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HOTLINE

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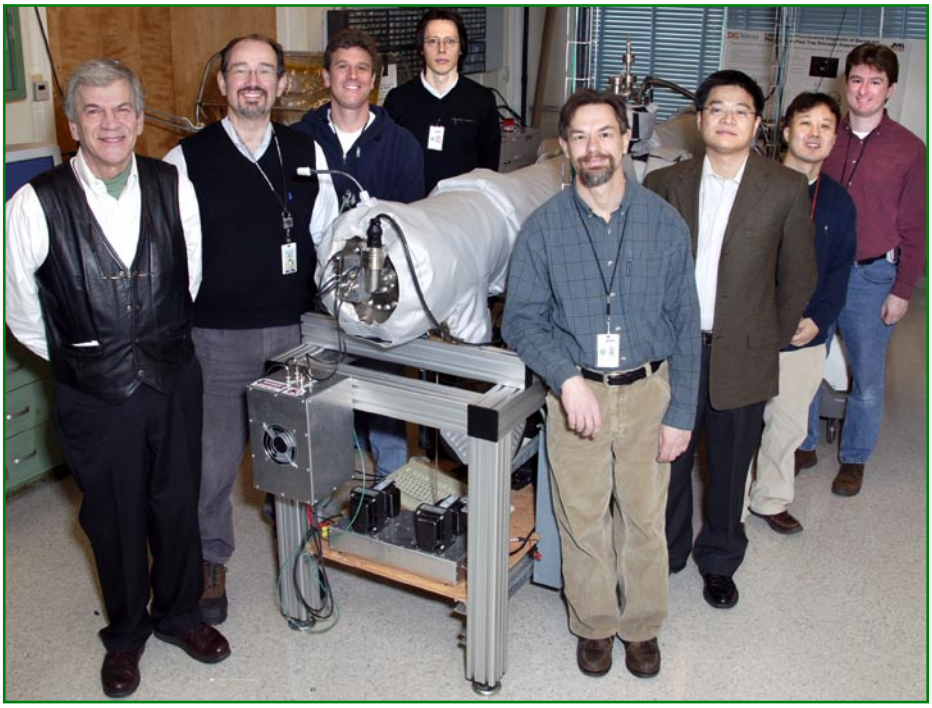
Small is Big for PPPL's Paul Trap

by Anthony DeMeo

Steve Paul, Paul Rutherford, and other PPPL Pauls need not worry. They won't be ensnared if they venture down the first floor L-Wing past the Paul Trap Simulator Experiment (PTSX). It doesn't trap Pauls nor does it simulate the trapping of Pauls. Its mission is much grander.

"We are trying to answer big physics questions that have costly implications in a small, compact relatively inexpensive device," notes PPPL physicist Erik Gilson. Research by Gilson and his colleagues, led by Principal Investigator Ron Davidson, could have a significant impact on several areas of science and technology, including particle physics, heavy ion fusion, nuclear waste transmutation, and high-energy-density physics — wherever charged particle beams are used as tools.



From left at the Paul Trap Experiment are Ron Davidson, Phil Efthimion, Andy Carpe, Ed Startsev, Dick Majeski, Hong Qin, Moses Chung, and Erik Gilson.

"The next generation of particle accelerators needs to transport more charge than before. The more particles in the beam, the more energy you can deliver to a target, or the more interactions and the better statistics you'll have. But when there is too much charge, the beam will blow itself up because of the electrical interactions. This is not a problem in present day experiments, but it is becoming more important to think about," said Gilson. Thus the PTSX team is trying to determine the properties of intense charged particle beams as they travel through transport systems. Experiments began in spring 2002.

Charged particle transport systems use quadrupole magnets, which confine the beam along a path. As the beam travels, it passes the magnets, which are equally spaced along the way. At any given time, the beam is focused in one direction perpendicular to the flow and defocused in another direction perpendicular to the flow of the particles. Gilson likens the beam to a water balloon, which if squished from the sides, will leak out the top and bottom. When pushed from the top and bottom, it will leak out the sides. "That's exactly what the alternating gradient quadrupole magnets do. As the beam passes one set of quads, it's focused in one direction and defocused in the other, the next set of magnets reverses the situation. The pattern is repeated over the length of the accelerator, which may have several hundred or even a few thousand quadrupoles," he said.

But PTSX, measuring only three meters in length — much shorter than a typical particle accelerator — uses

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Trap

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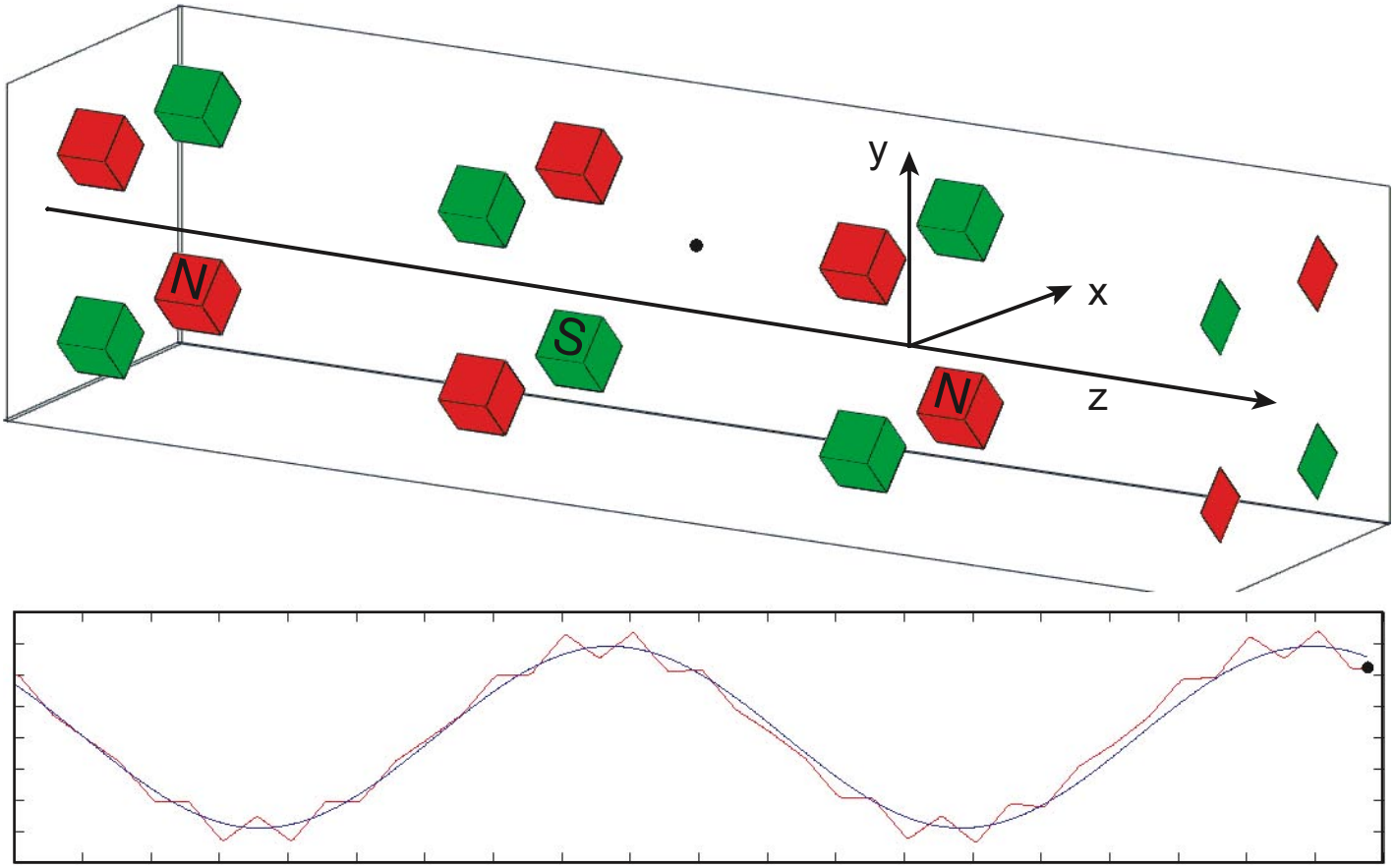
some interesting physics to simulate the conditions in an accelerator. "Imagine traveling along next to the beam with the magnets whizzing by. The beam would then appear to be a stationary cloud of charge with the magnets coming by periodically in time," according to Gilson. The charge cloud is a nonneutral plasma which experiences the alternating forces periodically in time. In PTSX, a stationary nonneutral cesium plasma, about two centimeters in diameter and two meters long, is subjected to a time-varying electric field, simulating the experience of a particle beam as it passes quadrupole magnets in an accelerator. The physics is comparable, providing researchers with a relatively inexpensive means to study properties of charged particle beams with greater flexibility than possible in an actual accelerator.

Initial Experiments Successful

First the PTSX team needed to determine if they could trap plasmas with enough space charge corresponding to really intense beams. In relative terms, they defined a parameter *s*, between zero (no space charge) and one (bursting at the seams).



Top: A particle (black dot) moving through an infinite set of quadrupole magnets of an accelerator. Just over three sets of quadrupoles are shown. Each time the particle passes through a set of magnets, it feels a force that either focuses it toward the axis or de-focuses it away from the axis. Between magnets, the particle just drifts.

Bottom: The distance of a particle from the axis is shown as a function of time as it passes through 40 sets of magnets. The red curve shows the exact trajectory — a bunch of straight lines (the drifts) connected by rapid changes in direction alternately toward and away from the axis (the passages through the magnets). The blue curve is a smooth approximation to the exact orbit. Since the entire beam is a collection of single particles, the overall shape of the beam is a pulsating ellipse, as Erik Gilson describes with his water balloon analogy.

Hotline

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"A place like SLAC might operate at 0.1, or 10 percent of the limit, the Spallation Neutron Source needs about 0.2, and for heavy ion fusion, values of 0.95 or higher are sought. In the Paul Trap, we have been able to achieve values of 0.8, but we still have more to go," Gilson said. The plasma temperature in the Paul Trap must be kept as low as possible, a few tenths of an electron volt, because temperature also affects the amount of charge density achievable. "In absolute terms, the particle density in the Paul Trap is very low, but the *s* value is high, because we confine a small amount of charge in a relatively weak trap," he noted.

The second test of PTSX's usefulness was its ability to confine a plasma long enough to simulate a beam traveling a meaningful distance in an accelerator. "We have been able to achieve about one-third of a second, not very long for a plasma experiment. But we use an electrode voltage with a frequency of 75 kilohertz. For one-third of a second, that's over 20,000 cycles. At SLAC the spacing between the magnets is about one meter, so we are able to simulate a beam that is propagating for over 20 km, and that's impressive," said Erik Gilson.

A major advantage PTSX has over an accelerator is the arbitrary function generator that makes the voltage waveform for its electrodes. The amplitude of the waveform corresponds to the strength of the magnets in an accelerator and the frequency of the waveform corresponds to the magnet spacing. As Gilson notes with enthusiasm, "Can you imagine going to the people at SLAC and asking them to move every third magnet set? They would have to rebuild the machine! But we just take our computer and draw a different waveform. If we don't like square pulse waves, we can draw a sine wave. We can even use a triangular waveform. So if someone has an idea to try with a different magnet configuration, we can just dial it up on the arbitrary function generator and see how it affects the plasma." The generator also allows the PTSX team to simulate minor imperfections in the magnets that are unavoidable in accelerators. They inject random noise into their waveform and study its effects.

In addition to predicting the transport properties of intense beams over long distances, PTSX is studying the problem of halos. Gilson explains, "The beam is this egg-shaped object being squished, but individual particles are zipping around inside. If its orbit is chaotic, a particle could wander out somewhere unpredictably. Particles find their way out to a larger radius. If you were to look at the beam end-on, you would see a diffuse ring, or halo, around it. Particles in an accelerator can travel near the speed of light. They have a lot of energy. If they hit the wall of the accelerator pipe accidentally, the wall will become radioactive — something to be avoided."

Interactions of the halo with the wall can be eliminated by making the accelerator pipe larger, but such over-engineering is inefficient and expensive. Particles cost money to make, and physicists want the maximum number to hit the target. Consequently, studying how halos form and how they can be controlled is a high priority for PTSX during the next few years.

PTSX Team

In addition to Ron Davidson and Erik Gilson, other members of the PTSX team include Phil Efthimion, Dick Majeski, and graduate student Moses Chung. Ed Startsev and Hong Qin provide theoretical support. Paul traps are named after Wolfgang Paul, who invented them in the early 1950s, and received the Nobel Prize in Physics in 1989 for his research on them. ●

IEEE to Honor Davidson for Beam Physics Work

In recognition of his important contributions to beam physics, PPPL's Ronald C. Davidson has been selected to receive the Particle Accelerator Science and Technology (PAST) Award for 2005.

Davidson is being honored for "*pioneering contributions to the theory of charged particle beams with intense self fields, including fundamental studies of nonlinear dynamics and collective processes."* Davidson will receive the award on May 18 during the biennial Particle Accelerator Conference in Knoxville, Tenn. The PAST Technical Committee of the IEEE [Institute of Electrical and Electronics Engineers] Nuclear and Plasma Sciences Society sponsors the award.

"Ron Davidson is truly a 'Renaissance' scientist working extremely productively both on intense beam physics, as well as on nonneutral plasmas, and thus bringing tools from each field to bear on the other. It is a pleasure that his excellent work has been acknowledged now by the IEEE through this very important award," said PPPL Director Rob Goldston.

Davidson is a professor of Astrophysical Sciences at Princeton University and the Deputy Director of the Virtual National Laboratory (VNL) for Heavy Ion Fusion, a collaborative effort among PPPL, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory. At PPPL, he is Deputy Head of the Theory Department and Head of the Beam Dynamics and Nonneutral Plasma Division.

The PAST Award nomination letter noted Davidson's seminal research in the physics of intense charged particle beams and one-component nonneutral plasmas, as well as his important contributions to graduate education and the

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Davidson

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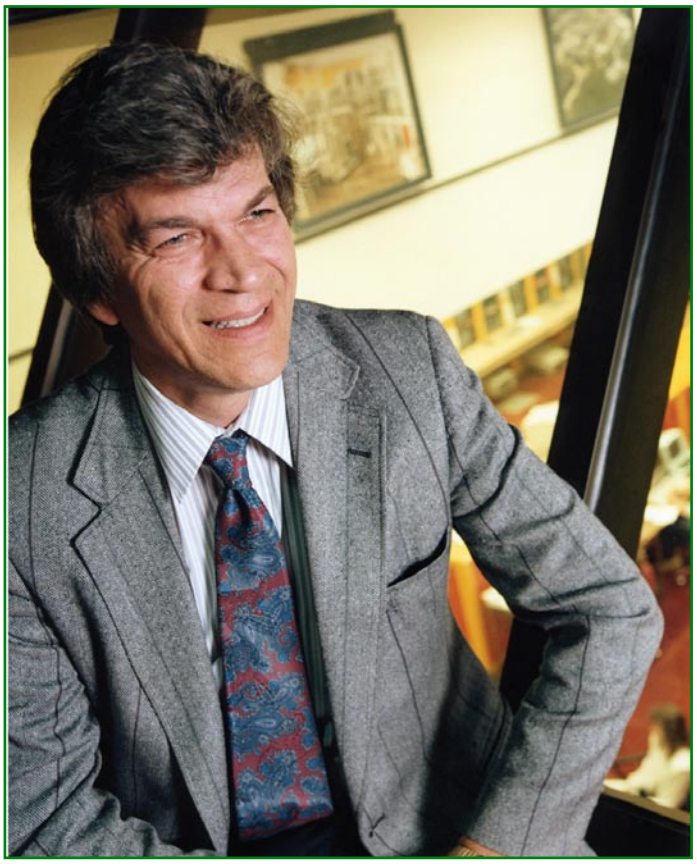
training of research scientists, and his enthusiastic community service and scientific management skills.

"Now is an especially opportune time to recognize his [Davidson's] important scientific contributions to beam physics, particularly as beam intensities in contemporary accelerators have increased to regimes where collective processes and self-field effects play a significant role. The significance of Davidson's work is increasingly evident," wrote the authors of the nomination letter.

Of Davidson's positive influence on students and the next generation of research scientists, they said, "For more than three decades, he has taught at the University of Maryland, Massachusetts Institute of Technology, Princeton University, and the U.S. Particle Accelerator School, and supervised the Ph.D. research of 23 graduate students. His students and postdoctoral associates now conduct research, many in leadership roles, at major research laboratories and universities." John J. Barnard, Edward P. Lee, Steven M. Lund, Jonathan S. Wurtele, and PPPL's Nathaniel Fisch and Hong Qin signed the letter and 10 other researchers co-nominated Davidson for the prestigious award. Barnard and Lund are from Lawrence Livermore National Laboratory, Lee is from Lawrence Berkeley National Laboratory, and Wurtele is from the Department of Physics at the University of California, Berkeley.



Ronald C. Davidson

Since his graduation from Princeton University with a Ph.D. in plasma physics in 1966, Davidson has held a number of distinguished positions, including Director of PPPL and Director of the Plasma Fusion Center of the Massachusetts Institute of Technology, in addition to being a professor at several academic institutions.

Fundamental Theoretical Contributions

Davidson has made fundamental theoretical contributions to many areas of pure and applied physics, including nonlinear dynamics and collective interactions, physics of nonneutral plasmas, kinetic equilibrium and stability properties, intense charged particle beam propagation in high-energy accelerators, beam-plasma interactions, and coherent radiation generation by relativistic electrons. He is the author of more than 300 archival journal articles and books, including four advanced graduate-level texts and research monographs.

"I'd like to thank the IEEE and the accelerator physics community for this important recognition. As a fortunate beneficiary of Princeton's graduate program in plasma physics, I'm especially grateful to my many talented teachers, collaborators, and students here at PPPL and throughout the plasma physics community. They have all played a key role in helping to make nonlinear beam dynamics and nonneutral plasmas such intellectually stimulating subfields of physics. I'm also grateful to my parents for all of their encouragement during those formative years, especially for knowing when to nudge me off the farm," said Davidson.

"I'm also grateful to my parents for all of their encouragement during those formative years, especially for knowing when to nudge me off the farm."

— Ron Davidson

Recently, Davidson was Chair of the National Research Council Panel on High Energy Density Plasmas (2001-2003) and the National Task Force on High Energy Density Physics (2003-2004) commissioned by the President's Office of Science and Technology Policy. He is the recipient of numerous awards, including the Kaul Foundation Award for Excellence in plasma physics and fusion energy development in 1993 and the Department of Energy's Distinguished Associate Award and the Fusion Power Associates' Leadership Award in 1986. Davidson is a Fellow of the American Physical Society and the American Association for the Advancement of Science. ●

Female Students Flock to PPPL for Conference

Above, West Windsor-Plainsboro High School South student Sumona Bhattacharya (right) watches Becky Barak, of the Princeton Environmental Institute at Princeton University, make "clouds in a bottle" to demonstrate that cloud formation is based upon changes in temperature and pressure.

Nearly 200 female eighth through 12th graders came to PPPL on Friday, March 11, for the fourth "Expand Your Horizons Mini-conference for Young Women in Science, Mathematics, and Technology." The conference included talks by various women in the sciences, exhibits, and lunch.

"It's a great opportunity to encourage science and engineering careers for young women. It was an exciting day for everyone involved, and so inspiring for the students," said Christine Ritter, Science Education Program administrator and organizer of the event.

Exhibitors were from the FMC Corporation, Mercer County Community College, the New Jersey Department of Environmental Protection's Division of Watershed Management, the New Jersey Institute of Technology, Princeton University, and PPPL. Guest speakers were from the Fashion Institute of Technology, Johnson & Johnson, the New Jersey Department of Environmental Protection, New York University, and the U.S. Army Corps of Engineers.

PPPL's Science Education Program, Director's Advisory Committee on Women, and Director's Minority Advisory Committee coordinated the day. ●

Careers and Family are Topic of Klawe's DACW Talk

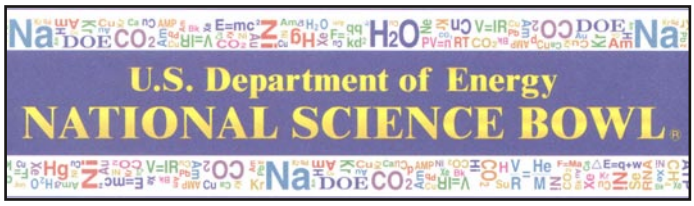
The Laboratory's Director's Advisory Committee on Women (DACW) coordinated a breakfast meeting and colloquium for all PPPL women on February 23 in the Commons. More than 30 women and managers came to network with one another and hear Professor Maria Klawe, Dean of Princeton University's School of Engineering and Applied Science, talk about "Strategies for Successfully Combining Work and Family." PPPL Director Rob Goldston, Deputy Director Rich Hawryluk, DACW Chairperson Lena Scimeca, Andrea Moten of Human Resources, and Christine Ritter of the Science Ed Program gave opening remarks. At right is Klawe and above is Klawe surrounded by those at the meeting. ●

NASA Talk Highlights Annual Safety Forum

Sheila Widnall (above) delivered the keynote talk, "Lessons Learned from the Columbia Accident Investigation and How They Apply to the R&D Environment," at PPPL's Fourth Annual Safety Forum on February 18. Widnall is a professor of aeronautics and astronautics at the Massachusetts Institute of Technology. The ES&H and Infrastructure Support Department hosted the forum, which included a series of presentations aimed at improving workplace safety.

Longtime Science Bowl Volunteers Lauded

The Laboratory honored three longtime Science Bowl volunteers from PPPL for their special efforts and dedication. Honorees (from left) Daren Stotler, Carol Phillips, and Bill Davis each received a plaque with the citation, "For outstanding commitment to increasing educational excellence in your community through volunteering for the annual New Jersey Regional Science Bowl." Congratulations, Daren, Carol, and Bill!



Join the Prospect Board

The search is on for a PPPL employee who wishes to serve on the Prospect (House) Association Management Board at Princeton University. Board membership is a four-year commitment to attend a monthly meeting (September 2005 through May 2009) and participate in social events sponsored by the Board. This position also provides an opportunity to meet interesting people at Main Campus and learn about the operation of the House.

If you are interested, please send Virginia Finley a brief bio via e-mail at vfinley@pppl.gov and she will submit your name to the nominations committee. If you have any questions, please call Virginia at ext. 2746 or send her an e-mail. The web address for Prospect House is: **http://www.princeton.edu/prospecthouse/**

What is ..."Lake-Effect Snow"

Area Students Buzz in to Answer Questions as PPPL Hosts Regional Science Bowl

Seated at the left table, PPPL Deputy Director Rich Hawryluk (left) and PPPL physicist Daren Stotler serve as the science judge and moderator, respectively, during one of the Science Bowl rounds at PPPL.

A question posed in the earth science category at this year's Science Bowl included: The New York cities of Buffalo and Rochester are among America's most frequent recipients of what type of snow, caused by a combination of low temperatures and an ample supply of open water?

Hint, hint: Read the headline.

Sans the well-known Jeopardy! tune and the presence of Alex Trebek, PPPL was transformed on February 26 into a site for a Jeopardy!-like tournament in which all the categories were disciplines of science.

Thirty-two teams from 20 area schools competed in the New Jersey Regional Competition of the National Science Bowl® . This is the thirteenth year the Laboratory hosted the bowl, which is sponsored by DOE.

The participants answered multiple-choice or short-answer questions in biology; chemistry; physics; astronomy; mathematics; and general, earth, and computer sciences. Each team was made up of four students, a student alternate, and a teacher who served as an advisor and coach.

"We love every year bringing these students here. It gives them a chance to compete in a challenging environment and to get acquainted with other excellent science students from this region," said James Morgan, PPPL Science Education Program Administrator. Morgan organized the event.

The top winner of the regional competition, East Brunswick High School, received an all-expense paid trip to Washington, D.C., to participate in the Fifteenth Annual National Science Bowl®, scheduled April 28-May 2, 2005.

A special thanks to the nearly 40 volunteers — from PPPL and the community — who helped to make Science Bowl such a success. ●

Thank You, Science Bowl Volunteers!

Rob Andre, PPPL
Steve Baumgartner, PPPL
Laura Berzak, Princeton University
Ted Biewer, PPPL
Bill Blanchard, PPPL
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Daren Stotler, PPPL
Emma Torres, PPPL
Tom Wedlick, The College of New Jersey
Patti Wieser, PPPL
Irving Zatz, PPPL

Spotlight

Name: Regina Worthy

Position: Training Manager in the Human Resources Division, with responsibility for ensuring that all staff, subcontractors, visitors, and students receive the job training they need. Worthy also updates courses, issues reminders for General Employment Training, organizes offsite and onsite training, and makes sure everyone's qualifications are current and up-to-date.

Quote: "What I enjoy most about my job is that our Human Resources group really works as a team. I call us the 'Sensational Seven.' Each of us is so different from one another in talent, age, educational background, and upbringing, and we seem to work off these differences. Everyone has her own strength and capitalizes on that. It just works really well.

This is the only job I've ever had where I wake up and don't say, 'Oh, I *have* to go to work.' I look forward to coming to PPPL every day and I learn something new every single day. One of the most interesting things about my days is that I have meetings with people from other departments and areas of the Lab, and I learn about what they do. Everyone at the Lab could benefit from doing that and learning something different."

Other interests: Worthy enjoys athletics, especially skiing and volleyball, but most of all her "gems," 5-year-old daughter, Mattison, and 9-year-old son, Bernard. "They are my precious stones, but they also are hard-headed," says Worthy of her children.

When she's not busy with the children — both youngsters run track and play basketball, and Mattison takes ballet and tap dance lessons — Worthy officiates at Princeton University track meets and avidly collects African-American art. "Mostly I purchase what I like. I'm always looking for something that's different." Her favorite artist in this genre is Leroy Campbell. "He paints with emotion," she said.

Hung around her home are about 25 pieces of African-American art. "My parents got me into collecting it," notes Worthy, who also has a collection of Longaberger baskets.

Athletics also take up much of her leisure time. "I enjoy skiing. I lived in the Poconos for four years when I was in junior high school and we had to take a skiing course," said Worthy, a self-acknowledged "Army brat," who was born in Germany and lived in Missouri, California, Texas, Colorado, and Pennsylvania while growing up. As a high school student, Worthy played basketball and was discovered by the track coach while she was on the basketball court. He

asked her to join the track team after watching her rebound. "He wanted me to join the team, and I said, 'no.'" Eventually, he approached her parents. When she found out she didn't have to run long distances to participate in track, she added track to her activities, dropping her marching band and lacrosse efforts, but keeping basketball. In her junior year, she was the high jump champion in the Pennsylvania state track meet. She placed second and third for the triple and long jumps.

She was recruited for a partial track scholarship at Rutgers University, where she received a degree in sociology and a master's in human resources. Worthy came to PPPL in 2000 as a training specialist, becoming training manager in 2004. Perhaps her athleticism led her to take on the responsibility of managing the PPPL Fitness Center. It certainly had a role in another off-hours pursuit — as a potential contestant on reality TV series. She auditioned for *Survivor*, along with James Morgan (PPPL Science Education Program administrator), and did a video that was sent to the producers of *Amazing Race* as a contestant application. "I was not chosen for either, but just the thought of traveling to foreign land and competing was half the fun." ●