University will contribute 15 cents per dollar on top of donations made through payroll deductions and 10 cents per dollar on top of other gifts, including bake sale proceeds.

Open Enrollment extended to Nov. 22 due to health benefit expense account changes

The Open Enrollment deadline has been extended to Friday, Nov. 22 due to changes in Princeton's Health Benefit Expense Account (HBEA). Under the new provisions, employees can now roll over $50 to $500 to the next year and use it to pay for medical expenses for the calendar year in which they were carried over. The rollover amount will not be included in the $2,500 HBEA limit for 2014. You still must re-enroll in the HBEA or the Dependent Care Expense Account.

This year, employees who are not already enrolled in the Supplemental Retirement Plan will be automatically enrolled at 2 percent unless they sign on to HR Self Service to increase, decrease or waive this benefit.

Go to HR Self Service http://www.princeton.edu/hr/progserv/sds/applications/selfservice.html to enroll in any expense accounts, change your retirement contribution or increase your supplemental life insurance.

COMING SOON!!! SIGNATURE SANDWICHES
- Chicken Bacon Ranch
- Greek Pita
- Sonoma Turkey
- Chicken Carbonara
- Basil Pesto Chicken

Café at PPPL Menu

BREAKFAST .... 7 a.m. • 10 a.m.
CONTINENTAL BREAKFAST .... 10 a.m. • 11:30 a.m.
LUNCH .... 11:30 a.m. • 1:30 p.m.
SNACK SERVICE .... until 2:30 p.m.

— MARK GAZO, Chef Manager

	MON. NOV. 18	TUE. NOV. 19	WED. NOV. 20	THU. NOV. 21	FRI. NOV. 22
					
COMMAND PERFORMANCE CHEF'S FEATURE	Pulled Chicken or Pork Soft Taco with Rice, Black Beans, Roasted Corn & Toppings	Cheese Tortellini with Sundried Tomatoes and a Creamy Pesto Sauce with Breadstick	BBQ Meatloaf with Fried Onions over Mashed Potatoes	Turkey, Stuffing, Potatoes, Vegetable, Cranberry, and Pumpkin Pie	Baked Stuffed Flounder Florentine with Cilantro Smashed Potatoes
EARLY RISER	Almond French Toast with Cranberries	Chicken, Spinach, Mushroom Cheddar Omelet with Potatoes	Egg White Scramble with Onions, Peppers, Potatoes & Cheese	Grilled Cheese with Bacon, Ham & Fried Egg	Pumpkin Cinnamon Streusal Pancakes
COUNTRY KETTLE	Chicken Tomato Basil	Potato Leek with Cheddar	Split Pea with Ham	Tomato Florentine with Orzo	New England Clam Chowder
GRILLE SPECIAL	Roast Beef Melt with Sauteed Onions	Kielbasa & Kraut Torpedo with Fries	Cajun Catfish Po' Boy with Slaw, Remoulade Sauce & Hush Puppies	Chicken Cacciatore on a Torpedo Roll	Grilled Portobello Mushroom on Wheat Roll
DELI SPECIAL	Chopped Veggie Antipasto Wrap	Portobello Mushroom Caprese with Fresh Basil, Tomato	BLT with Avocado, Smoked Ham on Whole Grain Toast	Classic Tuna Club Sandwich with Hard Cooked Egg	Chicken Carbonara Torpedo with Bacon, Mushrooms, Mozzarella
PANINI	Italian Sausage, Pepperoni, Peppers, Onions Stromboli	Buffalo Popcorn Shrimp Wrap with Blue Cheese & Jack Cheese	Honey Dijon Grilled Chicken on a Baguette	Eggplant Parmesan with Fresh Mozzarella Cheese on Ciabatta	Spicy Beef Taco Quesadilla
VALUE MEAL $5	Blueberry Pancakes with Sausage, Hash Browns, & 12 oz. Beverage	BLT with Housemade Potato Chips & 12 oz. Beverage	2 Stuffed Shells, Side Salad, Garlic Bread & 12 oz. Beverage	Sloppy Joe Sliders with Chips & 12 oz. Beverage	Chicken Tenders With French Fries & 12 oz. Beverage

MENU SUBJECT TO CHANGE WITHOUT NOTICE

VEGETARIAN OPTION

CLICK HERE FOR A PRINTABLE WEEKLY MENU

WEEKLY Editor: **Jeanne Jackson DeVoe** ◆ Layout and graphic design: **Gregory J. Czechowicz**
Photography: **Elle Starkman** ◆ Web: **Chris Cane** ◆ Admin. support: **Pamela Hampton**

The **PPPL WEEKLY** is published by the PPPL Office of Communications on Mondays throughout the year except for holidays. Deadline for calendar item submissions is noon on Thursday. Other stories should be submitted no later than noon on Wednesday. Comments: commteam@pppl.gov ◆ **PPPL WEEKLY** is archived on the web at: http://w3.pppl.gov/communications/weekly/.

The PPPL Weekly will not be published on Dec. 2 due to the Thanksgiving holiday. The next issues will appear on Nov. 25 and Dec. 9.