
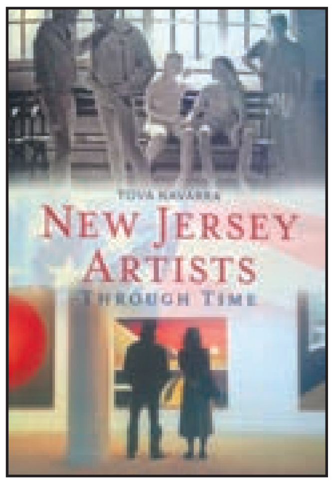

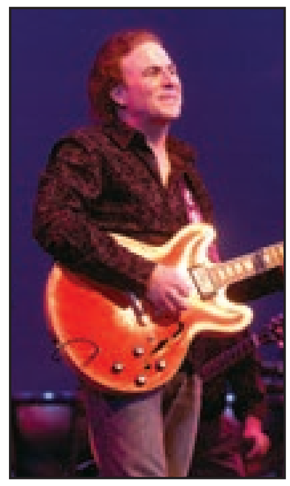

NJ Youth Ballet's 'Nutcracker' December 18-20; Santa's Book list, 24; Ernie White delivers some Jingle Bell Rock December 20, page 30.

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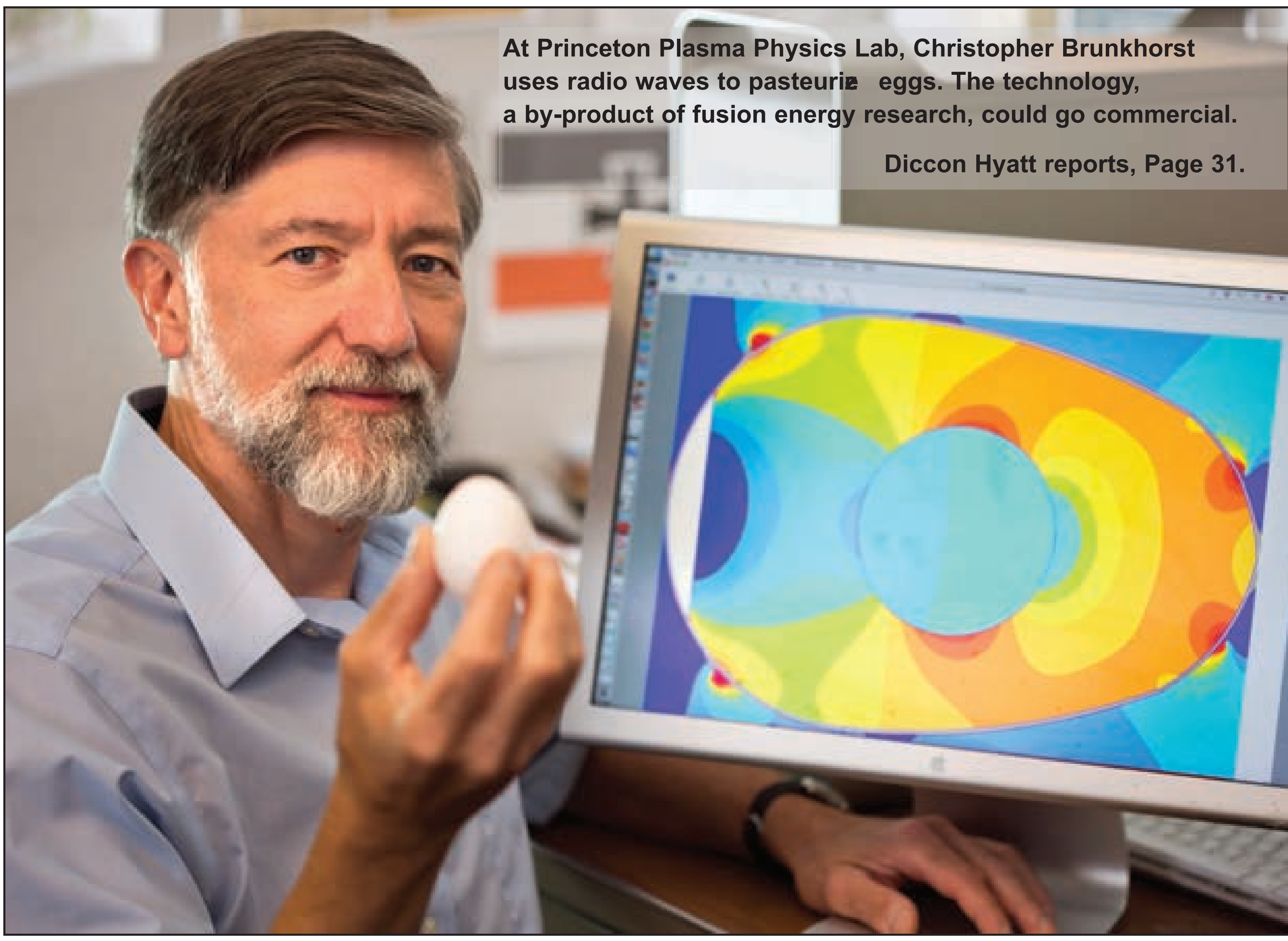
The Serendipity of Fusion Research

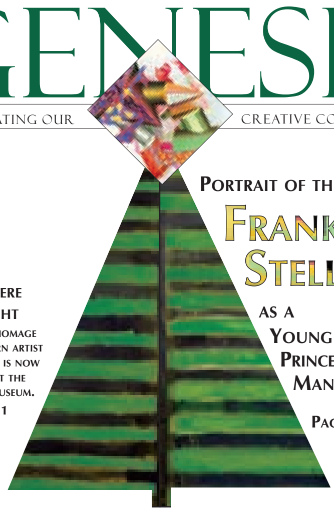


At Princeton Plasma Physics Lab, Christopher Brunkhorst uses radio waves to pasteurize eggs. The technology, a by-product of fusion energy research, could go commercial.

Diccon Hyatt reports, Page 31.

GENESIS

CELEBRATING OUR CREATIVE COMMUNITY



Portrait of the Artist Frank Stella as a Young Princeton Man

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Let There Be Light

A holiday homage to the modern artist whose work is now on view at the Whitney Museum.

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A SPECIAL INSERT IN THIS ISSUE

At PPPL: Fusion for Energy, Eggs, and More

by Diccon Hyatt

The research into fusion reactions currently being conducted at the Princeton Plasma Physics Laboratory could give humankind access to cheap, pollution-free power. That's the promise that the public has heard, time and time again since the secret project that eventually became the Princeton Plasma Physics Lab was built in an old rabbit hutch on Route 1 in 1951.

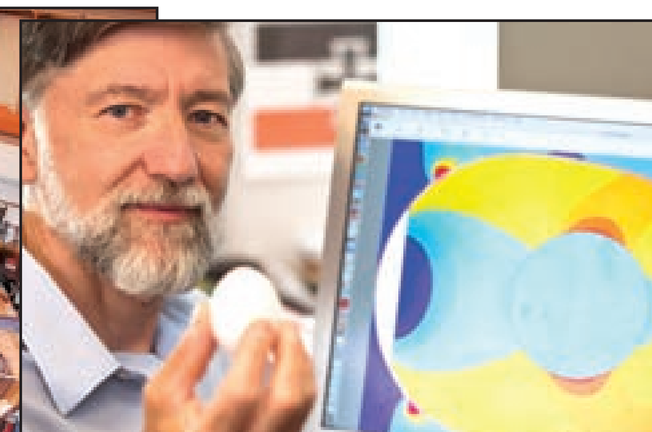
The lab has just finished work on a $94 million upgrade to its main machine, the National Spherical Torus Experiment. When the NSTX-U is fired up in the next few days, it will run every 20 minutes for one to five seconds at a time, and with each test researchers will gather data about how the powerful elemental forces are being unleashed inside. The machine is shaped sort of like a hollow apple, and the upgrade focuses on the "core" of the machine, which is made of a powerful electromagnet. The upgraded design is twice as powerful as the old one, and will allow scientists to push the limits of what is possible with the compact spherical torus design. The NSTX was built in 1999 as a way to improve upon the donut-shaped "tokamak" designs that preceded it.

The researchers hope to use the NSTX-U to solve some of the major problems that still stand in the way of fusion power, such as the technological limitations that prevent the experimental reactor from being turned on for more than five seconds at a time.

The NSTX-U is what grabs most of headlines and most of the research dollars. But some of the scientists at the Plasma Physics Lab are tackling other, smaller problems and realizing more immediate results. In addition to the promise of limitless energy, fusion also has the potential to send astronauts to Mars, save the Earth from a comet strike, and even allow us to eat cookie dough right out of the fridge without worrying about salmonella.

That last one might not be the most ambitious, but it's the closest to reality, thanks to the lab's ongoing efforts to commercialize the technology developed there as part of the quest to create fusion power. The lab, based on Stellarator Drive off Route 1, is owned by the Department of Energy and managed under a contract by Princeton University. At the lab, about 454 full-time employees plus a few dozen graduate students are working to perfect fusion technology. Scientists and engineers at the lab have learned much about plasma physics and stumbled upon many practical applications of their work that could pay off almost immediately, rather than the decades it would take to achieve their ultimate goal of fusion as a reliable power source.

Stewart Prager, director of the PPPL, says that commercialization is a minor focus of the lab, since it devotes most of its $86 million annual budget to high-energy plasma research. Nonetheless, at least one invention has come out of the lab and into the marketplace, and a number of others are in the works.



At the Lab: *Left, the upgraded National Spherical Torus Experiment. Above, Christopher Brunkhorst is using fusion to pasteurize eggs.*

The Future of Cookie Dough

One technology that seems well on its way to commercialization is a new way to pasteurize eggs that kills bacteria without cooking the egg. As anyone who's been scolded about eating raw cookie dough knows, there is a risk to eating raw eggs because of bacteria. The USDA says about 1 in 20,000 of them is potentially contaminated with salmonella, which can cause sickness and in rare cases, death. Pasteurizing the eggs could solve that, but the current methods of killing the bacteria also ruin flavor and texture.

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Christopher Brunkhorst, an engineer at PPPL, teamed up with U.S. Department of Agriculture scientist David Geveke, who works at a lab in Wyndmoor, Pennsylvania, and Andrew Bigley, a recently retired USDA technician, to create the new method of egg sterilization. To understand why an egg sanitizing method came out of a fusion energy research lab, it helps to know a little about how fusion works.

The PPPL is focused on harnessing fusion energy, which was first discovered in the 1920s and has been investigated as a potential power source almost as long. Much like its cousin, nuclear fission — powered by atoms breaking apart — fusion has both peaceful and warlike applications. Powerful hydrogen bombs using fission to ignite a fusion explosion were created as early as the 1950s, but making a contained fusion reaction that could be used to produce steam for a power plant has proven more difficult.

The might of fusion power is obvious, since it's the mechanism that powers the sun. Fusion happens when atoms are forced close together. Normally, the electrical charges of the atoms cause them to repel one another. But if somehow the atoms are forced to collide, the strong force that binds protons to neutrons overwhelms the electromagnetic repulsion, and the two atoms fuse together. (Scientists don't know why the strong force has a shorter reach but is more powerful than the electromagnetic force.) If the atoms fused together are light, such as hydrogen, there is a net release of energy. The only waste product is non-radioactive helium.

In the sun, the star's gravity forces the plasma — a hot cloud of ionized gas — into a small space, and thereby sustains the reaction. Here on earth, scientists have to find another way to create plasma and contain it within a reactor. Physically confining it is out of the question since plasma is usually millions of degrees and would melt any known material, so they use magnetic fields to keep it in check.

Nanomaterialists: *Physicist Yevgeny Raitses, right, with graduate students Jonathan Ng, left, and James Mitrani.*

The plasma must also be heated to get fusion going. At the NSTX-U a beam of neutrons heats the plasma. In smaller designs, the plasma is heated by radio waves beamed from outside the vacuum chamber. And this is where eggs and energy collide.

Brunkhorst and Geveke, who had worked together on previous projects, realized that radiofrequency waves could be beamed into an egg to heat it from the inside out. This would be perfect for pasteurization because they could focus the heat on the yolk, which is less sensitive to temperature changes, rather than the white, which loses its clarity when subjected to heat from the outside. Brunkhorst designed a prototype shoebox-sized machine that can pasteurize an egg in a matter of minutes compared to current methods, which take hours, in addition to affecting the flavor.

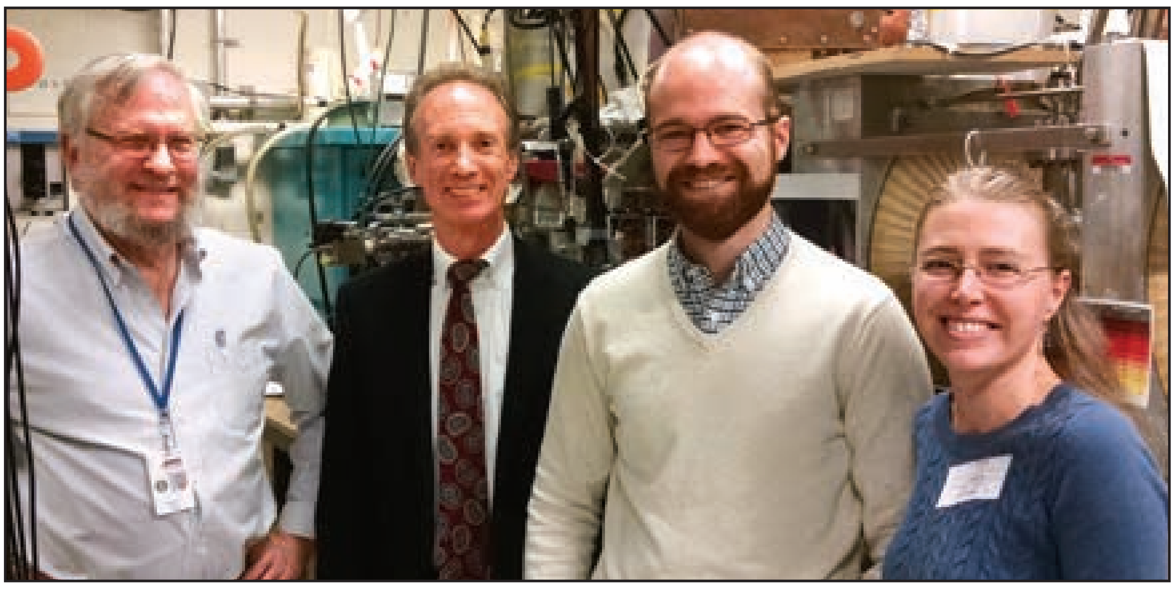
Laurie Bagley, head of technology transfer for PPPL, said that a major egg producer based in New Jersey is interested in licensing the technology for mass production.

Fusion in Space

While eggs are a decidedly earthbound topic, other scientists are reaching for the stars with their inventions. In a wing of the lab far away from the cavernous NSTX-U complex where the main high-energy research is taking place, physicist Sam Cohen toils away on a fridge-sized device that could be a model for humanity's best defense against total extinction.

Together with Princeton Satellite Systems, a consulting company based on Market Street in Plainsboro, Cohen is developing a fusion-powered engine for spacecraft. While Cohen's Direct Fusion Drive would not be able to get off the ground without traditional "giant firework" style chemical rockets, once in space it could be faster and more efficient than any other kind of propulsion. Cohen and the company have jointly filed four patents on spacecraft engine technology.

Cohen's little project has many differences from the main fusion reactor. For one thing, his goal is not to create a self-sustaining reactor that could create more energy than it uses. Instead, a spaceship with one of these direct fusion drives would carry its own supply of fuel — deuterium (a hydrogen isotope) and helium 3 — which would feed the engine. Its purpose would be twofold: to generate elec-



PPPL in Space: *Sam Cohen, left, of the Plasma Physics Lab, Mike Paluszek of Princeton Satellite Systems, graduate student Charles Swanson, and Stephanie Thomas, also of Princeton Satellite Systems.*

tric power for the spaceship, and to propel the craft through space at extremely high speeds not possible with conventional rocket engines.

Cohen points out that fusion engines, unlike fusion power plants, don't have to compete economically against solar, wind, and fossil fuels. The relative merits of spacecraft propulsion, such as electric drives powered by solar cells or nuclear fission, are largely argued on weight and engineering concerns rather than cost.

Cohen has been working on fusion drives for the last 15 years on an utter shoestring budget. The first test version of his plasma chamber was built inside an old piece of glass pipe that the lab had lying around from a previous experiment. He is the only physicist working on the project, and has relied on graduate and even undergraduate students to do much of the work. Michael Paluszek, founder and president of Princeton Satellite Systems, believes his colleague could do a lot more if he had a bigger budget and more help, which is not to say that his student assistants haven't been up to the task.

Rummaging through the equipment in the lab, Cohen pulled out a copper ring, used as an electromagnet to contain the plasma in his experimental fusion drive. Unfortunately, the copper magnets could only sustain a current for three milliseconds, and an engine that fires for three milliseconds is of little use to anyone.

To make a better drive, he needed a better magnet. Cohen tinkered with the electromagnet, and got it up to about a tenth of a second, then passed it on to a protege. "I gave the job to a graduate student, who improved it from 100 milliseconds to 12 seconds, which means he did 100 times better than me," he said. "I then gave it to an undergraduate student, and he was able to get it up to 20 minutes." The new rings have grooves cut into them for superconducting materials and tubes of super-cold liquid nitrogen. "Next, I'm going to give it to a high school student," Cohen joked.

One of his students, Charles Swanson, a graduate of Carnegie Mellon, joined the Princeton lab after a stint working at private spaceflight company SpaceX as a radio frequency engineer. "What I really wanted to do was electric propulsion," he said. "I fell in love with this machine because it's awesome, in my personal opinion." The Princeton Field-Reversed Configuration Reactor includes at least one major innovation: Cohen modified the conventional window pane-shaped RF antenna used to heat the plasma by adding a wire down the middle, which makes it far more effective at its job.

The possibilities of Cohen's design of the fusion drive have captured the imaginations of the Princeton Satellite Systems team, as well as Swanson. Cohen's fusion drive differs from other fusion engine designs in several key ways, including the mechanism by which it creates electricity. While other fusion engines emit neutrons, which are used to heat a boiler that creates steam for a turbine, Cohen's spits out protons going at extremely high speeds, which can be converted directly into an electrical current using a transformer — a feature that makes Swanson literally rub his hands together gleefully when he describes it. "A fast stream of charged particles, you can do a crazy amount of interesting things with," he says.

Paluszek and Princeton Satellite System's Stephanie Thomas are intrigued by the possibility of using Cohen's drive for interplanetary travel. They are currently in the process of submitting a plan to NASA for using it to power a mission to orbit Pluto. The agency has asked private contractors for proposals recently, because the New Horizons probe that bypassed the planetoid discovered interesting features that are worth a second look. Paluszek says a space probe that used a fusion drive could put its extra power to good use. For example, it would have enough power to enter Pluto orbit, something that no other spacecraft has done. It could even send a rover down to Pluto's surface and use an on-board laser to beam power down to it once a day.

PSS is competing against 75 other companies, but he says Cohen's lightweight fusion drive has so many potential advantages that it's worth taking a shot. "Competition is stiff," Paluszek says.

Paluszek and Cohen have been working together for about 15 years, starting with a joint paper on fusion propulsion. They have collaborated on a number of proposed fusion missions, including a craft to service the deep space Webb telescope, and a "100 year starship" proposal for a ship that would fly to Alpha Centauri, the closest star system to the sun.

Paluszek grew up in New York, where his father was a mechanical engineer and his mother was a secretary. He developed an interest in

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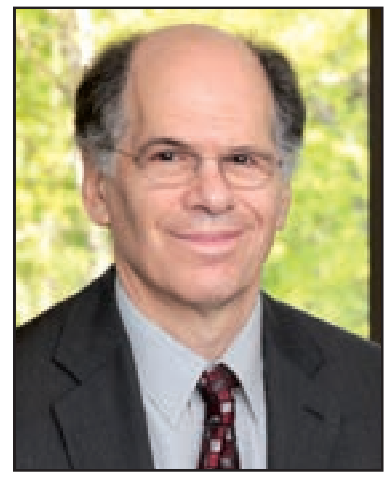

High Tech: *PPPL director Stewart Prager and Laurie Bagley, head of technology transfer.*

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fusion technology as a student studying electrical engineering at MIT. He worked for various aerospace companies, some in the Princeton area, until he founded PSS in 1992. His company has developed control systems for communications satellites, software applications related to satellites, and solar powered recharging stations for electric cars (U.S. 1, November 4.)

Thomas, Paluszek's second-in-command at PSS, grew up in West Windsor in a home full of her parents' sci-fi books. Her father, who worked for a bank, and her mother, a school paraprofessional, stocked the home with Heinlein, Arthur C. Clarke, and the works of other classic science fiction authors, and reading drew her toward a career in engineering. She joined PSS straight out of MIT, where she earned bachelor's and master's degrees. "I took a look at NASA, but I like working in a small business. You really get to do a lot of things," she said.

Thomas, Paluszek, and Cohen have envisioned even more far-out uses for the fusion drive. In a recent paper written together with Yosef Razin of PSS and David Farley of Quantal Technologies, they described how a fusion-powered spaceship driven by a minivan-sized engine could send a human crew into Mars orbit and then return, with the entire mission taking about 310 days.

When it comes to a Mars mission, speed is crucial for the health of the astronauts, because of the amount of radiation they would receive along the way, not to mention the atrophied muscles that come with any long stay in space. To Paluszek, a Mars mission is the most exciting use of fusion power.

There is one further advantage of fusion drives over one of their major competitors, fission reactors. Fission is the nuclear power technology in use today. While fusion energy comes from binding small atoms together, fission relies on blasting big atoms — such as plutonium or uranium — apart. The disadvantages of putting plutonium on a spaceship were demonstrated vividly in 1978, when a Russian Kosmos reconnaissance satellite crashed along with its onboard nuclear reactor, scattering radioactive debris across a 48,000-square-mile area of uninhabited Canadian wilderness.

Paluszek hopes to get NASA to support the mission because otherwise the $50 million needed to build a fully functional prototype reactor would be difficult to find.

Fusion for Survival

There is, however, another use for the fusion drive for which money is no object. In a paper titled "A New Vision for Future Energy Research: Fusion Rocket Engines for Planetary Defense," Cohen and several colleagues argue that only a fusion rocket would provide the speed necessary to defend the Earth from an incoming asteroid or comet. If astronomers detected a comet close enough that there was only a short time to react, they would need a fast spacecraft to reach it and either nuke it or deflect it with its own propulsion system.

Princeton Satellite isn't funding Cohen's research — he gets his money from the Department of Energy — but they are assisting with work from their own researchers, resulting in joint patents. The fusion drive developers are frustrated that NASA has not taken more of an interest in their work so far, considering the potential future benefits for space travel. Thomas described a "valley of death" in research funding where the agency was willing to fund highly speculative projects and ones that were almost ready to send into space, but that there seemed to be very little support for intermediate-stage projects like the direct fusion drive.

All of these projects are side shows, in terms of funding compared to the PPPL's National Spherical Torous Experiment, which the lab spends most of its time and effort on.

Prager began overseeing the final stages of the NSTX-U upgrade as soon as he started on the job in 2009. It was a complex project that included widening the reactor's magnetic "core" section, making it vastly more powerful, and adding a neutral beam injector that had been mothballed from a previous fusion reactor. The upgrade involved creating a gigantic magnet for the core of the 22-foot tall vacuum chamber of the device. It took a team of 10 working for two years to assemble the 36 350-pound copper conductors that make up the electromag-

Life in the Fast Lane

Edited by Diccon Hyatt

Two businesswomen have created an app for parents who are sick of expensive trips down the toy aisle. KidsTrade is a free smartphone program that functions a bit like a hybrid of Craigslist, eBay, and Tinder, but which exists to facilitate kids trading toys with one another rather than the more mature activities of conventional marketplace websites.

KidsTrade was founded by CEO Jennifer Wolffert, whose background is in the restaurant business in California, and chief marketing officer Kelly Harrison, a Princeton-based mother who formerly worked as a New York-based TV producer and director. Harrison described the app as a good way for kids to get toys that are new to them without the expense, waste, and clutter involved in buying new ones from the store.

> **KidsTrade encourages kids to create an ongoing Internet marketplace for their unwanted toys.**

On the KidsTrade website, www.kidstrade.com, Wolffert says the impetus for KidsTrade came after she bought her daughter a new doll at the American Girl store in New York City, spending $100 only to see it cast aside unwanted a few months later. "We all know, the love for a toy is fickle," she wrote.

Children can sign up for KidsTrade only with permission from their parents, at which point they can photograph their unwanted toys and write brief descriptions of them. They can then browse through items belonging to their own friends or other kids in their school, make trade offers, and exchange messages with other kids. Every trade must be approved by a parent on each side. Parents can also allow their kids to buy and sell toys.

Wolffert and Harrison's school-age children were the site's first testers, having recruited their friends into using it to trade toys. "Just yesterday, my son traded a dart board, and he got a football," Harrison said. "That's kind of a typical trade. My other son gave up a light-up bouncy ball and he got a beanie boo" (a version of a beanie baby).

Of course, kids trading with each other is nothing new, but KidsTrade adds a digital twist to the process, encouraging kids to create an ongoing Internet marketplace for their unwanted toys. The new toy trading method is intended to work better in today's era of overscheduled childhood, when kids might have a hard time finding time to play with their toys let alone play at their friends' houses.

"Sometimes you don't know what toys your friends have unless you're at the person's house and you start digging through their closet. But kids are so busy going from soccer practice to choir practice to cub scouts, there isn't as much casual playing at home as there used to be," Harrison said.

The app was developed by programmers working at the headquarters of the company, which is an office attached to Wolffert's home near the Princeton Battlefield.

The site incorporates a number of safety features. It restricts kids to trading within a closed group of friends and kids at school within one grade level. Parents can expand the boundaries if they wish.

Harrison knows the success of KidsTrade will depend on its popularity. "We don't have exact numbers on how many kids are using it right now," she said. "We've had a lot of smaller newspapers give us press, and there are little pockets all over the country where it is popping up." Unlike grown-up swapping sites, KidsTrade requires proof of identity, and comes with a swath of filters and reporting features designed to curtail anything inappropriate. Harrison says the free app is currently focused on growth and will find a way to become profitable later on.

The KidsTrade pitch to parents is that it will give children independence, reduce clutter, save money and teach children that toys aren't cheap.

The pitch to children is that "It will be like every day is your birthday."

— Diccon Hyatt

New in Town

Staging Executives, 3525 Quakerbridge Road, Suite 4450, Hamilton 08619; 856-449-7763; Leontyne Anglin, executive producer. **www.stagingexecs.com**.

Staging Executives, a company that offers consulting in media production design, has opened an office on Quakerbridge Road. Founder Leontyne Anglin is an executive producer at Princeton Community Television.

Tricon IT, 3525 Quakerbridge Road, Suite 903-D, Hamilton 08619; 609-336-3860; fax, 609-336-3857. Sukla Srivastav, president. **www.triconitsolutions.com**.

Tricon IT Solutions, an IT consulting company, was founded in June and has opened an office on Quakerbridge Road.

U.S. Architectural Products Inc., 103 Carnegie Center, Suite 320, Princeton 08540; 800-243-6677; **www.architecturalproducts.com**.

U.S. Architectural Products, a supplier of building supplies, has opened an office in Carnegie Center.

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net. The work had to be done with absolute precision because a single flake of metal in the wrong place would have created a spark and turned the machine into a multimillion-dollar paperweight. They also had to disassemble, decontaminate, and put back together a 1980s-vintage neutral beam box that weighs 75 tons.

The new reactor, which is twice as powerful as its predecessor, is designed to solve some of the persistent problems that still stand in the way of economical fusion power generation. Prager estimates it will be able to heat plasma to about twice the temperature of the inside of the sun — not a world record, but hot enough for their purposes.

"This will push into the new physics regime that would correspond to making commercial fusion energy," Prager said. "We need to learn how plasma behaves in this regime, and whether it gets as hot as we expect."

They will test out ways of getting around several problems that have dogged fusion reactions since the beginning, one of them being the fact that plasma could erode and eventually destroy the outer wall of a fusion reactor being used long term. Prager says the lab is going to test an idea that seems right out of the sci-fi movie Terminator 2: liquid metal. "The idea there is that liquids don't break," he says.

The goal is that the advances made at the PPPL could be used to help the ITER, the international fusion reactor mega-project currently being constructed in France. Prager says a more long term goal is that the NSTX-U will prove that the compact spherical tokamak design is the way to go for a future large-scale fusion project in the U.S. and even a demonstration power plant. When asked whether there is currently enough funding for this ambitious project, Prager smiles sadly and shakes his head.

Prager studied physics at Columbia University, eventually earning a doctorate there. While studying, he became interested in plasma physics and pursued it for the rest of his career. He worked for the company that today is known as General Atomics, before joining the University of Wisconsin as a professor. He made a number of scientific discoveries while at Wisconsin, including the "bootstrap current" — a crucial fusion phenomenon that most reactor designs now take advantage of — together with a colleague.

Exploring the unknown has always appealed to Prager, who grew up in New York City, where his father was a purchasing agent. His interest in science developed gradually, but he recalls one high school science class, where he asked his teacher a question about how the universe worked. Until then, it had seemed that all the important questions of the world had been answered by science. But the teacher's reply was much more fascinating than if he had given him an answer: "We don't know."

Also at PPPL

The **MINDS anti-terrorism device** is currently in use at ports, train stations, and airports around the country to scan moving vehicles for nuclear materials in hopes of catching anyone trying to smuggle a dirty bomb.

The **plasma-based centrifuge** is a potential way of reducing the volume of nuclear waste. Using this technology could reduce $250 billion cost of the cleanup of the Hanford site in Washington State, which was heavily contaminated during the Cold War when the military made nuclear weapons there.

Technitium 99m is a man-made element that is in high demand from hospitals for use in various kinds of diagnostic scans. A refrigerator-sized piece of equipment being tested at PPPL could create it in larger quantities and closer to where it is needed, giving hospitals around the world a more reliable supply of the critical substance.

Nuclear Weapons Verification: A device can probe dismantled nuclear weapons to see if they have been rendered harmless as advertised. The method tells if the weapon is still dangerous without revealing sensitive design information.

Nanomaterials made with plasma: One project now under way is the creation of advanced nanomaterials, such as carbon nanotubes, using plasma, which might prove to be cheaper than current methods.