The ADVANCED Photon Source at Argonne National Laboratory

Lighting the Way to a Better Tomorrow

Argonne NATIONAL LABORATORY

On the front cover: Aerial view of the Argonne 400 area. The Advanced Photon Source facility is adjoined by the Advanced Protein Characterization Facility (the white building at the top of the circular APS experiment hall) and the Center for Nanoscale Materials (the white buildings to the right of the experiment the hall).

Contents

The Advanced Photon Source

Ever since humans first used fire, light has shown us the way. Today, the high-energy, high-brightness, highly-penetrating x-ray beams from the U.S. Department of Energy Office of Science's (DOE-SC's) Advanced Photon Source (APS) at Argonne National Laboratory give us access to a powerful, versatile, invisible light that is ideal for studying the arrangements of molecules and atoms, probing the interfaces where materials meet, determining the interdependent form and function of biological proteins, and watching chemical processes that happen on the nanoscale.

This remarkable scientific tool helps researchers illuminate answers to the challenges of our world, from developing new forms of energy to sustaining our nation's technological and economic competitiveness to pushing back against the ravages of disease.

Each year, thousands of researchers representing universities, industries, and research labs from all 50 of the United States, the District of Columbia, Puerto Rico, and foreign countries are drawn to the APS. They depend on the APS as a vital resource in their pursuit of knowledge. Many of these institutions and companies invest millions of their own dollars to equip APS x-ray beamlines with sophisticated, high-technology instruments to carry out forefront research. The DOE-SC confidently invests in world-leading research centers such as the APS and the other SC user facilities (see page 20) because of the positive impacts of the science carried out on behalf of our nation and the world. UChicago Argonne, LLC, operates the APS and Argonne for the DOE-SC.

The APS facility — which is large enough to encircle a major-league baseball stadium — houses a suite of particle accelerators that, along with other equally sophisticated technical components such as x-ray beamlines and detectors, are the result of innovative research and development carried out by scientists, engineers, and technicians from Argonne, other institutions, and industry. The accelerators produce, accelerate, and store a beam of high-energy (relativistic) electrons. As the electrons orbit through powerful electromagnets, they are deflected by permanent-magnet devices and emit synchrotron radiation, which covers a broad segment of the electromagnetic spectrum with wavelengths that are shorter than visible light. These wavelengths are invisible to the human eye and they include extreme ultraviolet and x-ray radiation. They match the corresponding features of atoms, molecules, crystals, and cells — just as the longer wavelengths of visible light match the sizes of the smallest things the human eye can see.

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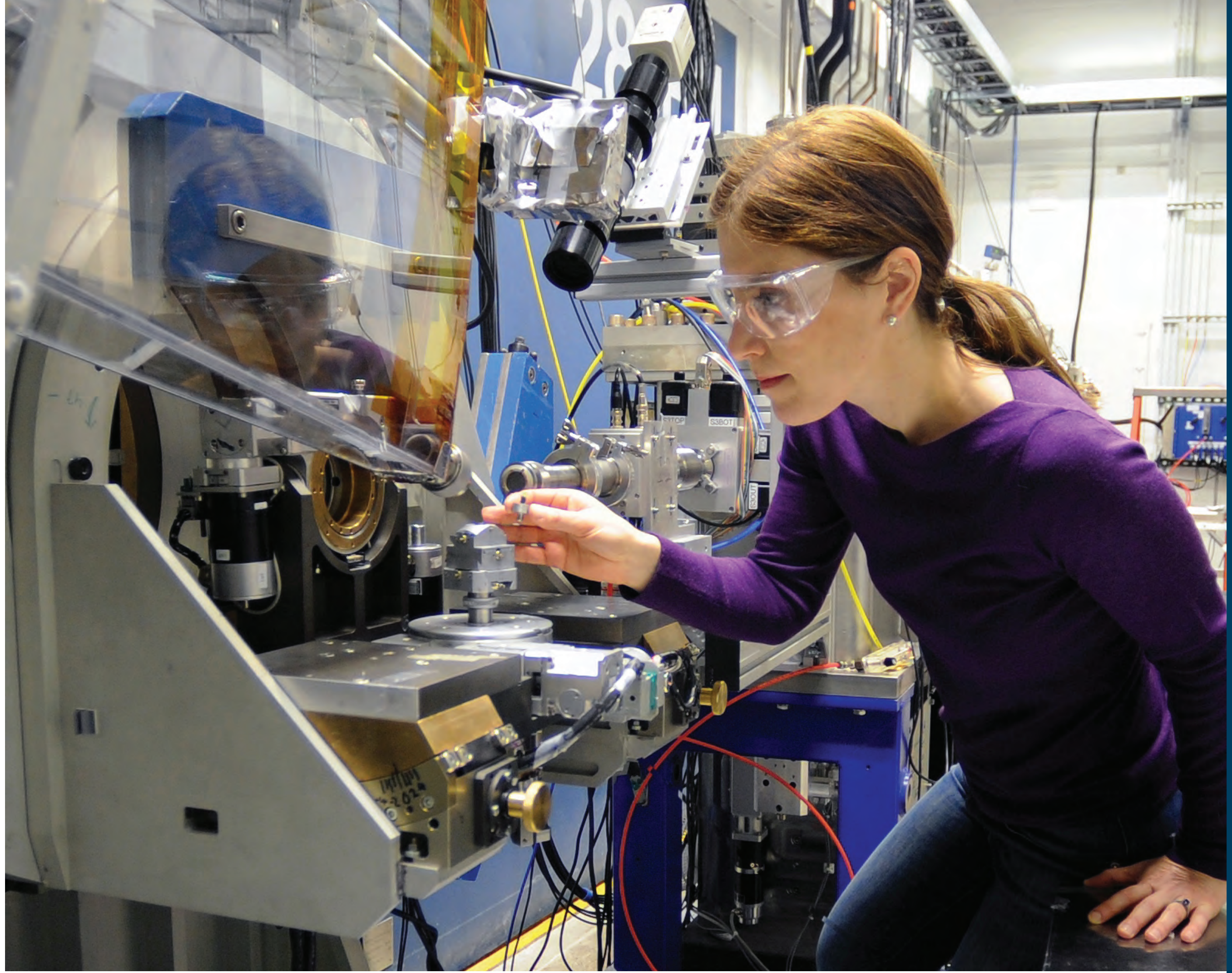

Placing a sample in the resonant inelastic x-ray scattering spectrometer at the XSD Sector 27 x-ray beamline. This instrument is used to measure the intrinsic properties of electronic excitations, which are key to understanding the electrical and magnetic behaviors of materials.

These high-brightness, high-energy x-ray beams, together with the latest in scientific instruments and techniques, allow researchers to carry out the cutting-edge experiments that positively impact nearly every aspect of our lives, while training the next generation of scientists for continuing discovery.

All three recipients of the 2009 Nobel Prize in Chemistry published papers on their award-winning work based on data collected at the APS, the National Synchrotron Light Source at Brookhaven National Laboratory, and the Advanced Light Source at Lawrence Berkeley National Laboratory, all U.S. DOE x-ray light sources. Biochemists Venkatraman Ramakrishnan of Cambridge, England's, Medical Research Center; Thomas Steitz of Yale University; and Ada Yonath of Israel's Weizmann Institute shared the award for their study of the structure and function of the ribosome (right, top figure), which works as a protein factory in all organisms from humans to bacteria. Nobel-related studies were performed at the Structural Biology Center Collaborative Access Team macro-molecular crystallography facility at APS Sector 19. Steitz and Yonath are also users of the National Institute of General Medical Sciences and National Cancer Institute (GM/CA-XSD) structural biology facility at APS Sector 23, the Northeastern Collaborative Access Team x-ray beamlines at APS Sector 24, and the BioCARS user facility at APS Sector 14.

The 2012 Nobel Prize in Chemistry was awarded to Brian Kobilka (Stanford University) and Robert Lefkowitz (Howard Hughes Medical Institute and Duke University) for their work on G-protein-coupled receptors (GPCRs), thanks in large part to research performed at the APS. In studies at GM/CA-XSD at Sector 23 of the APS, Kobilka and his colleagues made the first discovery of the structure of a human GPCR (right, bottom figure) that is responsible for a number of different biological responses, including facilitating breathing and dilating the arteries. A second breakthrough occurred in 2011, when the Kobilka group again used Sector 23 to determine the structure of a GPCR at the exact moment that the protein-receptor complex signals across the membrane. This study represented the first time that a GPCR had been caught "in the act" of carrying out its biological mission, a discovery the Nobel Committee called "... the Holy Grail, a high-resolution structure of an active ternary complex."

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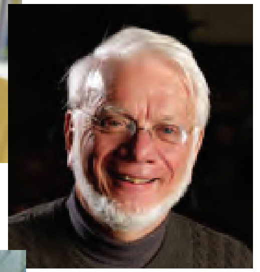
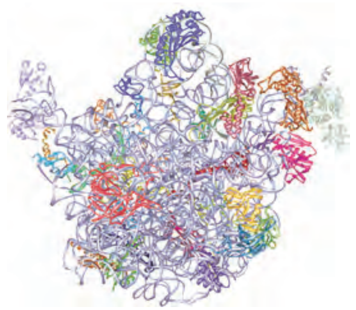
Venkatraman Ramakrishnan

Thomas Steitz



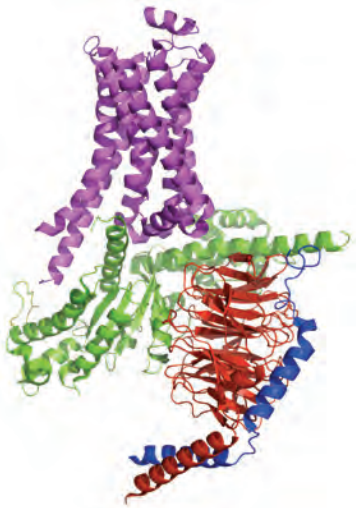
Ada Yonath



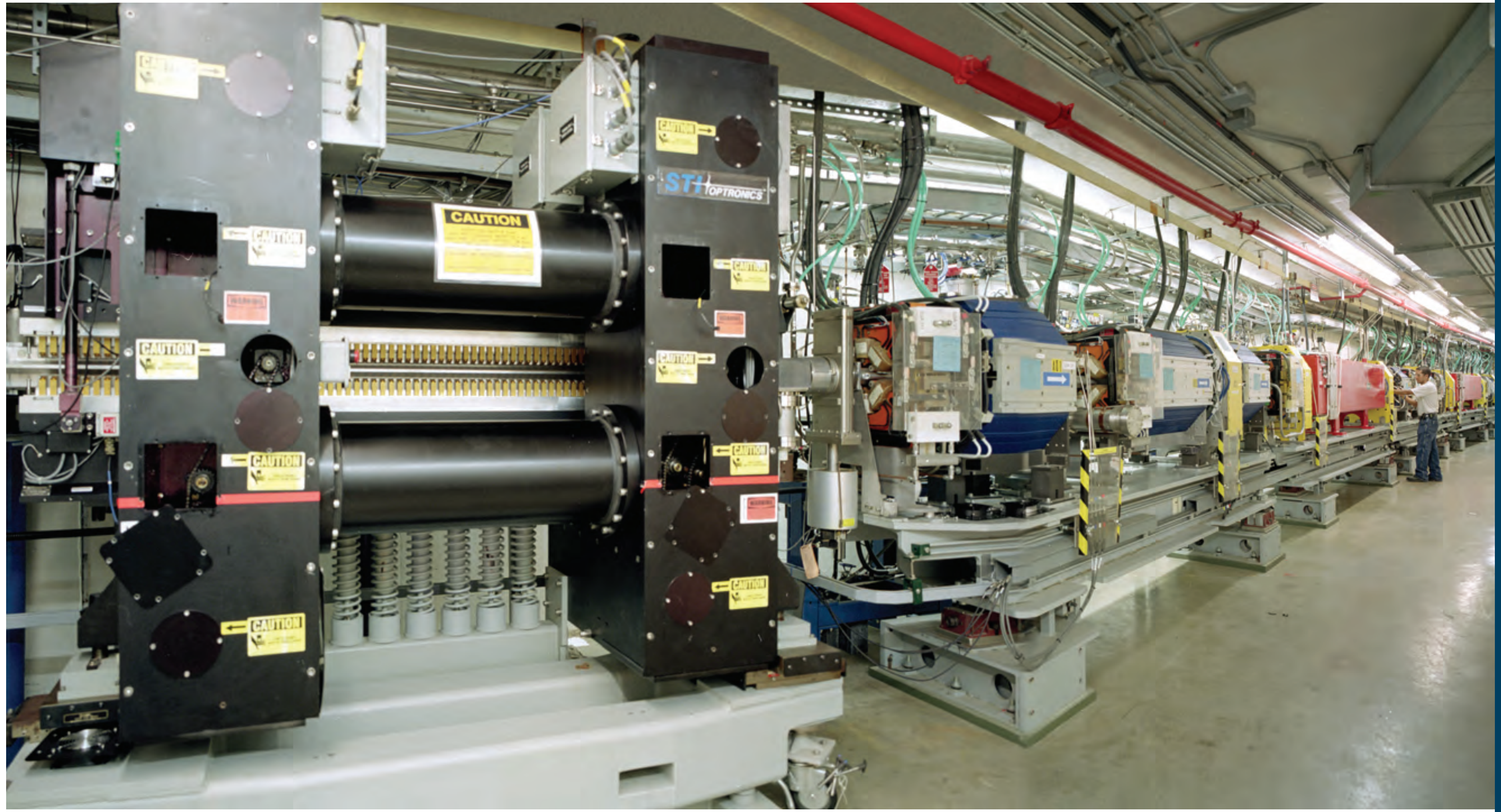
Ribosome

Brian Kobilka

Robert Lefkowitz



G-protein-coupled receptor



One sector of the 2/3-mile circumference APS storage ring, where electrons orbit at nearly the speed of light to produce x-ray beams for research. The large instrument at the left is an undulator insertion device, the source of high-energy, high-brightness, highly-penetrating x-rays.

At the APS, a sector comprises the radiation sources (insertion devices and bending magnets), x-ray beamlines, research stations, and instrumentation that are associated with a particular section of the electron storage ring and a particular research group. The APS has 40 sectors (see diagram at right), 35 of which are dedicated to user science and experimental apparatus. The rest of the sectors are taken up with electron storage ring equipment. All of the user-science sectors can operate simultaneously and they are available to the research community for experiments through an open, peer-reviewed proposal process.

Argonne X-ray Science Division (XSD) sectors are operated by the APS, while collaborative access team (CAT) sectors are built and operated by groups comprising scientists from universities, industries, and/or research laboratories. Some current XSD sectors have historic CAT origins.

Sectors 1-4, 6-9, 11, 12, 23, 29, 30, 32-34, and beamline 17-BM are managed by XSD. Beamline 14-ID-B is jointly operated by BioCARS and XSD. Sector 20 is managed by XSD in partnership with the Canadian Light Source. Sector 26 is operated jointly by the Argonne Center for Nanoscale Materials (CNM) and by XSD. Researchers using the beamlines in these sectors carry out experiments in materials and chemical science; environmental, geological, and planetary science; physics; polymer science; biological and life science; pharmaceutical research; atomic, molecular, and optical physics; and the properties of nanoscale materials, advancing our fundamental scientific understanding and the technologies that support a secure future for our nation.

Sector 5: The DuPont-Northwestern-Dow (DND) CAT is supported through E. I. duPont de Nemours & Co., Northwestern University, The Dow Chemical Co., the State of Illinois Department of Commerce and Board of Education, the DOE-SC Office of Energy Research, and the U.S. National Science Foundation (NSF) Division of Materials Research. It has as its scientific thrust, the study of two-dimensional or quasi-two-dimensional atomic structures (surfaces, interfaces, and thin films) and polymer science and technology. All are of immense technological importance.

Sector 10: The Materials Research (MR) CAT, which is supported by the DOE and the MR-CAT member institutions, enables scientific work that is broadly materials oriented. The main emphasis is on *in situ* studies of materials by x-ray spectroscopy, scattering, and reflectivity. There are strong environmental science and catalysis components to this research, in addition to furthering materials-based technologies, such as photochemistry and x-ray lithography.

Sectors 13 through 15 are managed by the Center for Advanced Radiation Sources (CARS):

Sector 13: GeoSoilEnviroCARS (GSECARS), supported by grants to the University of Chicago from the U.S. NSF-Earth Sciences and DOE-Geosciences, is dedicated to state-of-the-art research on Earth materials for a better understanding of our environment and planet.

Sector 14: BioCARS, which is mainly supported by the National Institute of General Medical Sciences (NIGMS) of the National Institutes of Health (NIH) is dedicated to the development of resources and facilities to foster frontier research in time-resolved macromolecular crystallography, and time-resolved biological small-angle and wide-angle scattering. Watching macromolecules in action furthers our understanding of how macromolecules function. This ultimately leads to advances in the cause, prevention, and treatment of diseases. Time-resolved x-ray scattering experiments in the physical sciences are also conducted at BioCARS under the auspices of CARS, with additional support from the APS.

Sector 15: ChemMatCARS, which is mainly supported by the U.S. NSF and the DOE, focuses on the study of surface and interfacial properties of liquids and solids as well as their bulk structure at atomic, molecular, and mesoscopic length scales with high-spatial and high-energy resolution to advance materials and chemical science. The APS ultra-small-angle x-ray scattering program has moved to Sector 15 under a collaboration between CARS and the APS.

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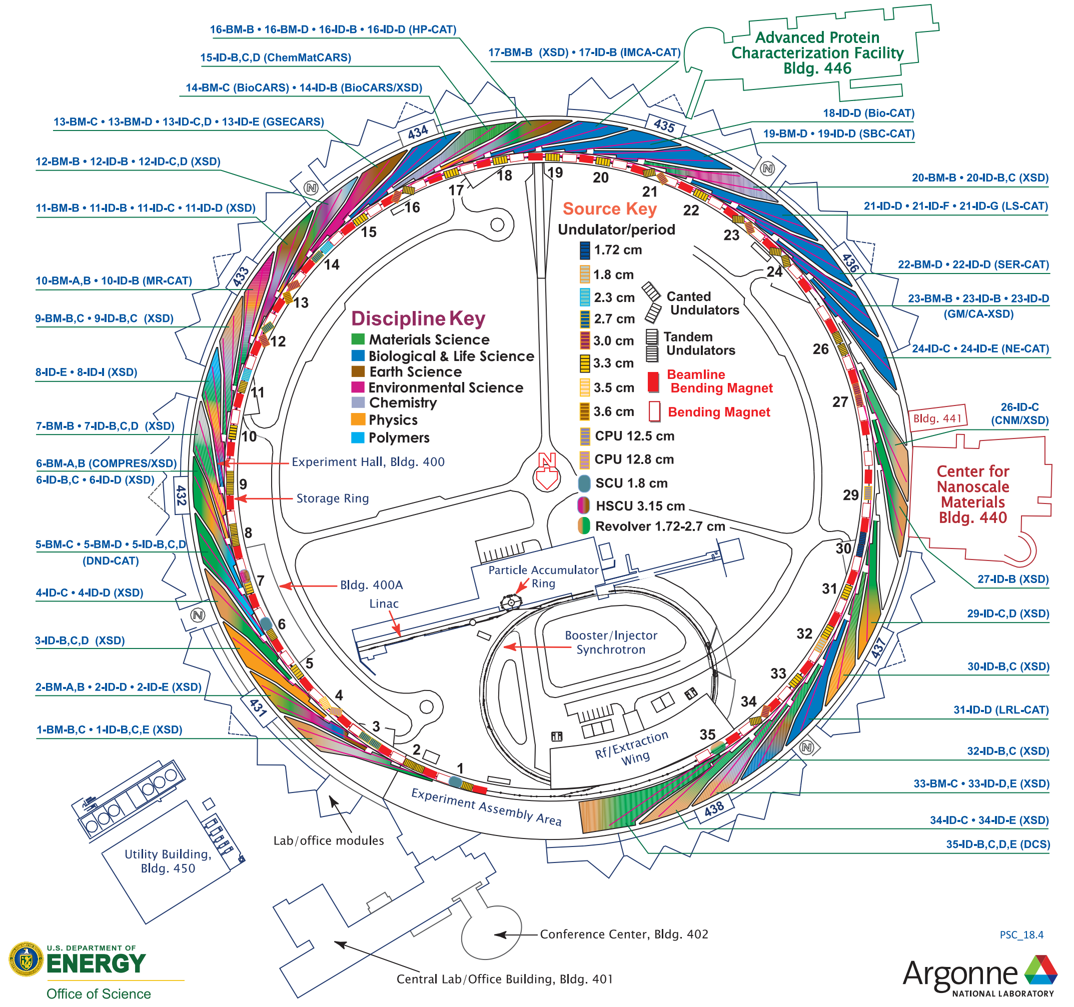
Argonne National Laboratory 400-Area Facilities

Advanced Photon Source

(Beamlines, Disciplines, and Source Configuration)

Advanced Protein Characterization Facility

Center for Nanoscale Materials

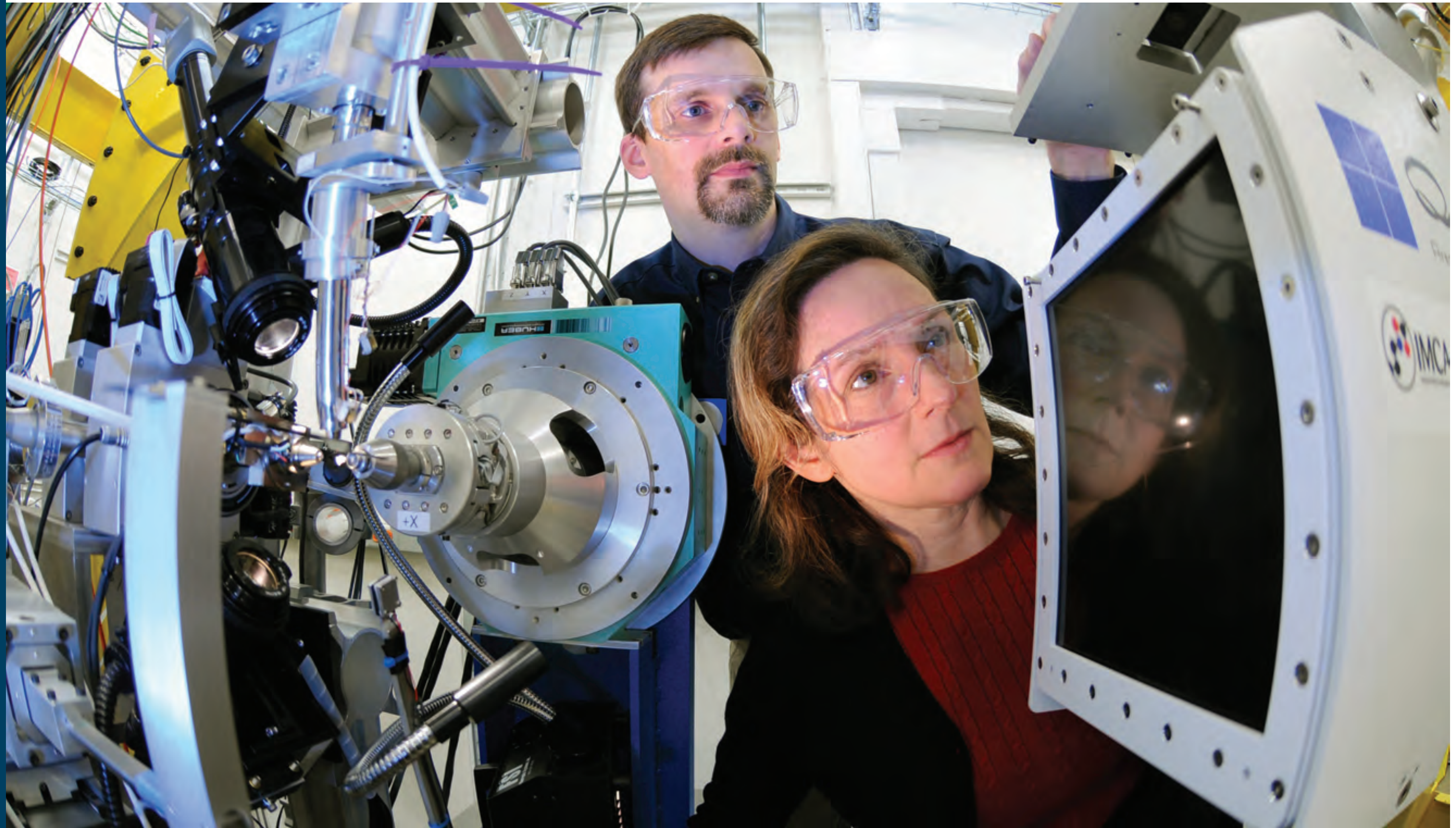


This plan view of the APS facility shows locations of x-ray beamlines and beamline operator groups, scientific disciplines investigated at the APS, and locations and arrangements of x-ray producing electromagnets and insertion devices in the electron storage ring.

Sector 16: The High Pressure (HP) CAT, which is supported by the DOE-National Nuclear Security Administration (NNSA) and DOE-Basic Energy Sciences, with partial instrumentation funding by the U.S. NSF, advances cutting-edge, multidisciplinary, high-pressure science and technology enabling myriad scientific breakthroughs in high-pressure physics, chemistry, materials, and the Earth and planetary sciences.

Sector 17 (beamline 17-ID): The Industrial Macromolecular Crystallography Association (IMCA) CAT, dedicated to accelerating drug discovery research, operates a state-of-the-art structural biology synchrotron beamline for the pharmaceutical industry. The facility is optimized for high-quality, high-throughput macromolecular crystallography experiments, producing essential data for determining the structures of key components in structure-based drug design. The facility is funded by the pharmaceutical members of IMCA (Industrial Macromolecular Crystallography Association): AbbVie, Bristol-Myers Squibb, Merck, Novartis, and Pfizer, and operated through a contract with the Hauptman-Woodward Medical Research Institute. Data from IMCA-CAT have been crucial to the development of a significant number of therapeutics for the prevention and treatment of disease.

Sector 18: The Biophysics (Bio) CAT, which is funded by the NIH, develops and operates state-of-the-art facilities for studies of the structure and dynamics of biological systems under non-crystalline conditions that are similar to their functional states in living tissues to better understand human physiology.



Sector 19: The Structural Biology Center (SBC) CAT, which is funded by the DOE Office of Biological and Environmental Research, operates a national user facility for macromolecular crystallography at the APS in order to advance and promote scientific and technological innovation in support of the DOE mission by providing world-class scientific research and advancing scientific knowledge. SBC-CAT is an important component of integrated biosciences and contributes to the expansion of existing programs and exploration of new opportunities in structural biology, proteomics, and genomics research with a major focus on medicine, bio-nanomachines, and biocatalysis that are highly relevant to energy resources, health, a clean environment, and national security.

Sector 21: The Life Sciences (LS) CAT, which is supported by the Michigan Economic Development Corporation and the Michigan Technology Tri-Corridor, provides macromolecular crystallography resources for those with a need to determine the structure of proteins. Mainly, LS-CAT provides access to state-of-the-art x-ray diffraction facilities at the APS.

Sector 22: The Southeast Regional (SER) CAT, which is operated by the University of Georgia and funded by supporting institutions (www.ser-cat.org/members.html), provides third-generation x-ray capabilities to macromolecular crystallographers and structural biologists in the southeastern region of the U.S. Emphasis is placed on structure determination, high-resolution structural analyses, large unit cells, drug design, structural genomics, soft x-ray data collection, and next-generation beamline automation.

Sector 23: The General Medicine and Cancer Institutes (GM/CA-XSD) facility, which is located organizationally within XSD, operates a national user facility for structural biology with synchrotron beamlines specializing in intense, tunable micro-beams for crystallography to determine the structure of proteins and other macromolecules at the forefront of biological research, with an emphasis on problems in structural genomics and structure-based drug design. The scientific and technical goals of GM/CA-XSD emphasize streamlined, efficient throughput for a variety of sample types, sizes, and qualities representing the cutting edge of MX research. GM/CA-XSD is funded in whole or in part with federal funds from the National Cancer Institute and NIGMS of the NIH.

Sector 24: The Northeastern (NE) CAT is managed by Cornell University for its seven member institutions (http://necat.chem.cornell.edu/ aboutus/Organization/Members.htm). NE-CAT, which is supported primarily by a grant from NIGMS of the NIH with additional financial support from the member institutions, operates an x-ray crystallographic research facility designed to address the most demanding and complex diffraction problems in structural biology and is organized to allow its operation to be driven by the requirements of its users.

Sector 31: The Lilly Research Laboratories (LRL) CAT, which is operated by Eli Lilly and Company, is dedicated to the determination of protein structures and the analysis of the interactions between potential pharmaceutical compounds and a protein of interest to further research into the causes, prevention, and treatment of disease.

Sector 35: The Dynamic Compression Sector (DCS) is funded by the DOE-NNSA. It is a partnership between the Institute for Shock Physics at Washington State University and the APS. The DCS integrates state-of-the-art dynamic compression platforms and drivers with an APS x-ray beamline to produce a first-of-a-kind experimental capability (worldwide) focusing on time-resolved x-ray diffraction and imaging measurements in dynamically compressed condensed matter. ●

< Preparing a macromolecular crystallography experiment at the IMCA-CAT facility at Sector 17 of the APS.

Argonne's Other User Facilities

The APS and its user program enhance the synergies among Argonne's existing user facilities and research programs. These include:

The Advanced Protein Characterization Facility enhances Argonne's structural biology and protein function analysis efforts by providing highly specialized laboratory space that is devoted to characterization of the most challenging classes of proteins and assemblies, work that is currently slowed by infrastructure limitations.

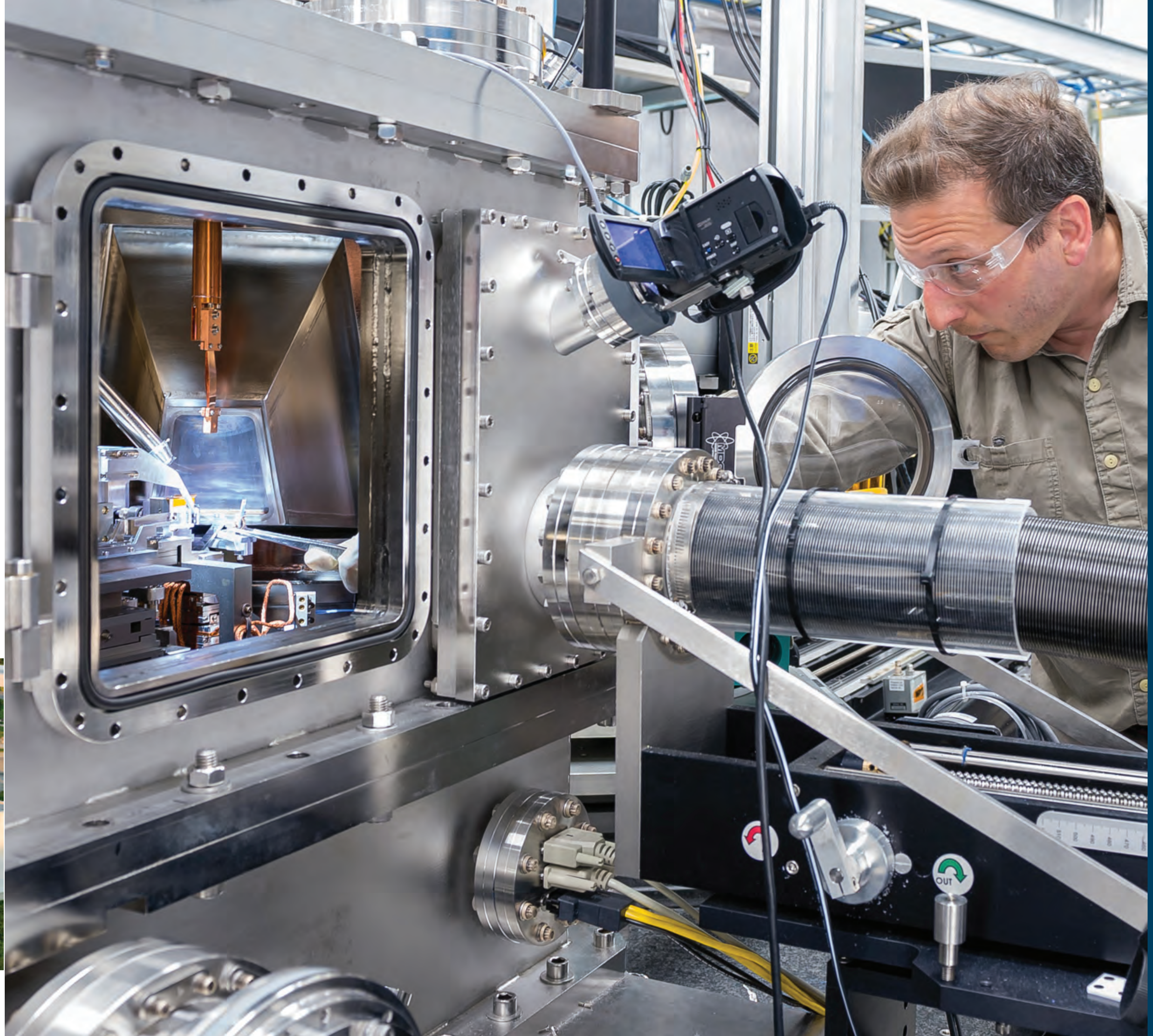
The Argonne Leadership Computing Facility provides researchers from national laboratories, academia, and industry with access to high-performance computing capabilities to enable breakthrough science and engineering.

The Argonne Tandem Linac Accelerator System, the world's first superconducting linear accelerator for heavy ions, enables research probing the properties of atomic nuclei and their roles in astrophysics, fundamental interaction physics, and applications. This research is performed through the use of the high-intensity stable ion beams at Coulomb barrier energy provided by the accelerator, neutron-rich ion radioactive beams available through the CARIBU source, and a suite of the state-of-the-art equipment optimized for work at this energy regime.

The Center for Nanoscale Materials is a premier user facility providing expertise, instruments, and infrastructure for interdisciplinary nanoscience and nanotechnology research to academic, industrial, and international scientists. From advanced x-ray, electron, and ultrafast optical microscopy to an unparalleled scanning probe suite, cleanroom-based nanofabrication techniques, and computational materials science, the CNM provides researchers with a powerful combination of scientific resources.

The Transportation Technology R&D Center brings together scientists and engineers from many disciplines across Argonne to work with the U.S. DOE, automakers, and other industrial partners. The goal is to put new transportation technologies on the road that improve the way we live and contribute to a better, cleaner future for all. ●

Below left: The Argonne Theory and Computing Sciences building (the Energy Sciences Building is behind it and to the right). Below right: The Center for Nanoscale Materials. Next page: The Hard X-ray Nanoprobe at CNM/XSD, Sector 26.



Energy Research

From batteries to nuclear reactors to engines, research by APS users is shining light on a panoply of energy-related solutions to an array of critical energy questions.

Research with Impact — Success Stories

Better, cleaner fuel injectors

Fuel injector efficiency and clean combustion are dependent on the best possible mixture of fuel and air in engines. To improve injector design, it is critical to understand how fuel is atomized as it is injected. Argonne researchers are using the APS to look inside liquid sprays from fuel injectors to help optimize combustion for cleaner and more efficient engines.

Better batteries

Researchers are using the APS x-ray beams to explore a variety of ideas aimed at improving battery technology. Here a just a few examples:

The growing demand for lithium-ion (Li-ion) batteries for electric vehicles and other portable devices may place a strain on global reserves in the coming decades. Sodium is abundant compared to lithium and shares the same charge, spurring research into the feasibility of sodium-ion batteries. Toward this goal, researchers at the APS carried out studies to help guide the development of better sodium batteries.

Another group of scientists used the APS to investigate improvements to the anodes (or negative electrodes) that store lithium ions in a Li-ion battery during charge up, revealing why these anodes often fail after multiple uses and providing clues to a battery that can drive us into the future.

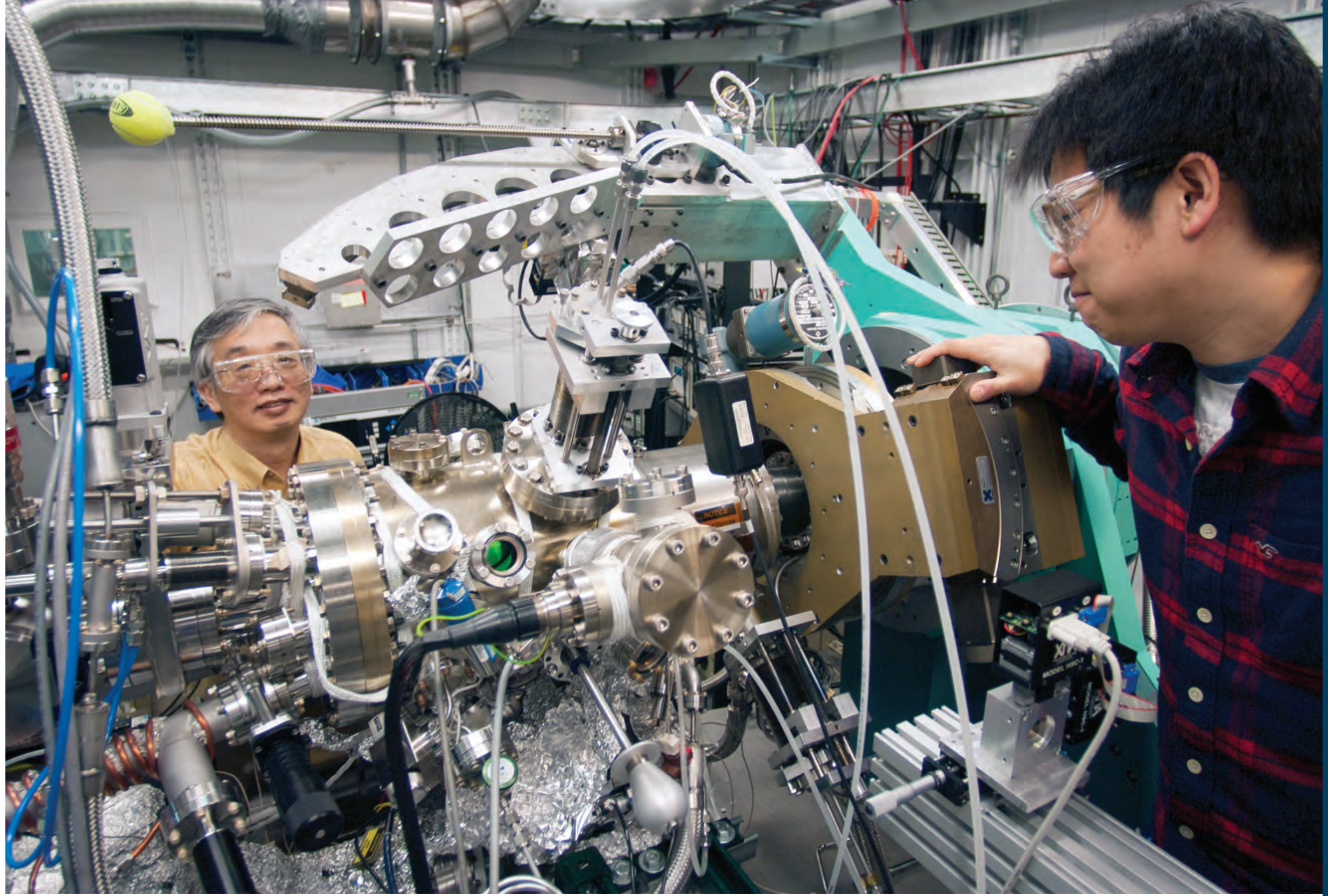
Selenium-sulfur batteries may someday offer a lower cost, higher energy-density alternative to Li-ion batteries, but they lag behind in their ability to be charged and discharged over and over without losing storage capacity. To figure out the capacity-fading mechanism of selenium-based batteries during multiple charge/discharge cycles, researchers studied their properties utilizing high-energy, highly penetrating x-ray beams from the APS. Their insights may help researchers design selenium-based batteries that can be endlessly recharged.

Nuclear safety

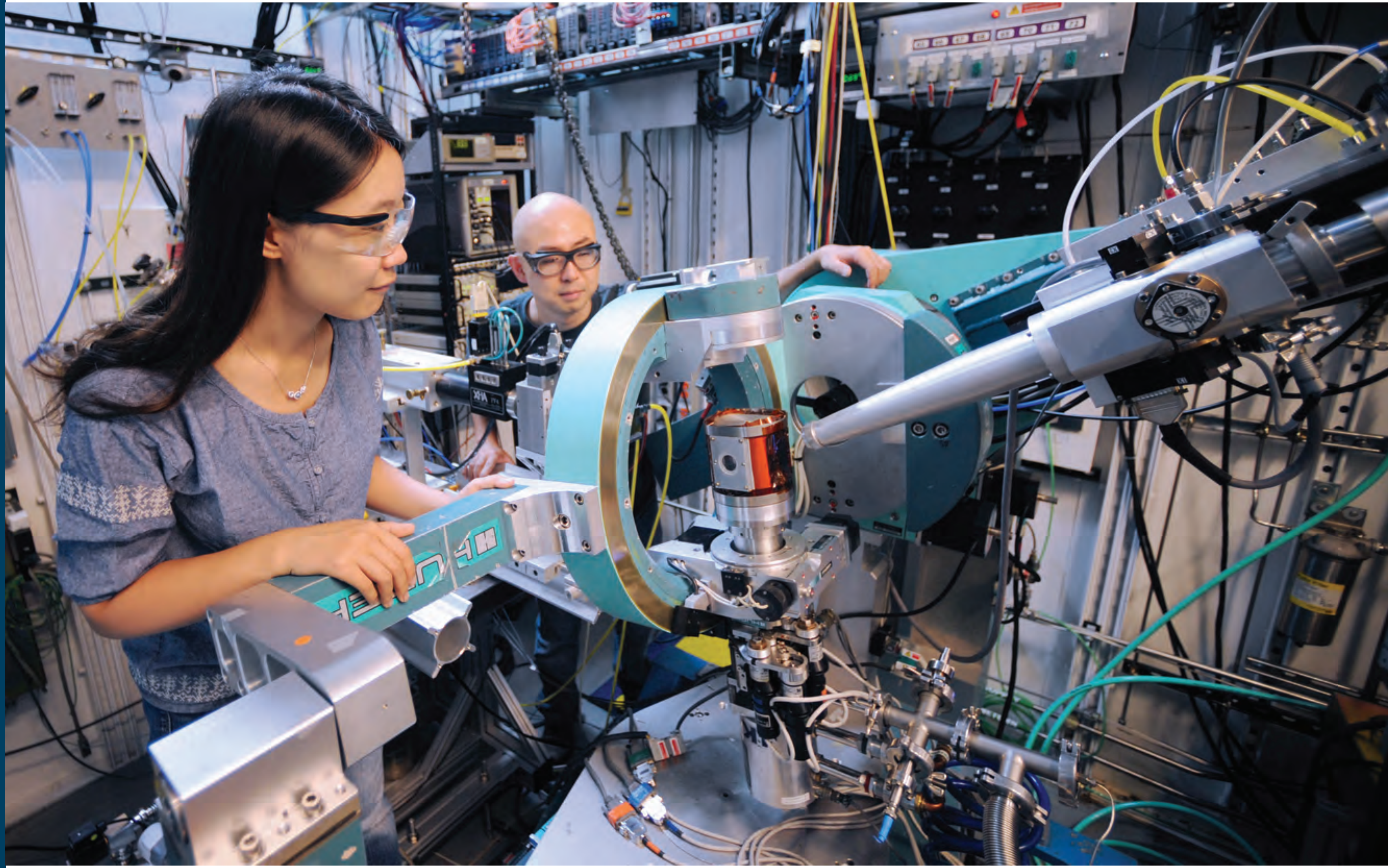
New materials are needed in order to extend nuclear reactor lifetimes and increase accident tolerance. Materials utilized within reactors face a variety of challenges, including the critical ability to withstand high radiation at high temperatures. Researchers working at the APS and other DOE facilities at Argonne developed and demonstrated a new technique for evaluating fuel and reactor materials that requires less time and expense than current techniques by irradiating potential materials with high-energy atomic nucleus ions and then assessing the damage using synchrotron x-ray diffraction and electron microscopy.

Miraculous, multi-use MOFs

Metal-organic frameworks (MOFs) are compounds consisting of metal ions or clusters connected by organic ligands to form extended architectures that define one-, two-, or three-dimensional pore networks. MOFs have the potential for wide-ranging uses, including gas storage, separation, and catalysis in the chemical industry; and even for destroying chemical weapons such as toxic nerve agents. So MOFs are the focus of numerous research initiatives at the APS, including: how and why structural changes occur in MOFs; how MOFs react to real-world conditions outside of the controlled conditions of the laboratory; how to MOFs can encapsulate enzymes for highly efficient and recyclable catalysis; and potential application as new light-emitting diodes and environmental and medical sensors. ●



The oxide growth molecular beam epitaxy system at XSD Sector 33, where researchers seek unique pathways to new materials relevant to the energy needs of the future.



The 6-circle diffractometer in the research station at APS Sector 4.

Materials and Chemical Research

Researchers utilize the APS to increase our understanding of the atomic structures, behaviors, and functions of existing and new materials and chemical processes in order to improve nearly every aspect of our lives.

Research with Impact — Success Stories

Next-generation electronic materials

A new class of layered oxide materials discovered at the APS offers unprecedented opportunities for creating next-generation electronic devices. The materials show physical properties resulting in a rich collection of phenomena including magnetic ordering, metal insulator transitions, superconductivity, magneto-resistivity, and ferroelectricity. By using these properties and the ability to tune them, scientists hope to create new all-oxide electronics that will enable groundbreaking new device functionalities.

Cementing the structure of calcium silicate hydrates

Surprisingly, the manufacture of cement is responsible for about 5% to 7% of all the carbon dioxide released by humans into the Earth's atmosphere every year. However, research at the APS is providing new insights into the nanostructure of calcium silicate hydrate (CSH), the main ingredient that gives concrete its great strength. With a better understanding of the crystalline structure of CSH, researchers are making it possible to use polymers and other materials to produce hybrid CSHs that are stronger and more environmentally friendly.

Building a molecular ball

Chemists fabricated a molecular ball, a cuboctahedron, just 6 nanometers across (about 1/15,000 the diameter of a human hair) and used the APS to watch the self-assembly process that resembles the way protein machinery in the body is constructed and how some viruses form, helping us better understand the self-assembly of proteins, viruses, and other microscopic biological entities.

The before and after of shock loading

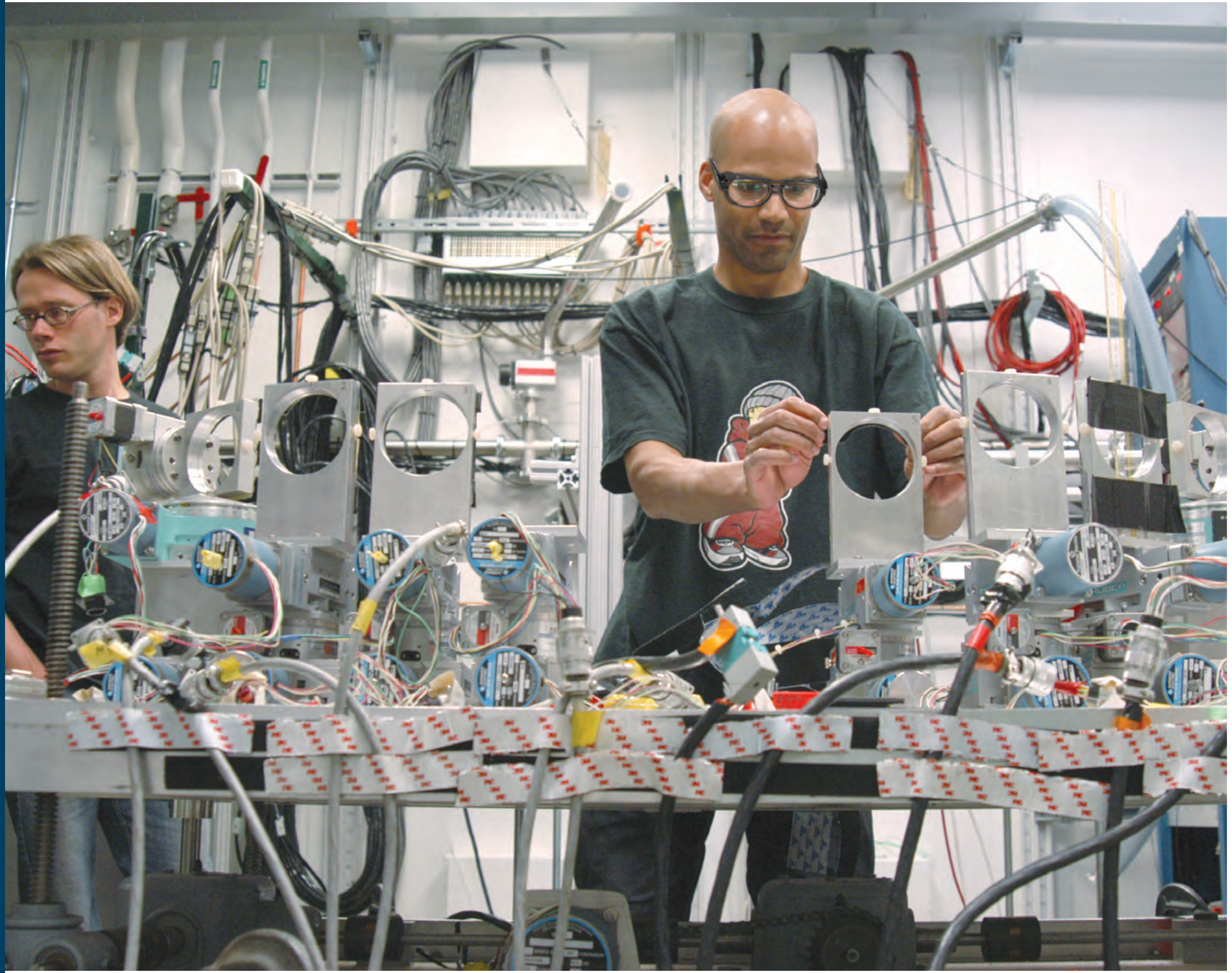
Researchers working at the APS have produced the first before-and-after images revealing the microscopic changes within a polycrystalline material subjected to high-speed impact. The highly detailed 3-D imaging of microstructural changes obtained in this study will help improve predictive modeling of shock loading, leading to materials capable of better withstanding specific shock loading conditions.

Imaging the spray from inhalers

The most popular type of device for delivering a measured amount of aerosolized medication is the compact, inexpensive, and generally effective metered-dose inhaler, but many patients receive less than the optimum drug dose. Experiments at the APS overcame the limitations of previous attempts to image the quickly-evolving inhaler spray plume with millisecond precision, promising improvements in the drug-delivery performance of the inhalers.

Improving the ubiquitous catalyst

Catalysts are crucial for a huge array of applications, including the manufacture of an estimated 90% of all commercially produced chemical products. Catalysis research by APS users includes finding less expensive and better performing alternatives to platinum catalysts for catalytic converters, understanding how strain on the surface of a catalyst could make it better at facilitating chemical reactions, how to optimize peptides (short chains of amino acids) for particular catalysis applications, providing critical insight that is needed to tune catalytic activity to reduce harmful gaseous environmental pollutants found in engine exhaust, and much more.



Health and Life Sciences Research

Macromolecular crystallographers utilize the APS to determine the structure and function of biological proteins in order to improve and develop pharmaceutical drugs, while biologists seek to better understand myriad biological and health-related processes.

Research with Impact — Success Stories

Fighting disease with x-ray research

Research at the APS was crucial in the development of: one of the world's most prescribed drugs for the treatment of AIDS; a drug that halts the progression of malignant and inoperable skin cancer; a pharmaceutical that helps lower blood sugar levels in adults with type 2 diabetes; a successful drug for fighting advanced kidney cancer; and a small-molecule drug that treats chronic lymphocytic leukemia in those with a specific chromosomal abnormality, to name a few.

Answering key questions about the common cold

After more than a decade of research, scientists at the APS pieced together the structure of the cold-causing human adenovirus, the largest complex ever determined at atomic resolution. By determining the structure of the entire virus, the researchers revealed how a major protein, called hexon, was incorporated into the virus and how it interacted with other proteins. The new findings about the human adenovirus, that causes respiratory, eye, and gastrointestinal infections, may lead to more effective gene therapy, in addition to new anti-viral drugs.

Creating artifical tissue

By creating tiny silicon nanowire assemblies full of nano-scale voids, researchers constructed a device that could attach to the plasma membrane of a cell and generate a current to stimulate that cell. They characterized the structure of the device using the APS, work that could one day lead to the creation of artificial human tissue or even a functioning organ.

Tracing metals and embryonic development

Exactly how are important trace metals, such as zinc and iron, used by a growing embryo? Researchers used data gathered from the APS to visualize zinc and iron in Zebrafish embryos at the onset of the hatching period, a critical period for development of many organs including the heart, liver, and eye. Their findings provide new insights into this early time in development and could eventually provide crucial information into why development might go awry.

Clues to fighting heart failure

To better understand the molecular mechanism underlying how the heart moves blood through the body in a regulated way by pumping out as much blood as it receives, experiments at the APS examined myocardial muscles of rats deficient in length-dependent activation of muscle fibers in the heart. This work shows that the protein titin is critically important for transmitting stretch-induced signals within the heart's muscles known to impact the strength with which the heart contracts, and provides an avenue for targeted development of drugs to treat heart failure.

Toward early cancer detection

Contrast agents that are selectively taken up by certain cells or tissues are widely used to enhance the effectiveness of magnetic resonance imaging (MRI), especially for the detection of cancers. Using the high-brightness x-ray from the APS, researchers have shown that a vanadium-based contrast agent greatly improves the detectability of colon cancers in mice by marking the presence of the most aggressive cancer cells. The work suggests that vanadium-based contrast agents used in conjunction with MRI could be a powerful tool for early cancer detection. ●

< Readying a life-science experiment at BioCARS, Sector 14.

Environmental and Geological Research

Research at the APS is expanding our knowledge about everything from the center of the Earth to materials in outer space. With a better understanding of the world around us, we are better prepared to protect and sustain our planet's precious natural resources.

Research with Impact — Success Stories

A key to drought resistant crops

Researchers at the APS have determined precisely how an important plant hormone works at the molecular level to help plants respond to environmental stresses such as drought and cold. The scientists were able to map the structure of the receptors that plants use to sense abscisic acid, a hormone that keeps seeds dormant and keeps buds from sprouting until the climate is right. Their findings could help engineer crops that thrive in harsh environments around the world and combat global food shortages.

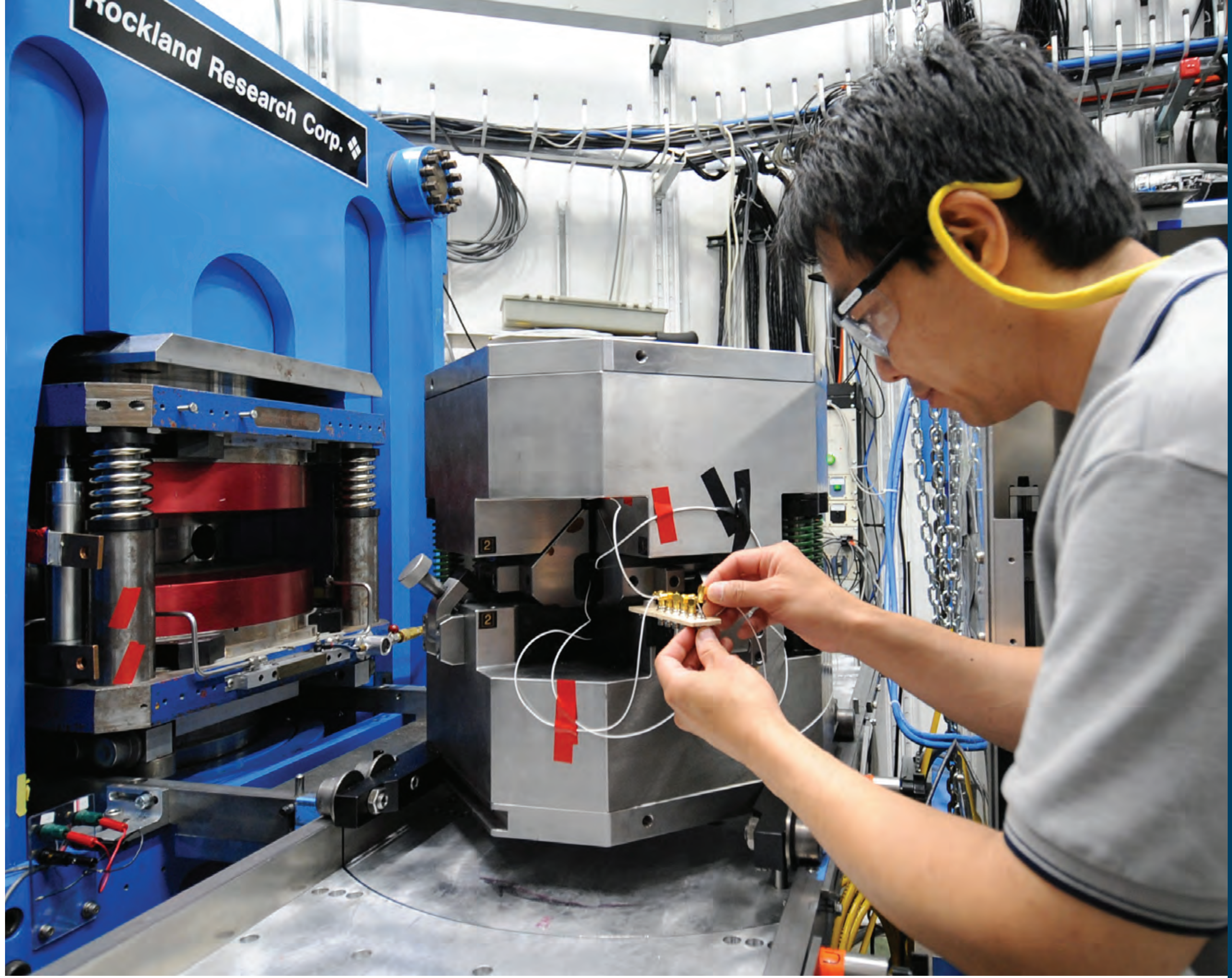
From the center of the Earth to the stars

Research at the APS included: the first elemental composition study of likely interstellar "space dust," structural studies of a recently discovered hydrogen-stuffed ice whose properties make it a candidate as a major "mineral" in the crust of ice-covered planetary bodies in the outer solar system, and a new technique for measuring oxygen fugacity in meteorite samples that previously could not be measured. Closer (and deeper) to home, researchers used the APS to increase our current understanding of coupling between Earth's tectonic plates and Earth's mantle, lto ocate the whereabouts of xenon missing from Earth's atmosphere (it might be somewhere in the mantle), and to show that carbon may be one of the lighter elements in the Earth's core.

Remediating waste uranium

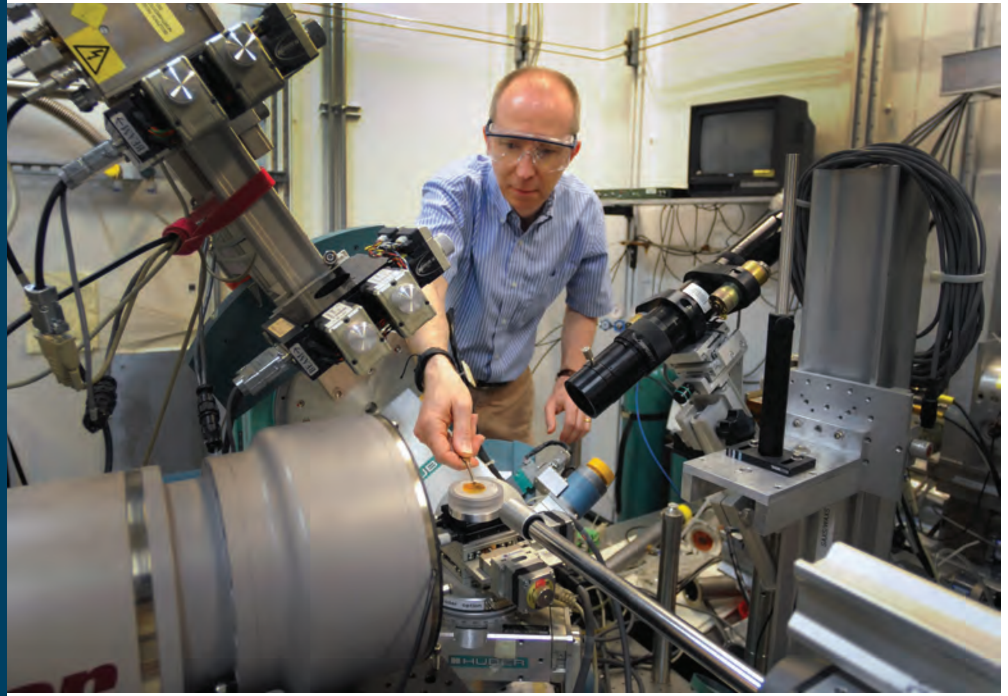
Waste uranium from mine tailings, fission power plants, and decommissioned nuclear weapons settles below ground where it can contaminate groundwater, so scientists search for ways to slow the underground migration of this toxic, radioactive hazard. One strategy involves introducing substances that retard the formation of highly-soluble uranium compounds. Scientists used the APS to track the chemical changes associated with this process, confirming that calcium and phosphate slow the transition from less-soluble to more-soluble uranium compounds. While the effects of the treatment eventually faded under real-world oxidizing conditions, the processes and the data gathered will substantially contribute toward the goal of reducing subsurface uranium hazards. ●

At MR-CAT, Sector 10: aligning a bent-crystal Laue analyzer for studies of the aging on commercial spent nuclear fuel.



A large-volume press like this one at GSECARS, Sector 13, subjects samples to extreme pressures and temperatures in order to study the physical properties of materials under deep-Earth conditions.

Industry and the APS



At DND-CAT, Sector 5: Placing a sample in the kappa geometry diffractometer used for measuring x-ray fluorescence, x-ray standing waves, and wide-angle x-ray scattering to determine the surface and bulk structure of thin films and other samples.

Scientists come to the APS to carry out investigations that increase our fundamental knowledge of processes and materials, which allows us to move beyond observation to control for a nearly endless array of technologically and economically important applications including advances in manufacturing, information technology, nanotechnology, pharmaceuticals, biomedicine, oil and gas, transportation, agriculture, environment, and many other areas that are critical to our technologies, economy, and physical well-being.

Research at a DND-CAT x-ray beamline at the APS allowed DuPont researchers to characterize the metal oxide contents of candidate substitute catalysts, resulting in the development of DuPont's SUVA®, a reliable, proven, and safe alternative to ozone-layer depleting refrigerants.

In another instance, research carried out at the IMCA-CAT beamline at the APS furthered the development of a GlaxoSmithKline pharmaceutical, Votrient®, that combats two deadly forms of cancer: soft-tissue sarcoma and kidney cancer.

More than 230 companies have research agreements with the APS, including (but not limited to) Chevron, 3M, Amoco, Bayer, Caterpillar, E.I. DuPont de Nemours & Co., Exxon, Ford Motor Co., GE Global Research Center, General Motors, Intel, Kraft Foods Technology Center, Monsanto, Packer Engineering, Texas Instruments, Westinghouse Electric, and a comprehensive roster of leading pharmaceutical firms.

The APS welcomes industrial users doing both proprietary and non-proprietary research and considers requests for work ranging from short-term feasibility studies to long-term research projects, either on a stand-alone basis or in collaboration with facility or academic colleagues. For more information contact: apsuser@aps.anl.gov ●

The Office of Science Light Sources

The U.S. DOE Office of Science supports the operation of many major research facilities across our nation that provide open, peer-reviewed access to sophisticated research tools for scientists (users) from academia, national laboratories, and industry carrying out research in all major scientific disciplines.

These facilities consist of a complementary set of intense x-ray sources, neutron scattering centers, electron beam characterization capabilities, and centers for nanoscale science. They allow scientists to probe materials in space, time, and energy with the appropriate resolutions that can interrogate the inner workings of matter — transport, reactivity, fields, excitations, and motion — to answer some of the most challenging science questions. More than 10,000 scientists conduct experiments at these facilities each year. Thousands of other researchers collaborate with those users, analyze data from the experiments, and publish scientific findings in peer-reviewed journals.

The synchrotron x-ray light sources, including the APS, produce radiation over a wide range of photon energies (from the infrared to hard x-rays) and shed light on fundamental aspects of the physical world, investigating energy, momentum, and position using techniques including spectroscopy, scattering, and imaging applied over various time scales.

The DOE Office of Science x-ray light source facilities are:

- Advanced Light Source, Lawrence Berkeley National Laboratory
- Advanced Photon Source, Argonne National Laboratory
- Linac Coherent Light Source, SLAC National Accelerator Laboratory
- National Synchrotron Light Source II, Brookhaven National Laboratory
- Stanford Synchrotron Radiation Lightsource, SLAC National Accelerator Laboratory

For information about all of the DOE Office of Science user facilities, see http://science.energy.gov/bes/suf/user-facilities/ ●

Fast Facts about the APS

Scientific disciplines investigated at the APS

- Materials and chemical science; environmental, geological, and planetary science; physics; polymer science; biological and life science; pharmaceutical research; atomic, molecular, and optical physics; and the properties of nanoscale materials.

Some benefits accruing from research at the APS

- Better materials for lithium-ion batteries and other energy-related technologies
- The path to more efficient designs for fuel-injection systems
- Clues to the causes of and treatments for a multitude of diseases including AIDS, and toxic threats such as anthrax
- A greater understanding of human physiology
- Ways of eliminating and remediating environmental depredations
- Insights about conditions at the center of the Earth, the causes of earthquakes and volcanoes, and the composition of cosmic dust
- A nearly endless array of new information about materials that support the development of practical applications like advanced digital storage media, more efficient lighting, environmentally friendly refrigerants, methods for increasing the durability of man-made structures, and the characterization of nanostructures whose sizes are measured in atoms

The APS facility

- Electrons cannot go faster than the speed of light, but the electrons in the APS storage ring have an energy of 7 GeV (7 billion electron volts), so the electrons are traveling at over 99.99999999% the speed of light
- There are more than 2000 conventional electromagnets and 16 pulsed electromagnets in the APS electron accelerators
- Over 700 beam-position monitors, 600 corrector electromagnets, and 80 computer systems monitor and correct the electron orbit, steering x-ray beams to within a fraction of the width of a human hair
- More than 120 programmable logic controllers monitoring over 25,000 signals comprise radiation interlock systems protecting personnel and equipment
- The APS has five 1-megawatt radio frequency (rf) power systems (the equivalent of 5000 microwave ovens) that are used to accelerate and maintain high-energy electron beams in the storage ring
- The storage ring rf systems contribute to a combined accelerating voltage equal to a 16-million-volt power supply
- APS rf systems produce more rf power than the combined output of every radio and television station in the city of Chicago
- The superconducting detectors that collect data from the interaction of high-brightness APS x-rays and the sample being studied operate at temperatures colder than outer space
- The outer diameter of the APS experiment hall is 1225 feet; slightly less than the height of the Willis (Sears) Tower in Chicago (1454 feet)
- Experiment hall construction required 56,000 cubic yards of concrete (equal to a football-field-sized block 30 feet high); 5000 tons of structural steel (enough for 3,500 mid-size cars); 2,000,000 linear feet (380 miles) of electrical wire; and 190,000 feet of pipe for water, steam, drainage, and HVAC
- Total floor space of all APS buildings is 1,042,811 feet^2
- Facility construction started in spring 1990; research started in the fall of 1996
- Total APS construction and project cost at completion in 1995 was $812 million
- The number of APS employees at any one time is approximately 450

The APS booster/injector synchrotron, where electrons are accelerated to nearly the speed of light before they are injected into the electron storage ring.

A helical superconducting undulator installed on Sector 7 of the APS storage ring.

Part of the APS computer room, where servers for the electron storage ring and x-ray beamlines are located.

Argonne National Laboratory

The nation's first national laboratory, Argonne National Laboratory (photo at right) is managed by UChicago Argonne, LLC, for the U.S. Department of Energy's Office of Science. The Office of Science is the single largest supporter of basic research in the physical sciences in the United States, and is working to address some of the most pressing challenges of our time. For more information, please visit science.energy.gov.

Argonne is a multidisciplinary science and engineering research center, where "dream teams" of world-class researchers work alongside experts from industry, academia, and other government laboratories to address vital national challenges in sustainable, clean energy; the environment; technology; and national security. Researchers at Argonne and their collaborators around the world strive to discover new ways to develop energy innovations through science, create novel materials molecule-by-molecule, and gain a deeper understanding of our planet, our climate, and the cosmos. As well, more than 6,000 scientists conduct experiments at Argonne user facilities each year.

Surrounded by the highest concentration of top-tier research organizations in the world, Argonne leverages its Chicago-area location to lead discovery and to power innovation in a wide range of core scientific capabilities, from high-energy physics and materials science to structural biology and advanced computer science.

Argonne is the Midwest's largest federally funded R&D center, employing about 3,350 employees and more than 1,250 scientists and engineers in dozens of fields as well as a unique suite of leading-edge scientific user facilities.

Argonne is located in DuPage County, Illinois, about 25 miles southwest of Chicago, just south of Interstate 55.

Argonne's annual operating budget of about $650 million supports more than 200 research projects.

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