PPPL PRINCETON PLASMA PHYSICS LABORATORY
A Collaborative National Center for Fusion & Plasma Research
U.S. DEPARTMENT OF ENERGY
WEEKLY
July 3, 2017

THIS WEEK

TUESDAY, JULY 4

Independence Day
Laboratory closed.

FRIDAY, JULY 7

Public Tour
10 a.m. ◆ LSB Lobby
Email tours@pppl.gov

REU MIRTHE tour
1 p.m. ◆ LSB Lobby

UPCOMING

JULY 19–21

Fusion Energy Sciences Advisory Committee Transformative Enabling Capabilities subcommittee community input meeting
MBG Auditorium

The next issue of the PPPL Weekly will be on July 17.

INSIDE

Laboratory physicists outline their research at the EPS Conference in Northern Ireland

By John Greenwald

PPPL researchers attending the 44th European Physical Society Conference on Plasma Physics detailed topics ranging from commissioning the NSTX-U to triggering events known as edge localized modes (ELMs) in tokamaks. More than 600 physicists and engineers from around the world participated in the June 26-30 conference, which was hosted in association with the Centre for Plasma Physics at Queen's University in Belfast, Northern Ireland, and held in that city's Waterfront Hall. Talks and posters ran the gamut from nuclear fusion to low-temperature plasmas, astrophysical plasmas and laser-plasma interactions.

continued on page 4

Predhiman Kaw, founder of India's fusion program and former PPPL physicist, dies at 69

By Jeanne Jackson DeVoe

Predhiman Kaw, an internationally-known plasma physicist who is considered the father of India's nuclear fusion program, was remembered fondly by his colleagues at PPPL last week after they learned of Kaw's June 19 death. He was 69.

Kaw was a physicist at Princeton University and PPPL's Theory Department for 11 years before moving back to his native country to help establish India's Institute for Plasma Research (IPR) and lead the effort to build India's first tokamak, the ADITYA. He also was a major driver for India to join six other partners on the international fusion experiment ITER.

Predhiman Kaw

"He was an indefatigable champion of fusion internationally," said Amitava Bhattacharjee, head of PPPL's Theory and Computation Department. "He was a world leader whose work touched upon nearly every aspect of plasma physics."

"Predhiman was a remarkable person, an inspiring leader of the program he created in India and a world-leading theoretical physicist," said Steven Cowley, president of Corpus Christi College in Oxford, former director of the Culham Centre for Fusion Energy and a former colleague of Kaw's at PPPL. "He will be missed by many."

continued on page 6

Hans Hendel, physicist on TFTR, passes away

By Larry Bernard

Hans W. Hendel, a physicist whose pioneering work at PPPL resulted in identifying drift waves in the laboratory, passed away June 18 in Princeton. He was 94.

Hendel was a visiting research physicist at PPPL starting in 1965 until his retirement, on permanent assignment from RCA Laboratories Astro-Electronics Division.

"Hans was as kind a gentleman as you could meet," said Masaaki Yamada, who was recruited as a post-doctoral associate by physicist Tom Stix to work with Hendel in 1973, and worked with him closely. "He was always gentle, and was a great man. He led an exciting life, but never bragged."

Hendel originally worked on a plasma device called a Q Machine, on the second floor of L-wing. The machine was used in experimental plasma physics designed to study the wave properties in a quiet plasma. "He did excellent work and was very productive," Yamada said. "Every year we would have one or two papers in Physical Review Letters. He was a very intuitively clever man for experimental science."

Hendel eventually turned his attention to neutron diagnostics, which were instrumental for experiments on the Tokamak Fusion Test Reactor.

"His work on drift-wave instability, its onset, induced plasma loss, and stabilization by external feedback technique, motivated many theorists," said T.K. Chu, a PPPL physicist who worked with him. Hendel joined Ken Young and took over planning and design of the neutron diagnostics on TFTR, critical for its success. Hendel then worked on actual neutron measurements until he retired.

As a teenager, Hendel was an elite paratrooper for the German army and was part of the invasion of Crete at the start of World War II, the first airborne invasion in military history. He also was part of Germany's invading force in the North African campaign under Gen. Erwin Rommel. He was injured several times and, at war's end, was captured by U.S. troops. He came to the United States and began his scientific work at RCA.

Hendel's athleticism and rugged good looks also earned him Hollywood's attention, and he was recruited for action series movies as a paratrooper, jumping out of planes, "almost like a stuntman," Yamada recounted. "He was an elite athlete. We played tennis every day but you couldn't keep up with him. I heard that when he was young he ran a superfast 100 meters." Also, he was a skilled hunter and traveled to near the North Pole to hunt with Eskimos and to the desert in Arizona to hunt with indigenous people, Yamada said.

Phil Efthimion, also a young researcher at the time, recalled Hendel's mentorship. "He taught me to cross-country ski, and I was struck by how adventuresome his life was, certainly compared to mine," he said. "I looked to him for many things early in my career."

Said Young: "He was known to his colleagues for his boundless optimism, energy and curiosity."

Hans W. Hendel received his B.S. in 1946, his M.A. in 1948, and his Ph.D. in 1953, all in physics, from the Technische Hochschule in Munich, Germany. During the summer of 1951, he held a fellowship at MIT, where he worked on angular and energy distribution of photoprotons. From 1953 to 1957, he was a research physicist at the Agfa Camera Works in Munich, where he developed and tested optical systems. From 1957 to 1961, he was a research physicist at the U.S. Army's Fort Monmouth in New Jersey, where he began research in plasma phenomena. He studied the emission of radiation from the acceleration of charged particles from pinch discharges, and developed plasmoid-ignited high-current plasma switches.

Hans Hendel

As the leader of the plasma physics group at RCA, Hendel researched mechanisms for accelerating ions to the high velocities necessary for space propulsion. He also worked on Bostick-type plasma guns and continuous acceleration of plasmas by electron cyclotron resonance heating.

Hendel was RCA's principal investigator for Air Force-sponsored research on electron cyclotron resonance plasma acceleration. His group also studied pumping methods for high power gas lasers, tuned laser spectroscopy and remote atmospheric probing by laser.

Hendel was a member of the American Physical Society and the American Institute of Aeronautics and Astronautics. He authored numerous publications on nuclear and plasma physics and had several patents.

He is survived by his wife of many years, Annelise, daughters Bambi and Eva and son, Bruce. Funeral arrangements were private.

Run for your health! PPPL Run Club

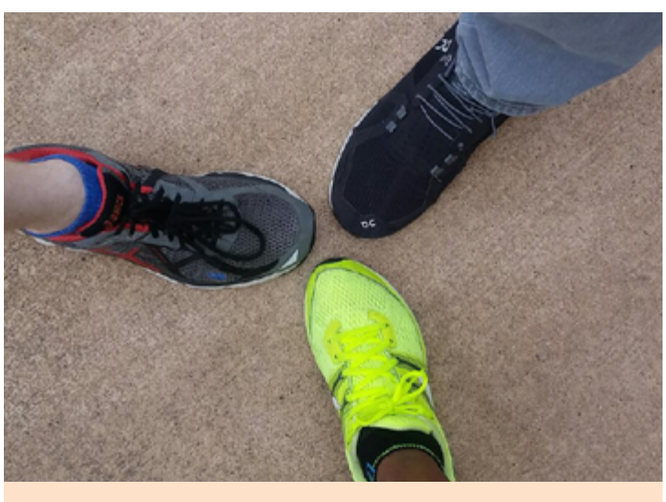
Daily meets at 12:15 p.m. in the LSB Lobby

See Angela Powell (x3347) or Laurie Bagley (x2425) for details.

PPPL's Run Club is a runaway success

Some members of the PPPL Run Club get ready for their noon run. The newly-formed club meets every day in the LSB Lobby for a 5-kilometer (3.1 mile) run. (See page 2).

From front, clockwise: Angela Powell, Janice Huang, Paul Henderson, Laurie Bagley, Michael Weller, and Atiba Brereton on the club's first day Monday. *(Photo by Angela Powell)*



Angela Powell, Atiba Brereton, and Michael Weller show off their running shoes. *(Photo by Angela Powell)*

Runners on the Wednesday run, from left: Deedee Ortiz, Paul Henderson, Janice Huang, Angela Powell and Michael Weller. *(Photo by Michael Weller)*

Members of the running club outside the LSB Building on Thursday. From left: Neil Gerrish, Dina Christie, Angela Powell's son Terris Burton, 16; Laurie Bagley, Michael Weller, Deborah Niemenski, and Angela Powell. *(Photo by Angela Powell)*

PPPL runners jump for joy on the their last run of the week Friday. Left to right, Deedee Ortiz, Paul Henderson, Angela Powell, Laurie Bagley, Michael Weller, and Andrew Zwicker *(Photo by Atiba Brereton)*

EPS Conference

continued from page 1

View of the Waterfront Hall in Belfast, Northern Ireland, where the week-long conference took place.

Among the PPPL presentations:

National Spherical Torus Experiment-Upgrade (NSTX-U)

Physicist Devon Battaglia gave an overview of the commissioning operations of the NSTX-U that successfully qualified a host of new systems and scientific tools installed during the upgrade of its predecessor, the National Spherical Torus Experiment (NSTX). The upgraded facility will advance the scientific understanding needed for creating fusion reactions in a spherical torus that is shaped like a cored apple, compared with the doughnut-like shape of conventional tokamaks.

Recently completed commissioning operations on the NSTX-U produced novel results. For example, Battaglia's data showed that the facility quickly produced plasma discharges that exceeded the longest pulses produced on the predecessor machine prior to the upgrade. Moreover, high-confinement, or H-mode discharges were achieved in the second week of operations, and the achieved stored energy and plasma current steadily increased to the levels needed for scientific operations over the following weeks.

Enabling such progress were capabilities that included advances in real-time control of the plasma shape and position as well as efficient identification and correction of error fields that can hinder the performance of fusion plasmas. Many new diagnostics were brought online, including a novel system for evaluating the condition of the tokamak's walls and a real-time measurement of the plasma rotation. The first operation with three injection sources from a new tangential neutral beam demonstrated that this heating system will provide a valuable tool for optimizing the stability and confinement of the ultra-hot plasmas in this powerful facility.

Physicist Eric Fredrickson presented the first observation and measurement of ion cyclotron emission (ICE) in the NSTX-U. Such emissions represent the electromagnetic radiation that is produced by superthermal fast ions, which have velocities much larger than normal thermal ions, that cycle around magnetic fields.

Fredrickson's poster showed that the NSTX-U emissions originate from deeper in the plasma than had been observed in either the Tokamak Fusion Test Reactor (TFTR), which operated at PPPL from 1982 to 1997, or the Joint European Torus (JET) at the Culham Centre for Fusion Energy in the United Kingdom. In those facilities the peak frequencies, or highest rate of ion emission, occurred near the plasma edge.

Since these observations differ from those on JET and TFTR, the sightings might provide a clue, or point theorists in a better direction, toward developing an improved theoretical model of ICE. At present, there is no understanding of precisely why the process occurs. Scientists also hope that similar measurements on ITER, an international tokamak under construction in France to demonstrate the feasibility of fusion energy, could serve as a diagnostic for studying the confined superthermal ions that will come from fusion reactions and neutral beam injections in that collaborative facility.

Use of lithium granules to induce ELMs on EAST and DIII-D

Controlling events called edge localized modes (ELMs) in tokamaks will be essential for next-step fusion devices such as ITER, the international fusion facility under development in France. Without such control, the unmitigated cycling of ELMs is expected to damage and shorten the lifetime of the divertor chamber that exhausts heat from the edge of the plasma.

A confirmed strategy for controlling ELMs is injection of lithium granules to rapidly trigger smaller and less detrimental events in a process called "pacing." This technique has been deployed on the Experimental Advanced Superconducting Tokamak (EAST) in China and the DIII-D National Fusion Facility that General Atomics operates for the U.S. Department of Energy in San Diego.

In a poster, PPPL physicist Robert Lunsford described the effect of injecting lithium granules with diameters ranging from 300 microns to 900 microns into the EAST tokamak. Experiments on EAST demonstrate a quantifiable size threshold for the granules that produce prompt triggering of ELMs, with the larger granules proving most effective. By calculating the impact of the granules on plasma pressure, and coupling this to measurements at the edge of the plasma, researchers were able to determine guidelines for the size of the granules for reliably triggering ELMs.

New computer code for preventing plasma disruptions

The recently developed Disruption Event Characterization and Forecasting (DECAF) code, written by Jack Berkery and Steven Sabbagh, Columbia University physicists on assignment to PPPL, aims to characterize and forecast events that can lead to disruption of a tokamak plasma. The goal is to determine the occurrence of chains of events that lead to disruption, and to cue avoidance systems. Berkery presented a

continued on page 5

EPS Conference

continued from page 4

poster that described the code and provided examples of how the program works.

Among the examples cited is an algorithm, or method, for detecting resistive wall mode (RWMs), a type of instability that can restrict the high plasma pressure that fusion reactions require. The algorithm can provide a test that looks for either simple magnetic signals that precede the instability, or for more sophisticated forerunners of RWMs.

Berkery has incorporated in DECAF a reduced model of complex plasma conditions that he streamlined for fast computation. This model has performed well. In its first look at data collected from the NSTX, the predecessor of the NSTX-U, the model identified instability 84 percent of the time in cases that were experimentally unstable, and found stability 77 percent of the time in experimentally stable cases.

The role of turbulence during plasma compression

Seth Davidovits, a graduate student in the Princeton University Department of Astrophysical Sciences who is studying plasma physics at PPPL, presented a talk on modeling the impact of compressing fluid turbulence in inertial confinement fusion (ICF) facilities. Such compression stores energy that can be transformed into high temperature to produce nuclear fusion, suggesting a new paradigm for ICF experiments.

This effect depends on the viscosity, or resistance to flow, of the plasma. By reducing or increasing viscosity, researchers can regulate the timing of ICF reactions. Also affecting reactions is the ionization, or amount of charged particles, in fuel composed of elements with higher atomic numbers than hydrogen. Changing the degree of ionization could serve to regulate the sudden dissipation of heat that leads to the reactions.

Similar considerations can also be used to set a lower bound on the amount of turbulent growth that takes place during astrophysical compressions, such as the gravitational contraction that occurs in molecular clouds. Inspiring all these investigations, Davidovits noted, were experiments on a Z-pinch inertial confinement machine conducted by Professor Yitzhak Maron at the Weizmann Institute of Science in Israel.

Plasma mass filter separation of nuclear waste

In an invited talk, physicist Renaud Gueroult described how plasmas could be useful for high-throughput separation of high-level from low-level nuclear waste at nuclear cleanup sites. Gueroult, now at the Laboratory on Plasma and Conversion of Energy (LAPLACE) at the University of Toulouse, began research on this topic as a physicist at PPPL.

Nuclear waste cleanup is considered to be a major technological problem facing society. In the United States, estimates are that cleanup will cost hundreds of billions of dollars and take decades to complete.

Gueroult described a suite of plasma techniques that would supplement existing methods of chemical separation, in cases where chemical methods are challenged, by ionizing radioactive waste and injecting it into a rotating filter. Centrifugal and magnetic forces in the spinning filter would create "differential magnetic confinement" properties that would separate high-level from low-level waste. Other applications for the process could include reprocessing spent nuclear fuel and recycling rare earth metals found in many high-tech products.

The largely theoretical presentation reviewed various differential confinement mechanisms and main applications considered to date, and identified key questions related to the development of plasma mass filters.

2017 Fishing Trip

Aboard the 80' Suzie Girl

Date: Sunday August 6th, 2017

Departure: 7:30 a.m. SHARP!!!

Location: Belmar Marina Hwy. 35, Belmar, NJ 07719

Cost: $80 Per person ALL INCLUSIVE

Cost includes everything Rods, bait, fish cleaning, food, beverages. All you need to do is show up!

If the trip is rescheduled due to bad weather there are NO REFUNDS.

Contact Andy Carpe, ext. 2118, acarpe@pppl.gov, Bob Tucker Jr., ext. 3190, rltucker@pppl.gov, or Andy Konca, ext. 2537, akonca@pppl.gov

Predhiman Kaw

continued from page 1

The physicist died at his home in Ahmedabad after suffering a cardiac arrest, according to P. K. Atrey, acting chief administrator of IPR. He is survived by his wife of 43 years, Saroj Kaul, a physician; and three grown children, Sidhartha, Prashant, and Pooja.

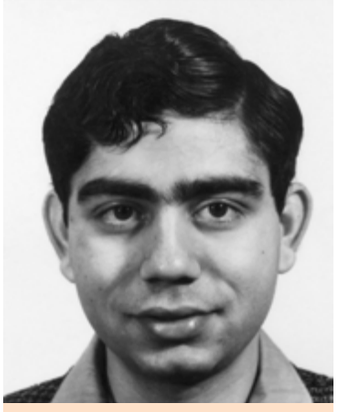
Kaw had continued his physics research until the end of his life. He was prolific: ResearchGate lists 457 publications for him and 7,588 citations.

"It is a huge and irreparable loss to the whole nation at large and IPR in particular," said Chenna Reddy, dean of IPR.

PhD at age 18

Predhiman Krishan Kaw was born in 1948 in Srinagar, India. He was a prodigy who graduated from Agra University at age 14 and received his PhD from the Indian Institute of Technology in Dehli in 1966 at age 18. He came to PPPL as a postdoctoral fellow in 1967 at age 19 and became a researcher and Princeton University lecturer in 1969 at age 21.

Physicist Russell Kulsrud, who is retired from PPPL, recalled Kaw as a young man with an impressive resume. "When he came here he was 19 years old and he had already written 20 papers," he said. "When he attacked a problem, he didn't mess around. He went right to the heart of it."



Kaw in a PPPL ID photo from the 1970s.

"It took me a little time to recognize that I needed to listen carefully to Predhiman's gentle prodding," Cowley recalled of his collaboration with Kaw. "He was never forceful but he was almost always right."

Kaw left PPPL in 1971 and returned to India for four years, where he was a professor at the Physical Research Laboratory. He returned to PPPL in 1975 as a principal research physicist and a lecturer in Princeton's Astrophysical Sciences Department.

A dynamic lecturer

Bhattacharjee said Kaw was his first lecturer in graduate school in 1977 when Kaw was just 29. "He was a dynamic lecturer, lucid and insightful, and very much in command," Bhatacharjee recalled.

PPPL physicist John Krommes, a former colleague of Kaw's, said Kaw was a gifted teacher and colleague. "He was gentle, kind, very interested in the well-being of his students," Krommes said. "He was the kind of person one would like to emulate. He was a pure gentleman and humble in spite of the fact that he was super-bright."

"There was no doubt he was going to be a leader, none whatsoever," said another former colleague, physicist Ernest Valeo. "His intellect was obvious and he had a great breadth of interests. He delved into lots of topics."

Physicist Roscoe White, a friend and colleague of Kaw's, collaborated with him on five publications. He recalled his many good conversations with Kaw about E.M. Forester's "A Passage to India," and the role of England in India. White recalled Kaw's "good sense of humor. He was very intuitive," he said. "He liked to find elegant analytic solutions to things."

Starting India's nuclear fusion program

In the early 1980s, Kaw and some of his colleagues convinced the Department of Science and Technology in the government of India to set up a major program in fusion and plasma physics. Kaw returned to India in 1982 to direct the program, which began at the PRL, and eventually separated to become its own institution in 1986. Kaw remained director until he retired in 2012. The institute was taken over by India's Department of Atomic Energy in 1996, which provided more funding for its fusion experiments.

Kaw was one of the leaders of the institute's project to design and fabricate an advanced steady-state tokamak SST-1, which is being commissioned and uses superconducting magnets, the first of its kind in India. He held an endowed professorship at the IPR until his death.

India joins ITER

A major proponent of nuclear fusion, Kaw led the effort for India to join the international ITER experiment in 2005. The massive project is currently under construction in France. Kaw chaired the Science and Technology Advisory Committee of the ITER Council in 2007.

A fellow of the American Physical Society and the Indian National Science Academy, Kaw won numerous awards during his career, including India's prestigious Padma Shri award in 1985. In 2016, he received the Subrahmanyan Chandrasekhar Prize of Plasma Physics from the Association of Asia-Pacific Physical Societies for his contributions in the areas of laser-plasma interactions, strongly coupled dusty plasmas, and turbulence in magnetic fusion devices.

Bernard Bigot, Director-General of the ITER Organization, sent Kaw a congratulatory letter after her received the prize, thanking him for his work to promote India becoming an ITER partner and for his research. "Over a long and productive career you have greatly enriched our understanding of physics processes in very different types of plasma with important implications for applications in many areas of modern plasma research," Bigot wrote.

Nat Fisch, associate director for academic affairs at PPPL, collaborated with Kaw on a paper, and the two kept in touch all their lives. Fisch and Krommes attended a symposium in honor of Kaw's birthday in India a few years ago. Kaw in turn gave a lecture at the symposium in honor of Fisch's 65th birthday at PPPL and Princeton University last year.

"What impressed me was his style in physics," Fisch said. "He was a deep thinker, and it wasn't just about physics, it was about life in general. He was a guy I would have conversations with about the meaning of life. He was not just a colleague on a one-dimensional scale. He was a multi-dimensional person with whom you had multifaceted conversations, both within and without the context of plasma physics."

Kaw outlined his vision for fusion energy in his 1992 talk for the Artsimovich Memorial Lecture at the 14th IAEA Conference on Plasma Physics and Controlled Fusion in Wurzburg Germany. "I think that it is time to reorient ourselves and define a new goal which I would like to put down as follows," he said. "We must bring fusion systems to a level such that fusion power is considered as a credible energy alternative on the fastest, technically realistic, time scale. We must demonstrate generation of fusion electricity as early as possible and show that it is environmentally better than the other competing energy sources."

BROCK

NICK PETTI
Chef Manager

Café at PPPL

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.

	Monday July 3	Tuesday July 4	Wednesday July 5	Thursday July 6	Friday July 7
COMMAND PERFORMANCE **Chef's Feature**	**Chicken-Fried Steak Melt** with Fries	**Happy Independence Day!** 	**Chicken Gyro** served with Greek Salad	**Pineapple Chicken Kabob** served over White Rice	**Four-Cheese Baked Macaroni and Cheese** with Stewed Tomatoes.
Early Riser	**Banana-Walnut Pancakes**		**Chicken Omelet**	**French Toast Sticks**	**2 Eggs,** Choice of Breakfast Meat & Tater Tots
Country Kettle	**Spring Vegetable**		**Tuscan Bean**	**Split Pea**	**New England Clam Chowder**
Deli Special	**Seafood Salad Croissant**		**Curried Ham Salad Ciabatta**	**Asparagus Wrap** with Sundried Tomatoes, Roasted Peppers & Mozzarella Cheese	**Italian Chopped Antipasti Wrap**
Grill Special	**Fried Mortadella Sandwich**		**Italian Hot Dog**	**BBQ Beef Grilled Cheese**	**Crab Quesadilla** with Asparagus & Roasted Pepper
Panini	**3-Cheese Panini** with Cheddar, Swiss, Blue Cheese & Tomato on Sourdough		**Sausage Torpedo** with Peppers & Onions	**Falafel Wrap**	**Tuna Melt English Muffin** with Fries

	Monday July 10	Tuesday July 11	Wednesday July 12	Thursday July 13	Friday July 14
COMMAND PERFORMANCE **Chef's Feature**	**Chicken Cacciatore**	**BBQ Chicken** with Baked Beans and Roasted Corn	**Grilled Ham Steak** over Barley Pilaf with Green Beans	**Vegetable Baked Ziti** with Garlic Bread	**Pork Tinga Tostada** with Rice and Beans
Early Riser	**Belgian Waffle Sticks**	**Huevos Rancheros**	**Frittata Lorraine**	**Omelette Florentine** with Spinach, Tomato & Mozzarella	**Breakfast Tacos**
Country Kettle	**Chipotle Chicken**	**Pasta Fagioli**	**Turkey Wild Rice**	**Tomato Lentil**	**Chicken Tortilla**
Deli Special	**Smoked Turkey Baguette**	**Greek Tuna Salad** with Pita Chips over Lettuce	**Southwest Roasted Vegetable Wrap** with Guacamole	**Tomato & Fresh Mozz** on Ciabatta with Basil, Red Onion & Arugula	**Southwest Turkey,** Peppers & Cheddar with Jalapeño Ranch Spread
Grill Special	**Italian Grilled Cheese**	**Buffalo Chicken Steak Sandwich** with Fries	**Pizza Burger**	**Chicken Zen Sandwich**	**Chicken Fajita** served with Rice and Beans
Panini	**Buffalo Shrimp Wrap**	**Italian Beef** with Spinach and Provolone	**Turkey** with Arugula and Cranberry Compote on Multi-grain Bread	**Crab Cake** on a Kaiser with Lettuce & Tomato	**Baja Chicken Panini** with Pepperjack, Pico de Gallo, and Jalapeño Ranch

MENU SUBJECT TO CHANGE WITHOUT NOTICE

HEART HEALTHY

VEGETARIAN OPTION

WEEKLY

Editor: **Jeanne Jackson DeVoe** ◆ Layout and graphic design: **Kyle Palmer** ◆ Photography: **Elle Starkman** ◆ Science Editor: **John Greenwald** ◆ Science Writer: **Raphael Rosen** ◆ Webmaster: **Chris Cane** ◆ Communications Director: **Larry Bernard**

The **PPPL WEEKLY** is published by the PPPL Office of Communications on Mondays throughout most of the year and biweekly during the summer, except for holidays.
DEADLINE for calendar item submissions is noon on WEDNESDAY. Other stories should be submitted no later than noon on TUESDAY.
Comments: commteam@pppl.gov ◆ **PPPL WEEKLY** is archived on the web at: http://w3.pppl.gov/communications/weekly/.

The next issue of the PPPL Weekly will be on July 17.