ARGONNE NOW
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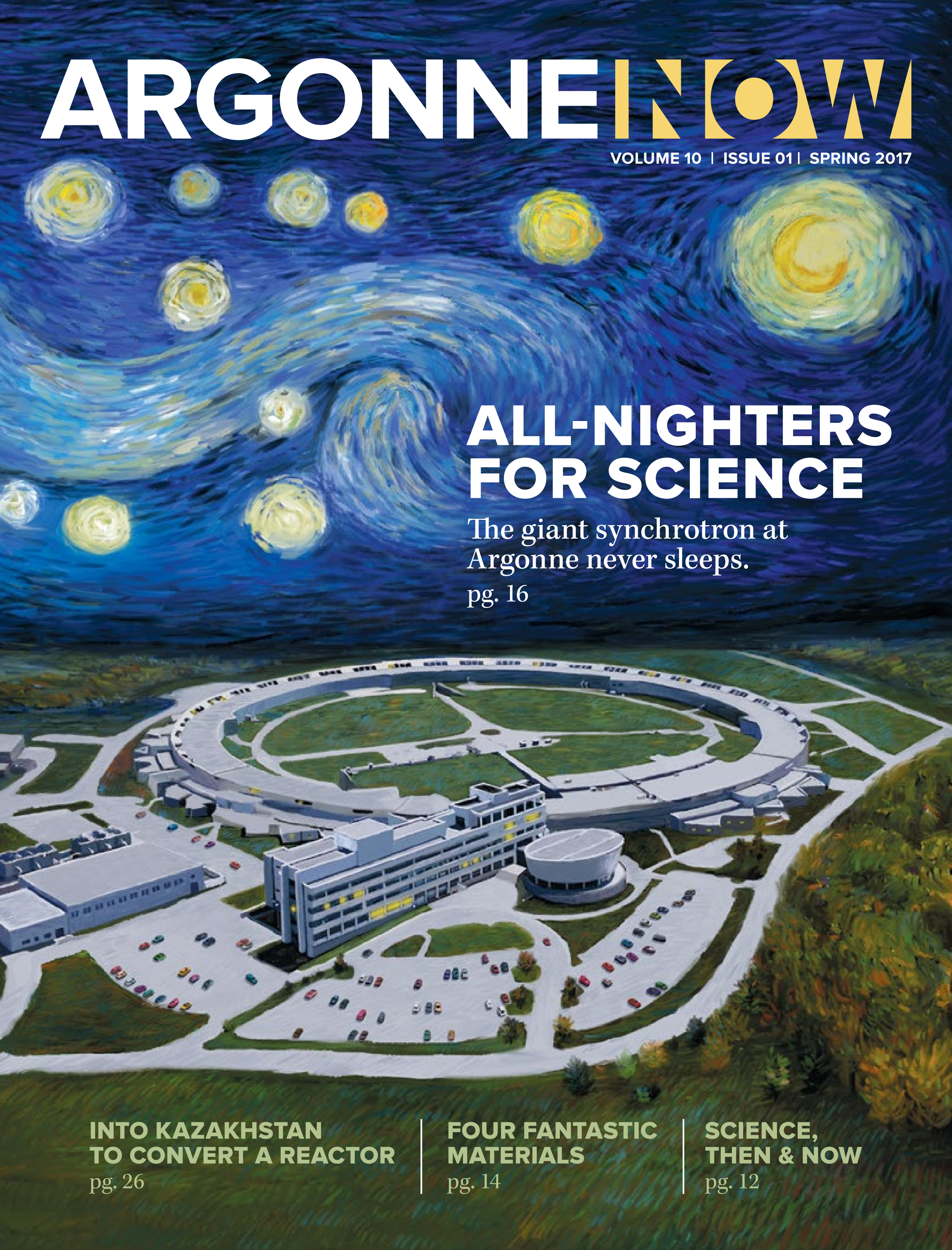

ALL-NIGHTERS FOR SCIENCE

The giant synchrotron at Argonne never sleeps.

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INTO KAZAKHSTAN TO CONVERT A REACTOR

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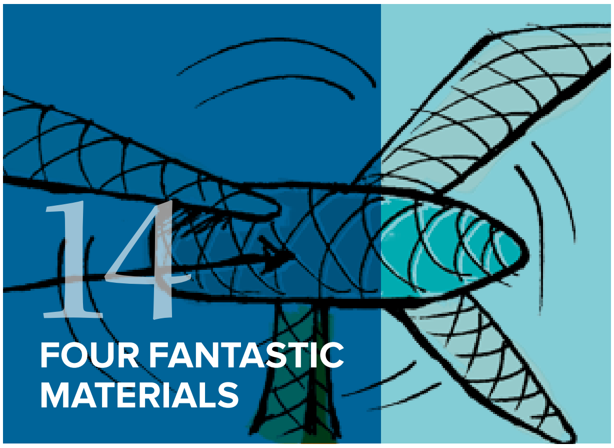

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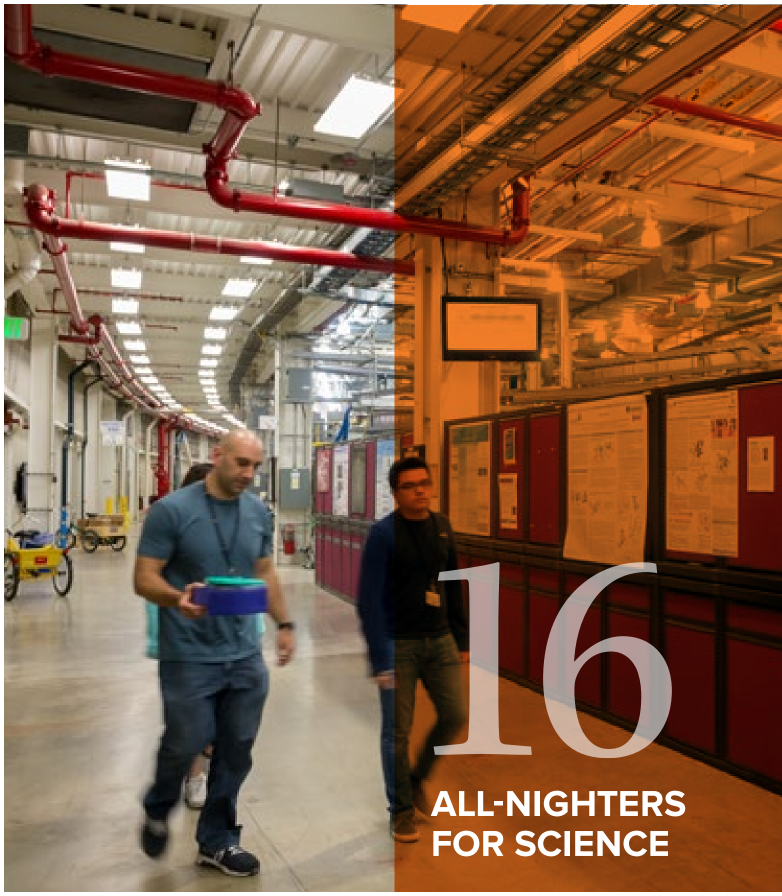

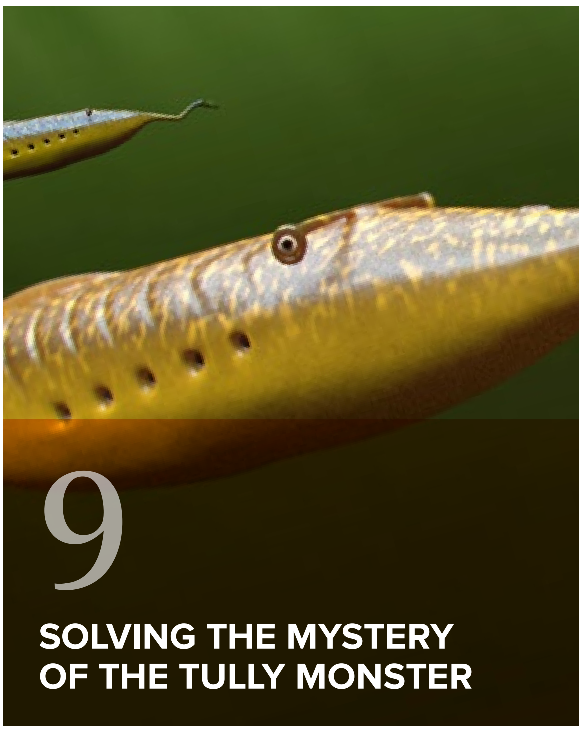

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FACES

TIJANA RAJH

Rajh helps lead Argonne's Center for Nanoscale Materials. Turn to page 40 for her thoughts on the future of nano.

DAVID KAZENKO

Kazenko and his colleagues keep the Advanced Photon Source running 24/7 for experiments.

KATHERINE RILEY

Riley directs science at Argonne's supercomputing facility, and she's always thinking about the next step ahead.

JOHN STEVENS

Stevens runs a program to convert reactors around the world to run on low-enriched uranium.

MARK WOLF

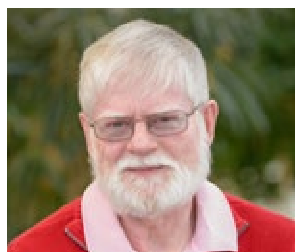
Wolf is tapping X-rays to study the inner workings of batteries to make them better.

JIE LI

Li is working on glass with tiny nanobubbles that could block heat and light from passing through windows.

MARYJO BROUNCE

Brounce, a Caltech geologist, has 36 hours to tap X-rays at Argonne to study glass from ancient volcanoes.



PATRICK GARNER

Garner runs safety calculations for converting reactors, all to reduce the risk of proliferation.

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Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC. The laboratory's main facility is outside Chicago at 9700 South Cass Avenue, Argonne, Illinois 60439.

DIRECTOR'S NOTE

Dear Reader,

Drive around the campus of Argonne National Laboratory after "normal" working hours and you're bound to see lots of cars still in the parking lots—time is of no concern to our researchers deeply engrossed in all order of scientific challenges and puzzles.

At one area of the lab in particular, however, the parking lots remain occupied into the truly wee hours: the Advanced Photon Source (APS), our giant synchrotron, where scientists from around the world are using high-energy, high-brightness X-ray beams to probe everything from the composition of volcanoes to the molecular workings of batteries. So useful and so popular is the APS that it runs 24 hours a day to accommodate as many users as possible.

For this issue's cover story, we wanted to offer a window into the world of round-the-clock science by following along just a few of the APS's thousands of annual users. Witness these inquiring, persevering scientists as they endeavor to pack as much scientific discovery as they can into the hours they're allotted.

We'll also introduce you to the dedicated personnel who serve the users by keeping the synchrotron running at all hours, through weekends and holidays, earthquakes and equipment glitches. Turn to page 16 to walk with them along the nearly mile-long perimeter and see what it takes to keep the APS safe, secure, and running at tip-top shape for scientific discovery.

Our other cover story features another dedicated group of Argonne staff operating in unusual environments: the team of nuclear engineers and experts who help convert reactors in dozens of different countries around the world to run on safer low-enriched uranium, reducing the risk of nuclear proliferation or theft. Turn to page 26 to travel with this impressive group to Kazakhstan as they tackle the 69th reactor in the history of the program.

In the rest of the magazine, we give you a glimpse of a few of the hundreds of projects underway at Argonne on any given day, at any given hour. Each has its own important goals, whether they be scientific discovery for future technologies, deeper understanding of our earth and the complex systems running in and on it, or working towards keeping the world safer and more peaceful.

As Argonne works day and night to provide sustainable, safe, and secure energy to the world, we appreciate your interest and your support. Find out more about us on our website, **www.anl.gov**, or follow us on social media for the latest updates on the necessary—and fascinating—work we're doing.

Thank you, and I hope you enjoy this issue of **Argonne Now**.

PAUL K. KEARNS
Interim Director
Argonne National Laboratory

THIS YEAR IN SCIENCE HISTORY

1767

250 YEARS AGO

Joseph Priestly discovers how to carbonate water for a refreshing drink, an invention he called his “happiest discovery” (other inventions of his included erasers, Unitarianism, and the chemistry of gases).

1817

200 YEARS AGO

Terrible famines and resulting horse shortages lead Karl Drais to invent the “running machine” (aka velocipede or dandy horse), the first ancestor of the bike. Though it looked like a modern bicycle, you rode by pushing your feet along the ground.

1927

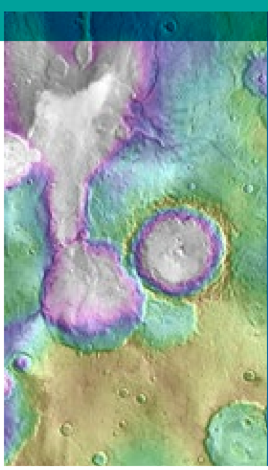
90 YEARS AGO

A young inventor named Philo T. Farnsworth demonstrates a prototype for the first all-electronic television—although it wouldn’t become widespread until after World War II.

1987

30 YEARS AGO

Argonne director Alan Schriesheim demonstrates high-temperature superconductors for President Ronald Reagan. These odd materials have many practical applications, but still hold plenty of mystery (see our 2014 issue, “The Science that Stumped Einstein”).



2007

10 YEARS AGO

The Odyssey spacecraft finds evidence for vast amounts of water ice on Mars, buried just below the surface in the polar regions. Odyssey now orbits Mars, serving as a communications relay for rovers like Curiosity.

IN THE NEWS

A DIAMOND-LIKE CARBON COATING THAT HEALS ITSELF

Fans of Superman may recall how the Man of Steel used immense heat and pressure generated by his bare hands to form a diamond out of a lump of coal.

The scientists at Argonne will probably never be mistaken for superheroes. However, they recently applied the same principles and discovered a revolutionary diamond-like film that is generated by the heat and pressure of an automotive engine.

The discovery of this ultra-durable, self-lubricating tribofilm—a film that forms between moving surfaces—could have profound implications for the efficiency and durability of future engines and other moving metal parts.

The original discovery occurred when two scientists decided to see what would happen when they coated a small steel ring with a catalytically active nanocoating and then subjected it to high pressure and heat using a base oil that doesn't contain the complex additives that modern lubricants do.

To their surprise, the scientists found no rust or damage—only the ring, which was perfectly intact and covered with a new blackish deposit. They tested it again, and realized the film was developing spontaneously between the sliding surfaces—and that it was replenishing itself.

Experiments showed the coating interacts with the oil molecules to create the diamond-like carbon film, which adheres to the metal surfaces. When the film wears away, the catalyst in the nanocoating is re-exposed to the oil. This causes the reaction to restart, developing new layers of tribofilm. The process is self-regulating, which keeps the film at a consistent thickness.

The tribofilm's implications for engine efficiency and reliability are huge. Manufacturers already use many different types of coatings—some developed at Argonne—for metal parts in engines and other applications. The problem is those coatings are expensive and difficult to apply, and once they are in use, they only last until the coating wears away.

Because the tribofilm develops in the presence of base oil, it could also allow manufacturers to reduce, or possibly eliminate, some of the modern anti-friction and anti-wear additives in oil. These additives can decrease the efficiency of vehicle catalytic converters and can be harmful to the environment because of their heavy metal content.

Computing power to analyze the results was provided by the Argonne Leadership Computing Facility and the National Energy Research Scientific Computing Center at Lawrence Berkeley National Laboratory. The research was funded by the U.S. Department of Energy's Office of Energy Efficiency & Renewable Energy.

From left, Subramanian Sankaranarayanan, Badri Narayanan, Ali Erdemir, Giovanni Ramirez, and Osman Levent Eryilmaz show off metal engine parts that have been treated with a diamond-like carbon coating similar to one developed and explored by the team.

NANOBUBBLES COULD MAKE TRANSPARENT GLASS THAT BLOCKS HEAT

A team of researchers at Argonne was awarded a $3.1 million grant to use nanomaterials to improve the energy efficiency of single-pane windows in commercial and residential buildings.

The nanofoam uses gas bubbles less than 100 nanometers in diameter—that's so small that five bubbles could fit in the period at the end of this sentence—to block the transfer of heat and sound through glass, while still allowing visible light to pass through like it does through normal windows.

"That's really the trick, blocking the heat and sound transfer while maintaining transparency," said Argonne building scientist Ralph Muehleisen. "It's fairly simple to develop a coating that insulates, but getting one that is thin and that you can still see through is a substantial technical challenge."

According to the U.S. Department of Energy's Advanced Research Projects Agency-Energy, single-pane windows make up 30–40% of windows in the United States, depending on the region. Single-pane windows conduct at least twice as much heat as double-paned, so retrofitting all those windows could save consumers about $12 billion a year in energy costs.

"There are billions of square feet of windows in the United States. Imagine the impact of making all those windows more efficient. That's when you really start to see benefit from your science," said Argonne chemical engineer Jie Li, who will lead the project.

Funding comes from the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E).

Chemical engineer Jie Li, left, and postdoctoral researcher Alina Yan create coated nanoparticles in a continuous flow reactor.

RESEARCHERS MAKE QUANTUM LEAP WITH PRECISION CONTROL

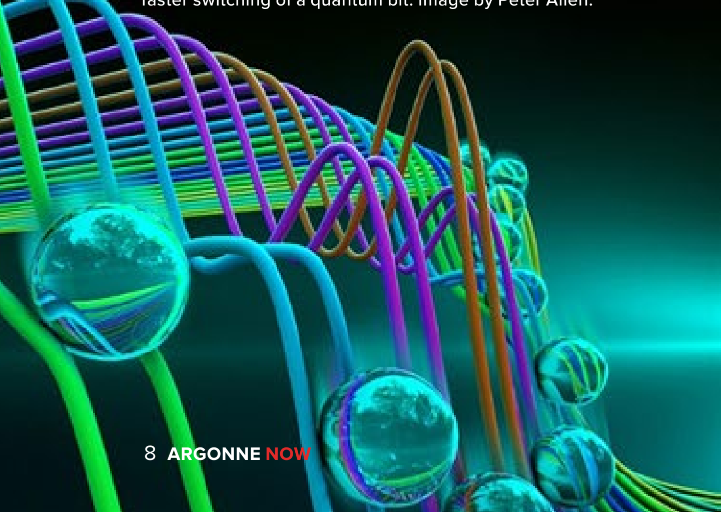
Someday, quantum bits could make computing lightning fast—if we can only figure out how to control them at high speeds.

The dream took a step forward as researchers from the University of Chicago, Argonne, McGill University, and the University of Konstanz demonstrated, on a single electron in a diamond chip, how we could potentially create quantum devices less prone to errors when operated at high speeds.

They shone intricately shaped, synchronized laser pulses inside their diamond chips to direct the motion of quantum particles, similar to how NASCAR racetracks are banked along the sides to help the cars stay on the track even at extremely high speeds.

“We demonstrated that these new protocols could flip the state of a quantum bit, from ‘off’ to ‘on,’ 300% faster than conventional methods,” said David Awschalom, a professor in spintronics and quantum information at the University of Chicago’s Institute for Molecular Engineering and a senior scientist at Argonne. “Shaving every nanosecond from the operation time is essential to reduce the impact of quantum decoherence,” he explained, referring to the process by which quantum information is lost to the environment.

Adapted from an article by Greg Borzo. Research was funded by the U.S. Department of Energy’s Office of Science, the Air Force Office of Scientific Research, and the National Science Foundation.



Intricately shaped pulses of light pave a speedway for the accelerated dynamics of quantum particles, enabling faster switching of a quantum bit. Image by Peter Allen.

A NEW (ARTIFICIAL) LEAF: SCIENTISTS TURN CARBON DIOXIDE BACK INTO FUEL

Much like trees and plants capture carbon dioxide from the air and convert it to sugars that store energy, a new study from the University of Illinois at Chicago and Argonne discovered a similar way to convert carbon dioxide into a usable energy source using sunlight.

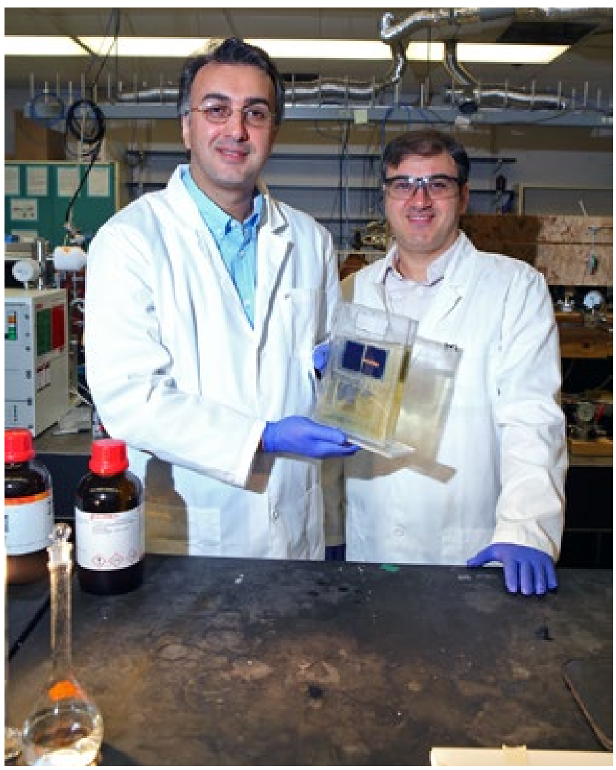
Carbon dioxide is not a very reactive chemical, so it’s been difficult for chemists to find ways to make it into useful things.

But the new system combines water, sunlight, and a tungsten catalyst to convert carbon dioxide into carbon monoxide, which can be easily turned into useful fuels like methanol. The setup for the reaction is similar enough to nature that the research team was able to construct an “artificial leaf” that could complete the entire three-step reaction pathway.

The study found that the reaction occurs with minimal lost energy (i.e., the reaction is very energetically efficient) and that the catalyst appears to be unusually durable, lasting for more than 100 hours.

The study’s authors are working to commercialize the leaf, but they said it could one day be made into big solar farms that recycle greenhouse gases into energy—or even form the basis of portable solar fuel devices for astronauts to use on Mars.

The research was funded by the U.S. Department of Energy’s Office of Science and the National Science Foundation.



University of Illinois at Chicago researchers Amin Salehi-Khojin (left) and Mohammad Asadi with their breakthrough solar cell that converts atmospheric carbon dioxide directly into syngas.

NEW ENERGY INCUBATOR TO SPEED TECHNOLOGY IDEAS TO MARKET

A new program called Chain Reaction Innovations debuted last year at Argonne to help innovators focused on energy and science technologies bring their early-stage ideas to market.

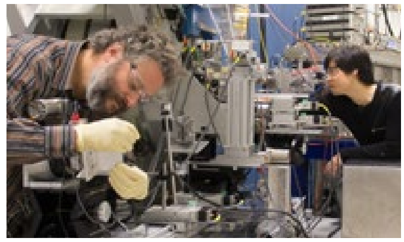
"Traditionally, energy technologies take longer to produce a return on venture capitalists' investments because of their longer development timeline," said Andreas Roelofs, director of Chain Reaction Innovations. "But embedding entrepreneurs for two years into Argonne National Laboratory to validate and scale their technologies will accelerate the path to the consumer and investor marketplaces and compress the return timeframe."

Entrepreneurs selected into the two-year program will have up to $350,000 to use on research at Argonne and up to $100,000 in a fellowship that covers living costs, benefits, and a travel stipend.

They'll have access to many tools at Argonne, including the expertise of 1,600 scientists and engineers and five national user facilities, as well as predictive modeling tools and fabrication, validation, and scale-up facilities. This can reduce costly and time-consuming trial-and-error testing, enable faster development pivots, and provide benchmarks to increase investor confidence.

Chain Reaction Innovations is the second energy and science technology accelerator to open at a national laboratory and the first one located in the Midwest, a hub of energy technology innovation.

Chain Reaction Innovations is supported through the Department of Energy's Office of Energy Efficiency and Renewable Energy.



Entrepreneurs embedded in Argonne National Laboratory through the Chain Reaction Innovations program will be surrounded by more than 1,600 scientists and engineers and world-leading R&D tools such as the Advanced Photon Source, above.

Illustration: Sean McMahon/Yale University.

SOLVING THE MYSTERY OF THE TULLY MONSTER

For decades, the Tully monster has been one of the great fossil enigmas. The first Tully monster was discovered in an Illinois coal mining pit in 1958. This odd sea creature, which lived 300 million years ago, had teeth at the end of a trunk-like extension of its head and eyes that perch on either side of a long, rigid bar.

But even as more and more of them popped up—thousands of Tully monsters were eventually discovered at the mining site—until this year, we had no idea where it belonged on the tree of life.

"With all of the exceptional fossils, we had a very clear picture of what it looked like, but no clear picture of what it was," said Yale's Victoria McCoy, lead author of a new study that revealed the monster's true nature.

"The fossils are not easy to interpret, and they vary quite a bit," said Derek Briggs, curator of invertebrate paleontology at the Yale Peabody Museum of Natural History and a co-author. "Some people thought it might be this bizarre swimming mollusk. We decided to throw every possible analytical technique at it."

The team examined the Field Museum's collection of 2,000 Tully monster specimens. Then they used the X-rays at Argonne's powerful synchrotron, the Advanced Photon Source, to get a unique, non-destructive peek inside the fossil creatures, where they discovered: a backbone. Tully was a vertebrate, with gills. It's part of the same lineage as the modern lamprey.

But the Tully monster is still keeping plenty of secrets—such as the function of that odd trunk. "It might have been a sort of protrusive, lamprey-like feeding apparatus, like the jawed tongue of the monster in 'Alien,'" Philippe Janvier, another scientist studying the Tully monster, told *The Atlantic*.

But no one knows for sure.

Scientists examined Tully monster fossils from Chicago's Field Museum at the Advanced Photon Source at Argonne.

Argonne scientist Carmen Soriano (left) and Yale researcher Victoria McCoy position Tully monster fossils for close examination at a beamline in the Advanced Photon Source.

NEWS+ DISCOVERIES FROM OUR SISTER NATIONAL LABORATORIES

COMPILED BY KATE THACKREY

1

MAKING HYDROPOWER MORE FISH-FRIENDLY

Pacific Northwest National Laboratory
Richland, Washington

To help migrating fish get past hydropower dams, a Seattle company invented the Whooshh Fish Transport System, aka the "Salmon Cannon" (*Ed. note: Googling this video is highly recommended*). With a grant from the Department of Energy's Small Business Vouchers program, Pacific Northwest will evaluate the system to compare it with currently used fish ladders, which are a series of stepped waterfalls for fish to jump up around dams. The results could help the technology obtain federal approval to transport Endangered Species Act–listed Pacific salmon around dams.

2

FINDING PLAQUE BEFORE A HEART ATTACK

Lawrence Berkeley National Laboratory
Berkeley, California

Berkeley's Engevity Cuff prototype measures changes in pulse pressure as blood flows through arteries in the upper arm, and uses software to figure out a patient's level of plaque buildup. The technology is more sensitive and cheaper than the current mode of checking the health of blood vessels using ultrasound. In the United States, where cardiovascular diseases are a leading cause of death, a version of the Engevity Cuff might help doctors better diagnose and treat patients.

3

X-RAY EXPLOSIONS GET AIRTIME

SLAC National Accelerator Laboratory
Stanford, California

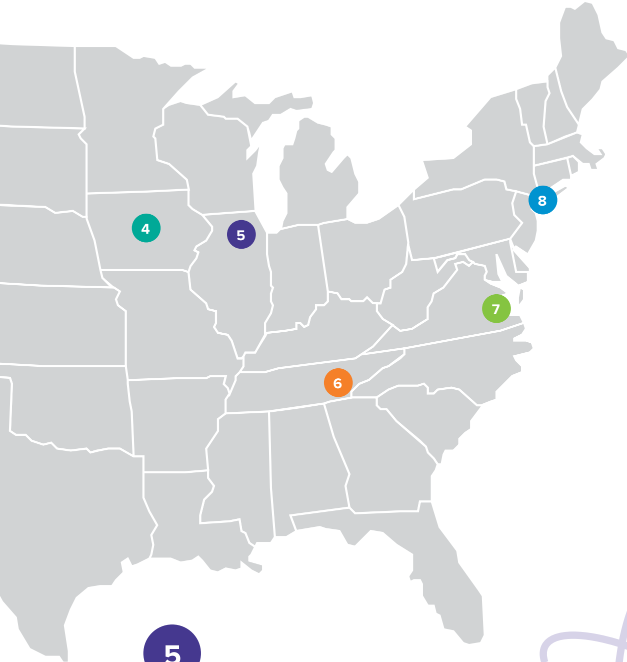
Hollywood explosions have gone microscopic with new movies that show X-ray lasers vaporizing liquid samples. Researchers injected individual drops or a continuous stream of liquid into the path of an ultra-bright X-ray. The team took pictures for a fraction of a second after each X-ray pulse, combining hundreds of images to create the first time-lapse videos of the process. These videos have helped researchers to perfect experimental timing and predict explosive reactions of liquids.

4

THIS DEVICE WILL SELF-DESTRUCT IN 30 SECONDS

Ames Laboratory
Ames, Iowa

"Transient electronics" is the field trying to develop self-destructing electronics (yes, like those in "Mission: Impossible"). They could keep military secrets out of enemy hands, save patients the pain of removing a medical device, or allow environmental sensors to wash away in the rain. An Ames Laboratory researcher announced the first practical transient lithium battery: it dissolves in water in 30 minutes.



5

A CLOSER LOOK AT NEUTRINO-NEUTRON INTERACTIONS

Fermi National Accelerator Laboratory
Batavia, Illinois

A new detector developed at Fermilab promises to study neutrino-neutron collisions in more detail than other sensors. The Accelerator Neutrino-Neutron Interaction Experiment uses new photosensors to measure the light radiation left behind when neutrinos smash into water molecules and knock off particles. The experiment will improve physicists' understanding of radioactive decay by helping them measure the energy exchanges between the two particles.

7

JUST TIN: MAKING ACCELERATORS MORE EFFICIENT

Thomas Jefferson National Accelerator Facility
Newport News, Virginia

Tin could make particle accelerators twice as efficient when added to existing niobium metal components, according to researchers at the Thomas Jefferson National Accelerator Facility. Both tin and niobium become superconductors—able to conduct electricity with zero loss—when they are cooled to temperatures near absolute zero. The team will work for the next five years to bond superconductive metals such as tin to the surface of niobium cavities, which would make accelerators more efficient by allowing them to work at higher temperatures and lower energy levels.

6

SOME CATALYSTS WORK BETTER UNDER STRESS

Oak Ridge National Laboratory
Oak Ridge, Tennessee

In energy storage devices, such as batteries, the job of many catalysts is to add or remove electrons from oxygen in order to speed up the transition from chemical to electrical energy. Most catalysts only work in one direction, but researchers from Argonne and Oak Ridge found that increasing strain on the structure of certain catalysts enables them to work in both directions. By mismatching the lattice structure, researchers forced molecules to become unstable, which made them more likely to carry out catalytic reactions.

8

INSPECTING "FREEDONIA" FOR UNDECLARED NUCLEAR ACTIVITY

Brookhaven National Laboratory
Upton, New York

For one week in June, Brookhaven National Laboratory became a scientific facility in the mythical country of "Freedonia." There, a team of inspectors, analysts, and technical specialists from the International Atomic Energy Agency participated in a training exercise to inspect Freedonian scientific facilities for undeclared nuclear material and activities. The course is one of a dozen training courses the United States offers annually to the International Atomic Energy Agency's Department of Safeguards.

NEWS

SCIENCE **THEN** AND **NOW**

Last year Argonne celebrated its 70th anniversary. Here's what state-of-the-art science facilities looked like decades ago when Argonne was a fledgling laboratory—and what their descendants look like now.

BY KATIE ELYCE JONES

THEN

1964 / ZERO GRADIENT SYNCHROTRON
MISSION: DETECTED SUBATOMIC PARTICLES

The ZGS accelerated protons to 12.5 GeV (or 12.5 billion electron volts) in a 200-foot ring. When it began operation in 1963, it was the highest-energy weak-focusing proton synchrotron in the world. In 1970, a 12-foot bubble chamber was added for studying particle momentum, and the neutrino was observed in a hydrogen bubble chamber for the first time. Once thought to be massless, the neutrino is a tiny but abundant particle important to our understanding of the Standard Model of particle physics. Although neutrinos had been detected before, little was understood about their nature, and the ZGS was suited for further studying this elusive particle because its bubble chamber was the largest in the world, able to capture a neutrino interaction in a photograph of the bubble chamber after less than 3,000 pulses of the ZGS.

Today, Argonne is part of the international ATLAS experiment located at the Large Hadron Collider, a 13-teraelectron-volt particle accelerator with beams 500 times more powerful, in terms of electron-volts alone, than the ZGS was 50 years ago. As accelerators have increased in power, physicists have discovered heavier particles and rarer particle interactions.

Illinois governor Otto Kerner visits the Zero Gradient Synchrotron, which accelerated protons to 12.5 billion electron volts.

1982 / INTENSE PULSED NEUTRON SOURCE
MISSION: STUDIED THE STRUCTURE AND BEHAVIOR OF MATERIALS AT ATOMIC AND MOLECULAR LEVELS

When the ZGS was retired in 1979, its synchrotron ring became the booster (an initial accelerator that "boosts" a particle's energy before it enters the main ring) for Argonne's next imaging venture: the IPNS, the world's first pulsed neutron source. Similar to X-ray studies with photons, neutrons can probe the atomic structure of materials, but their lack of electrical charge allows them to penetrate some materials more deeply with less disruption to the material. Scientists had been producing neutrons for research through fission in experimental reactors, but those neutrons, delivered in steady streams, limited the range of what could be studied. IPNS leveraged accelerators to deliver short, intense pulses that added a new dimension to materials characterization. During the 26 years the IPNS was in operation, researchers used it to solve the structure of a high-temperature superconductor and identify the structure and formation of Alzheimer's plaques, among many other discoveries.

Scientists used the Intense Pulsed Neutron Source to probe the atomic structure of materials using neutrons.

NOW

ADVANCED PHOTON SOURCE
MISSION: PROVIDES ULTRA-BRIGHT, HIGH-ENERGY X-RAY BEAMS

X-rays are powerful and versatile tools of scientific exploration: they can penetrate materials and provide detailed information on atomic and molecular structure and behavior. By manipulating electrons with magnets, the Advanced Photon Source produces radiation at different wavelengths across the electromagnetic spectrum, creating an incredibly high-powered "microscope" to study many kinds of materials—from proteins to metal alloys. Because of its versatility and large number of visiting researchers, the APS contributes to discoveries in fields from electronic and magnetic materials to the environmental and life sciences, among many others. In fact, two Nobel Prizes have arisen from APS research, including the 2009 Nobel Prize in Chemistry for the structure of the ribosome and the 2012 Nobel Prize in Chemistry for the structure of the human G-protein-coupled receptor.

The Advanced Photon Source accelerates electrons to nearly the speed of light to make X-rays that can penetrate deeply into materials to help us understand them.

THEN

1953 / AVIDAC

MISSION: SOLVED MATHEMATICAL PROBLEMS USED IN REACTOR ENGINEERING AND THEORETICAL PHYSICS RESEARCH

Argonne computer scientist pioneer Jean F. Hall operates the AVIDAC, a top-of-the-line 1953 supercomputer with a memory of about 5.1 kilobytes.

When the AVIDAC was installed in 1953, it was described as working "approximately 100,000 times as fast as a trained computer [a person] using a desk-type electric calculating machine [a calculator]." The computer could add, subtract, multiply, divide, and perform other arithmetic operations for numbers up to 999,999,999,999. The computing capability was determined, in part, by memory. AVIDAC had a memory of about 5.1 kilobytes. Twenty years later, the first floppy disk would store about 80 kilobytes—16 times more than the AVIDAC "supercomputer." The growth in computer memory continues to be tremendous. The Mira supercomputer at Argonne today has over 700 terabytes of memory—1.5 trillion times that of AVIDAC. To make use of all this memory toward solving ever more complex problems, today's supercomputers have different computing architectures capable of performing more operations much more quickly.

NOW

MIRA

MISSION: ACCELERATE MAJOR SCIENTIFIC DISCOVERIES AND ENGINEERING BREAKTHROUGHS THROUGH SUPERCOMPUTING

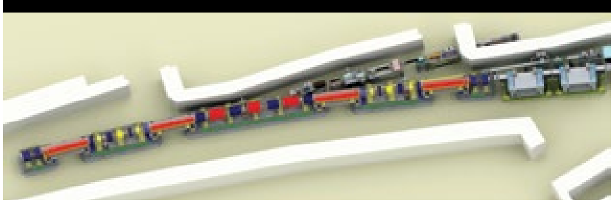
Today, Argonne's supercomputer Mira can crunch numbers at 10 quadrillion operations per second.

Argonne's first supercomputer, AVIDAC, could, in 20 minutes, complete work that would take two mathematicians three years to complete with electric calculators. At 10 quadrillion operations per second, it is a challenge to even compare Mira's capability to what a mathematician could do with pen and paper. Rather, Mira can do in a day what it would take a modern-day personal computer 20 years to do. Mira is one of the most powerful computers in the world, and its architecture, or the way it solves problems, is highly suited to simulating physical processes (like protein folding, galaxy formation, ion solvation, and more) with great realism based on the fundamental laws of physics.

ON THE HORIZON

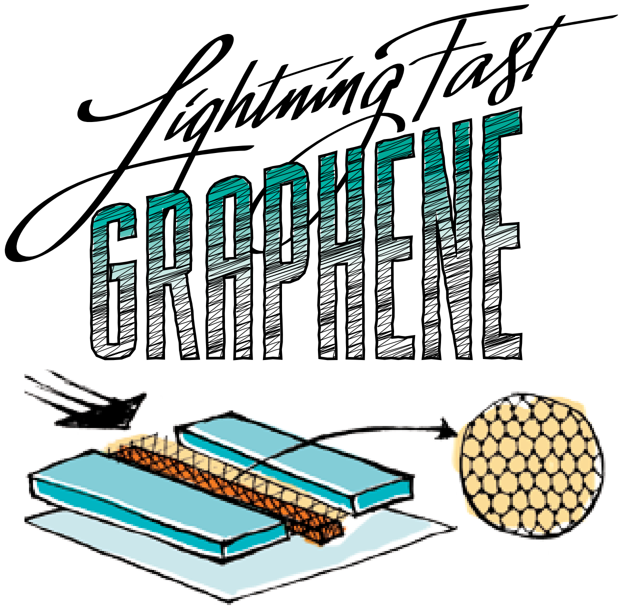
APS

A planned upgrade to the Advanced Photon Source will transform the synchrotron into the ultimate 3-D X-ray microscope, creating the most technologically advanced hard X-ray light source the world has ever seen and transforming our ability to understand and manipulate matter at the nanoscale. It will increase the beam's brightness by a hundredfold, to create highly penetrating X-rays more than 10 trillion times brighter than the X-rays used in routine medical imaging.



AURORA

In 2018, supercomputing power at Argonne will take another leap with Aurora, a system that will be about 20 times more powerful than Mira. It will be able to resolve scientific problems, such as quantum mechanical processes, that are simply beyond our understanding without computer modeling and simulation—yet have very real scientific and engineering applications.

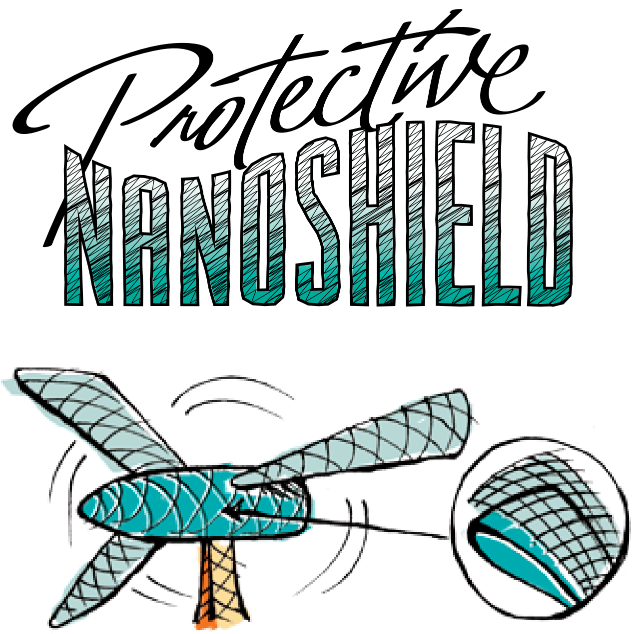


GRAPHENE

The first scientists to create graphene, a single layer of carbon atoms, did so by progressively peeling away layers of graphite, the stuff of No. 2 pencils. Despite its origins as pencil ash, graphene is extremely hard and strong, tougher than diamond, and thin and flexible. As a single layer, graphene is a semiconductor, rapidly ushering electrons across its 2-D plane. In fact, electrons can travel up to 100 times faster through graphene than the silicon used in computer chips.

Today at Argonne, researchers are exploring this amazing material's potential for electronics and other applications by creating different 2-D graphene structures—sheets, ribbons, scrolls, and more. For one study, scientists are designing circuits of graphene ribbons as thin as 50 atoms wide to take advantage of the super speed of its electrons for faster, more energy-efficient electronics. Specifically, they are observing the circuits' band structure, a directional property of semiconducting materials that must be understood before designing new devices.

4 FANTASTIC MATERIALS



NANOSHIELD

Roughly 80% of the cost of wind energy is tied up in machinery. Exposed to variable and often extreme conditions, turbines need to be tough. Resilient, long-lasting gears, rotors, and other machine parts are important to advancing the future of wind energy. But inevitably, after so many stop-and-go rotations, turbines begin to feel stress in the form of tiny fractures known as micropitting that lead to bigger problems as rotations continue.

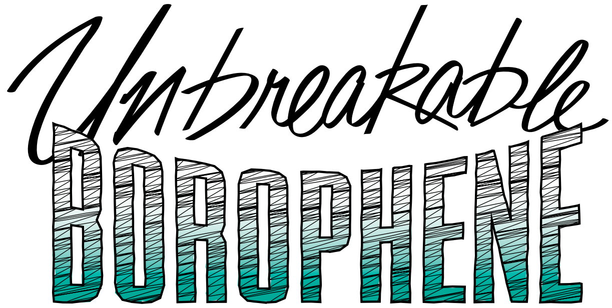
Luckily, Argonne has scientists who specialize in understanding the nanoscale vulnerabilities of mechanical parts and developing protective materials like coatings to reduce the friction that leads to cracks and pits. One such coating, called N3FC, has diamond-like carbon bonds—but instead of being hard as diamond, N3FC is relatively soft, providing a flexible shield that absorbs the impacts of cranking and sliding. 100 million test cycles later—about three times the typical number of test cycles—N3FC-coated parts have not incurred significant micropitting, which is already a pretty amazing track record.

FOUND AT ARGONNE

New materials are the seeds for new technologies. Here are four discoveries with never-before-seen properties that could lead to new devices, innovations, or breakthroughs.

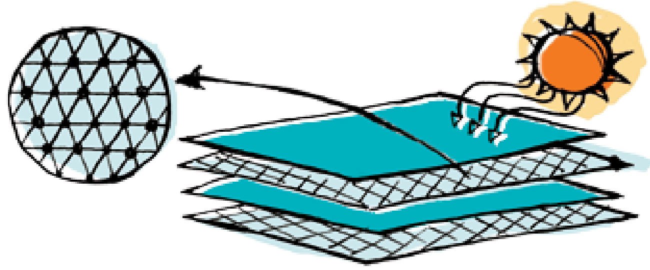
BY KATIE ELYCE JONES

BOROPHENE



Something special happens when you take atoms of the carbon-like element boron and spread them into a single layer: you transform a hunk of non-metallic boron into a brand new 2-D material known as borophene. As the first metallic and lightest 2-D material that also sports a high tensile strength, or resistance to breakage, borophene could lend greater flexibility and durability to electronic devices and solar cells at a lower environmental cost than industry staples like silicon.

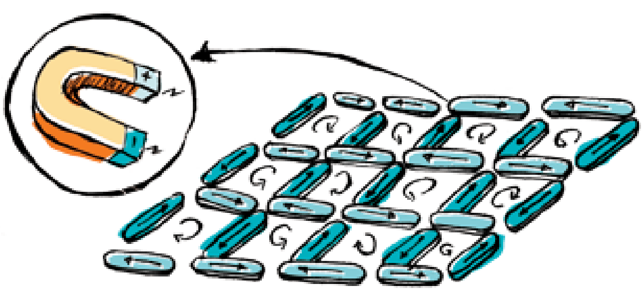
Argonne scientists were the first to create borophene, and did so in a way that is easier and less toxic than previous experiments synthesizing boron-based materials.



MAGNETIC CHARGE ICE

In the game “20 Questions,” a player must guess an object chosen by another player by asking a series of “yes” or “no” questions. Working within similar limits, computers store information based on only two states created by the opposing forces of tiny magnets (represented as 0s and 1s). If you have ever wanted to say “maybe” in 20 Questions, you understand why researchers want to develop technologies that can store information in multiple states: you can reach a complex answer much faster.

Recently, scientists at Argonne developed a 2-D material called “rewritable magnetic charge ice” that can store eight units of information—quite an electromagnetic vocabulary compared to yes and no. After separating magnetic spins and charges to achieve greater control over the magnetic charges, researchers used a local nano-magnet to “tune” eight charge configurations for relaying information. An external magnetic field can also be applied to easily erase and rewrite information, opening up the possibility for new computing functionalities.



COVER STORY

ALL-NIGHTERS FOR SCIENCE

The giant synchrotron at Argonne never sleeps.

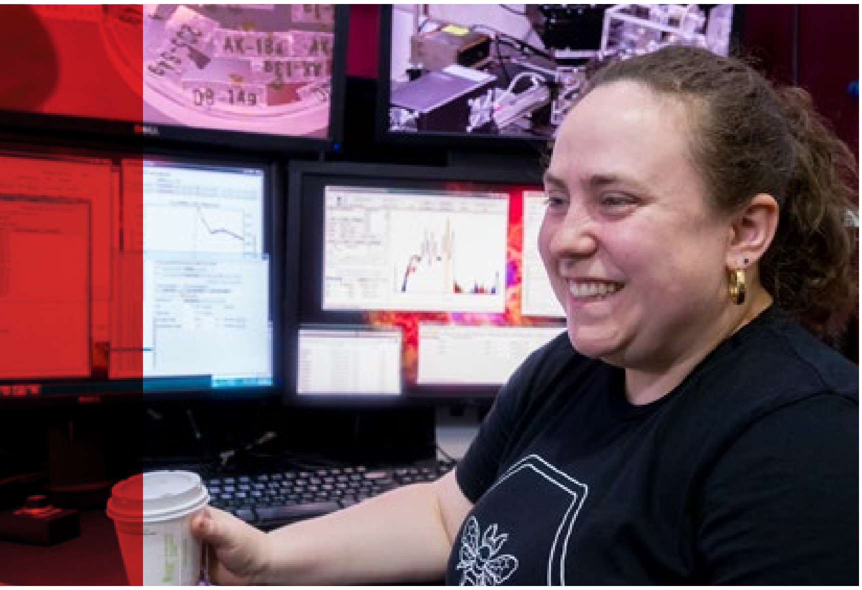
BY LOUISE LERNER

IT'S JUST AFTER THREE IN THE MORNING on a Friday in early summer, and geologist Maryjo Brounce is racing against the clock. In a few short hours, she'll have exhausted a 36-hour window she's earned to get a glimpse into the early days of the planet using one of America's most advanced scientific tools.

Brounce and her colleague, Mary Peterson, have collected tiny chips of glass formed by volcanic eruptions all over the world and brought them to Argonne's Advanced Photon Source, known to its users as the APS. Here at Sector 13, they'll use powerful X-rays from the APS to unlock the secrets of each volcano's elemental composition.

Right now, as the X-ray beam scans a chip of a 61-million-year-old volcano from Baffin Island in Canada, Brounce and Peterson have been awake—save for quick naps—for almost a full day. But the APS is, by necessity, indifferent to the circadian rhythms of its users. To squeeze as much scientific discovery as possible out of every minute, the APS runs around the clock, 24 hours a day, with only scheduled breaks for maintenance every few months.

Geologist Maryjo Brounce is on hour 25 of a 36-hour window to use powerful X-rays to study ancient volcanic glass.



Geologist Mary Peterson relies on caffeine as she prepares samples of volcanic glass for study at the Advanced Photon Source.

For the geologists, access to such a unique facility is worth the sacrifice of sleep. "I feel like you can do anything for 48 hours," Brounce says.

Before the two scientists traveled here, Brounce from Caltech and Peterson from the University of New Hampshire, they spent weeks assembling a collection of glass from colleagues studying volcanoes from Madagascar to Guam to Iceland. Then they carefully shaved and polished each piece down, like a jeweler might, so that each chip is no more than 150 microns thick—about the width of a single human hair.

During their remaining few hours at the beam, they will use two sets of tweezers to position each chip in the path of the beam, where the APS's intensely bright X-rays will strike it. Each element in the chip will absorb the X-rays slightly differently and re-emit them at a specific energy. This will tell Brounce and Peterson the exact elemental composition of the glass. Armed with this information from chips from volcanoes around the world, they can infer whether the young Earth's atmosphere and rocks were oxygen rich or not, and how this changed as the world aged.

Researchers like volcanoes because they bring up ancient rock from deep below the surface. "The Baffin Island rock could turn out to have very primitive signatures," says Brounce. "Perhaps even a record of the formation of the Earth; that is, 4 billion years ago."

THE ADVANCED PHOTON SOURCE IS A GIANT RING, two-thirds of a mile in circumference, in which electrons circle at nearly the speed of light. Its job is to make very powerful X-rays, which it does by accelerating the electrons and then bending their paths with magnets. This throws off energy in the form of X-rays.

The Sector 13 beamline is part of the Center for Advanced Radiation Sources at the University of Chicago.

These X-rays are enormously useful to scientists who want to see the chemical and molecular structures of objects. Unlike researchers at accelerators like the Large Hadron Collider, who are looking to understand the fundamental particles that make up the universe, scientists use the APS like a giant microscope to look at the materials things are made of: solar cells, cast iron, spider silk, batteries, even the paint from famous paintings. (A few days after Brounce and Peterson leave, a team will be at Sector 13 to study the composition of the paint in Edward Munch's painting "The Scream.")

There are 35 different "sectors" where X-rays peel off from the ring, so at any given moment the APS actually houses dozens of different experiments conducted by scientists from all over the world under one roof.

Fortunately for Brounce and Peterson, some parts of their experiment can be monitored remotely, from a little hotel built near the APS expressly to house researchers in the midst of round-the-clock studies.

"We'll go back to the hotel and catch a little sleep in a few hours," says Peterson, surrounded by coffee cups. "But we do set an alarm every hour just to wake up and check the feed to see that it's all going smoothly. You don't want to have something go wrong and then you're sleeping away your beam time."

> “Our group has been here many times,” May says. “We learn something new every time.”

Each sector has its own group of resident beamline scientists who assist visiting scientists with their runs, work on equipment and detectors to improve performance, and do their own research. When Brounce and Peterson had a hardware issue at about 8 p.m. that they couldn’t fix, they called Matt Newville, a Sector 13 beamline scientist. He was home for the day, but he went to his computer at home, connected to the beamline, and made a tiny adjustment to the beam’s trajectory that fixed the problem.

In all, Brounce and Peterson will test 50 to 75 samples from different volcanoes during their allotted beam time. Once they have their data, they’ll take it back to their home universities to dissect all the information they’ve just collected, and see what they can tease out about the beginning of the planet.

ON THE OTHER SIDE OF THE RING, in Sector 34, two other scientists are tapping the same flow of X-rays. But Brian May and Mark Wolf, both from the University of Illinois at Chicago, are using their X-rays to look at batteries: specifically, lithium-ion batteries, like the kind in your cell phone or laptop.

Scientists are racing to find new ways to make better lithium-ion batteries because in today’s society their progress is inextricably linked to leaps forward in technology (can we power cars for 500 miles?) as well as electricity and sustainability (can we make a battery that can store enough energy to make widespread wind and solar power more realistic?).

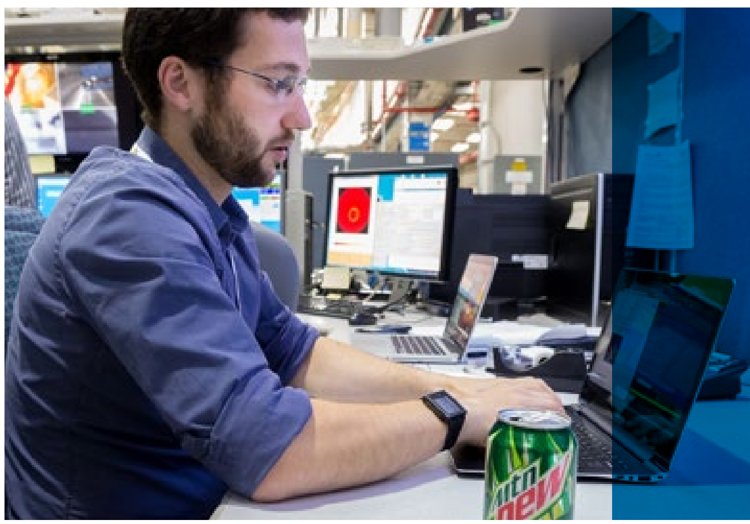
Batteries, however, are a complex bit of technology. When you charge and then use your battery, you are shuttling lithium ions back and forth between the two terminals of the battery. Inevitably, as with all moving things, this wears out the physical structure of the battery. May and Wolf are using X-rays to see exactly how that structure breaks down over time.

“Our group has been here many times,” May says. “We learn something new every time.”

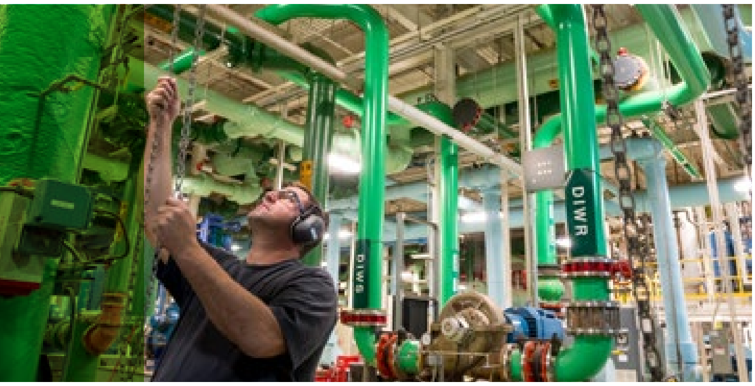
May and Wolf have worked on several different beamlines. Each beamline has specialized equipment designed to tackle specific scientific questions. Some are set up to take very precise readings over a small area; others scan a larger area more quickly. Some specialize in geology; others examine frozen proteins, or objects under high pressure. And some are designed to take readings as a battery is running—that’s the one May and Wolf are using right now. This beamline gives them information about the atomic structure of the battery; they’ll combine it with data from another beamline to get chemical information as well, for a more complete picture.

May and Wolf are also experimenting with a new technique to create a 3-D reconstruction. If they can watch how the battery’s structure breaks down over time, they can figure out how to build a more resilient one.

Brian May is collecting information on how batteries break down at a special beamline that allows scientists to take readings as the batteries are actually running.



May and colleague Mark Wolf, above, don’t mind the long hours at the synchrotron—it gives them time to think—but come prepared with their own caffeine.



The Advanced Photon Source is an extremely complex and delicate facility; maintenance crews and control room operators keep its brain working and blood flowing around the clock.

Their experience on the beam also means they've had time to refine their technique for keeping their focus late into the night.

"I budget about a case of Mountain Dew per run," May says.

"Sometimes to stay awake, I'll go for a ride on the trikes, just to get the blood flowing," Wolf says. (There are big three-wheeled bikes scattered around the ring for people who have to travel far around the experiment hall.)

"I like it. I get in my zone late at night," May says.

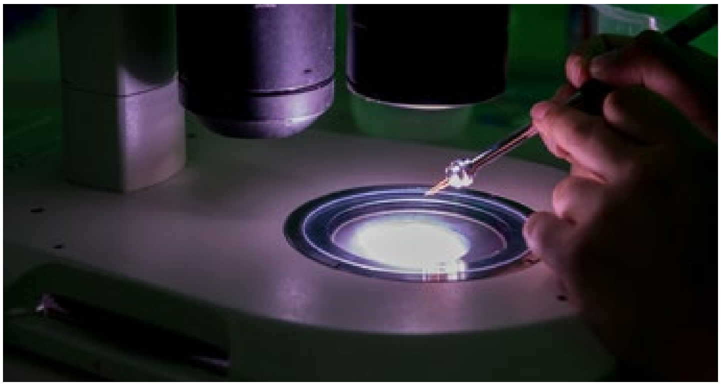
At 8 a.m. May and Wolf's run ends, and they collect their battery samples and data. More teams are waiting right behind them, ready to begin their shifts at the beam.

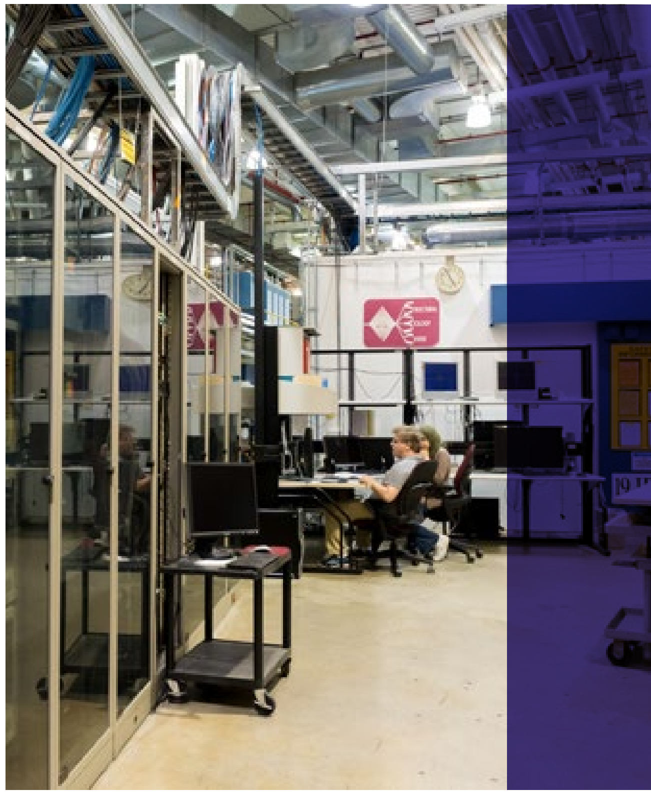
BUT THERE'S ANOTHER GROUP working at the APS that stays as the others come and go. They're the people that keep the APS's brain working and blood flowing, and that means they keep watch 24 hours a day, every day.

The highest priority for the dozens of people who run the APS is keeping interruptions to the X-ray beam at an absolute minimum. The APS is so large that it has its own utility plant, a large hall beating with water pumps and deionizers, air compressors, electrical equipment, and emergency backup generators. "If the APS experiment hall is the body, this is its heart," says Argonne maintenance mechanic Dave Kazenko, and it's his and his colleagues' job to keep it pumping.

On the floor of the ring, engineer Glenn Kailus' maintenance team walks the experimental hall night and day, checking for water leaks and responding to emergencies: everything from disconnecting the power locally so that a scientist can tweak the equipment (usually a few times a day) to leaks, malfunctions, or a bat loose in the lobby (Argonne is surrounded on all sides by a nature preserve). "No two days are ever the same here," Kailus says.

"Something like an earthquake, we can deal with that easy," says Randy Flood, who heads the control room.





Professor Emina Stojković and her student team use the Advanced Photon Source to study the proteins of a mysterious bacterium called *S. aurantiaca*.

Even though the APS hosts thousands of users and visitors every year, it still has its very occasional lonely moments for those to whom the ring is most familiar. “It can get a little weird when we’re in a maintenance shutdown and you’re maybe the only person in a million square feet of space,” says maintenance engineer Roger Camacho.

The beam pauses only for scheduled maintenance. When President Obama visited the APS to hold a press conference in 2013, and before him President Bush in 2002, the APS crew kept the beam running as usual. Science stops for no one, not even the president of the United States.

It barely even stops for a natural disaster.

“Something like an earthquake, we can deal with that easy,” says Randy Flood, who heads the APS control room.

When a magnitude-7.6 earthquake shook the ground in Peru last year, the vibrations traveled thousands of miles across the world and threw the APS’s exquisitely sensitive beam off by a few microns. It shut itself down, sending dozens of alarms sounding in the control room.

It was less than 10 minutes before his team got the beam back online, Flood says. These earthquake pauses happen perhaps once every year or two. Beam pauses are more generally caused by routine equipment failures, but all are typically fixed in less than 30 minutes. He’s proud of his team, he says, as well as the other 450 employees at the APS, who work rotating shifts and miss holidays so that the beam is exactly where the users need it to be.

Thanks to all these people, the beam is running smoothly. One of its next stops around the ring is destined for the flash-frozen proteins of a bacterium called *Stigmatella aurantiaca*.

DEPENDING ON YOUR PERSPECTIVE, *S. aurantiaca* may or may not be considered a beautiful organism—wherever it travels, it leaves copious trails of slime as it goes—but it is certainly a unique one. It forms odd fruiting bodies by means of the most complex behavior and life cycle of any known bacterium; and it lives on decaying organic matter, such as logs on a forest floor, eating both the rotting wood and the things that have come to eat the rotting wood.

Which is why it’s strange that it also carries genes for photoreceptors: proteins that react to light and dark, even though *S. aurantiaca* can’t photosynthesize food from light.

Emina Stojković, a professor at Northeastern Illinois University, wants to know why. This desire fits into a larger movement in the biology world. Researchers love photoreceptors because they're tailor-made bits of complex machinery that we could adapt for our own purposes. For example, scientists are looking into using bacterial photoreceptors as fluorescent markers, which "could revolutionize the way we visualize internal organs," Stojković says.

But all this depends on having a complete understanding of how they work, which we don't. Photoreceptors are actually made up of lots of proteins assembled together into an intricate machine, and no one has ever managed to collect a full picture.

Luckily, the APS has a storied history of helping researchers figure out the structures of proteins. Protein work here has led to drugs to combat HIV and several forms of cancer, as well as two Nobel Prizes for chemistry.

So Stojković and her students at the university have grown hundreds of petri dishes of *S. aurantiaca* under both light and dark conditions, then carefully isolated the photoreceptor proteins and crystallized them.

They bring the crystals here to Sector 19, carefully covered because they will shatter if exposed to light, and flash freeze them with liquid nitrogen in order to put them into the beam. Then, from what the X-rays reveal, they can piece together what the photoreceptors look like.

"It's like a puzzle," says Rima Rebiai, one of Stojković's graduate students, and each crystallized protein they test gives them another tiny puzzle piece.

"The crystals are gorgeous. They look like emeralds," says graduate student Trish Waltz, because you can only look at them under a green light so as not to shatter the crystals. "But they might have ice crystals in them." Ice crystals interfere with the picture they're trying to take of the structure, and they won't know which crystals have ice until they get them in the beam. "Some of the ugliest crystals turn out to make the best diffractions," she says, shrugging.

For Stojković, the APS is a comfortable and familiar place. She's come to the APS almost as long as it's existed: she first ran experiments here as a graduate student, and now, as a professor, she brings her own students. People still work

Marius Schmidt (University of Wisconsin-Madison) and Rima Rebiai (Northeastern Illinois University) check the data being collected as X-rays scatter off the frozen crystallized proteins in their experiment.

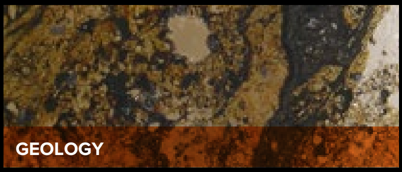

REMOTE
ACTIVITY

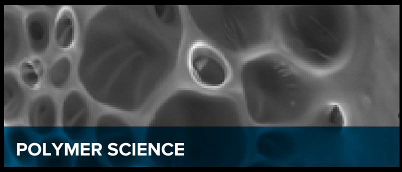
SCIENTIFIC DISCIPLINES INVESTIGATED AT THE APS


PHYSICS


ENVIRONMENTAL SCIENCE


PHARMACEUTICAL RESEARCH


GEOLOGY

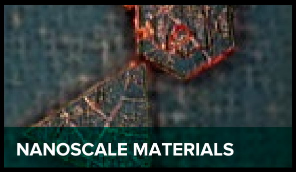

POLYMER SCIENCE

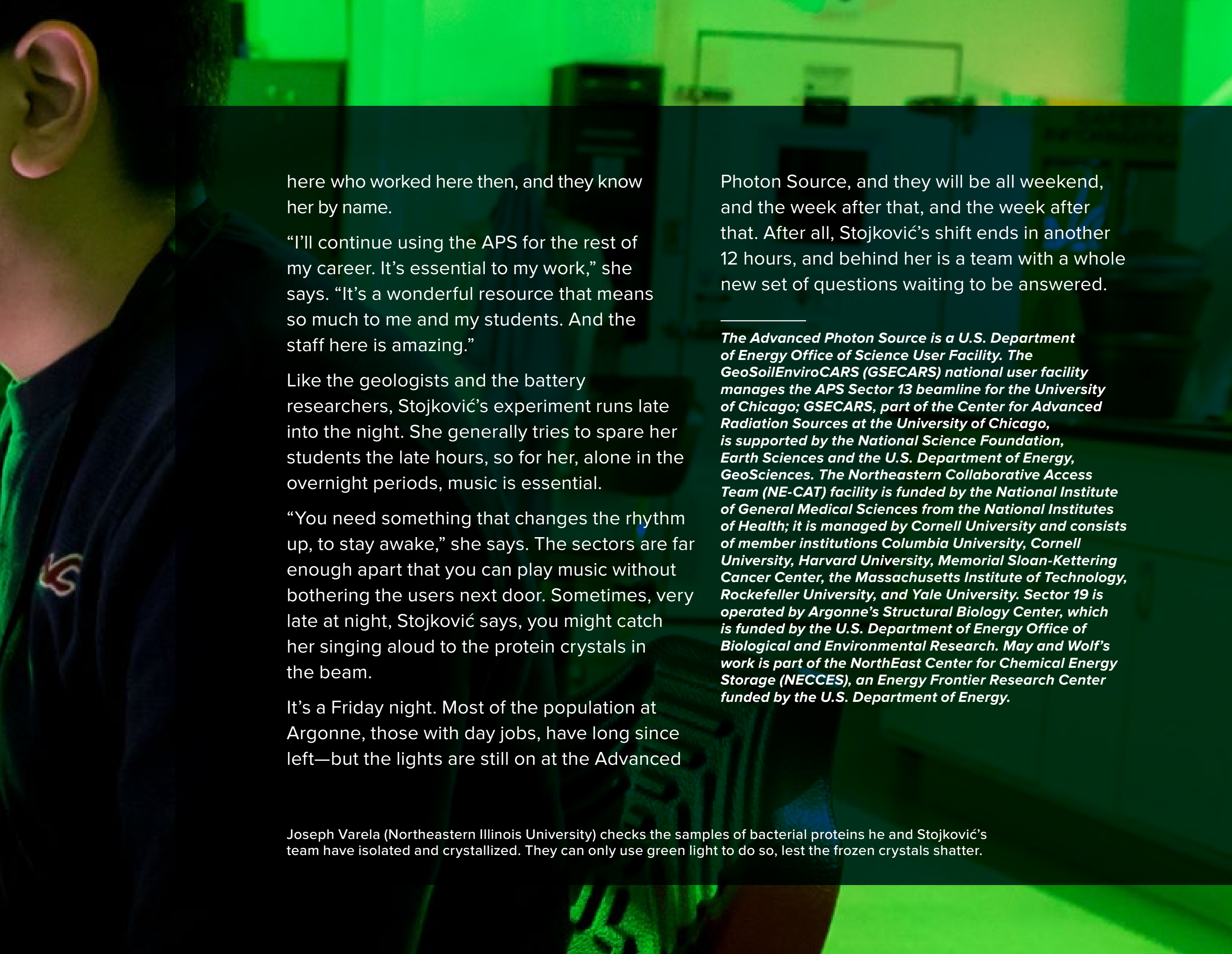

CHEMISTRY


PLANETARY SCIENCE


LIFE SCIENCE


MATERIALS SCIENCE


NANOSCALE MATERIALS



here who worked here then, and they know her by name.

“I’ll continue using the APS for the rest of my career. It’s essential to my work,” she says. “It’s a wonderful resource that means so much to me and my students. And the staff here is amazing.”

Like the geologists and the battery researchers, Stojković’s experiment runs late into the night. She generally tries to spare her students the late hours, so for her, alone in the overnight periods, music is essential.

“You need something that changes the rhythm up, to stay awake,” she says. The sectors are far enough apart that you can play music without bothering the users next door. Sometimes, very late at night, Stojković says, you might catch her singing aloud to the protein crystals in the beam.

It’s a Friday night. Most of the population at Argonne, those with day jobs, have long since left—but the lights are still on at the Advanced Photon Source, and they will be all weekend, and the week after that, and the week after that. After all, Stojković’s shift ends in another 12 hours, and behind her is a team with a whole new set of questions waiting to be answered.

The Advanced Photon Source is a U.S. Department of Energy Office of Science User Facility. The GeoSoilEnviroCARS (GSECARS) national user facility manages the APS Sector 13 beamline for the University of Chicago; GSECARS, part of the Center for Advanced Radiation Sources at the University of Chicago, is supported by the National Science Foundation, Earth Sciences and the U.S. Department of Energy, GeoSciences. The Northeastern Collaborative Access Team (NE-CAT) facility is funded by the National Institute of General Medical Sciences from the National Institutes of Health; it is managed by Cornell University and consists of member institutions Columbia University, Cornell University, Harvard University, Memorial Sloan-Kettering Cancer Center, the Massachusetts Institute of Technology, Rockefeller University, and Yale University. Sector 19 is operated by Argonne’s Structural Biology Center, which is funded by the U.S. Department of Energy Office of Biological and Environmental Research. May and Wolf’s work is part of the NorthEast Center for Chemical Energy Storage (NECCES), an Energy Frontier Research Center funded by the U.S. Department of Energy.

Joseph Varela (Northeastern Illinois University) checks the samples of bacterial proteins he and Stojković’s team have isolated and crystallized. They can only use green light to do so, lest the frozen crystals shatter.

A BRILLIANT UPGRADE

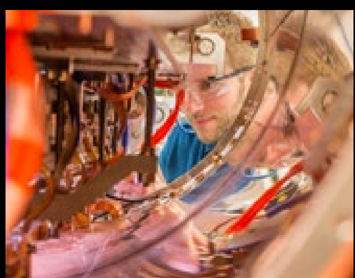
The planned upgrade to the Advanced Photon Source will transform today’s third-generation storage ring into the ultimate 3-D X-ray microscope, creating the most technologically advanced hard X-ray light source the world has ever seen.

This extraordinary machine will combine a next-generation accelerator and advanced, highly specialized experimental apparatus to enable grand challenge research impossible with today’s instruments and to transform our ability to understand and manipulate matter at the nanoscale.

The APS Upgrade will use a revolutionary “multi-bend achromat lattice”—a complex system of high-tech magnets that shapes and tightens the beam into a brilliant thread one-fifth the diameter of a human hair. Using the lattice, the Upgrade will increase the beam’s brightness by a hundredfold, to create highly penetrating X-rays more than 10 trillion times brighter than the ones used in routine medical imaging.

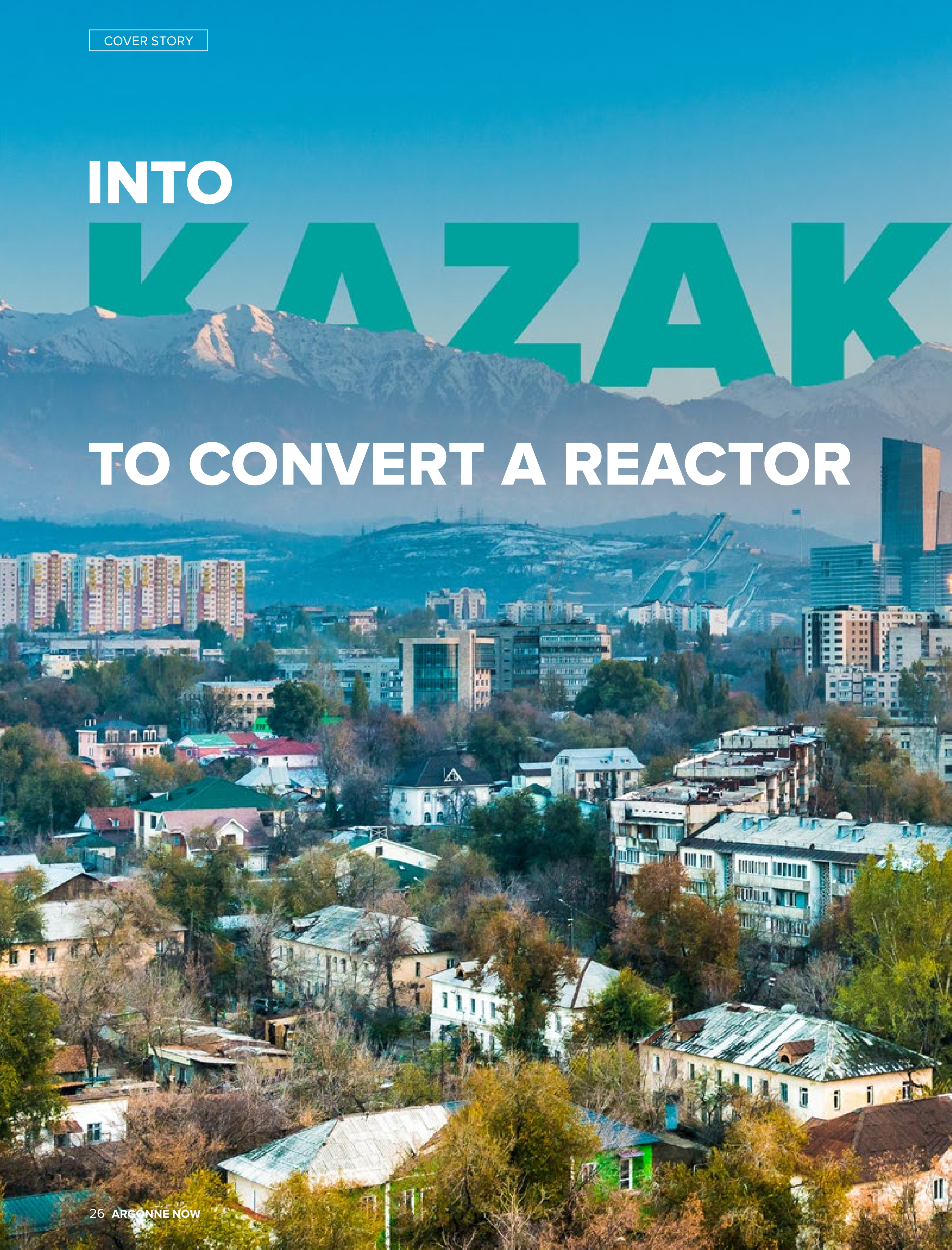
With this powerful, versatile new tool, scientists will gain access to a now-invisible world: the infinitesimal matter where the most stubbornly difficult problems begin. This new microscope will make it possible to see the now-elusive changes that happen before a steel girder starts to crack, before a healthy brain succumbs to Alzheimer’s, before an electric car’s battery begins to fail.

By creating these conditions in the lab and then studying the materials using the ultimate 3-D microscope, researchers will be better equipped to find solutions to the daunting problems of our time—so as to benefit humankind and make life better.



INTO KAZAK

TO CONVERT A REACTOR



BY LOUISE LERNER

HSTAN

The world is dotted with research reactors that run on highly enriched uranium. Argonne engineers are traveling the world to convert them one by one.

IN ALMATY, KAZAKHSTAN, in the foothills of the Tian Shan mountain range, there is a small nuclear research reactor that has been running for half a century. It doesn't look like the nuclear energy plants that provide a fifth of the electricity in neighboring Russia. Instead of electricity, this reactor churns out neutrons for scientific research and isotopes for medicine—and it has been doing so using a highly controlled substance.

Until last year, the Almaty plant ran on highly enriched uranium fuel, which has been processed to contain a lot of one particular uranium isotope that is very easy to split. This makes the fuel a powerful tool for scientific research. But it also makes it easier to use to make nuclear weapons.

The world is dotted with similar reactors, fueled by uranium from the U.S., Russia, and later China, in a decades-long push to export nuclear technology for scientific study. The three nations helped build reactors in more than three dozen countries—such as Kazakhstan, Brazil, Jamaica, Ghana, Denmark, and Vietnam—and most of these reactors are still running.

For nearly four decades, scientists and engineers at Argonne National Laboratory have been leading the global effort to convert these reactors to run on low-enriched uranium instead. In Almaty, these scientists worked with the Kazakhs on a decade-long conversion of this particular reactor, called VVR-K. Earlier this year, Argonne staff traveled to Almaty to watch VVR-K become the 69th reactor they have converted.

The goal is to reduce the amount of highly enriched uranium circulating in the world, to lower the risk that it might be stolen or diverted as it is manufactured, shipped, used, and then finally sent for disposal. To do this, the Argonne team, part of a U.S. Department of Energy program called Material Management and Minimization (M3 for short), works to redesign these reactors so that they can run on low-enriched uranium, which is much harder to make into weapons. Like converting a car engine to run on diesel instead of gasoline, the conversion takes a great deal of careful engineering—as well as diplomacy, knowledge, experience, and a little bit of luck.

IN DECEMBER OF 1953, President Eisenhower told the United Nations that the U.S., in a reversal from the absolute secrecy it had enforced around nuclear technology following the Manhattan Project, would instead share its research with scientists around the world who wished to use it for peaceful purposes.

From this “Atoms for Peace” speech sprang the research reactors: hundreds of them, designed and built with uranium and expertise from the U.S., and later Russia and China, and scattered around the world’s universities and scientific institutions.

Why did scientists want them?

The atoms in nuclear fuel are very heavy and unstable. Researchers like them because they shoot off particles called neutrons, which can be used for many types of science and engineering. You can use neutrons to look deep inside objects; to process materials to give them new properties, such as making silicon more conductive; and to make isotopes for medicine, such as technetium-99, which is used around the world in tens of millions of medical procedures every year.

You can also use these atoms to make isotopes to track molecules as they move through complicated biological processes. The U.S. government began shipping radioisotopes to scientists from its reactors right after World War II. In the first decade of this program, those isotopes contributed to more than 10,000 published studies. We owe a significant chunk of today’s body of scientific knowledge to radioisotopes, including how cells make DNA, how our metabolism works, and how nutrients move through an environment.

So when the opportunity was offered, researchers around the world jumped at the chance to have their own research reactors.

This wide variety of purposes meant the reactors were all built a little differently, according to what scientists in each place wanted to use them for. Kazakhstan has three such research reactors, and each one has a fuel setup that’s completely different from the others.

So when it’s time to switch the reactors to low-enriched uranium, Argonne nuclear engineers have to solve several problems at once. They must redesign the core so that it fits in the same space while offering the same range of scientific capabilities, but uses a lower proportion of that easily splittable uranium isotope, U-235. And this is often all in a totally different setup from any reactor they’ve previously converted.

The task is not an easy one. But that’s why Argonne researchers wanted it.

“I really fell in love with the work—how each one is its own unique challenge,” said John Stevens, a nuclear engineer who runs the M3 program at Argonne. (Before this, he worked in the power industry for 20 years. Most reactors that produce power are very similar to one another.)

Eisenhower delivers his famous “Atoms for Peace” speech to the United Nations, setting a precedent to export nuclear reactor technology for science. Image: UN.

Argonne scientists worked with the Kazakh Institute of Nuclear Physics to convert their scientific reactor to run on less dangerous low-enriched uranium.

Scientists and engineers at Argonne National Laboratory have been leading the global effort to convert these reactors to run on low-enriched uranium.

"Each one is different, but I like the hard ones. It keeps it interesting," agreed Patrick Garner, a nuclear engineer who has done safety calculations for M3 for the last 15 years.

HERE IS HOW YOU CONVERT A REACTOR.

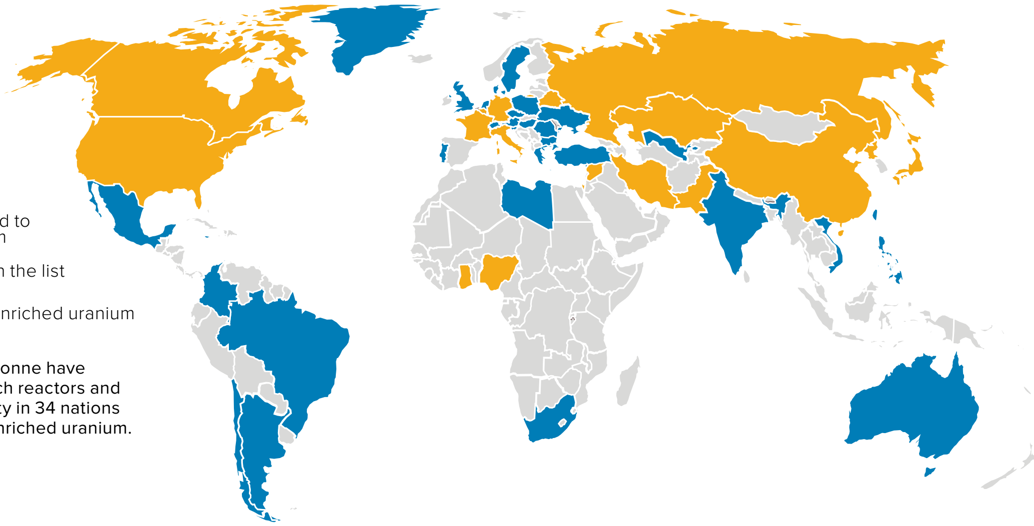
First, you talk with the scientists who use this reactor, which in this case is run by the Kazakh Institute of Nuclear Physics. You ask questions such as: How often do they change the fuel? What specific scientific applications do they use it for? What operating temperatures does it run at? This helps you design a new configuration for the reactor core.

In VVR-K's case, the fuel design changed quite a bit, said Jordi Roglans-Ribas, who runs the nuclear engineering division at Argonne. He's worked on the VVR-K conversion with his Kazakh counterpart, Petr Chakrov, since the conversion project began.

The institute selected a new core design: eight concentric hexagonal tubes, instead of five. Water flows between the tubes to cool the reactor. "Because the spacing changes, the cooling properties change," Roglans-Ribas said.

Simulations with powerful computers help provide data to assure the safety and reliability of the new configuration. You also need to make sure there's a company willing to manufacture that fuel.

The whole time, you're working with the scientists at the home institute. "They do the analysis. It has to be their reactor," Garner said. "We provide training and do an independent set of backup calculations. We're the extra set of eyes."



All reactors converted to low-enriched uranium

Some reactors still on the list

Did not have highly enriched uranium

Since 1978, experts at Argonne have helped convert 69 research reactors and 1 isotope production facility in 34 nations and areas to run on low-enriched uranium.

In the last fiscal year, the Argonne team actively worked on 27 reactor conversion projects in 11 countries, including the U.S.

The next step is to build test fuel and run experiments on it. This gives scientists at the foreign institution and the officials in that country's nuclear regulatory agency lots of information to make their decisions. VVR-K's test fuel spent 2 ½ years being irradiated before the team concluded it was up to speed, Garner said.

At this point, you remove the highly enriched uranium that was already in your reactor core, making arrangements to ship it for recycling and disposal. Leftover unused fuel can be "down-blended," which means it's mixed with freshly mined natural uranium to make low-enriched fuel.

Next, make any necessary changes to fit the new core design into the old. Then do more tests. Sometimes the new core requires additional changes, or perhaps the home institute wants to take this opportunity to update the control room or other parts of the facility with the latest technology—for example, the new core design in VVR-K needed an upgrade to the control system. VVR-K is moving to dual analog and digital systems that are faster and more reliable, said Argonne mechanical engineer Hual-Te Chien; sensor technology has improved significantly in the past 40 years, he explained.

Other safety upgrades took advantage of new data on how to keep reactors safe in seismic zones. The large, beautiful mountains to the south of Almaty look calm, but may not always be.

Then, finally, your core is ready to be loaded with fresh, low-enriched uranium and tested.

THE INITIATIVE TO CONVERT the world's research reactors dates back to 1978. John Glenn, the astronaut and later senator, was an early supporter. Argonne's history of reactor design—most operating nuclear reactors around the world have some common roots in Argonne research—and the lab's depth of nuclear engineering expertise made it a natural fit for the program.

Early on, the Argonne team designed a replacement fuel that is now the international standard for many such reactors. The first two reactors they converted, as demonstrations, were at the University of Michigan in 1981 and at Oak Ridge National Laboratory in 1986. Then they converted several foreign reactors, in Argentina, Austria, and Denmark, and moved on to reactors around the world.

In 2004, new agreements opened up pathways to several reactors the group had been eyeing for decades. The program completed 12 conversions in eight countries over the next four years, and it's completed 18 conversions in 13 countries since then.

"Our goal is to be ready on the technical side when the political moment comes," Stevens said.

In the last fiscal year, the Argonne team actively worked on 27 reactor conversion projects in 11 countries, including the U.S., he said.

The background work is substantial. More than two dozen scientists and engineers in Argonne's nuclear engineering division work on conversions, and they can tap dozens of experts in other areas around the lab if they have a specific question.

Once the Energy Department and the State Department have secured an agreement with a country and the conversion begins in earnest, "we visit about four or five times per year," Garner said. "There are some things you just need to sit down with people at the same table to work out."

In most places they have to hire an interpreter who they try to hang on to across visits, because even native speakers may not know all the words in both languages for "thermal expansion coefficient."

Last March, the Kazakh Institute of Nuclear Physics loaded the brand-new fuel into the VVR-K reactor. On April 1, they brought the reactor up to criticality—the point when the nuclear fission chain reaction becomes self-sustaining. In the weeks that followed, Garner, Roglans-Ribas, and other members of the team flew in to watch the Kazakh team perform all the tests you do on a brand-new reactor: measuring the power distribution within the core, testing the control rods to see exactly how much they affect the power, and calibrating the control systems. "When you're starting up with brand-new fuel, you take a lot of baby steps," Garner said.

After the Argonne researchers left, the Kazakh team began a full-scale test run with experiments inside: they've since finished. "The preliminary data looks good," Garner said. The new core is expected to be even more useful than before—producing up to twice the quantity of medical and scientific isotopes for the institute.

Back at Argonne, the engineers are analyzing the data from the tests as part of the final procedures. But long before they even paused to consider the success of the VVR-K conversion, the team was already looking ahead. All along they've also been working on feasibility studies for IGR and IVG-1M, the second and third research reactors in Kazakhstan. IGR uses a unique fuel arrangement that's cooled by air, rather than water; it would be the first reactor of that type the Argonne team has ever handled—another technical challenge.

With the help of the International Atomic Energy Agency, the Argonne reactor conversion team is also looking at Chinese-origin miniature reactors in Ghana and Nigeria, as well as several reactors in Pakistan, Iran, and Syria. The schedule of reactor conversions stretches out to 2035.

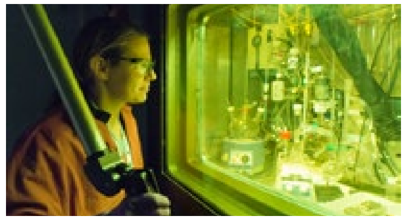
"I love it. The program is fantastic. For me, as an engineer, my job is to solve problems, and there's always more. And I love the international nature of it," Stevens said.

"I do feel we're reducing a real risk, and I take pride in that," he said.

The M3 program at Argonne is supported by the National Nuclear Security Administration's Office of Material Management & Minimization. Other organizations involved in the VVR-K conversion project included the Committee for Nuclear Energy Supervision and Control and the Institute of Geophysical Research, both of which are part of the Ministry of Energy of the Republic of Kazakhstan; as well as NIKIET, VNIINM, TVEL, SNIIP Systematom SKODA, and the Ulba Metallurgical Plant. Additional assistance in the early stages of the project came from the Nuclear Threat Initiative and the International Atomic Energy Agency.

GOOD MEDICINE

Argonne has also worked to design particle accelerators that can be used instead of reactors to make medical isotopes like technetium-99, which is used in tens of millions of medical procedures every year in the U.S.



Chemist Amanda Youker operates a remote manipulator arm in a radiation-shielded cell. The cell is used for the purification of molybdenum-99 in a process recently demonstrated by Argonne that could lead to a domestic source of the important medical isotope.

WHAT CAN SCIENTISTS DO WITH **RESEARCH REACTORS?**

- Use them to probe the atomic structure of a material.
- Make isotopes for scientific research.
- Detect tiny amounts of an element, like pollutants in soil, water, or food.
- Create isotopes for medical procedures to diagnose or treat cancer and other diseases.
- Bombard a material with neutrons to make it stronger or more conductive.
- Test a new alloy to see if it will last longer in a commercial energy reactor.
- Determine the structural integrity of a material.

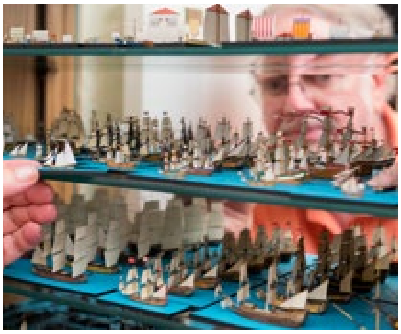
THE SECRET LIVES OF SCIENTISTS

ROBERT WIRINGA

PHYSICIST & MODEL SHIP COLLECTOR

Meet researchers from Argonne with unusual hobbies and interests.

BY KATE THACKREY



What do you do at Argonne?
RW: I'm in the Physics Division Theory Group, which is nuclear physics, the study of what's happening inside the nuclei of atoms. I develop models for nucleon-nucleon and three-nucleon interactions. That's a description of how two or three nucleons, which are protons or neutrons, interact with each other.

What is your hobby?
RW: I collect model ships, mostly military ships, on a scale of 1:1250. That means that one inch of a model is about 100 feet of a real ship. I have collected almost 2,000 ships over 20 years.

How did you start collecting?
RW: I was always interested from childhood in models—one of the things I especially appreciated was when you could have things in the same scale. When I was a teenager I had more than a hundred model airplanes I put together, all in one scale. It gives you an appreciation of how big one thing is relative to another.

How are the models made?
RW: Almost all of them are metal, but a few have been resin-printed. For most of the models someone has a "master" version and a mold from that master, and then they cast as many copies as they can before the mold wears out.

Where did these models come from?
RW: They started out as recognition models. In World War I, all the major navies made these models, and then trained people to determine whether ships on the horizon were "one of theirs or one of ours." It went further in World War II because then you had to train people who might be sighting from airplanes. After that, people who liked the models started making more and more detailed ones, most of which are made in Germany.

Which are your favorites?
RW: I'm particularly interested in the World War II U.S. Navy, and of all my ships the Franklin D. Roosevelt aircraft carrier is probably my favorite. The model was built by a Frenchman named Alain Picouet; it's actually a resin, unlike most models, and it came with all of the airplanes attached. It was the most expensive one I bought, but it was worth it.

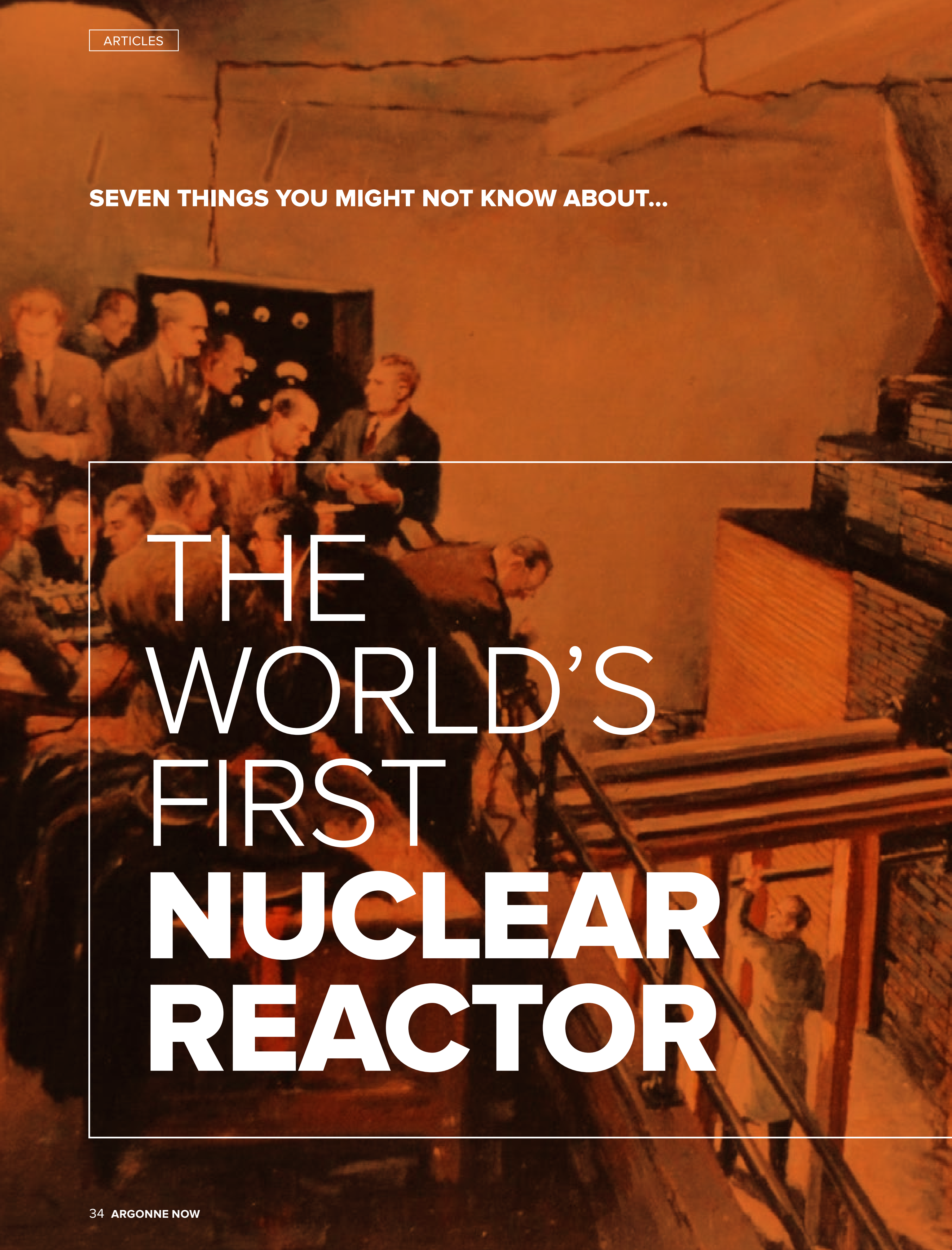
What sorts of things does the model ship community do?
RW: I'm part of a group called the Society of Miniature Ship Collectors that holds annual meetings, and this year we'll go to Los Angeles to see the Battleship Iowa, and we'll actually have our meeting on the ship. We've been to Norfolk, San Diego, and Hawaii, just to name a few trips. A friend of mine also wrote a book about the hobby, called *Miniature Ship Models*, and he asked me to take photos of a few of my models for him.

What's it like to see the ships in person?
RW: It's great. They're huge, just huge. You can see the proportions with models but to actually see it in person is still very different. It's like looking at a picture of the Grand Canyon versus going to the Grand Canyon.

You also have a website, Bob's Ship Collection.
RW: By the time I reached around a hundred models I decided I should start my own website to keep track and to learn more details about the ships. A lot of the ships initially were ones that I knew about historically, and then I gradually learned more and more. Now people even use my website as a reference.

I collected a seven-masted schooner, the only one that was ever built, called the Thomas W. Lawson. It was carrying oil to England and foundered in a storm. Only two people survived, and I wrote up in my history "only two survived, Captain George Dow and one other." Some time later, I got an email from a guy saying "I'm the grandson of the 'one other.'" So I went back and put in the other name.

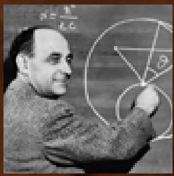
A lot of people go looking for some sort of connection, looking for the history of a relative or some feature they saw, and they stumble across me.



SEVEN THINGS YOU MIGHT NOT KNOW ABOUT...

THE WORLD'S FIRST **NUCLEAR REACTOR**

1



IT CREATED THE FIRST HUMAN-MADE CONTROLLED NUCLEAR CHAIN REACTION EXACTLY 75 YEARS AGO.

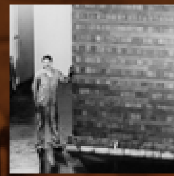
It was 1942, and word in the U.S. was that the German scientists under Hitler were hurrying towards an atomic breakthrough of their own. Led by famed physicist Enrico Fermi, who had fled fascist rule in Italy, a team of scientists rushed to construct a reactor to prove atoms could be fissioned in controlled chain reactions.

2

IT WAS BUILT BENEATH THE FOOTBALL STANDS OF THE UNIVERSITY OF CHICAGO.

The Manhattan Project had branches in several different parts of the country; the effort to build a working reactor was headquartered at the University of Chicago. Fermi needed a space with ceilings high enough to hold the reactor, and that's how they wound up in a squash court beneath the unused football stands of Stagg Field, working to build the "pile."

3



IT, AND THE FIRST FOUR REACTORS AFTER IT, WERE CALLED "PILES."

This was a fairly accurate description of the reactor, which consisted of a carefully engineered latticed pile of graphite blocks studded with uranium in the precise locations to encourage chain reactions. Chicago Pile-1, as it was called, contained 22,000 uranium slugs and 380 tons of graphite.

4

THE SCIENTIFIC TEAM INCLUDED 48 MEN AND ONE WOMAN.

Leona Woods was the youngest person on the team; she was still in the middle of finishing her graduate degree when she was called up because Fermi needed a spectroscopist to build detectors to monitor the neutrons in the pile. She recorded the progress as the neutron count grew.

5

IT HAPPENED ON DECEMBER 2, 1942.

Fermi stood on the squash court spectator balcony with everyone but one man, who stayed on the floor to operate the control rod, and several others poised to dump neutron-absorbing solution on top of the pile if things got out of hand. The neutron count clicked higher and higher—and at 3:25 p.m., Fermi announced it had become self-sustaining. It ran for 28 minutes before Fermi ordered the control rod reinserted to shut the pile down.

6

THEY CELEBRATED SUCCESS WITH A BOTTLE OF CHIANTI.

Eugene Wigner had brought a bottle of Chianti, which he distributed in paper cups. Most of the scientists present signed the bottle (a replica, along with other artifacts from the era such as a microbarometer and some of the graphite they used, is displayed at the Nuclear Energy Discovery Center at Argonne). Then they all got back to work.

7

AFTERWARDS, THE LAB MOVED TO THE WEST AND BECAME ARGONNE NATIONAL LABORATORY.

The new lab, officially commissioned in 1946, was to study peaceful rather than military uses of atomic power. It was to conduct basic research in biology, physics, reactor analysis and engineering, and applied mathematics. The last of the original Chicago Piles was Chicago-Pile 5, which ran until 1979; one of its many uses was to train technicians for Illinois' first commercial nuclear power plants.

ARGONNE IN THE MARKETPLACE

FOUR EXAMPLES OF INDUSTRY GAINING AN EDGE BY USING ARGONNE FACILITIES

Companies large and small regularly collaborate with Argonne, tapping into the lab's expertise, facilities, and unique tools. Here are four examples of industry gaining an edge by working with Argonne.

2

1 One of the most successful drugs used to stop the progress of HIV got its start at the Advanced Photon Source at Argonne. The facility—one of the most complex machines in the world and large enough to house a major-league baseball stadium in its center—provides high-energy X-ray beams used to study how viruses interact with cells. This information helps researchers design drugs to block or reduce those interactions. This facility is used by more than 5,000 scientists from around the world each year. In 1996, scientists from **Abbott Laboratories (now AbbVie)** who were using the Advanced Photon Source discovered a way to stop HIV from replicating in the body. Out of that work came the drug Kaletra®. In 2002, Kaletra® became the most-prescribed drug in its class for AIDS therapy, and it remains widely used today. Kaletra® has extended the lives of thousands of AIDS patients.

2 By collaborating with Argonne and software developer Convergent Science, Inc., heavy equipment manufacturing giants **Caterpillar** and **Cummins** gained access to cutting-edge computer modeling and analysis tools and expertise that have allowed them to achieve major advances in fuel economy and reduce development costs and time-to-market for internal combustion engines. The Argonne Leadership Computing Facility is home to a number of high-performance computers, including Mira, the world's ninth-fastest supercomputer, which is capable of 10 quadrillion calculations per second. Through its Virtual Engine Research Institute and Fuels Initiative (VERIFI), Argonne has developed engine models and software for large-scale computer simulations that provide—in virtual space, before costly physical production ever begins—a better understanding of how internal combustion engine parameters interact.

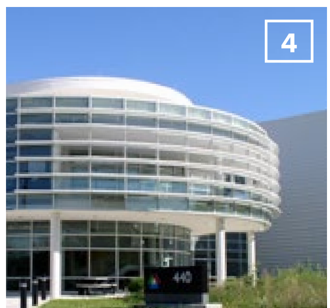
3 **Electro-Motive Diesel, Inc.**.—a locomotive manufacturer that is a subsidiary of Progress Rail Services Corporation, a subsidiary of Caterpillar, Inc.—has a long-standing research partnership with Argonne. Argonne's Engine Research Facility is home to two of the company's diesel locomotive test engines. The goal of the collaboration is to develop and test new emission-reducing technologies for locomotive engines in response to EPA regulations, and to identify ways to improve overall engine performance. As a result of Argonne research, Electro-Motive Diesel produces locomotive engines that are more reliable, efficient, and environmentally friendly; they meet EPA emission standards without costly losses in fuel economy.

4 In cancer patients, a tiny number of cancer cells break off from a tumor and circulate in the blood. If researchers can capture these, they can grow them in the lab and test them to find the best drugs to treat the patient. Collaborating with Argonne's Center for Nanoscale Materials, **Creatv MicroTech, Inc.**—a company that specializes in microfabrication and biodetection—has developed a specialized microfilter that encourages the captured cancer cells to grow into clustering domes, which more closely resemble actual tumors and are thus better for testing treatments. Creatv MicroTech plans to commercialize its specialized microfilter in the near future.

To learn how your business might work with Argonne to improve processes, create products, or discover breakthrough, disruptive innovations, contact Argonne's Technology Development and Commercialization Division at **partners@anl.gov** or **800-627-2596**.

79

industrial firms (U.S. and foreign) used the Advanced Photon Source in fiscal year 2015



20

industrial users conducted research at the Center for Nanoscale Materials in fiscal year 2015

EDUCATION

FROM THE CLASSROOM TO THE REAL WORLD

BY JOAN KOKA

Argonne's educational opportunities help students apply classroom knowledge to real-world problems.

Before participating in the Electric Car Competition, T.J. Cosler, an 8th grader at Jerling Jr. High, never really had a chance to explore his interest in electronics outside of class.

But getting involved at Argonne gave him a richer understanding of gear ratios—as well as the role of teamwork in the life of an engineer.

"Working with people and incorporating other people's ideas is important, especially with engineering, which is what I've always been interested in," Cosler said.

Argonne's educational programs offer what most classrooms can't—authentic research experiences, interactive approaches to learning science, technology, engineering, and math, and one-on-one contact with some of the brightest minds in the nation. Students have access to all of these through opportunities from middle school competitions to college internship programs.

At the high school level, students can actually develop their own research questions and seek answers with the help and guidance of teachers and Argonne scientists.

The highly acclaimed Exemplary Student Research Program gave Miraj Shah and Dillon Vadgama, students from nearby Hoffman Estates High School, their chance to do nanoparticle research using the Advanced Photon Source, a giant synchrotron on Argonne's campus.

"Many scientists, when they're older and are no longer eligible for this program, they fight for a spot on the beamline, so for a high school student to have that kind of access is really a great opportunity, because through this program you can create some research that actually can change things," Vadgama said.

Vadgama and Shah, who are both interested in pursuing engineering careers, agree that the most valuable part of their research experience was applying their classroom work in a real-world setting.

"It was cool to realize just how little I knew about different fields and the real-life applications of the stuff that we learn in school," Shah said.

College-level studies also open up new opportunities for older students to work more closely with Argonne scientists and fine-tune their research skills. One of the most popular internship programs is the U.S. Department of Energy's Science Undergraduate Laboratory Internship program, which Holly Dinkel, a chemical engineering major at the University of Missouri, Columbia, joined in the spring of 2016. Through the internship, Dinkel studies the development and application of medial isotopes using accelerator technology.

Having done three internships prior to her arrival at Argonne, Dinkel said her experience here stands out because it has helped her to mature more as a researcher.

"Just the fact that I can collaborate with my mentors and am invited to express my concerns with different procedural steps in an investigation is helping me to develop a sense of personal accountability for the science I am doing, and to develop some maturity in experimental design," Dinkel said.

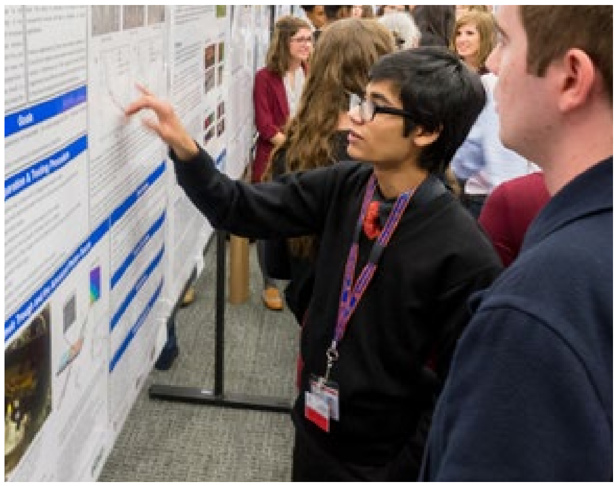
"You have to be in a lab and actively doing research in order to develop those kinds of skills—it's not just something you can learn in a classroom," she said.

Meridith Bruozas, manager of Argonne's educational programs and outreach, says efforts to engage students at all different levels helps support the science, technology, engineering, and math career pipeline and ensure that the students who emerge from it have the skills they need to take on global challenges.

"We want to continue building on Argonne's legacy of discovery and innovation for generations to come, and show students that they can be a part of that legacy in a very meaningful and exciting way," she said.

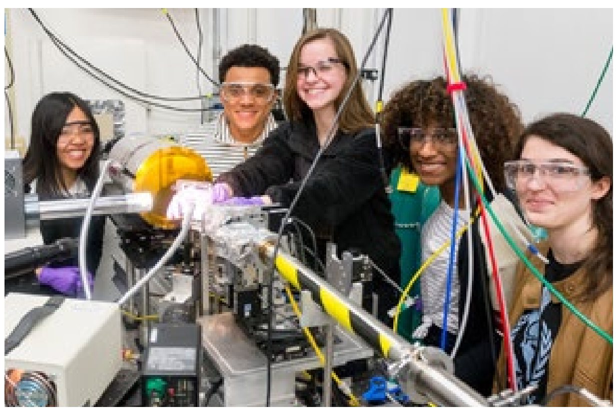
The Science Undergraduate Laboratory Internship Program is sponsored by the Department of Energy Office of Science's Office of Workforce Development for Teachers and Scientists. The Exemplary Student Research Program is supported by resources at Argonne's Advanced Photon Source. The Middle School Electric Car Competition is done in partnership with Case New Holland.

For more information about education at Argonne, **visit www.anl.gov/education.**



"Working with people and incorporating other people's ideas is important, especially with engineering, which is what I've always been interested in."

– T.J. Cosler, Jerling Jr. High



Clockwise from top: Students race their cars in the 2016 Electric Car Competition; Miraj Shah shows off his team's research poster to scientists at a meeting; students from Neuqua Valley High School learn what a typical day in the life of a scientist is like as they insert samples on the beamline at the Advanced Photon Source; intern Holly Dinkel and her supervisor Megan Bennett, left, investigate purification techniques for radioactive isotopes.

CROWDSOURCE

WHAT WILL YOUR FIELD OF SCIENCE LOOK LIKE IN 50 YEARS?

JARRAD HAMPTON-MARCELL
Microbe Researcher

MICROBIAL ECOLOGY

"Microbial ecology—the study of the microbe populations living in and around us—is evolving so quickly that this is a really interesting question. The DNA sequencers from ten years ago look like dinosaurs. A reach used to be 10 million units of data. Now we go through that in a day.

In 50 years, maybe we could get a sample and analyze it—that is, identify all the species of microbes and sequence their DNA—in hours or days rather than weeks or months. That would make possible all kinds of things. We could expand study sizes. A lot of studies right now are like 30 people. We could really get into understanding how species interact, how to make better spaces and quality of life, how to predict the best drug treatments for an individual.

A field moving so fast is definitely a challenge. But it's also very exciting. Anyone could uncover new things at any time."

TIJANA RAJH
Nanoscientist

NANOSCIENCE

"Up until now, nanoscience has been exploring relatively simple structures. Now we're finally at the point where we have the background knowledge to build more complex structures.

I look at nature for inspiration here. Nature is good at adapting and reproduction. It's not good at longevity. Individual cells die all the time; your body just makes new ones. Right now it's too energetically expensive for us to do that in artificial systems. We need to master reproduction, and adaptation. How can we think about making it easier to repair individual units in artificial systems? We saw hints on how to approach adaptation and repair when we worked with batteries that were spontaneously adapting with cycling. Nature's also good at sensing and communication between units; can we do that?

In many ways we are just now getting to the true potential of nanoscience. What if we made things malleable, that change colors, or that bend light around themselves so that they are invisible to our eye? That's what inspires us."

Argonne scientists from different disciplines provide a perspective on a complex question.

JEREMY LOVE

High Energy Physicist

HIGH ENERGY PHYSICS

"The timescales of our projects in high energy physics are different from most other fields: the Large Hadron Collider, where I work, started taking data in 2009 and will run until 2035, but it was first proposed back in 1984. The timescales for these experiments are growing, too: we're already in discussions on the next collider, which might be as much as a factor of 10 more powerful and would start delivering data in perhaps 2045. But as we start to reach the limits of our accelerators, people are starting to look increasingly at other sources of high energy particles, like cosmic rays, to study the highest-energy interactions.

I suspect that will all still be the case in 50 years, unless—and this is my hope—we find something that completely defies the Standard Model at the Large Hadron Collider, and then we'll be investigating that. My personal opinion is that there's something beyond the Standard Model, but right now we have no clues what that is."

KATHERINE RILEY

Director of Science at the Argonne Leadership Computing Facility

SUPERCOMPUTING

"The move to get to exascale supercomputers—two orders of magnitude more powerful than we have now—is underway now and it will be very different from what we had to do to make the last leap.

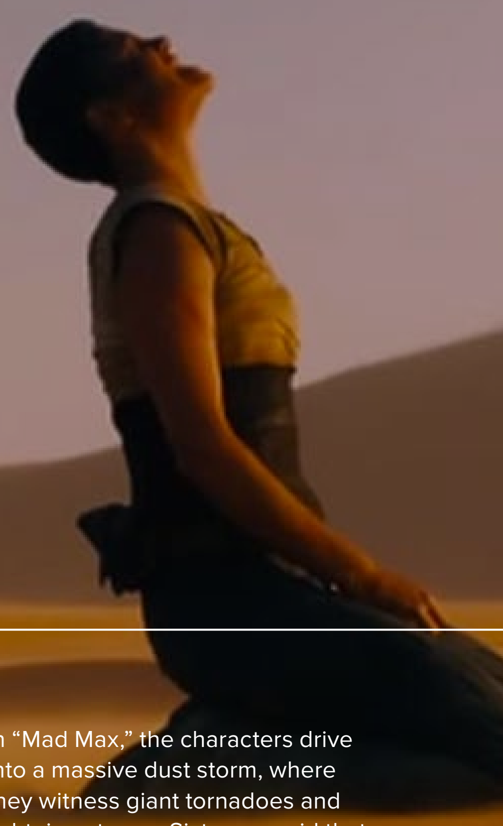
Hardware and software will be changing; in 50 years, the way we ask a question of a computer might be very different. Right now it's linear: you write an application, run a simulation, analyze the generated data. That process could take months, maybe years. What if you could ask a question and get an answer in a day when it normally takes months?

50 years ago, we were using punch cards to program a computer. Perhaps in 50 years spending months writing code might seem as foreign as organizing hundreds to thousands of punch cards."

SCIENCE BEHIND THE FICTION

EXTREME WEATHER CATASTROPHES

BY KATE THACKREY



In the past few decades, Hollywood has responded to our own fascination with disaster, pumping out movies in which humans try to survive on an Earth that's been flooded, dried out, poisoned, frozen, or devastated by flying sharks.

At Argonne, many scientists are studying the effects humans have on the Earth. We asked two researchers at the forefront to take a look at three of the most popular extreme weather disaster movies from the past 30 years, and help separate fact from fiction.

Doug Sisterson is a senior manager for the U.S. Department of Energy's Atmospheric Radiation Measurement Climate Research Facility. Seth Darling is a researcher at Argonne's Center for Nanoscale Materials who studies materials with applications in energy and water.

MAD MAX: FURY ROAD (2015)

This epic action flick was not just an opportunity to join in the antics of Mad Max and Imperator Furiosa as they attempt to survive in a violent post-apocalyptic Australia—it was also a haunting picture of how mismanagement of natural resources could change the world we live in.

After mankind has decimated the earth through nuclear war over oil and water, the film's characters find themselves in a desert wasteland where only the most powerful have access to water and vehicles. This future, according to Darling, might not be so very far from our own.

"There will be water wars," Darling said. "Many of our sources of water are dwindling due to pollution and other factors, and demand is increasing."

In "Mad Max," the characters drive into a massive dust storm, where they witness giant tornadoes and lightning storms. Sisterson said that lightning actually does occur in dust storms—the moving dust particles can create friction, producing enough energy for a lightning bolt.

Sisterson and his colleagues expect extreme weather events to increase in magnitude and frequency

THE DAY AFTER TOMORROW (2004)

This 2004 film takes the phrase "the perfect storm" to the next level when melting ice caps change the salinity of the oceans, causing widespread tornados, hurricanes, and flooding to wreak havoc on the Northern Hemisphere before leading into the next major ice age.

Sisterson says that the fears of the movie's protagonist, paleoclimatologist Jack Hall, are supported to some extent by the scientific community.

One current theory suggests that as polar ice caps melt, more fresh water enters the marine system, decreasing the salinity necessary to keep ocean currents moving.

"If this happened, warm water wouldn't make its way up north, which shuts off the poles from access to warm air," Sisterson said, "And the water would start to freeze."

After that, water beneath the surface would slowly freeze over time, creeping from the poles toward the equator, and there would be an increasing number of extreme weather events such as floods and tornados.

The problem with "The Day After Tomorrow" is that its plot spans a timeframe of only a few days. In reality, this would take place over thousands of years.

"The premise is based on things that could happen, but not on the timescale the movie has provided," Sisterson said.

20th Century Fox

WATERWORLD (1995)

"Waterworld" provides the opposite setting to the Mad Max series: here the polar ice caps have melted completely, covering the Earth's surface almost entirely with water. As a result, only a few remaining humans survive on manmade islands and boats.

Sisterson explains that even if the ice caps melted completely, they'd cause a sea level rise of only 220 feet compared to the film's 25,000 feet. That amount of water would endanger low-lying areas like New Orleans and New York, but wouldn't touch higher altitudes.

"220 feet doesn't quite cover the entire Earth in water," Sisterson said. "But where are you going to displace these ten million people when water floods the subways and Manhattan's underwater?"

Universal Pictures

over the coming years. These weather patterns will endanger food sources, expand habitats for disease-carrying insects, and force mass migrations of refugees from severely affected countries.

All of these natural disasters could result in the hoarding of resources that we see in the film.

"'Mad Max' is symbolic of the types of social issues we may face due to extreme weather events," Sisterson said.

According to Darling, we need to start thinking about how we react to disaster now, rather than later.

"When water resources are limited, it's true that you can't give it away for free," Darling said. "But water is a human right, so at least a base source of water is needed for everyone."

Warner Bros. Pictures

ASK A SCIENTIST

WHEN IS IT MORE EFFICIENT TO TURN OFF MY CAR INSTEAD OF IDLING?

LINDA GAINES
Argonne Transportation Systems Analyst

When I pick up my kids after school, should I let my car idle or should I shut down and restart a few minutes later?

LG: You should shut off your engine. Unless you drive a vintage, carburetor-equipped vehicle, you'll save fuel and reduce CO_2 emissions by turning it off. Some drivers think that idling uses less fuel than restarting, but our research has found that drivers save fuel and reduce emissions by shutting down for stops as brief as 10 seconds.

That being said, we don't recommend turning your car on and off in stop-and-go traffic; driving safely means being able to respond quickly to traffic conditions.

Won't I wear out my car's starter with the extra restarts?

LG: We actually published a study on that topic last year. For typical drivers (i.e., 10 or fewer starts per day), the starter motor is unlikely to need to be replaced during the vehicle's life. Today's starters are more robust than those in older cars.

What about winter? Don't car engines need to be warmed up?

LG: Assuming that your windows are free of ice—safety first, of course—run the vehicle for about 30 seconds and drive gently (i.e., no hard acceleration). The engine will warm up more quickly by being "at work" than by idling, which will also help the car's interior warm up more quickly. Also, the catalytic converter, which reduces harmful emissions, reaches operating temperature much more quickly if the car is driven rather than idled. Most auto manufacturers recommend against idling even on the coldest days.

I see a lot of trucks idling—what about them?

LG: Some vehicle types do need power while stationary, such as emergency vehicles and long-haul trucks stopped for drivers' overnight rest periods, and idling the main engine is one way to provide that power. Increasingly, though, there are alternatives to idling for this power. For example, you can use smaller, auxiliary power units, including those powered by batteries, or you can tap into grid power. To learn more, Google search "IdleBox"—a resource developed by me and my team for the Department of Energy's Clean Cities program and now available to the public.

Patricia Weikersheimer and Imelda Francis contributed to this article.

BY THE NUMBERS

ARGONNE'S **COMBINED HEAT AND POWER PLANT**

24/7

At Argonne, experiments, supercomputers, and particle accelerators are running **24/7**, so the lab has its own power plant onsite.

Last year Argonne broke ground for a new **COMBINED HEAT AND POWER PLANT**, which will save the lab money and reduce emissions.

20%

It will provide **20%** of Argonne's electricity and **80%** of its steam heat.

The old plant was more than **50 YEARS OLD**.

6.3 MW

The new plant will provide **6.3 MEGAWATTS** of electricity.

That's enough to power about **5,000 HOUSES** per hour.

3 MILLION

It will save the lab **$3 MILLION** in power costs in its first year and **$52 MILLION IN ITS FIRST 15 YEARS**.

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It will keep **33,044 TONS** of greenhouse gases out of the air every year.

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ART OF SCIENCE

TURBULENCE IN LIQUID GALLIUM AND SODIUM

By Janet Scheel & Joerg Schumacher

Much technology, from advanced nuclear reactors to ways to cool computer chips, is based on the fact that a flow develops between areas of unequal temperatures. Researchers use simulations like these on supercomputers at Argonne Leadership Computing Facility to better understand the complex dynamics in such flows.

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