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Sandia National Laboratories

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Sandia National Laboratories

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NNSA National Nuclear Security Administration

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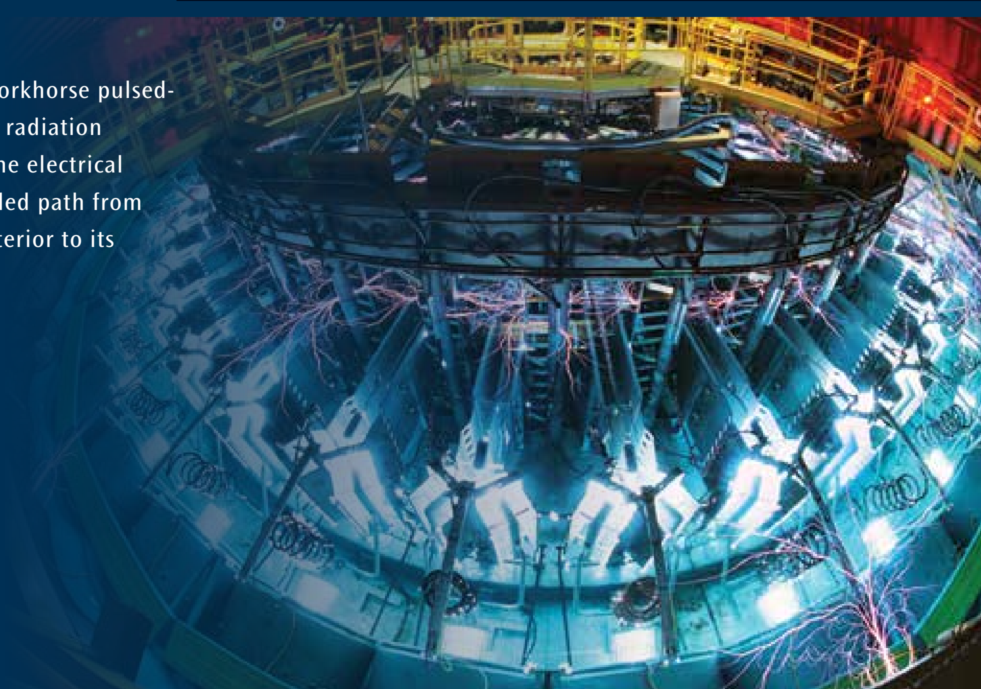
ON THE COVER



Saturn, one of Sandia's workhorse pulsed-power machines, delivers radiation during one of its shots. The electrical pulse travels on its intended path from the machine's circular exterior to its central target.

(Photo by Randy Montoya)

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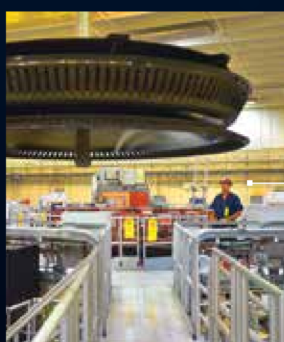

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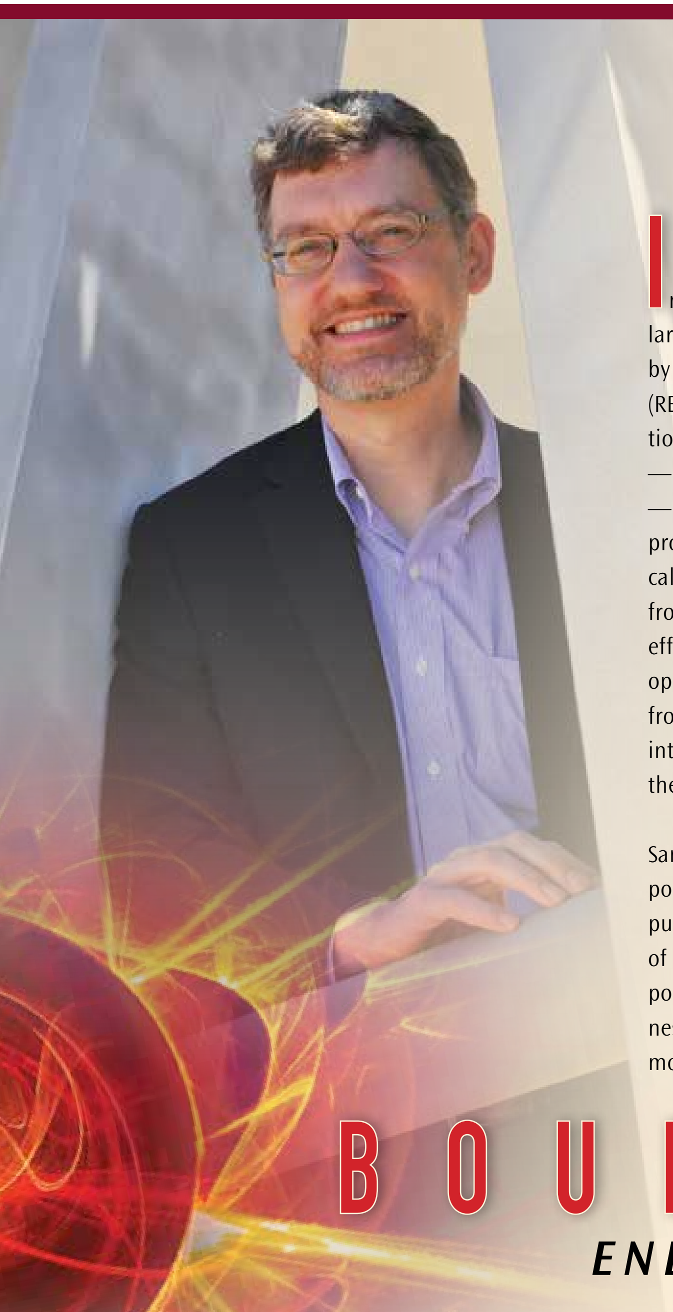


In the absence of nuclear weapons testing, the expertise, large-scale test facilities and computational capabilities used by Sandia's Radiation Effects and High Energy Density Science (REHEDS) Research Foundation are critical to certifying the nation's nuclear weapons stockpile. Pulsed power experiments — most notably those conducted on Sandia's Z Machine — create the extreme radiation, pressure and temperatures produced in a nuclear blast. Technical experts apply theoretical, computational and diagnostic tools to analyze results from Z and other experimental platforms to help ensure the effectiveness of our nuclear weapons. The results also create opportunities for new science and engineering discoveries, from understanding materials behavior and providing insights into astrophysics and planetary science, to one day achieving the elusive goal of creating fusion energy in the laboratory.

Sandia has become the undisputed leader in fast pulsed power science and technology. Beginning in the 1960s, our pulsed power devices have helped assure the performance of every nuclear system in the stockpile. We rely on pulsed power today to ensure the stockpile's continued effectiveness as it undergoes component replacements, upgrades and modifications through life extension program activities.

BOUNDLESS

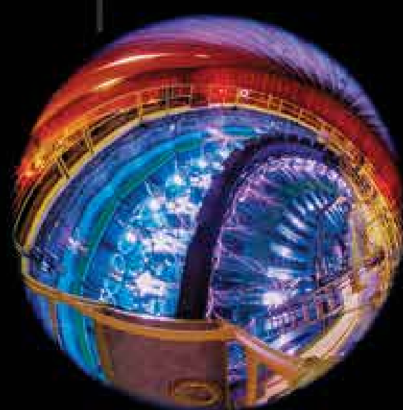
ENERGY IN AN INSTANT

In this issue of *Sandia Research*, you will learn about the amazing capabilities of the Z Machine and the critical work it performs. One story discusses the role Z plays in ensuring the stockpile stewardship program has the data needed on material properties at the extreme conditions found in nuclear weapons. Another story shows how Z is being used to examine heat travel from the Sun's center to its surface, investigate the existence of water on planets within and beyond our solar system, and resolve the age of white dwarf stars, which could determine the age of the universe itself. And the long term future of high energy density science is discussed, including our work on magnetized liner inertial fusion (MagLIF), a new and exciting approach to fusion, which, if successful, could eventually lead to high-yield fusion in the laboratory. You will also read about other important research tools, including the Qualification Alternative to Sandia Pulsed Reactor (QASPR), which conducts experimental work to qualify weapons components to survive fast neutrons produced by a nuclear blast. And you will meet some of the nation's great scientists and engineers who are conducting this extraordinary research.

Mark Herrmann
Director
Pulsed Power Sciences

THE NEXT BEST THING

VELOCITY



Long gone are the days when the U.S. could test nuclear weapons by setting one off. But there's another way. Sandia's formidable Z accelerator delivers power that can take components to the wall, a power that could bring on fusion.

By Neal Singer

Certain components of the U.S. nuclear stockpile were designed in the 1960s. Replacing a broken, missing or burned-out part of limited production from 50 years ago is even more difficult than finding an engine valve for, say, a 1965 Studebaker.

Components no longer in stock must be fabricated on machines more advanced but for that reason not identical to those used the first time around.

Common sense would say that the functionality of the stockpile therefore should be periodically tested, just as a car goes in for an exhaust check or tune-up. Yet the last time the United States exploded a nuclear device to test the long-term durability of its components, new or replaced, was in 1992.

"There are lots of great political and environmental reasons not to test our nuclear stockpile," says Sandia manager Daniel Sinars. "But if you can't manufacture a widget anymore and you want to know whether its replacement from a new foundry will work, you'd want to test the new part by sticking it in, driving it down the road, and finding out if it's reliable. With the stockpile, we can't do that."

Sinars and others are working to remedy the lack of actual tests with experiments at Sandia's Z accelerator that compress materials to extremely high pressures and temperatures. Under these extreme conditions, processes such as fusion can take place, releasing nuclear energy by the merging of atoms of light elements like hydrogen to make a heavier element, in this case helium, and releasing significant energy in the process. This reaction powers the stars as well as nuclear weapons.

A potent pinch

Sandia's work on fusion extends back 30 years, with the past 19 spent conducting experiments with imploding arrays of very thin wires in an effect called a Z-pinch. The pinch releases radiation similar to that of a nuclear detonation. A newer Sandia approach called MagLIF (magnetized liner inertial fusion), led by Sinars, is providing realistic data about neutron production, another key component of nuclear fusion.

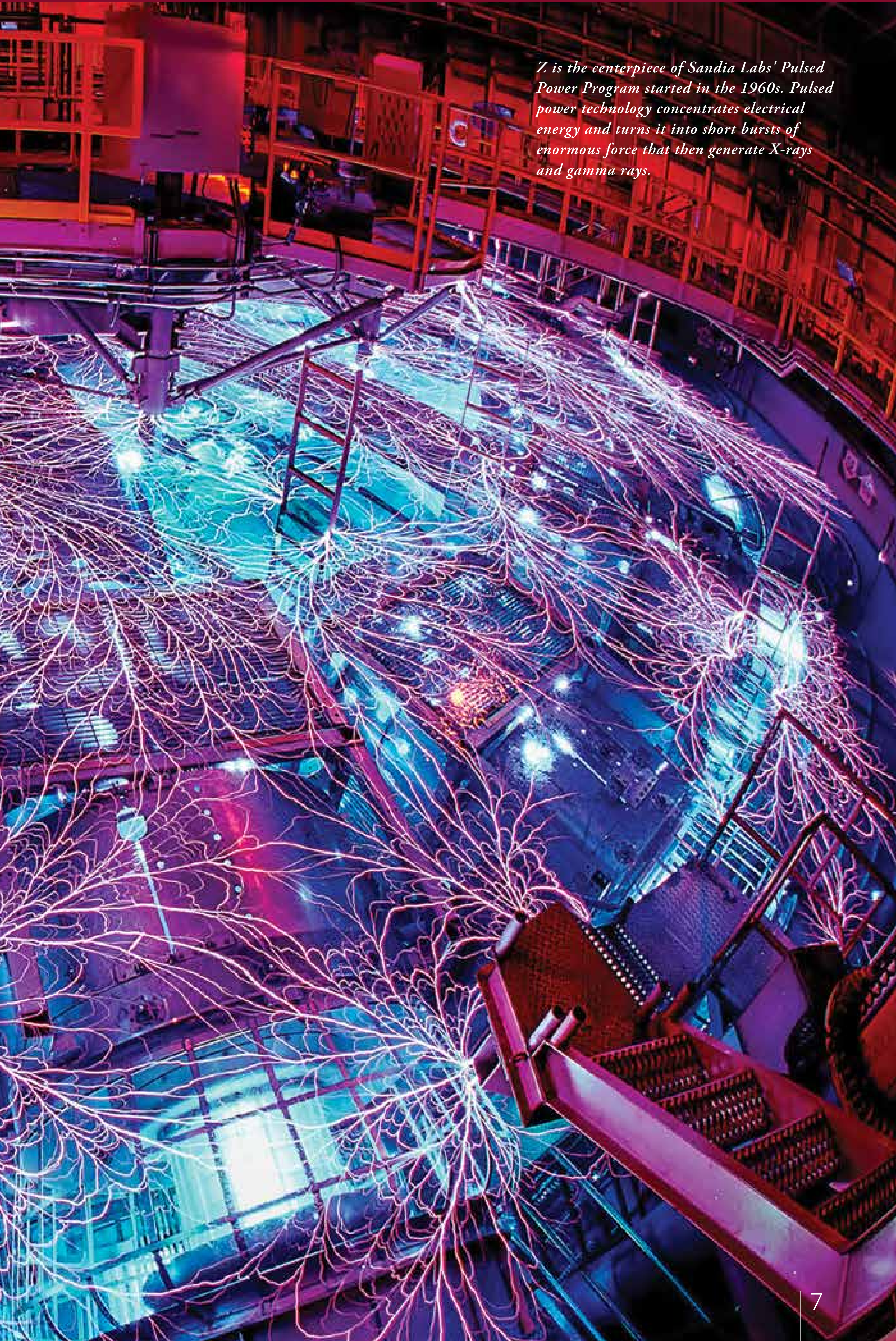
Radiation and neutrons produced under particular laboratory conditions provide the data needed to develop computer models that can predict how materials evolve under the extreme conditions in a nuclear weapon. A major challenge of stockpile stewardship is to provide reliable data for supercomputer simulations in place of actual nuclear explosions. "We do all we can with surrogate tests," Sinars says. "We would like to create a burning plasma in the laboratory because that's a key physical process that happens in a nuclear weapon." A burning plasma means the energy produced by the process is enough to maintain a plasma's temperature without adding outside energies.

Fortunately, Sinars says, it's not necessary to reproduce the huge destructive energy of a nuclear weapon's explosion to get data. Instead, a relatively small amount of energy such as the equivalent of four or five sticks of dynamite will do the trick, if it is delivered quickly. A relatively small amount of power delivered in a second becomes an awesome amount when delivered in nanoseconds. MagLIF, which functions in nanoseconds, is therefore operating in the right realm to provide neutron data.

Magnetic fields as cops

First proposed by Sandia theoretical physicist Steve Slutz in 2010, MagLIF combines Sandia's specialty — fast, very powerful electromagnetic pulses — with a laser that pre-warms the fusion fuel and a secondary weaker magnetic field that confines the free-floating plasma produced in the process.

The fusion fuel is a gas made of deuterium atoms — hydrogen atoms that each have a neutron that ordinary hydrogen atoms lack. Two electrical coils provide secondary magnetic fields that act as cops to put free-floating charged particles in a holding pattern, stopping them from leaving the party and unacceptably lowering the temperature of the



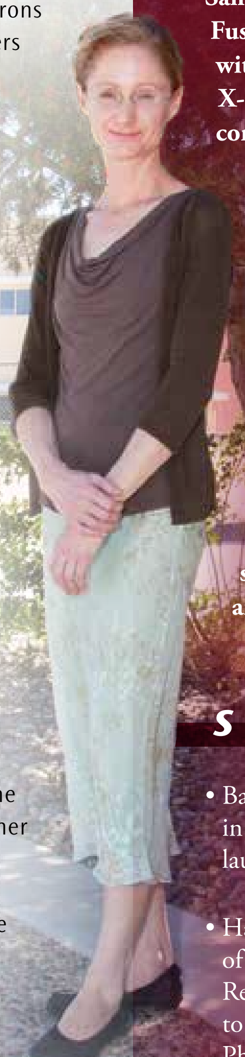
Z is the centerpiece of Sandia Labs' Pulsed Power Program started in the 1960s. Pulsed power technology concentrates electrical energy and turns it into short bursts of enormous force that then generate X-rays and gamma rays.

fusion reaction. MagLIF's key component — primeval looking in this world of lasers and electromagnetic fields — is a thin cylinder, a tube usually formed of beryllium, which is compressed by the huge pulsed magnetic field of Z. Within a hundred nanoseconds, Z's field contracts the cylinder to as little as 1/40th of its original diameter, smashing together the preheated deuterium fuel. Meanwhile, magnetic fields generated by the external coils keep charged particles spiraling in the reaction, much like a shower curtain confines spraying water around a free-standing bathtub.

Because the method looked promising from the get-go, the components required to try out Slutz's conception were tested individually and then brought together by late 2013. Hot plasma-emitting neutrons have already resulted, and researchers are optimistic that the yield will rise substantially as they fine-tune their experiments.

That's neutrons. To produce the X-rays needed to create and study radiation effects, the longer-standing arrangement at Z involves sending its huge, 26-mega-amp pulse through a cylindrical array of hundreds of wires, often made of metals like stainless steel or aluminum, and each about 1/7th the width of an average human hair. The huge current pulse vaporizes the wires like a short circuit vaporizes a fuse. The enormous magnetic field grabs the momentarily free-floating metal ions and drives them inward at a considerable fraction of the speed of light to the center of the cylinder. When they all suddenly encounter the center because there's nowhere further to go, they release heat, just like the tires of a car going 80 mph become hot to the touch when the brakes are slammed on.

In the case of the wire array, the heat is released from objects



MEET Stephanie Hansen

Stephanie Hansen gained an early passion for science and nature from her father, a geologist. In high school she worked in a chemistry lab testing soil and water samples for organic contaminants. She attended the University of Nevada in Reno, her home town, where she earned degrees in philosophy and physics.

In 2004, Hansen was hired by Lawrence Livermore National Laboratory, where she developed atomic-scale models of high-energy-density material. "It was a fantastic opportunity to work with great theoretical and computational scientists," she says. Her fascination for plasma physics brought her to Sandia in 2008 to join the Inertial Confinement Fusion (ICF) Target Design Team. She works with the Z accelerator, the world's largest X-ray generator, designed to test materials in conditions of extreme temperature and pressure. She uses spectroscopy to infer and analyze the properties of these extreme states of matter.

"Sandia fields eight to 10 spectrometers for each shot. Having so much high-quality data is like being a kid in a candy store," she says. "Working with the exceptional people here has been one of the great privileges of my life."

Outside of work, Hansen spends time with her two young daughters, hikes in the mountains and draws wildflowers. Her daughters, Hansen says, are developing that same love of science and nature.

STATS

- Bachelor of Arts in philosophy, Bachelor of Science in physics and Ph.D. in physics, all summa cum laude from the University of Nevada, Reno.
- Hansen is one of 35 recipients of the Department of Energy's Office of Science 2014 Early Career Research Program awards. She gets a five-year grant to pursue her proposal, "Non-equilibrium Atomic Physics in High-Energy-Density Matter."

moving much faster and stopped much more abruptly than a braking car; thus, energy is released in the more intense form of heat called X-rays. The X-ray power, if translated into units of electrical power, is much greater than the combined output of all the electricity-generating plants on Earth, though only for nanoseconds. The causative effect, called by scientists a Z-pinch because the matter is compressed to the geometric Z axis at the center of the cylinder, became the dominant experimental configuration at the accelerator from 1996 to 2010 and was the reason the machine, formerly called PBFA (for pulsed-beam fusion accelerator), became known as Z.

Contributions to stockpile stewardship

Z's magnetic force – the natural accompaniment to its huge electrical current — can be used to test materials by propelling so-called flyer plates the size of a dime 40 times faster than a rifle bullet to see how material samples fare under the huge momentary pressures of impact. This dynamic compression can't be achieved in slow, continuous compression experiments. The magnetic field can also be used to squeeze a material without adding any heat over hundreds of billionths of a second. This method has been used to study the properties of materials under extreme compression, resulting in unique and critical contributions to the stockpile stewardship program. And, unlike the flyer plate in which only one data point is obtained at each sudden impact, the relatively slowly increasing pressure explores material behavior over a range of pressures in a single experiment, creating a continuous graph of material behavior.

Z is rarely idle. While an experiment can be over in a flash, it can take weeks of preparation to set up the test. Z attracts a steady stream of visitors, from government officials to outside scientists.

Given the extraordinary rapidity of the sequence of events inside Z, sophisticated diagnostics are needed to read what is happening within the maelstrom of energies released as the huge machine fires. A two-inch-long crystal that reflects at only a single frequency enables researchers to filter out more than 99.99 percent of the X-ray energies generated. Researchers make use of that single liberated frequency to generate a series of pictures, taken at nanoscale intervals, of the machine's key processes.

Other diagnostics use crystals to disperse the X-ray frequencies emitted by the target to different detector points for analysis. Adding tiny amounts of argon or krypton to provoke radiation generation allows researchers to infer a deuterium plasma's density and temperature, while other diagnostics measure the number and intensity of emergent neutrons.

All this technical input helps researchers adjust Z's parameters to create increasingly favorable conditions for higher energy outputs.

A product to meet a need

Computer simulations have been very helpful in designing the thickness of the MagLIF target, the thickness and material of the wire arrays, and the speed and compression needed for the magnetic fields.

"We create hypotheses using our models and simulations," says Sinars. "The hypotheses of MagLIF, for example, were compelling enough that we were willing to spend several years building up the capabilities needed to go into our labs and test it."

All this activity resulting from a computer simulation, he says, is "really no more amazing than someone with an idea for a startup company saying, 'I have something that I think everyone will want to buy.' Venture capitalists will give money if they think there's a need for the product or service. Well, the government has a need for stockpile stewardship. We think we have a product that will meet that need. So they are content to fund us. Entrepreneurs make a prototype, work on the hardest problem first, and convince their funders that they're making progress. That's not so different from us." ■

MEET

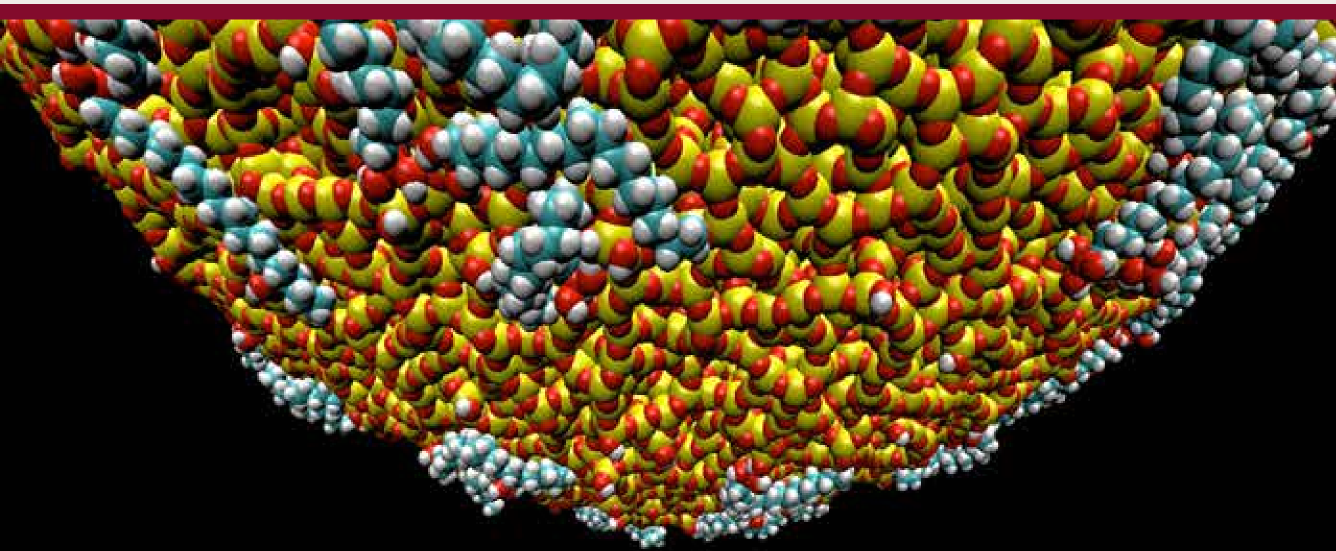
Seth Root

As a kid growing up in Gering, Neb., Seth Root was interested stars, planets, dinosaurs and blowing things up. "Normal kid interests," he says. Knowing that physics would open the door to getting paid to study explosions, he was determined to pursue that profession. At a conference in college he heard about experimental shock physics and decided that was the route to take. Root earned his doctorate in 2007 from the Institute for Shock Physics at Washington State University. He joined Sandia in 2008 for the opportunity to work on the Z accelerator. He's now investigating planetary formation and interiors and examining granular material under dynamic loading.

In his free time, Root enjoys running, biking, swimming and competing in triathlons. He is captain of an Albuquerque kickball team, "Das Boot," that took the league championship three of the past four seasons.

STATS

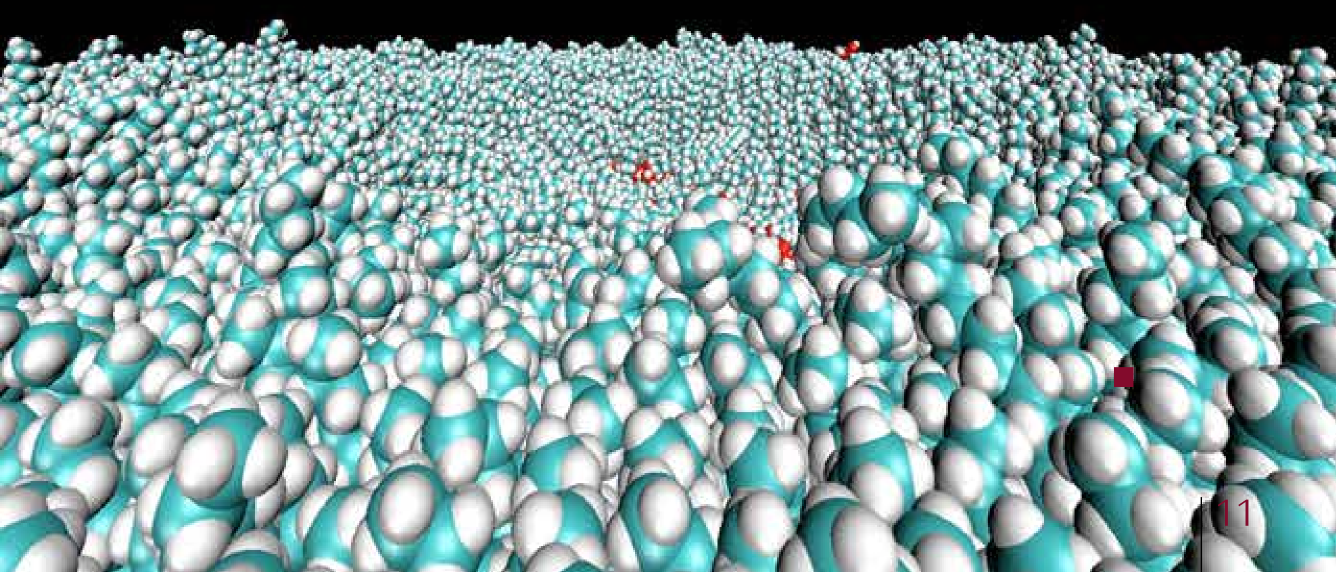
- Bachelor's and master's degrees in physics from the University of Nebraska, Lincoln.
- Ph.D. in physics from the Institute for Shock Physics at Washington State University.
- Awarded the National Nuclear Security Administration Defense Programs Award of Excellence in 2010; Xenon Equation of State Team.
- Institute for Shock Physics Graduate Scholar Award 2002-2007.
- Received the prestigious Presidential Early Career Award for Scientists and Engineers in 2014. PECASE is the highest honor bestowed by the U.S. government on science and engineering professionals in the early stages of their independent research careers.



TOUGH ENOUGH

For 45 years, the Sandia Pulsed Reactor was the go-to place to test the impact of radiation on nuclear weapons. When it closed, engineers had to come up with new and safer ways to be sure critical parts will hold up.

By Sue Major Holmes



It sounds strange — that nuclear weapons must survive radiation. But as part of Sandia Labs' role in ensuring the nation's stockpile is safe, secure and effective as a deterrent, it must make sure crucial parts can function if they're hit by radiation, especially a type called fast neutrons.

Sandia is responsible for non-nuclear components in weapons systems and for overall system engineering and integration. It qualifies, or ensures the safety and effectiveness of systems, through computer simulations and unique test facilities that mimic environments a weapon could face during deployment or an accident. Sandia developed a new way to do that after the Department of Energy shut down its facility for creating fast neutrons, the Sandia Pulsed Reactor (SPR), when security concerns over its highly enriched uranium increased after 9/11.

Enter QASPR, Qualification Alternative to Sandia Pulsed Reactor. QASPR combines computer modeling and simulation, experiments and technology development, and draws on expertise all over the labs, from materials science to transistor fabrication. The idea is to create better radiation-hardened microelectronics for high-voltage transistors, part of a nuclear weapon's safety electronics, and to offer a way to qualify the electronics without SPR.

Sandia does more modeling and experimental work than ever before to qualify components to survive fast neutrons produced by a nuclear burst, either from an enemy weapon or one of our own exploding nearby, says QASPR project manager Len Lorence. "It's very important both in the modeling and the experimental worlds that you not only get the right result but you get it for the right reason," Lorence says. "It's very important to understand the physics of what's going on."

What happens in an eternity

Experiments not only validate computer models but are key to developing them in the first place. QASPR didn't have the models it needed when it began in 2005. But the project had time to work on them because the next reentry system that needed the tools and expertise to support qualification was still years away.

QASPR focuces on how transistors that provide gain, which can be present in analog circuits, react to fast neutron radiation and what happens to gain in less than a second — an eternity in nuclear weapons work. Transistor gain is the amplification of current passing through the device. Neutron damage can cause gain to plummet. Designers can compensate for that in their circuit designs, but used SPR to check whether their designs operated correctly.

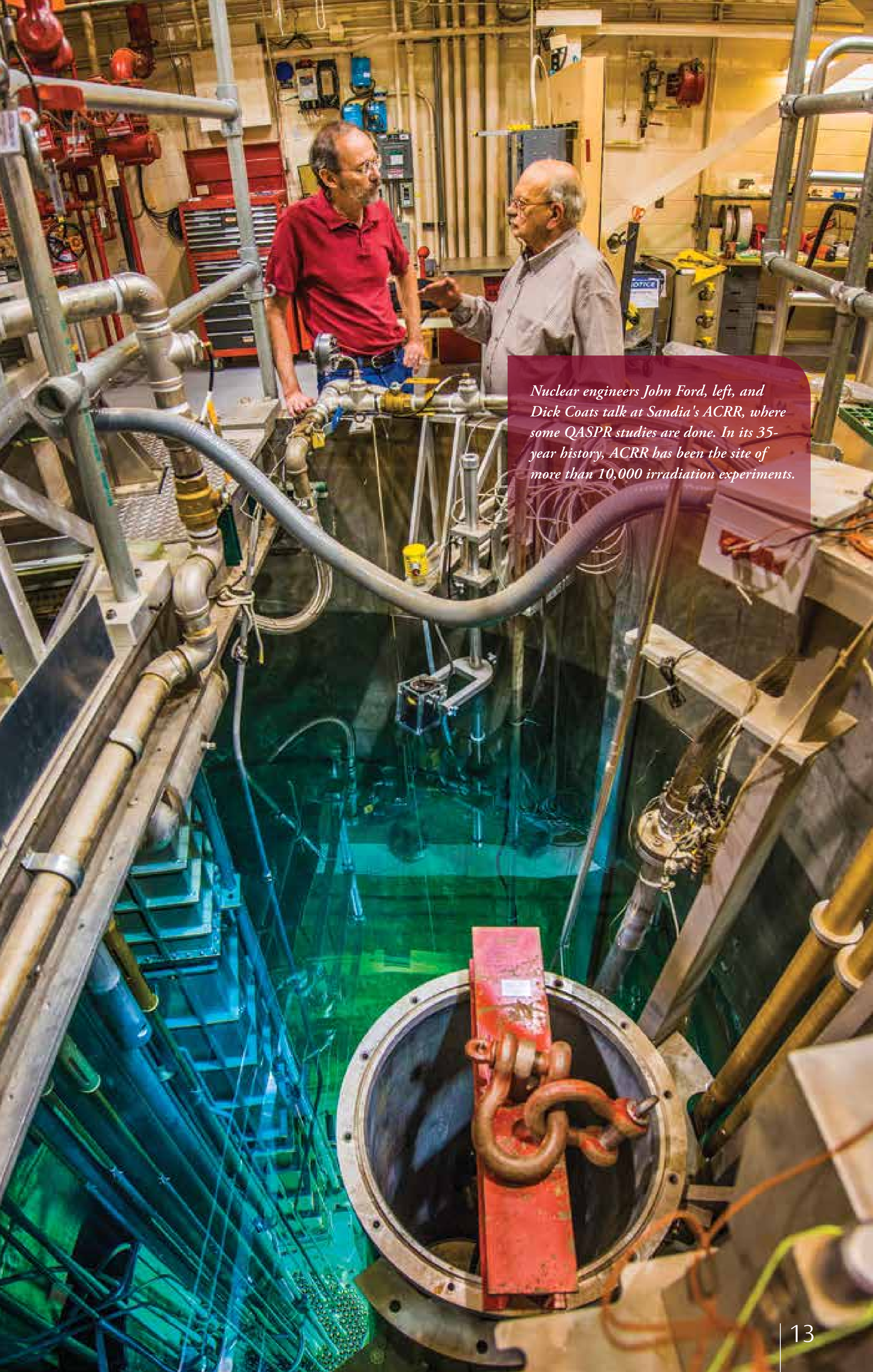
QASPR does similar studies in four facilities: Sandia's Annular Core Research Reactor (ACRR), its Ion Beam Laboratory (IBL), a reactor similar to SPR at the Army's White Sands Missile Range (WSMR) and an Air Force facility for gamma testing in Utah.

The WSMR reactor is a fast burst reactor like SPR, but with less intense neutron radiation. The Air Force facility in Utah is used to test gamma radiation response since neutrons are accompanied by gamma radiation under real world conditions. ACRR, a long pulse reactor, creates the same high levels of damage as SPR, although its long pulse makes it less similar than SPR to the conditions a weapon would experience. Still, it provides a calibration point, which simplifies modeling and lets researchers concentrate on phenomena associated with changes in transistor gain that occur incredibly fast. The IBL acts as a surrogate for neutron radiation because ions can impart the same kind of neutron displacement damage as neutrons. It combines high damage levels like ACRR and short pulses like WSMR in one facility. However, it only can irradiate a transistor or a few transistors together, rather than a circuit or component, like the larger ACRR can. Aggregate testing at these four facilities, each of which has significant shortcomings, cannot be used to replace the testing that used to be done at SPR. When combined with computer modeling developed under QASPR, the tests on electronics at these facilities can be extrapolated to predict the response under real-world radiation conditions.

A semiconductor success story

QASPR also is creating better radiation-hardened microelectronics in Sandia's Microsystems & Engineering Science Applications (MESA) fabrication complex. Some of those transistors are based on compound semiconductors, known as III-Vs because they're made up of elements from the periodic table's columns III and V. Such compound semiconductor transistors are much more resistant to neutron radiation.

Researchers spent QASPR's early years combining modeling and experiments to understand the basic mechanisms of silicon commercial-off-the-shelf components then in use and studying III-V devices. The III-V technology has matured to the point that it



Nuclear engineers John Ford, left, and Dick Coats talk at Sandia's ACRR, where some QASPR studies are done. In its 35-year history, ACRR has been the site of more than 10,000 irradiation experiments.

is becoming an attractive and viable option. “It was a success story for QASPR,” Lorence says. “We are able to provide information that ended up affecting the design for the future stockpile modernization effort.” Researchers are interested in the design phase because “we can catch things earlier, we can help guide the design and ultimately do better qualification,” Lorence says.

QASPR’s computer modeling is hierarchal, beginning with studies of materials inside transistors, using fundamental physics modeling and quantum mechanical tools to understand how radiation damage occurs and evolves. Then researchers create a model of how transistor gain changes during and after radiation exposure, using a Sandia-created transistor model code, Charon. Radiation exposure is modeled with a Sandia code, NuGET. Next, the analog circuit level aggregates transistors and devices such as resistors and capacitors as well as ever-changing voltages — a complex world where some devices respond to gamma radiation but not neutrons. Researchers use another Sandia code, Xyce, to model circuit behavior under radiation.

“The hierarchical approach is very powerful, since it allows traceability from a high-level circuit response all the way down to the most fundamental atomistic material level,” Lorence says. Thus, QASPR offers important information to designers, he says. “At the circuit level we can be very impactful, so much so that we can help the system qualification process, which was our goal.”

The more detailed understanding of circuit sensitivity to radiation, achieved through QASPR’s experimental and modeling efforts, did not exist during the days of SPR testing. This new understanding provides greater confidence in predicting how a circuit would behave in actual radiation environments.

QASPR-like capabilities will be needed as long as nuclear weapon electronics continue to evolve, Lorence says. “It’s hard to put in the stockpile the exact same thing that was originally put in the stockpile. At some point it's not possible or cost-effective. Moreover, thanks to QASPR, the technology that we are putting in the stockpile is better at resisting radiation, and we have the confidence to make that claim even without the Sandia Pulsed Reactor.” ■

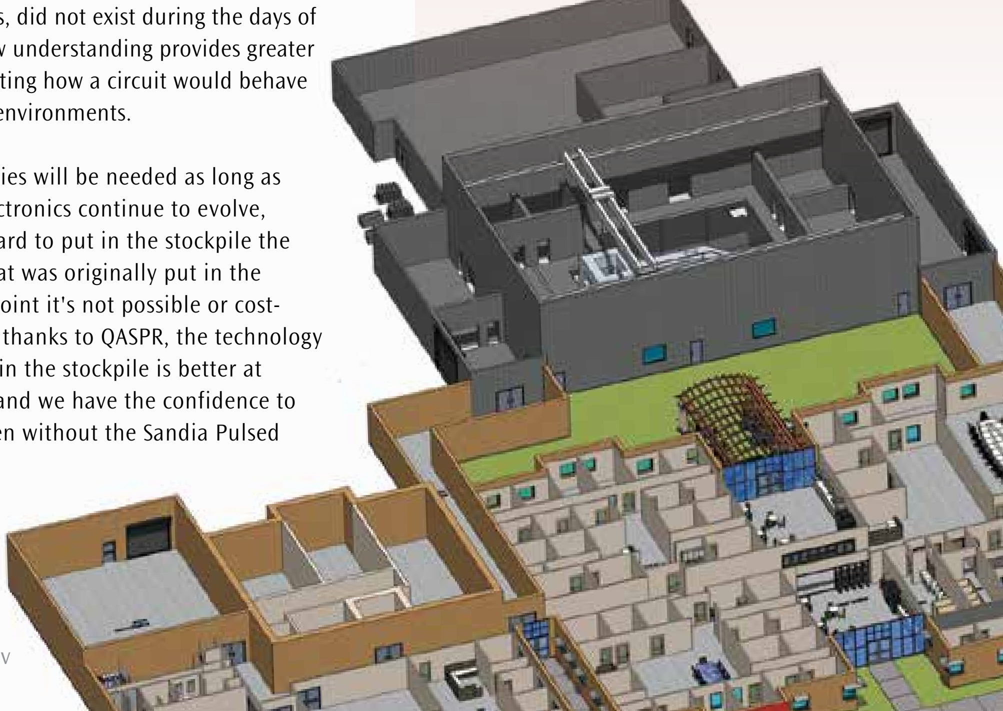
what’s next

HOME SWEET HOME

By Nancy Salem

Sandia Labs has a nuclear research reactor that can do physics handsprings. The ACRR, or Annular Core Research Reactor, produces neutron beams that enable complex, cutting-edge irradiation experiments. “We have world-class capability,” says nuclear engineer Lonnie Martin.

What ACRR doesn’t have is a home befitting its venerable status. The building that



A lodging upgrade is in the cards for hard-working nuclear reactor

houses the reactor has, shall we say, been around a while. "It's old," Martin says. But not forever. On the drawing board is a plan and design for a new campus to house ACRR and the smaller Sandia Pulsed Reactor/ Critical Experiments (SPR/CX) reactor a stone's throw from the existing site. "We will completely replace, recover and return to green grass the old systems that are out there now," Martin says.

The new facility will be more robust and better able to withstand natural phenomena, says Matt Burger, the nuclear facilities senior manager. "The new design improves safety, reliability and efficiency of operations," he says.

And there will be room to expand the physics. "There will be a significant improvement in beam-line capabilities," Martin says. "We can take a beam of neutrons from the reactor and run them into a space where a researcher can use neutrons and gamma radiation to conduct experimental activities. Our current ability to do that is limited."

The campus will have three primary functions: train engineers throughout the labs on preventing nuclear materials accidents, test the effects of radiation on materials and electronics, and basic research and development into nuclear technologies. "Radiation-effects testing has been our meat and potatoes. We do experiments on advanced nuclear fuels, space reactor technology, satellite components and weapon systems," Martin says. "These are high-level functions."

He says new beam lines will allow researchers to develop radiation diagnostic detectors that more accurately measure energy levels. "This would lead to safer nuclear fuels and improved testing of stockpile components, better and cheaper electronics, better communications, and better nuclear medicine," Martin says.

The central feature of the new facility will be an above-ground nuclear island, including the tank and experimental systems. The current reactor is built around a big hole in the ground with fuel at the bottom. "We'll take the fuel out of that tank and build a whole new facility with the tank above ground. The same fuel will move to the new facility," Martin says. "The reactor and tank will be encased in concrete at the ground level. There will be beam ports around the exterior to access radiation fields inside the reactor."

A more detailed conceptual design is due in 2020, and the new facility could be up and running by 2028 with several reactors.

"Everyone is excited about the opportunity to design a new facility with unique capabilities," Burger says. "This will increase our state-of-the-art ability to provide nuclear technology that really is exceptional in service to the nation." ■

A conceptualization of Sandia's planned nuclear facility shows space for several reactors and support operations.

Z's final frontier is far, far away in the vast expanse of mysterious galaxies, black holes

AMAZING

and dying suns.

SPACE

By Neal Singer

Work at Sandia's Z machine has a cosmic aspect.

It's not only earthbound physics that Z investigates, but the universe itself. "We're kind of a truth squad," says Ross Falcon, a Sandia graduate student from the University of Texas at Austin. "We compare Z's experimental data with current cosmological theories."

Researchers and students use the extreme temperatures, pressures and electromagnetic waves created when Z fires to examine how heat travels from the center of our sun to its perimeter, or determine the amount of water on giant planets within or beyond our solar system, or resolve the age of white dwarf stars. This last may help more closely determine the age of the universe, since these dying, contracting suns are its oldest inhabitants.

The work is sometimes done by putting gases in containers at the center of Z and heating them to the state of plasma that accurately represents the temperature and densities of stars. Or little pieces of metal called flyer plates are shot into targets at speeds faster than the Earth moves through space to measure, if momentarily, the effects of enormous compression caused by the gravitational fields of exoplanets — planets that circle other suns. The conditions reached at Z are similar to the pressures in the cores of those planets. Or, it could be done by fixing a small sample of iron near the massive radiation source Z can provide to see a snapshot of energy transport within the sun via iron heated to more than 2 million degrees.

How old is the universe?

Falcon and fellow UT-Austin graduate student Thomas Gomez are interested in the temperatures of white dwarf stars because these burnt-out suns are the oldest structures in the universe. "Find the oldest dwarf star, and you can be sure the universe is at least that old," Falcon says. The pair put hydrogen in a container about the size of a sausage so that Z can heat it to the surface temperatures of the dying stars. From that they analyze the spectroscopic signature for comparison to what is observed by the telescopes.

Why can't they look directly inside the star? Sandia physicist Jim Bailey says, "The inside of a star is one of the most remote parts of the universe. We can't directly observe what's happening in there because it's obscured by the tremendously hot and dense matter that comprises it. We don't have an instrument that can pierce that high energy density matter. But at Z, we can create the same conditions in a sample that's big enough and lasts long enough and is uniform enough to measure the state of materials of interest to us."

Bailey is interested in solving the riddle of our sun's heat transport mechanism. "The models astronomers use for radiation transport in our sun are used for many other stars," he says. "But without experimental tests, we don't know whether the models are accurate or not." That could mean astrophysical theories of the stars are off-kilter. His experiments intend to replicate the energy states of iron in the sun because iron atoms are a key component governing heat transport from its center to the surface.

So far Bailey's measurements of the opacity of the Sun's matter to radiation don't match established models. "There are deep implications there," he says. He's close to publishing his results but first wants to create an even denser iron plasma to more closely match solar conditions.

This looks like a close encounter of the third kind, but it's an experiment at Z, not a UFO.

MEET

Patrick Griffin

There's nothing Patrick Griffin enjoys more than to read philosophy and science fiction or play a game of duplicate bridge. Unless, of course, it's doing exciting and challenging work in radiation sciences at Sandia National Laboratories.

Griffin came to Sandia in 1988 after turning down an engineering job in Connecticut that would have paid 25 percent more. Sandia, he says, offered the chance to do groundbreaking work in radiation modeling and simulation, neutron effects testing, radiation dosimetry and radiation damage to materials, areas that pose research challenges and contribute significantly to national security.

"I enjoy understanding things at the fundamental level," he says. "This work provides that opportunity and also allows me to apply both physics and engineering, two areas where there typically is a rivalry."

Griffin played a big role in two related projects. The first was the dismantling of the Sandia Pulsed Reactor, or SPR, which began operating in 1961. It provided intense neutron bursts for radiation effects testing of materials and electronics, and was upgraded twice before its retirement in 2007. He was also the science and technology lead on developing Qualification Alternative to Sandia Pulsed Reactor, or QASPR, a new approach to qualifying nuclear weapons systems without SPR. **(Read more about QASPR on page 12.)**

STATS

- Bachelor of Science and Ph.D. in physics from Ohio University.
- Professional society memberships in the American Physical Society, American Nuclear Society, Institute of Electrical and Electronics Engineers, ASTM International fellow, affiliate of the National Academies, Hardened Electronics and Radiation Technology and Council on Ionizing Radiation Measurements and Standards.

Ice giants of the solar system

Turning down the scale from suns to planets, Marcus Knudson uses flyer plates to determine how much water exists on certain exoplanets and on the ice giants of the solar system. His team uses Z's magnetic fields to shoot tiny flyer plates — from 12 to 27 kilometers a second, or up to 60,000 mph — into a water-sample target a few millimeters away. The impact of each plate into the target creates a huge shock wave that compresses the water to roughly one-fourth its original volume. This momentarily creates conditions similar to those in the interior of the ice giants. Z can create pressures up to 20 megabars, or 20 million times the pressure of Earth's atmosphere at sea level. The pressure at the center of Neptune, for comparison, is roughly 8 megabars.

The results of the work challenge current astrophysical models that, compared with Z's actual data, overstate water's compressibility on distant planets by as much as 30 percent. "Our results question science's understanding of the internal structure of these planets," Knudson says, "and should require revisiting essentially all the modeling of ice giants within and outside our solar system."

Z's cosmological interests also include plasmas, important in astrophysics, and the formation and evolution of Earth and Earth-like planets.

Since 2010, says Sandia manager Thomas Mattsson, there have been more than 40 experiments (shots) at Z dedicated to these basic science efforts. At least 40

Pulsed power at work

The Saturn accelerator, top photo, is a modular, high-power, variable-spectrum X-ray environment simulation source. Saturn replicates radiation effects on electronic and material components and is a diagnostic test bed. The Hermes III accelerator, below, is the world's most powerful gamma environment simulator.

more shots consisted of cosmological experiments combined with defense-related needs. The work has produced significant publications "and some very interesting manuscripts submitted or in progress," says Mattsson. The experiments have involved a number of national labs and universities, as well as tens of students at different stages in their careers.

All this cosmological work is being performed at a national defense lab for several reasons, says Sandia pulsed power director Mark Herrmann. "The highest value of the fundamental science program for me," he says, "is it engages our staff in unclassified work they can publish. This visibly demonstrates we have good scientists and by proxy a credible deterrent."

Sandia manager Dawn Flicker adds, "NNSA [the National Nuclear Security Administration] has as one of its missions nurturing the community of high-energy-density scientists in order to create a pipeline of students and new employees into the national labs. So NNSA authorizes us to have a program that addresses fundamental scientific problems and uses a few percent of Z's unique resources to increase our interactions with universities.

"We draw from fields like astrophysics, geophysics or planetary sciences, where researchers have a concern about how materials behave under high pressures and temperatures. We learn from their results as they get access to our unique facilities, and science is stronger for it."

"Science builds upon itself," says Keith Matzen, former director of Z and Sandia's pulsed power program, who now heads the lab's Nuclear Weapons Science and Technology program. "This is fundamental science that emerges from science important for the weapons program. The national labs provide an environment and capabilities where this research can be done."


BARE

what's next

A ROADMAP TO HIGH-YIELD FUSION

By Stephanie Hobby

If you had a knife big enough to slice into the sun, you would witness pressures and temperatures intense enough to crush the very atoms making up the core, releasing vast amounts of energy. That nuclear reaction, known as fusion, fuels the sun. Scientists are trying to recreate those conditions in the laboratory to simulate the environments created in or near nuclear weapon explosions. Sandia researchers have been voraciously studying the science of nuclear fusion using the Z pulsed power facility.

Z can create conditions found nowhere else on Earth. Capable of zapping diamonds into puddles, Z uses the magnetic fields associated with high electrical currents to produce intense temperatures and pressures and powerful radiation. Electrical energy is stored from a wall outlet for about a minute and a half then discharged over a few hundred nanoseconds. Electric currents up to 26 million amperes produce a magnetically driven implosion that accelerates objects to velocities of 10 to 100 km/sec. It generates very hot, dense plasmas that can be used to study radiation effects and fusion.

"The way I like to think about this is that we're making a little bit of the sun and we're holding it in our hands in this facility," says Mike Cuneo, a senior manager in Sandia's pulsed power program. Comparing Z to forces of nature is appropriate; each shot carries more than 1,000 times the electricity of a lightning bolt and is 20,000 times faster.

Z is an amazing piece of technology, but its researchers are beginning to think about how to take it to the next level to further increase confidence in certifying the nation's nuclear stockpile. They have developed a roadmap to be the First to High-Yield Fusion, as one of Sandia's newly developed research challenges. The goal over several decades is to lay the groundwork for high-yield fusion in the lab, at least one gigajoule per pulse.

Right now Z can produce up to 80 terawatts of electrical power for a few tens of nanoseconds. To put that in context, the total electrical power generated on Earth at any given time is roughly

Left: physicist Thomas Awe examines coils that reduce plasma instabilities in the quest for controlled nuclear fusion at Sandia's Z accelerator.

2 terawatts. Cuneo says the team is pursuing the development of Z300, which would increase the electrical power to 300 terawatts. The Z300 facility would generate hotter and denser plasmas and would be a stepping-stone to building the Short-Pulse Accelerator and Reactor Center, or SPARC. It is proposed to have an 800 TW pulsed power facility that may be capable of high fusion yields. To meet the requirements of these higher electrical powers, Sandia is developing a more efficient approach to pulsed power, called linear transformer driver accelerator technology, which can be scaled beyond Z's capabilities.

With the end of underground nuclear testing in 1992, the onus is on the national laboratories to certify, with increasing confidence, that weapons will always work when needed but never operate when not intended. "These huge fusion yields could simulate much better the conditions both in and near nuclear weapons," Cuneo says.

"We have to know what's possible to do in the laboratory. If things are possible to do in the laboratory, the U.S. should be doing it first," he says, paraphrasing Sandia Director Paul Hommert's statement that "if ignition is possible in the laboratory, we have to do it first, or have to understand why it's not possible." Cuneo continues, "We don't want another country to get there first. We don't want to be surprised. And furthermore, stewarding the stockpile is a tremendous responsibility and a tremendous privilege and we want to do it the very best way we can. These facilities will allow us to push on that boundary of what's possible and what we know." ■

MEET

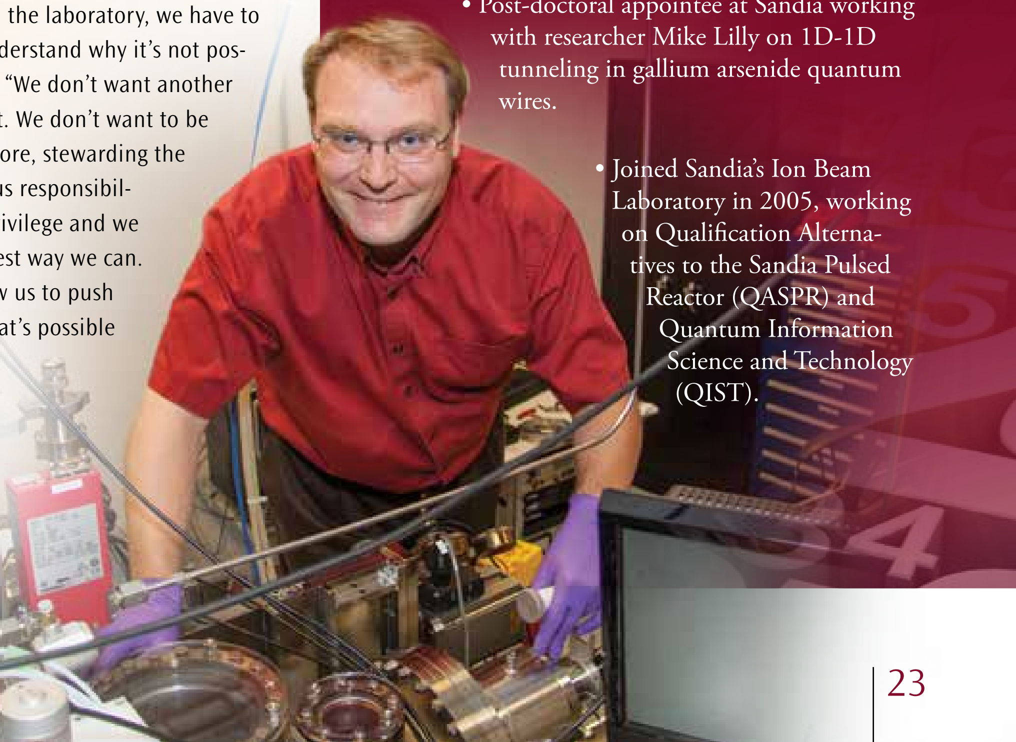
Ed Bielejec

Ed Bielejec enjoys exploring new and novel physics in innovative ways. In his first five years at Sandia's Ion Beam Laboratory, four new beam lines were built for research he initiated. He spent most of the past three years developing a high-energy (100 kV) Wien-filtered focused ion beam system designed to modify and fabricate materials and devices at the nanometer scale. The instrument is used for research projects from single-donor device fabrication — adding one donor atom to a nanostructure to form the basis of qubit for quantum computing applications — to understanding the effects of localized damage centers that occur with single ion implantation and how that affects semiconductor device performance.

Bielejec is also delving into ever-smaller dimensions, looking forward to the delivery of a helium ion microscope that will let researchers push the frontiers of lithography and high-density patterning. For fun, he and his wife like getting outdoors to camp and hike with their three children.

STATS

- Ph.D. in physics from the University of Rochester.
- Post-doctoral appointee at Sandia working with researcher Mike Lilly on 1D-1D tunneling in gallium arsenide quantum wires.
- Joined Sandia's Ion Beam Laboratory in 2005, working on Qualification Alternatives to the Sandia Pulsed Reactor (QASPR) and Quantum Information Science and Technology (QIST).



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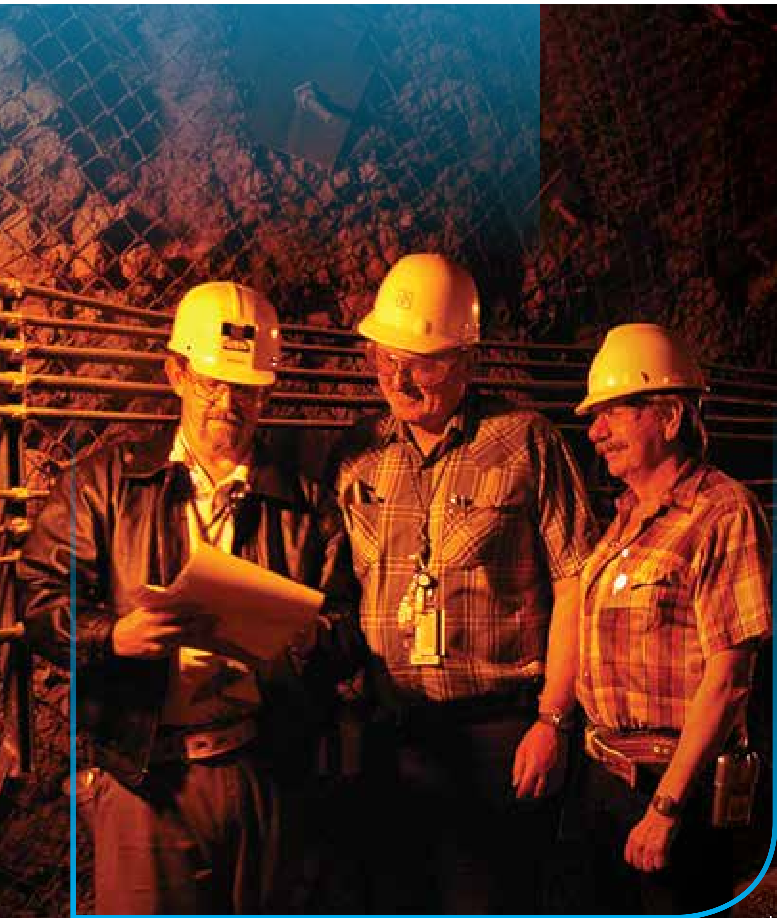

Sandians, from left, Dan Bozman, Mike Burke and Jerry Chael work 1,000 feet underground at what was then the Nevada Test Site. The site no longer tests nuclear weapons but still conducts subcritical experiments, which produce no nuclear yield.

Underground nuclear weapons testing in the U.S. in the 30 years before it ended in 1992 meant burying a device, detonating it and measuring the results. Tests were massive, expensive and needed 24 months and 100 people to design and set up. Sandia's Paul Raglin was a test director for the Defense Nuclear Agency in the 1980s and oversaw many shots in Nevada.

“Sandia fielded a number of different diagnostics to support the tests and fielded all the experiments for components as part of the effort to ensure components would survive such intense environments,” Raglin says.

Some tests were done in a long pipe, pumped to exoatmospheric conditions 10^{-6}. The device would be at one end with the intrumennts for the experiments at the other and at intervals through the pipe. Building the test beds cost roughly $50 million, not including the experiments.

“Today, we rely on modeling and simulation coupled with testing at critical above-ground facilities,” Raglin says. “We have come a long way in our ability to understand some of the complexities, thanks to advances in computing technology and the sophisiticated computational models that we now take for granted.” The laboratories’ proposed Short-Pulse Accelerator and Reactor Center would provide critical radiation environments for model validation that previously could only be done in an underground test.

It was a hard way of life. Engineers lived in a remote test facility in Nevada for six months, and operations ran around the clock. “But being able to do things that couldn’t be done anywhere else was very rewarding,” Raglin says. “There was, and continues to be, a strong sense of mission.”

—By Stephanie Hobby