

FRONTIERS

RESEARCH HIGHLIGHTS 1946-1996

ARGONNE NATIONAL LABORATORY

9700 SOUTH CASS AVENUE, ARGONNE, ILLINOIS 60439

To Editors and News Directors:

Enclosed is a copy of *Frontiers*, Argonne National Laboratory's annual review of its research and outreach activities. This special edition commemorates the laboratory's 50th anniversary of service to science and to society. *Frontiers: Research Highlights 1946-1996* examines not only Argonne's current programs, but also its major accomplishments of the past 50 years.

The first two sections of the book, "From Ice Caps to APS" and "Atoms Forge a Scientific Revolution" trace the histories both of the Argonne site in Illinois and of science itself, from its beginnings into the early days of the atomic age, when Argonne was founded.

While Argonne is justifiably proud of its past, the laboratory also looks forward to a promising and challenging future. The Laboratory's work is designed to help prepare the United States for technological leadership into the next century.

The section entitled "The Lab and Its Resources" introduces many of the research facilities that make Argonne a magnet for scientists from around the world. Beginning with the Lab's newest facility, the Advanced Photon Source, which begins operations in 1996, *Frontiers* describes the range of cutting-edge equipment and devices that make the U.S. Department of Energy national laboratories unique among research institutions.

In "Scientific Excellence and Leadership," the report looks at Argonne research programs that span the scientific disciplines – biology, chemistry, computer science, engineering, materials science, environmental science and physics.

"Serving the Region" examines another of Argonne's significant roles, as a provider of community service through education, technology transfer and outreach.

For more information on any of the stories in *Frontiers*, or any other aspect of Argonne research, contact Catherine Foster at 708/252-5580 (e-mail catherine_foster@qmgate.anl.gov) or Evelyn Brown at 708/252-5510 (evelyn_brown@qmgate.anl.gov). All current photographs in *Frontiers* are available in both color and in black and white; the historical photos, for the most part, are available only in black and white.

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TO OUR READERS

Fifty years ago, Winston Churchill delivered his "Iron Curtain" speech in Missouri. Scientists dedicated the first digital computer in Philadelphia. The United Nations held its first session in London. President Truman established the U.S. Atomic Energy Commission in Washington. And America's first national laboratory began operating near Chicago. The nation — and the world — have changed dramatically in the ensuing half-century. Yet that national laboratory — Argonne National Laboratory — continues to hold its place at the forefront of U.S. scientific and technological research for the benefit of society.

This year, 1996, marks both the end of our first half-century as a premier national lab, and the beginning of what I am confident will be a second half-century of unparalleled achievement. Accordingly, this commemorative issue of Frontiers highlights the lab's proud past and previews its exciting future. Today, the 5,000 men and women who are Argonne National Laboratory work with scientists and engineers across the nation and around the world. As we pursue some 200 research projects, our goals include: more stable and safer energy supplies; longer and healthier lives through medical breakthroughs; lighter, stronger, safer materials for home and industry; and continuing advances in physics, chemistry, biology and the other basic sciences.

All these goals are future-oriented, for such is the nature of science. In a sense then, Argonne already has entered the 21st Century — proud of our heritage, mindful of our accomplishments, yet focused as always on America's scientific and technological needs for tomorrow.



Alan Schriesheim
Director and Chief Executive Officer



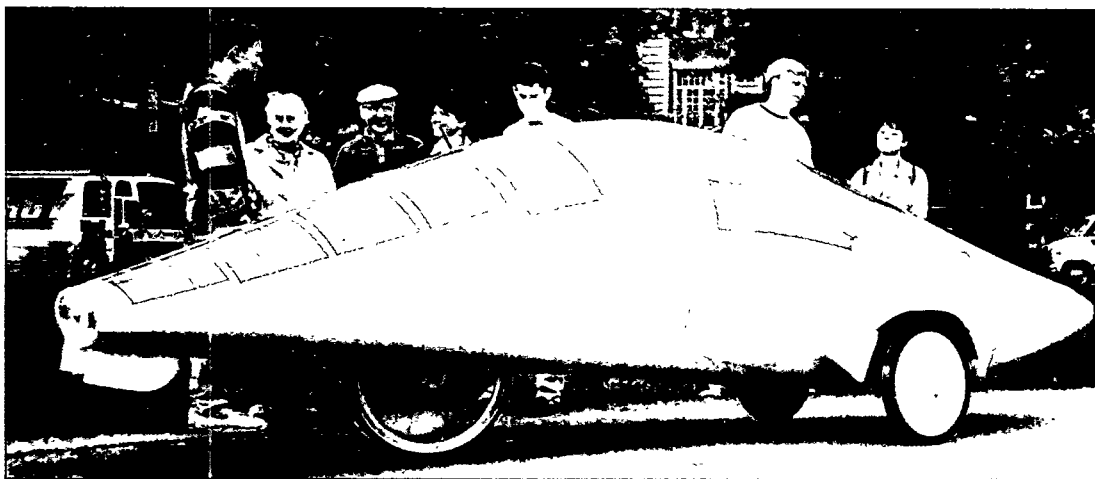
ARGONNE AND YOU IN THE YEAR 2046

Your personal robot wakes you in the year 2046. You tell your household computer to open a window, and you take a deep breath of clean, fresh air — despite the big factory just a half-mile away. The plant's emissions are continuously monitored by a device developed at Argonne National Laboratory that keeps pollution to a minimum. You make sure the solar cells on your window shades are correctly angled to capture the sun's beams and produce the electricity your home will use today. The solar cells, too, resulted from Argonne research. If your home doesn't need all that electricity right away, it can be stored for future use on a cloudy day without any loss of energy, because the storage device uses a frictionless superconducting flywheel — still another product of Argonne research.

You could stay home today, doing your work through an instantaneous, interactive computer link that virtually recreates your office — or your boss's office — in your home. Argonne's computer research and development has put all the information resources and communication tools you need at your fingertips, in a tiny computer linked to a mighty wireless international network — the "global village" that Marshall McLuhan envisioned years earlier. The virtual-reality panels on your walls and ceiling allow 3-D videoconferencing with your friends and professional colleagues around the world. They also let you take a break by playing the role of the hero in a medieval or futuristic adventure, or going on a virtual sailboat ride around an island in the Caribbean.

Instead, you decide to resist the temptation and go to the office. You could ride a pollution-free, smooth-riding people mover — nobody calls them "buses" anymore — that efficiently uses oxygen-enriched fuels, yet another research accomplishment from Argonne. Or you might commute on a superconducting levitated monorail that cleanly and efficiently travels across the state, carrying commuters at speeds of more than 300 miles an hour. Today, however, you choose to drive your electric vehicle to work. It can travel at high speeds over the Argonne-designed Intelligent Transportation System, which allows your car computer to plot and drive the quickest route, while you scan the electronic newspaper or read your e-mail.

And that's just the beginning of your day. Before it's over, you'll encounter the fruits of hundreds of other technical advancements whose origins lie in research done between 1946 and 1996 at Argonne National Laboratory. Read on — you'll find the seeds of your future inside this issue of *Frontiers*. We hope you like it.



In the year 2046 you could travel to work in a solar-powered vehicle programmed to drive the car on a route to avoid traffic jams thanks to Argonne research.

FRONTIERS

RESEARCH HIGHLIGHTS 1946~1996

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For more information, see Argonne's home page on the
World Wide Web via the Internet at "<http://www.anl.gov>".



FROM ICE CAPS TO THE APS

Walking through the dense woods, listening to nature's sounds — careful not to disturb a doe and her fawn feeding, upset a slithering snake, or trip over a buck's discarded antlers — you could be almost anywhere that Mother Nature holds sway. But just a few steps away from a pond filled with geese, proud swans, lily pads and green turtles, patches of daylight draw you closer to clusters of red brick buildings. And inside those buildings, some of America's leading researchers are busy recreating particles of matter not present since the Big Bang; developing devices to witness molecular chemical reactions; and seeking limitless sources of energy. Welcome to Argonne National Laboratory!

PAST ~ Argonne found its home in 1946 near Lemont, Ill., about 25 miles southwest of Chicago — along what used to be the storied Route 66 and before that was a major Indian trail. Now Argonne is a stone's throw from busy Interstate 55 — the Stevenson Expressway. More than 5,000 employees now work on nearly 1,700 acres, comprising what some regard as a mysterious place but which is, in fact, a world-class government laboratory whose research is no mystery but brings benefits to everyone. Argonne traces its origins to the World War II era, when Enrico Fermi and his colleagues were creating the first controlled self-sustaining nuclear chain reaction at the University of Chicago's Metallurgical Laboratory. But more than a century before this event, Chicago and its surrounding suburbs began their development almost as if in anticipation of Argonne's emergence as one of the nation's premier scientific research facilities, with ties throughout the United States and around the world.

GEOLOGICAL FORCES ~ Earlier still — more than 2.5 million years ago — geological forces endowed the midwestern United States with vast bodies of water, rich limestone and lush vegetation. During the Ice Age, huge sheets of ice covered North America — from New York to St. Louis. These frigid slabs extended to the Ohio Valley and covered most of Illinois. As the glaciers moved southward, they left behind tiny ponds, enormous lakes, moraines and flood plains that would bring people, trade and wealth into the Great Lakes region. Near the area that is now Argonne, plains drop steeply to the Des Plaines River, which carved out the hills and valleys of what is now the town of Lemont. And when the winds blew and the dust settled, grainy sediments left rich soil where mighty oak trees flourished.

A valuable, thick stone later used for construction was also deposited on the sea bottom: limestone. The fortitude of this stone was demonstrated by the Great Chicago Fire of 1871, when the Chicago Water Tower was one of a handful of buildings left standing.

EARLY RESIDENTS ~ The area's water, vegetation and wildlife drew Native Americans into what is now Illinois. From the 17th through the early 19th centuries, the Miami, Winnebago, Kickapoo and Potawatomi were just some of the tribes that populated this rich region. Throughout the years since then, many remnants of their dwellings, pottery and wells have been unearthed. The Potawatomis, one of the predominant tribes, lived in cone-shaped lodges covered with bark. They raised maize, or Indian corn, made maple syrup, and hunted buffalo, elk, bison, caribou, deer and waterfowl.

EXPLORERS AND IMMIGRANTS ~ Native Americans weren't the only people enjoying the region's riches. In 1673, two French explorers, Father Jacques Marquette and Louis Jolliet, paddled north of the Mississippi River via the Illinois and Des Plaines rivers. They traded cloth, beads, metal, ornaments, copper and other goods for Indian animal fur. The Indians also bought weapons, which they used in later battles between neighboring tribes. During the early 19th Century, Irish, English, Scottish, German and other immigrants emigrated westward to Illinois. Eventually the Native Americans lost their sovereignty, and their numbers dwindled. In 1848, the 96-mile Illinois and Michigan Canal, built on land obtained by the government in the 1816 Indian Boundary Treaty, opened the way for easy transportation between the cities of the West and East. This is also the land on which Argonne now stands. The immigrant farmers worked the land as diligently as the Native Americans had before them. They shipped corn, wheat, oats, potatoes and other goods via the I&M Canal until the railroads offered faster travel.



Some of the farmland which became the site of Argonne National Laboratory.

LEMONT ~ Lemont was incorporated in 1873 and took advantage of its proximity to Chicago, which was then and still is the hub of the Midwest and the crossroads of the nation. "No other town located within 25 miles of Chicago has such natural advantages as Lemont . . . good, pure water, healthful climate and fine building sites," read an 1898 inducement to draw builders to Lemont. In the 1940s, the inducement was world-changing research. Scientists and others traveled Route 66 by the busload to the government-reclaimed farmland, now turned into a research laboratory.



The snow-white fallow deer are a part of Argonne's landscape.

THE NASCENCE OF ARGONNE ~ Fermi's experiment on the squash courts under Stagg Field at the University of Chicago was referred to as Chicago Pile-1 (CP-1). After the initial experiments, the reactor was dismantled, reconstructed on a site southwest of Chicago near Palos Hills — a prudent distance from downtown Chicago — and renamed CP-2. The nearby "Argonne Woods" had been named for the Argonne Forest in France, a famous World War I battle site. In 1946, the Atomic Energy Commission was formed, and on July 1 of that same year, Argonne was designated as the nation's first national laboratory. A model for the U.S. national laboratory system, Argonne was the first government-funded organization to apply academic research and problem-solving methods in the national interest.

THE DEER ~ Two years later, Argonne moved six miles from its original site to the outskirts of Lemont, occupying what was eventually a 3,700-acre site purchased by the federal government from local residents. The lab's permanent home included a 200-acre rustic retreat which had been owned by Erwin Freund, the inventor of "skinless" casings for hot dogs. A friend gave Freund a herd of fallow (white) deer to roam his estate, and before moving, he sent most of the deer herd to game parks. But, as legend has it, two does remained, and at least one was pregnant with a buck. And while scientists were conducting research, the deer were proliferating. By 1965, the herd had grown to around 100 deer; and by the mid-1990s, both the fallow and native white-tailed deer herds had become so large that there was insufficient forage on the site to sustain them. Working with the U.S. Department of Agriculture, the Department of Energy undertook a wildlife management plan in the fall of 1995 to control the deer population at sustainable levels and to maintain the site's ecological integrity. Now several hundred white-tailed and fallow deer will be able to roam free and healthy on the grounds of Argonne. Fallow deer, or *Dama dama*, are normally found in North Africa, Europe and parts of Asia. They are born creamy tan with white spots and turn completely white naturally upon reaching their first year. Both species stand about 4 feet high at the shoulder.

THE SCIENTISTS ARRIVE ~ To expedite research in the lab's early days, Quonset huts, or white, half-moon shaped buildings, were quickly erected to temporarily house the staff. After a while, these became more-or-less permanent buildings, and a few are still standing. During the early 1950s, Argonne planted vigorous young pine seedlings to discourage erosion on the acres that had been farmland. This reforestation project protected the soil against snow and dust storms. Now there are more than one

million 20-foot tall pine trees on the site, upholding the legacy of Argonne's old-world namesake. In the late 1950s, Argonne erected substantial red brick laboratories and office buildings dedicated to the different scientific disciplines. Built around a quadrangle, the lab took on the air of a college campus.



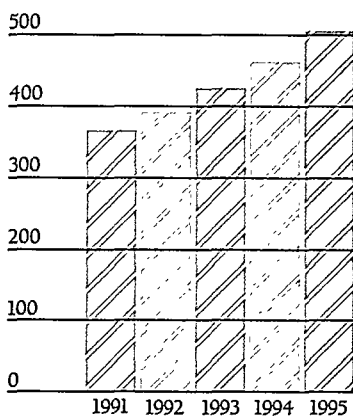
Argonne National Laboratory's main site near Chicago.

Argonne National Laboratory's facility in Idaho Falls.

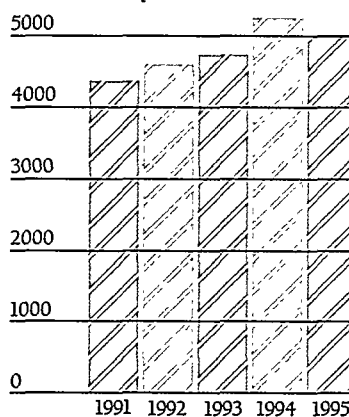
MODERNIZATION ~ The red-brick look was abruptly altered when Chicago architect Helmut Jahn was commissioned to design Building 201, which opened in 1982 as the new administration building and was dubbed "the hallmark for the future." The three-story aluminum building, complete with skylights, received national recognition for its modernistic design. Now another building on the Argonne landscape is sure to receive both national and worldwide recognition. Attached to a high-tech high-rise office building, the doughnut-shaped structure, some 3,500 feet in circumference, is home to Argonne's newest scientific gem—the Advanced Photon Source (see page 24). And just as the land on which Argonne stands has a rich history stretching back for millennia, there is every reason to expect that Argonne will continue to enrich, and illuminate, the world of science well into the next millennium.

ARGONNE TODAY ~ More than 5,000 people work at the lab and 1,775 of them are scientific and engineering professionals. Argonne has a reputation for assembling interdisciplinary teams of specialists and providing the resources for them to develop novel solutions to critical research and development issues. Argonne is operated by the University of Chicago for the U.S. Department of Energy.

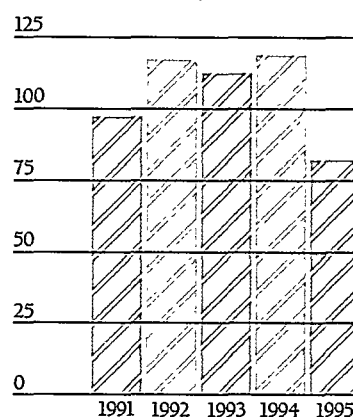
ANNUAL OPERATING BUDGET
(Millions of Dollars)



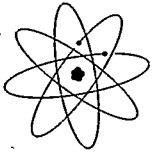
EMPLOYMENT
(Full-Time Equivalents)



CONSTRUCTION
(Millions of Dollars)



330 B.C.
Democritus develops
indivisible
atomic theory



1830
John Dalton advances
quantitative theory of atoms.

1842
Peligot discovers uranium

1895
Lorentz determines the
structure of atoms.

1897
Thomson discovers the
electron, disproving
Democritus' theory.



1905
Einstein's Special Theory
of Relativity published.



PROMETHEAN BOLDNESS:

ATOMS FORGE A SCIENTIFIC REVOLUTION

On December 2, 1942, fifty-plus men and a lone woman gathered in a squash court under the west stands of The University of Chicago's Stagg Field. Their mission was to find a way to bring a decisive end to World War II. They had joined in a great national collaboration to develop nuclear weapons ahead of the Germans. The sense of urgency was palpable. They knew what they were about to do would change the world — for better or for worse. Nonetheless, their work was in the true tradition



Argonne's first site in the Palos Hills Forest Preserve was located in the Argonne Forest area, giving the lab its name.

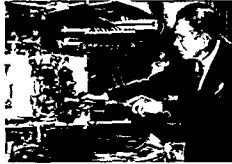


1911

Rutherford devises a nuclear model of an atom.

1932

Lawrence builds the first practical cyclotron.



Cockcroft and Walton split the atom.

1937

Bohr and Wheeler develop theory of nuclear fission.

1938

Hahn produces first nuclear fission.



1938

Fermi, Szilard, Zinn and others are the first in the U.S. to split the atom.

of pure science. As Robert Oppenheimer later noted: "It is a profound and necessary truth that the deep things in science are not found because they are useful; they are found because it was possible to find them."

Within three years, their scientific work led to the atomic bomb. Yet, the energy they unleashed also held great promise for peaceful uses. To harness that energy for that purpose, Argonne National Laboratory was created in 1946. The early nuclear fission research was built upon decades of scientific inquiry into the nature of the atom. Slowly, inexorably, its components were discovered, the mystery of its structure unlocked, its power harnessed. Throughout Europe and America, atomic physics moved from the realm of academic theory to applied research and development.

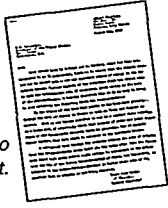


The University of Chicago's Stagg Field was the site of the first controlled self-sustaining nuclear chain reaction.

Until the 1930s, two subatomic particles were known: the electron and the proton. But there was reason to question the viability of the proton-electron nucleus. Many scientists believed the nucleus must contain an uncharged particle to compensate for the proton charge. And the atomic theorists were right. During the 1930s, the neutron was discovered; so were the positron and meson. And in 1938, nuclear fission was first accomplished in Germany. The atom was split. Four years earlier, the Italian physicist Enrico Fermi had unknowingly identified the same phenomenon but thought his "product" was new elements.

Meanwhile, Fascism and Nazism were on the rise in Europe. Between 1933 and 1941, more than 100 refugee physicists from Germany, Italy, Austria and Hungary fled to the United States and England. Among them were the most brilliant minds in science, including Albert Einstein, Enrico Fermi, Leo Szilard and Eugene Wigner.

1939
Szilard and Zinn confirm self-sustaining fission.



Einstein's letter to President Roosevelt.

1939
The Manhattan Project is established.

1942
MetLab is organized at the University of Chicago.

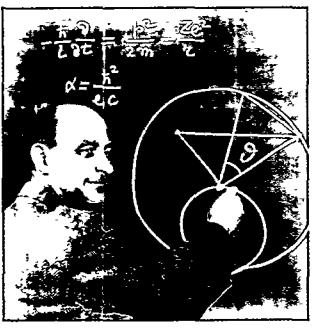
1942
CP-1, the world's first reactor, is built in the squash courts at Stagg Field.



THE "LAST UNIVERSAL SCIENTIST" TAKES CHARGE

In New York City in 1940, Enrico Fermi continued to conduct nuclear fission experiments at Columbia University. Fermi's team, including Leo Szilard and Walter Zinn, confirmed that absorption of a neutron by a uranium nucleus can cause the nucleus to split into two nearly equal parts, releasing several neutrons and enormous amounts of energy. The potential for a self-sustaining nuclear chain reaction had become a strong possibility.

With the 1938 discovery of nuclear fission, Germany had a two-year head start on developing nuclear energy; the Americans' fear was that the Nazis would shape it into a weapon of mass destruction. Germany also had in its grasp two materials critical to its development — heavy water and uranium. They were available in abundance only in Norway and Czechoslovakia, both under Nazi control. The emigré scientists urged the American scientific community to explore the potential for nuclear energy. They also urged caution and secrecy. The early fission experiments had been reported in the newspapers. Szilard urged American nuclear physicists not to publish their work. Germany must remain unaware of American progress.



ENRICO FERMI, PHYSICIST
The Last Universal Scientist

Arthur Compton recalled his visit to Columbia to invite Fermi onto the MetLab project: Fermi "stepping to the blackboard... worked out... simply and directly, the equation from which could be calculated the critical size of a chain-reaction sphere."

In August 1939, Szilard and fellow Hungarian physicists Eugene Wigner and Edward Teller urged Albert Einstein to sign a letter they had drafted for President Roosevelt. Einstein's letter noted that the work of Fermi and Szilard "leads me to expect that the element uranium may be turned into a new and important source of energy in the near future." President Roosevelt responded by appointing an Advisory Committee on Uranium. The Office of Scientific Research and Development was established on June 28, 1941, under the direction of Vannevar Bush, to develop atomic energy. On December 6, the day before the bombing of Pearl Harbor, Roosevelt authorized the Manhattan Engineering District. The decision to pursue the making of an atomic bomb had been made.

Bush organized the nuclear fission effort — code-named the Metallurgical Project — into three parts. Harold Urey headed uranium isotope separation at Columbia. Ernest Lawrence, who had built the first practical cyclotron, supervised electromagnetic separation of uranium-235 at Berkeley in California. Arthur Holly Compton, dean of physics at The University of Chicago, was put in charge of finding fissionable material at what would be called Chicago Pile-1 at the Metallurgical Laboratory, or MetLab.

1942

Fermi and his colleagues achieve the first controlled nuclear chain reaction.



1944

The first heavy water reactor is built at Site A, which became Argonne's original location.

1946

Argonne National Laboratory is chartered.



1948

Argonne is designated the lead laboratory for reactor research.



Albert Einstein



Arthur Compton



Leo Szilard



Eugene Wigner



Enrico Fermi



Walter Zinn

The collaboration of refugee scientists, the American government, and the American scientific community tackled the secret task of building the first atomic bomb.

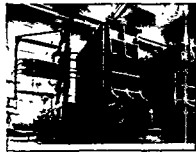
The task of building a pile for self-sustaining nuclear reaction was assigned to Fermi, by then considered the "last universal scientist." He was the perfect man for the job. He had intense personal drive and combined experimental skill with theoretical talent. He was simple, direct, and had a passion for clarity. He once said, "If I could remember the names of all these particles, I'd be a botanist."

Compton recalled his visit to Columbia to invite Fermi into the MetLab project: Fermi "stepping to the blackboard... worked out... simply and directly, the equation from which could be calculated the critical size of a chain-reaction sphere." He determined the amount of uranium-235 or plutonium needed to achieve a nuclear explosion.

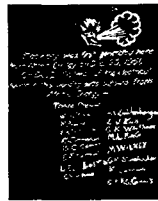
Although uranium and graphite were the materials used at MetLab, an actual bomb would need pure fissionable materials — pure uranium-235 or plutonium. Work continued on elements beyond uranium and on heavier elements. In March 1940, Glenn Seaborg (later chairman of the Atomic Energy Commission) co-discovered the transuranic element 94, plutonium. When it was isolated the following year, its plutonium-239 isotope promised to be more fissionable than uranium. Compton, in fact, believed that electromagnetic separation of uranium-235, under study at Oak Ridge, would be the fastest route to building a bomb.

Once control of a self-sustaining nuclear chain reaction became a probability, other scientific disciplines were brought into the pile project. Joining the team of physicists were chemists — including Seaborg and Frank Spedding — biologists, engineers, metallurgists, chemical engineers and health researchers. Compton hired one of his protégés, Norman Hilberry, as administrative assistant to, among

1950
The Argonne-developed Zero Power Reactor, the first submarine reactor, becomes operational.



1950
The first power-producing atomic reactor is established.



1951
The first usable nuclear electricity is produced.

1954
The first nuclear-powered submarine, the Nautilus, is launched.



other duties, receive “all kicks intended for the project leader, and carry through all the unpleasant tasks from which the project leader wants to escape.”

The search for a safe and adequate site for the pilot plant led Compton to the Palos Hills Forest Preserve, nearly 30 miles southwest of Chicago. A 1,000-acre tract in the Argonne Forest area of the preserve was deemed appropriate — it was named Site A. Because of construction difficulties, however, it was impossible to build even the first experimental pile there. Work on the first man-made atomic reactor was conducted at The University of Chicago. Space was found under the unused football stands of Stagg Field, in a converted squash court (the Soviets would later translate its name to “pumpkin field”). On everyone’s mind was Germany’s leadership in neutron research — and the need for utter secrecy. The race for the bomb had been joined.

PIGLET AND THE PUMPKIN FIELD



This drawing depicts the historic December 2, 1942 event: the first self-sustaining nuclear chain reaction.

The brilliant and eccentric Szilard didn’t like to get his hands dirty doing experiments. He had, however, an original mind, a flair for invention, and a genius for getting industry to provide materials — although Hilberry was in charge of actual procurement. Massive amounts of graphite and uranium were needed. There was only one significant source of uranium in North America and only one supplier of large quantities of graphite, a dirty and slippery carbon. Frank Spedding, by then at Iowa State University, produced two tons of pure uranium; additional uranium was delivered by Westinghouse Electric. Goodyear Tire constructed a square balloon in which to encase the final pile.



1954
The Atomic Energy
Act is signed.

1955
International School
of Nuclear Science
and Engineering
is established.



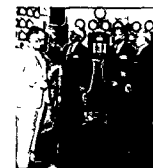
ZPR-3 is operational.

1955
Arco, Idaho becomes the
first town lighted
entirely by
nuclear power.



1957
Argonaut completed.

Experimental Boiling
Water Reactor dedicated.



CP-1 Scientists

The fourth Anniversary Reunion on the steps of Eckhart Hall, The University of Chicago, December 2, 1946. Back row, left to right: Norman Hilberry, Samuel Allison, Thomas Brill, Robert Nobles, Warren Nyer, Marvin Wilkening. Middle row: Harold Agnew, William Sturm, Harold Lichtenberger, Leona W. Marshall, Leo Szilard. Front row: Enrico Fermi, Walter Zinn, Albert Wattenberg, Herbert Anderson.

Work on the final experimental pile — the 31st — began on November 16, 1942. It was a prodigious effort. Physicists and staffers, working around the clock, built a lattice of 57 layers of uranium metal and uranium oxide embedded in graphite blocks. A wooden structure supported the graphite pile. Fermi was reading “Winnie the Pooh” to improve his English so the instruments were given names of characters in the Pooh stories — Tigger, Piglet, Kanga and Roo. A Fermi protégé, Leona Woods — the only woman on the project — took careful measurements as the pile grew. Fermi, stripped to the waist, was black and glistening; Hilberry said he could have played Othello.

December 2, 1942, the day wartime gas rationing began, was bitterly cold. The pile was ready for testing. It contained 22,000 uranium slugs and had consumed 380 tons of graphite, 40 tons of uranium oxide, six tons of uranium metal. It cost an estimated \$2.7 million. The experiment began at 9:45 a.m. More than 50 people were in attendance: Fermi, Compton, Szilard, Zinn, Hilberry, Woods; the young carpenter who built the graphite blocks and cadmium rods; members of the laboratory’s health and protection unit; students and other scientists. Just before noon, Fermi declared he was hungry and called time out for lunch. All minds were on the experiment, but no one discussed it. At 2 p.m., Fermi’s team was back at the squash court.

The three-man “suicide squad” — part of the automatic safety control system — stood by to douse the reactor if anything went wrong. There was a main control. And there was ZIP, a weighted safety rod devised by Zinn; it would automatically trip if neutron intensity became too high. There was an emergency ZIP, tied to the balcony rail, which Zinn operated by hand. And there was SCRAM — the

1960
Juggernaut completed.



1962
Van de Graaf accelerator
operational.



1966
Liquid Hydrogen Bubble
Chamber operational.

1966
Argonne Braille Machine
developed.

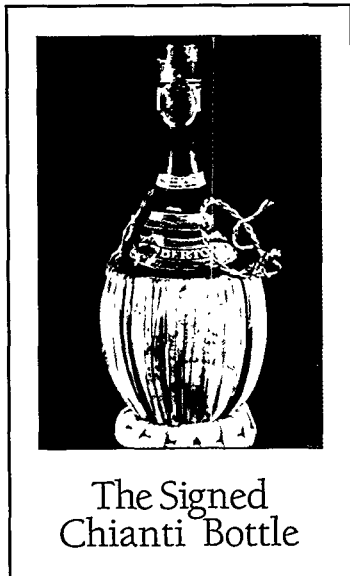
1977
The U.S. Department of
Energy is formed.



safety control rod ax-man. That was Hilberry. He stood ready, ax in hand, to cut the rope. "I felt silly as hell," he later recalled. "This was a lot of nonsense. We all knew the scientific work would be all right." At 3:53 p.m., a self-sustaining nuclear chain reaction was achieved for the first time ever. It had taken 28 minutes. Hilberry described it as "one of the birth certificates of the atomic age."

THE ITALIAN NAVIGATOR LANDS

It was a flawless execution — achieved one year ahead of schedule. Compton noted that the chain reaction was "slow enough to be controlled" and later recalled hearing the "sigh of relief from the suicide squad." "Atomic power!" he wrote. "It had been produced, kept under control, and stopped. The power liberated was less than that needed to light an electric lamp, but that power marked a new era in man's history."



Compton's phone call to James Conant, chairman of the National Defense Research Committee, was in code, though not a prearranged one: "The Italian navigator has landed in the New World." "How were the natives?" Conant asked. "Very friendly." Thus Compton conveyed his recognition of the success of the pile as the fastest way to harness nuclear energy. (The first Italian navigator discovered the New World in 1492; the second found another in 1942.)

Wigner brought a bottle of Chianti to mark the occasion; most of the MetLab scientists and crew signed their names to the wine bottle's basket. Toasts were drunk from paper cups, but the celebration was a muted one. All knew the next step was the bomb. There were other concerns. Were they the first to succeed? Had their secret been kept from the Germans? The secret *had* been kept — even from the wives of the scientists. At a social gathering a few days later, Laura Fermi noticed her husband being bombarded with congratulations. She wanted to know why, but no one would give her a reason. Woods finally whispered to her: "He has sunk a Japanese admiral!" When Laura Fermi asked her husband if that was true, he replied, "Did I?" The obvious next question was asked: "So you *didn't* sink a Japanese admiral?" Without changing his sincere expression, Fermi said, "Didn't I?" Laura Fermi would not learn of the events of December 2 for another two-and-a-half years. After its success with the chain reaction, parts of the Metallurgical Project moved to Oak Ridge, Hanford in Washington, and Los Alamos, N.M. There, the military aspects of devising a bomb went forward under the high-priority, \$2 billion "Manhattan Project" — the biggest national investment until mankind's voyage to the moon.



1981

High Voltage Electron
Microscope
dedicated.



1985

ATLAS, first superconducting
accelerator for heavy ions,
completed.

ALEX operational.

1987

Argonne becomes
the only national
laboratory that is
part of the National
Science Foundation
Center for Superconductor
Applications.



A HOME FOR HEFFALUMP AND POOH

The U.S. government's emphasis on "atoms for war" did not preclude interest in peaceful uses of atomic energy among nuclear scientists. They dreamed of new worlds where nuclear reactors would produce unbelievably cheap electrical power, a world in which nuclear science would revolutionize industrial production, medical practice and agricultural harvests. Fermi clearly recognized that nuclear fission would lead to ever-expanding peaceful applications that would surpass its military uses. Those remaining at MetLab at that time — including Fermi, Seaborg, Szilard and Zinn — began to investigate the civilian potential for nuclear fission and transuranic elements. As with later space technology, continuing research and what followed at Argonne would produce spin-offs of benefit to the population at large.

MetLab began moving to Site A at Palos Hills in February 1943. The facilities were renamed Argonne Laboratory for the woods that surrounded and secluded them. Fermi was the first division director of "Argonne Laboratory" — until he joined the Manhattan Project in Los Alamos in 1945 — and Zinn was his assistant. The reactor Chicago Pile-1 was dismantled, reconstructed at Site A and renamed Chicago Pile-2. The counting room at the one-building site contained instruments that were given whimsical names like Heffalump and Winnie the Pooh. According to Elmer Rylander, a scientist at the site: "A favorite pastime during the first winter at Site A was playing a game called 'peggity.' It involved moving wooden pegs on a board with a cross formation of holes. Fermi was its chief proponent."



Quonset huts were quickly set up at the lab site near Lemont, Ill.

On July 1, 1946, the laboratory was formally chartered as Argonne National Laboratory to conduct "cooperative research in nucleonics." It was a model for the U.S. national laboratory system: the first attempt to establish a new kind of scientific research institution — a government-funded organization that would apply academic research traditions to problem-solving in the national interest. Walter Zinn was its first director. A tall blond Canadian, Zinn was determined and self-confident; he was also

1989

First Cooperative Research and Development Agreement signed between Argonne and private industry.



1992

Structural Biology Center opened.



1996

Argonne's Advanced Photon Source dedicated.

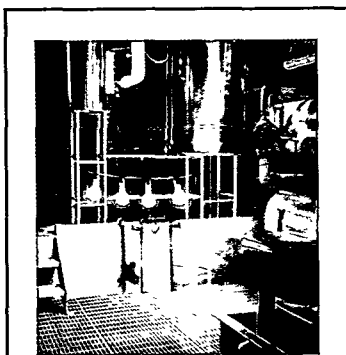


extremely demanding and tended to be hardheaded. Some of these attributes would stand him in good stead during the laboratory's formative years. Glenn Seaborg recalled the early days during the laboratory's 25th anniversary celebration: "The MetLab, then, provided a strong and valuable heritage for the new Argonne National Laboratory. The MetLab experience engendered a sense of mission and a standard of excellence which every great laboratory must have. Thus from its very origins Argonne has operated from a principle that others are only now beginning to understand — namely, that the scientists' responsibilities extend far beyond the technical data of the laboratory. These are worthy traditions."

The initial responsibility of Argonne National Laboratory was to study peaceful rather than military uses of atomic power. It was to conduct basic research in medicine and biology, physics, reactor analysis, applied mathematics, and nuclear engineering. On December 26, 1947, the laboratory's role was broadened considerably. At the request of the Atomic Energy Commission, Argonne assumed the development of reactors for the nation's nuclear energy program.

A new and much larger location at Lemont, Ill., six miles from Site A, became the laboratory's new home. Staff began moving there in August 1948. The following year, the National Reactor Test Site in Idaho was established to test various reactors — reactors with separate missions and with distinct personalities. A portion of this site is now Argonne-West.

REACTORS: MODERN-DAY ALCHEMY



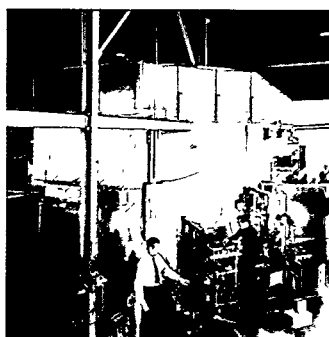
First electricity
from atomic
energy supplied
by EBR-1.
1951

Once a nuclear chain reaction was achieved, the role of the MetLab shifted to development of peaceful uses for nuclear power, especially electricity generation. Argonne National Laboratory, as the successor to MetLab, led the research that supports every main nuclear power system throughout the world. Continuing study of nuclear reaction continued to be of paramount importance in the lab's early days — properties of uranium, plutonium, and other nuclear elements; structural materials and coolants; nuclei and other atoms. Scientists from different disciplines worked to elucidate the process of fission — chemists, physicists, reactor designers. Chicago Pile-3, the world's first heavy water moderated reactor, was designed by Eugene Wigner. At Fermi's request, Zinn directed its construction in Illinois; it achieved criticality in 1944. Zinn also studied fast neutron reactors and designed the Experimental Breeder Reactor-I — originally called CP-4. Like the safety rod he devised for CP-1, it was nicknamed ZIP (this time meaning "Zinn's Infernal Pile") and built in Idaho at the National Reactor Testing Site.

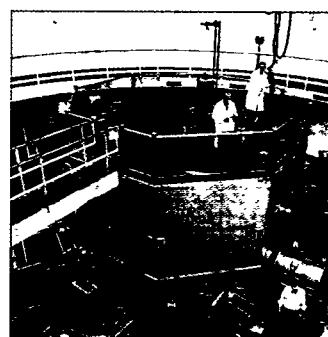




CP-2



CP-3



CP-5

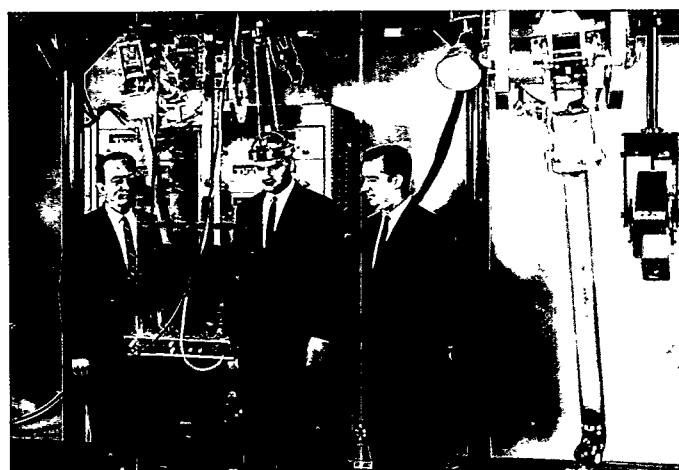
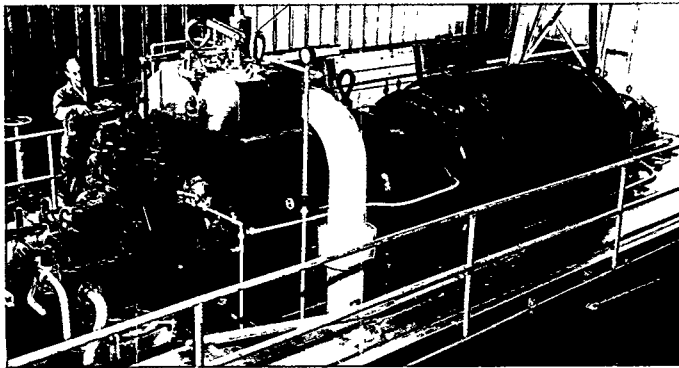
Argonne National Laboratory, as the successor to MetLab, led the research that supports every main nuclear power system throughout the world.

Among the earliest reactors designed by Argonne scientists was a pressurized-water submarine thermal reactor developed for Westinghouse in 1947. They designed and developed the reactor core for the world's first atomic-powered submarine and, in 1950, built and operated the first submarine reactor prototype, the Zero Power Reactor-I (ZPR-I). In January 1954, the *USS Nautilus*, the first atomic submarine, was launched. *Nautilus* introduced engines with virtually unlimited sources of power, allowing submarines to remain under water for indefinitely long periods and to travel at significantly increased speeds. The Argonne-designed reactor in the *Nautilus* lasted for 62,500 miles including a dramatic crossing of the Arctic Ocean in 1958. Its scientific mission determined that the ocean depth at the North Pole, two-and-a-half miles, was far greater than previously estimated.

In 1953, ZPR-II experiments at Argonne demonstrated the design feasibility of the Savannah River Production reactor in South Carolina. A decade later, the ninth in the series of zero power reactors, built in 1964, explored fundamental issues associated with full-size reactors. ZPR-9 provided data for nuclear rocket reactors and on the use of aluminum as a neutron reflector. The series of Zero Power Reactor experiments — including the Zero Power Plutonium Reactor on which physics studies were conducted — continued until 1982 when ZPR-6 was shut down.

The Experimental Breeder Reactor-I (EBR-I) achieved many benchmarks during its 14 years of operation. It was the first nuclear reactor to produce electric power when it lighted a string of four 150-watt bulbs on December 20, 1951; the next day 100 watts were generated. In 1953, it was the first reactor to demonstrate the breeder principle — generating, or “breeding,” more nuclear fuel than it consumed. It was the first, in November 1962, to achieve chain reaction with plutonium; and the first to demonstrate the feasibility of using liquid metals at high temperatures as a reactor coolant. EBR-I gained National Historic Landmark status in 1966.

Benchmark research in boiling water reactors began with a series of BORAX experiments in 1953, the year Argonne staff was fully established at the laboratory. In 1955 BORAX-3 produced enough electricity to light up the town of Arco, Idaho. The last of the BORAX series — BORAX-5, completed in 1964 —



(Top) Zero Power Plutonium Reactor. (Top middle) BORAX-3. (Lower middle) EBWR Facility. (Bottom) The Master-Slave Manipulator.

allowed scientists to evaluate and study nuclear heat concepts and to demonstrate actual nuclear super-heat operation. The BORAX experiments led to the construction and operation of the extremely stable Experimental Boiling Water Reactor (EBWR) in 1956. It proved that a direct cycle boiling water reactor system could operate, even at power levels five times its rated heat output, without serious radioactive contamination of the steam turbine.

EBWR, operated with a largely plutonium core, provided valuable information on plutonium recycle operation of water reactors — it generated plutonium-based electricity for Argonne's physical plant in 1966. When closed down the following year, EBWR had established a reputation as the forerunner of many commercial nuclear energy plants. One of those is the Commonwealth Edison facility at Dresden, Ill. In 1960, it became the first privately operated nuclear energy plant.

In the early 1960s, two major programs were underway — construction of the Experimental Breeder Reactor-II (EBR-II) in Idaho, and fast breeder reactor studies. EBR-II, an experimental fast breeder reactor power station of 20 Megawatt capacity, produced electricity *and* proved the feasibility of the closed fuel cycle. It thus demonstrated the potential advantages of using fast reactors for central station power plants.

The scientists' concept was a bold departure from traditional reactor design. The Experimental Breeder Reactor-II and its primary system components — including pumps, heat exchanger, instrumentation, and fuel handling system — were submerged in a large tank of sodium during operation. This pool, or pot, concept gained wide acceptance. The closed fuel cycle was also unusual. Basically, the Experimental Breeder Reactor-II was the first reactor to contain, as an integral part, a fuel reprocessing system that allowed spent uranium fuel to be removed from the sodium-cooled reactor, purified and made into new fuel elements, and then replaced into the reactor — the ultimate recycling, energy-saving, and waste



management system. All this modern-day alchemy was done by remote control from behind five-foot thick walls. The multi-disciplinary effort included chemical engineers who devised new chemical treatment methods; metallurgists who developed tools and techniques for making fuel pins; and engineers who designed and built remote viewing and handling devices. An early device, operational in 1949, was the "master-slave manipulator." A mechanism of bars, semi-universal joints, and claw-like hands for handling "hot" isotopes by remote control, it provided many applications for industries in which dangerous and corrosive chemicals were used. It also provided basic research into robotics.



(Far left) AEC Chairman Glenn Seaborg and President John F. Kennedy celebrate the 20th Anniversary of the first chain reaction. (Left) Glenn Seaborg and President Lyndon B. Johnson with one of the original light bulbs from the first use of nuclear power to produce electricity.

Experimental Breeder Reactor-II began operation in 1964. The turbine generator was synchronized and first delivered power to the Idaho test loop at Argonne-West on August 7. One-third of the core was filled with experimental subassemblies. Plutonium-uranium oxides, carbides and nitrides were among fuels tested to evaluate their performance after long exposure. The highest burnup attained was 13.8 percent in an oxide-type fuel, significantly higher than the usual 10 percent. By the end of 1970, the reactor had generated more than 250 million kilowatt-hours of electricity. During the first five years, the reactor's Fuel Cycle Facility processed 38,000 fuel elements, produced 366 subassemblies, and assembled 66 control and safety rods. In 1970 alone, nearly 20 reactor manufacturers and research organizations designed experiments based on EBR-II tests.

In the 1960s, the reactor program was reoriented from water reactors to liquid metal-cooled reactors. As the civilian power reactor program began to focus on the Liquid Metal Fast Breeder Reactor (LMFBR), the EBR-II function changed to a fast neutron irradiation facility. This was highly unusual — the reactor was converted from one mission to another not visualized in its original design. In essence, the success of the LMFBR was shaped by information garnered from the converted EBR-II. Ten laboratory units were virtually devoted to the Liquid Metal Fast Breeder Reactor — including fast reactor physics, development and testing of new fuels, irradiation testing, post-irradiation studies, fast reactor safety. In 1965, the testing facility confirmed their predictions with an initial output of 250 watts of power. Four years later, 1,000 Megawatt studies on LMFBRs had been completed.

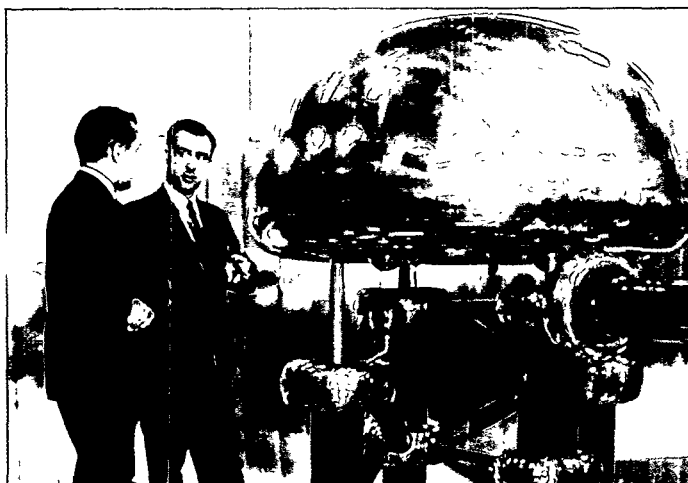
By the end of the 1970s, Argonne was geared for fast reactor development. At Argonne-West, in addition to EBR-II, support facilities included the Zero Power Plutonium Reactor physics studies; the Transient Reactor Test Facility, a versatile irradiation tool for producing extreme pulses of nuclear energy with

resulting high temperatures; and the Hot Fuels Examination Facility, which began operation in 1975 to examine highly radioactive experimental reactor fuel elements — and other components — all by remote control. EBR-II was converted again, beginning in 1982. The next generation reactor, the Integral Fast Reactor (IFR), was a major initiative in advanced reactor concepts. The IFR was designed to reprocess its own fuel and to burn up its own long-lived atomic wastes. The design allowed creation of energy from waste — not only its own waste, but also that used in commercial reactors as well as plutonium from dismantled nuclear weapons. The passive safety characteristics of metal fueled liquid metal reactors (LMRs) were clearly demonstrated and confirmed in 1986 with the conclusion of the Experimental Breeder Reactor-II landmark testing program. Other technical accomplishments included: development of metal fuels for LMRs capable of very high burnup — up to 20 percent; development of electro-metallurgical technology for possible applications to spent nuclear fuels, weapons plutonium, and LMR fuels; and performance of a series of safety-related transient reactor experiments which established the failure mechanisms, failure limits, and post-failure behavior of oxide and metal LMR fuels.

Work on this next generation of fast reactors — clean, resource-efficient, waste-reducing reactors — was halted by Congress in September 1994 as the laboratory's mission was redirected by the Department of Energy into the development of electrometallurgical technology for DOE spent fuel treatment, reactor and fuel cycle safety, and decontamination and decommissioning technology. By then, Argonne's original mission — to provide safe nuclear energy for civilian purposes — had been achieved.

EVOLVING MISSION: THE SYNCHROTRON ERA

By the mid-1950s, industry was becoming interested in nuclear power — a resource which had been virtually monopolized by the U.S. government by mandate of the Atomic Energy Act of 1946. In 1954, shortly after President Eisenhower proposed his Atoms for Peace program, the Act was broadened. Nuclear energy research began to move into universities and private industry. Argonne no longer



With the development of the Zero Gradient Synchrotron, Argonne became a user-orientated laboratory accessible to all sectors of society.

Director Albert V. Crewe explains the ZGS Cockcroft-Walton Preaccelerator.

concentrated on reactor science alone; it was turning into a multipurpose laboratory, with stronger ties to basic research than ever before. Ten years after Argonne was chartered, it began work on a high-energy research facility based on a weak-focusing synchrotron. In 1957, the Zero Gradient Synchrotron, a huge atom-smasher, was authorized. It was the beginning of a new era, changing Argonne from a virtual in-house “job shop” for the Atomic Energy Commission into a user-oriented laboratory accessible to all sectors of society.

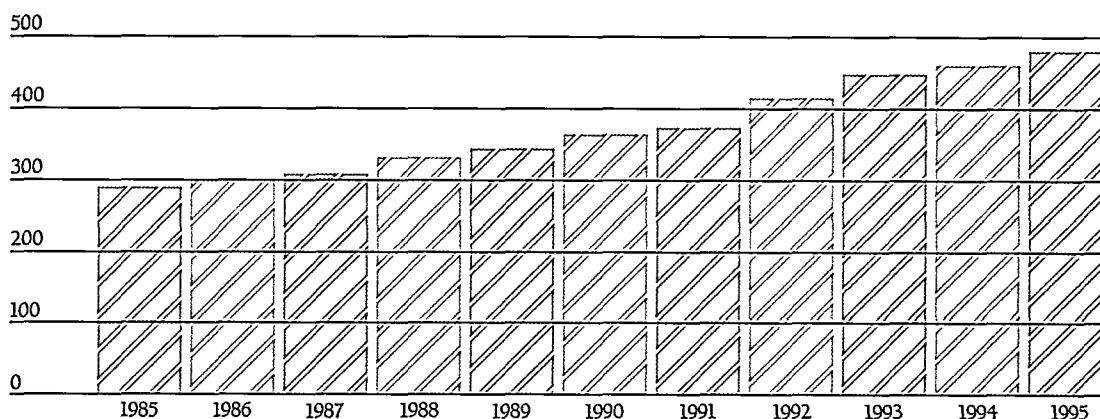
During the 1970s, the potential for non-nuclear energy sources grew, and the public’s concern with environmental issues deepened. The Breeder Reactor program, aimed at developing a reactor that produced plutonium faster than it consumed it, was expanded in 1973, during the energy crisis. In 1976, a demonstration breeder reactor plant on the Clinch River at Oak Ridge, Tenn., was endorsed by the Ford administration. Argonne scientists calculated the physics of large uranium and plutonium reactor cores, developed new instrumentation, tested fuels and materials, and assembled and simulated full-scale reactor cores for the Clinch River Breeder Reactor. In 1977, Argonne’s mandate began to expand to include non-nuclear research areas — advanced batteries, magnetohydrodynamics, solar energy collectors, heavy ion fusion.

Throughout the late 1970s and 1980s, Argonne scientists designed and built state-of-the-art facilities and achieved a high rate of innovation. The lab quickly earned a reputation for developing frontier technology in all areas of basic research. Nevertheless, nuclear reactors were becoming increasingly controversial, and their support in Washington was eroding. In 1983, the Senate stopped funding the Clinch River Breeder Reactor, a program that reflected 40 percent of Argonne’s budget. Its elimination meant severe cutbacks in budget and staff and a dilution of the laboratory’s mission.

1984~1996: YEARS OF RENEWAL

In the early 1980s, Argonne’s fate was very much in doubt. Devastating declines in funding, morale and staff had left the laboratory vulnerable and directionless. A special person was needed to reverse Argonne’s fortunes — someone with the management skills to arrest the declines, with the vision to propel Argonne forward and the credibility needed to be heard and believed. Just when the gloom hung thickest, such a person emerged. Not only did he come to Argonne, he stayed — becoming the longest-serving director in the laboratory’s history, retiring July 1, 1996.

LABORATORY FUNDING (Millions of 1993 Dollars)





At Argonne's Child Development Center in 1992, Anibal Taboas, DOE Argonne Area Office manager, and Beatrice Schriesheim help Charles Earl (left) and Michael Haggerty with building blocks.

With the demise of the Clinch River Breeder Reactor program and cutbacks resulting from policy changes that occurred as a result of Ronald Reagan's election, morale at Argonne plummeted. The lab had just lost the competition for an electron accelerator. The laboratory was believed to be in imminent danger of closure. The need to refocus the lab's mission and to develop a new portfolio of initiatives was essential.

Alan Schriesheim, a research chemist and top executive at Exxon Research and Engineering Co., became the first industry executive to head a national laboratory. His appointment to direct Argonne signaled a new emphasis on strategic initiatives. Schriesheim was faced with three

significant challenges: restructure the laboratory and undertake a campaign of fresh initiatives; increase funding and rebuild relations with Congress; and repair morale among a highly talented staff. He took a strategic approach, reorganizing the laboratory into "thematic" areas that brought projects together in more logical, interlocking groupings. He identified talented managers and established assistant directorships to run strategic divisions. He streamlined government relations and used his political savvy and Washington contacts to forge a strong relationship with Congress.

And he enlisted his wife, Beatrice, to help him with the critical morale-building effort. Schriesheim recalled the Argonne campus as "a grungy place" when he arrived in 1983. He asked his wife to get involved in the upgrade of the physical plant, believing it important for staff to take pride in their working environment. During the past decade, renovation projects have included the Freund Lodge, cafeteria and main auditorium, as well as numerous meeting rooms. The site was landscaped, and new signs ordered. The Visitors' Reception Center was erected. A much-needed child development center and program was put in place. Also, in order to enhance the sense of community, an Arts



Argonne's first four directors from left to right: Walter Zinn (1945-1956), Norman Hilberry (1957-1961), Albert V. Crewe (1961-1967), Robert Duffield (1967-1973) were photographed at a 1967 American Nuclear Society meeting.



Director Robert G. Sachs (1973-1979) with Dixy Lee Ray, Atomic Energy Commission chairman.

at Argonne program was initiated consisting of two elements: a chamber music series and a jazz and blues concert series.

Meanwhile, Schriesheim worked to increase funding for key programs: the Integral Fast Reactor, superconductivity, biology and biostructural science, environmental science and technology, and advanced computing among others. The lab's budget doubled and staff grew substantially as a result of the initiatives. Another goal, to couple basic research with commercial development, was accomplished through various initiatives including (with Walter Massey, the previous lab director) the establishment of ARCH Development Corp. — a joint venture with The University of Chicago. Most importantly, the strategic initiative thrust was rewarded when Argonne was chosen as the site of the Advanced Photon Source, a major national user facility involving industry, academia and the government. As Schriesheim later reflected, Argonne had become “a corporate laboratory for the nation.” As befits a major national institution, Schriesheim fostered strong ties between the lab and the educational community. This effort was highlighted by an innovative Chicago Science Explorers program developed with PBS newsmen Bill Kurtis. Schriesheim also concerned himself with the role of women and minorities and fostered the development of a women-in-science program which has been replicated in other labs.

He also rebuilt the lab's fragile infrastructure, which was not geared up to support major new projects. And he delegated. Once the lab's divisions were reorganized, talented managers were made responsible for their areas and were given the resources to run them. His intent was to make each thematic area “a tub on its own bottom.” This was especially true of the Advanced Photon Source — a lab within a lab — that Schriesheim believes “will span several generations of directors and changes of Washington administrations” (see page 24). The project's expected longevity looms even more critical in light of the 1994 Congressional decision to halt the lab's inherently safe, efficient, waste-recycling Integral Fast Reactor program just as it was on the verge of proving its capabilities. Nevertheless, Schriesheim believes, Argonne must continue to generate initiatives — more, even, than can possibly be funded — if it hopes to celebrate the anniversary of its *second* 50 years. As Schriesheim puts it, the laboratory “must undertake prime responsibility for its own survival.” With its long history of winning important programs and adjusting to change, there is every reason to believe that Argonne will continue to be an essential element of the U.S. science and technology resource base for many years to come.



Director Walter E. Massey (1979-1984) with President Jimmy Carter.

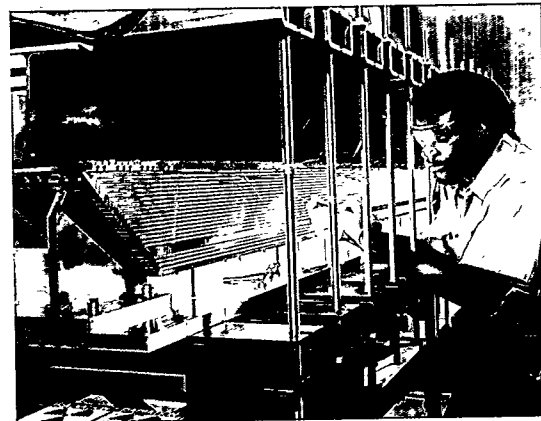


Director Alan Schriesheim (1984-1996) with Illinois Governor Jim Thompson at the Advanced Photon Source groundbreaking.



(Below) The Juggernaut reactor was a versatile research tool for Argonne scientists and students.

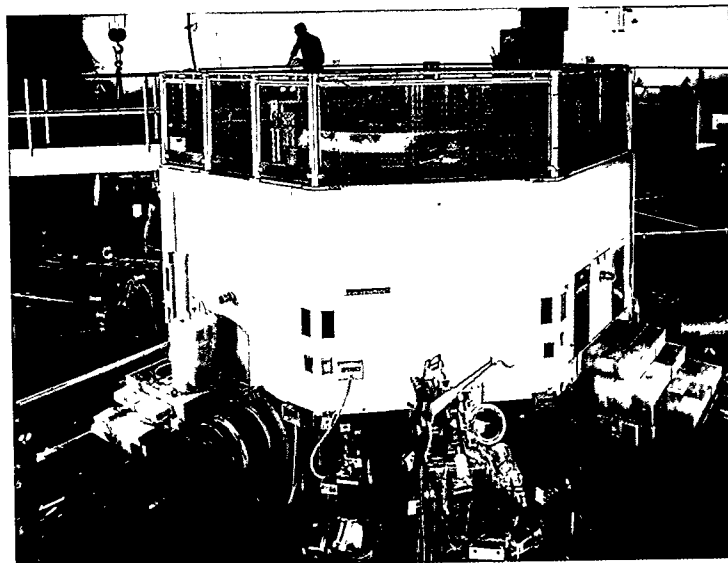
(Middle right) John Pace prepares a detector module for the HERA Colliding Beam Facility in Germany.



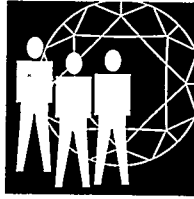
(Top left) Intense Pulsed Neutron Source neutrons reveal material structure that aids scientists in developing improved composites, ceramics and metals.

(Middle left) Advanced Photon Source Linac Group Leader Marion White verifies linac magnet alignment.

(Bottom) CP-5 was built in the 1950s to produce neutrons for research. It was the last in the Chicago Pile series — the first of which was built under the University of Chicago's Stagg Field.



THE LAB AND ITS RESOURCES



1800
Herschel discovers
infrared radiation.

1869
Maxwell proposes laws
of electromagnetism.

1888
Hertz produces first radio
waves.

1895
Roentgen discovers x-rays.

1801
Ritter discovers
ultraviolet radiation.

1889
Rutherford discovers alpha
rays and beta rays.

1897
X-rays first used for medical
diagnosis.



ADVANCED PHOTON SOURCE

X-RAYS REVEAL SECRETS BEYOND ROENTGEN'S IMAGINATION

On March 26, 1995, at 7:13 a.m., scientists and engineers at Argonne's Advanced Photon Source (APS) entered a new era in x-ray research with the production of "first light" in the facility. After nearly a decade of planning and building, APS produced x-ray beams for the first time. The x-rays came as the huge doughnut-shaped machine, large enough to encircle Chicago's Comiskey Park or Wrigley Field, entered a final phase of testing. When the APS revs up to full power early in 1996, it will produce the brightest x-rays available for scientific research in the world.

For 100 years, x-rays have been ideal for revealing what visible light can't, for seeing past "impossible" barriers. One of the first x-ray photographs allowed humans to see the image of a living skeleton for the first time. That photograph was taken in 1895 by William Roentgen, the physicist who had just discovered the strange new form of radiation. In the process of characterizing the rays, Roentgen found he could photograph balance-weights in a closed box, the chamber of a shotgun, and the bones in his

wife's hand. In the last century, scientists have come to depend on x-rays to reveal hidden details of the world around and within us. Within a few months of Roentgen's discovery, x-rays were being used as a powerful new tool in medical diagnosis. Scientists have since learned how to use the radiation to probe amazing intricacies: the atomic structure of biological molecules such as proteins or DNA, the chemical reactions and processes that occur as polymers and ceramics form, and even the atomic structure of some elements. One hundred years after Roentgen's discovery the APS will give the scientific community the most powerful x-ray beams ever created for these kinds of research, allowing scientists to probe more deeply and reveal more detail than ever before.



WILLIAM ROENTGEN, PHYSICIST
Discovered x-rays in 1895.

Within a few months of Roentgen's discovery, x-rays were being used as a powerful new tool in medical diagnosis. One hundred years after Roentgen's discovery the APS will give the scientific community the most powerful x-ray beams ever created for research.

Roentgen called his radiation "x-rays" because he understood so little about it. X-rays are no longer so mysterious. They are a form of electromagnetic radiation, very similar to the light that our eyes can see. All electromagnetic radiation, including radio waves, microwaves, visible light and x-rays, is made up of discrete packets of energy called photons. The photons travel (by definition) at the speed of light with different wavelengths and energies that characterize different kinds of radiation. X-rays have wavelengths much shorter than visible light. These shorter wavelengths can penetrate



1897
Thomson discovers
the electron.

1900
Rutherford discovers
gamma rays.



1913
W. D. Coolidge invents
the x-ray tube.

1917
Millikan measures
electron charge.

1923
Arthur Holly Compton
concentrates x-rays
using lenses
and mirrors.



1925
Rutherford discovers
the proton.



This aerial view of the Advanced Photon Source shows the storage ring bordered by office modules for researchers. APS offices are to the top right of the ring.

into and distinguish the details visible light can't, just as a sharp probe can fit into and characterize smaller shapes than a blunt one. This property makes x-rays uniquely useful in probing submicroscopic pieces of the world around us.

As scientists found more uses for x-rays, they also found a need for more powerful and dependable sources of the radiation. One of the best sources was a serendipitous one. In the 1960s, particle physicists were building huge "atom smashers" to try to discover the basic building blocks of matter. They accelerated charged particles such as electrons in huge rings to speeds as close to the speed of light as they could get. They wanted their particle beams to have as much energy as possible. But they had a problem. Their particles kept throwing off energy in the form of radiation. The atom smashers that produced the rays were called synchrotrons and so they called the nuisance "synchrotron radiation."

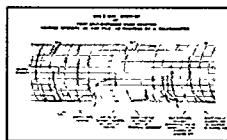
Though the laws of classical physics don't work quite the same way in atom smashers and particle accelerators, the early builders of these machines ran into much the same problem as a race car driver on the Indianapolis Speedway. It's easier to maintain high speeds (and high energies) on a straight-away. When a car slows down suddenly to squeal around a bend, it gives off energy in friction-generated heat

1934
First instruments for high-resolution measurements of absorption and emissions of x-rays in solids developed at Cornell University.



1934
Fermi suggests neutron's ability to split atom

1942
First sustained controlled nuclear chain reaction.

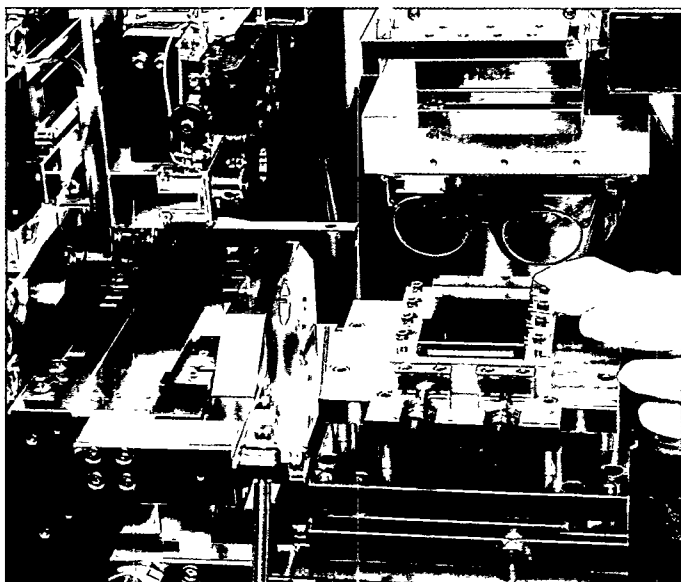


1946
Argonne National Laboratory founded.

1950
Zero Power Reactor operational.



Rows of "undulator As," specialized magnets that help direct the x-ray beam in the APS, await installation in the insertion device magnet measuring enclosure. Argonne technicians Renuka Apparao and Joe Morrison check out the devices.



The vacuum and mechanical housing for a double-crystal monochromator to be used in the APS is calibrated by Argonne scientist Wah-Keat Lee.

and sound waves. In a similar process, the physicists' particle beams kept slowing down around the curves. In the process of slowing down, they would give off energy in the form of x-rays, ultraviolet, infrared and visible light.

This problem for particle physicists, who wanted their particles to keep all the energy they could, was a boon to materials scientists and molecular biologists. Suddenly they had a new source of powerful x-rays. At first the x-ray researchers had to "piggyback" and work at the physicists' atom smashers. But by the 1980s, the scientific community recognized the value of synchrotron radiation and built a second generation of accelerators especially to produce the synchrotron x-rays. At Argonne National Laboratory, a third-generation facility, the APS, is nearing completion.

The APS will consistently produce "hard" x-rays, x-rays with extremely short wavelengths. In addition, the beams from the facility will be 10,000 times more brilliant than some second-generation sources. Brighter light reveals more details in structure and allows faster image-taking. A photographer attempting to photograph in dim light uses a slow shutter speed to allow time for more light to reach the photographic film. In bright light, much faster shutter speeds are possible. Often bright-light pictures are sharper, because they capture a shorter moment in time. In the same way, sharper, more detailed images of materials from proteins to ceramics will be possible with the brighter light of the APS.

With such fast picture-taking abilities, scientists hope they will even be able to make motion pictures of chemical processes in action. The radiation from the APS can be pulsed like a



THE MIGHTY MACHINES

1952

EDVAC, first computer with storage capabilities, invented.

1955

International School of Nuclear Science and Engineering established.



1956

Experimental Boiling Water Reactor built.



1957

ARGONAUT completed.

1960

Juggernaut built.

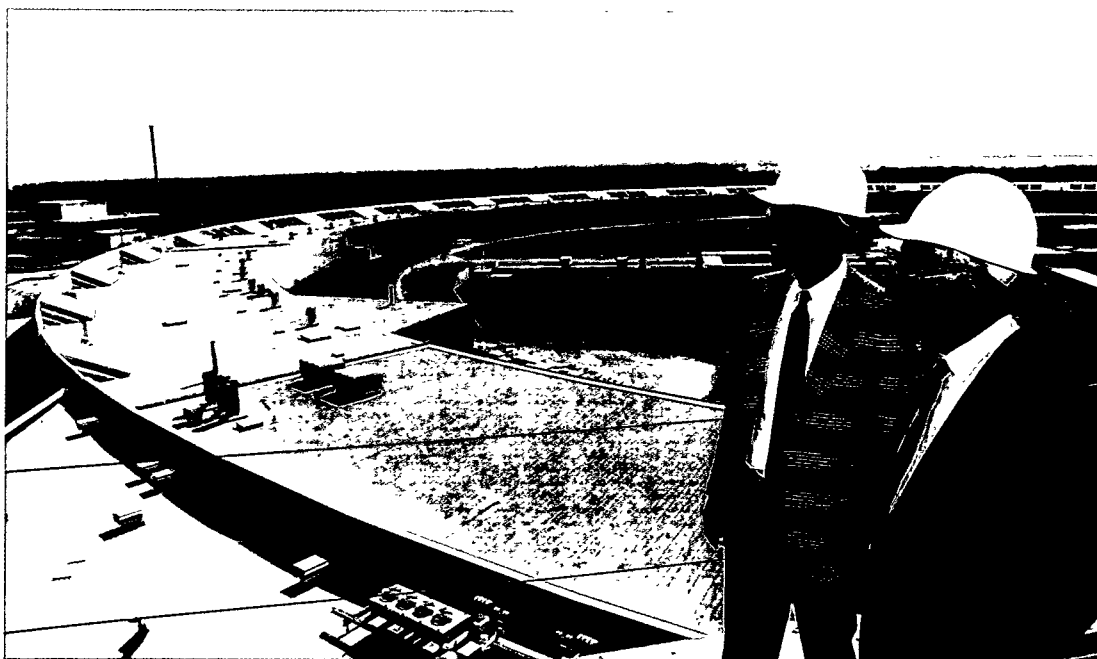
1963

Van de Graaf accelerator operational.



strobe light and will be able to capture images of the intermediate arrangements of atoms and molecules as they react with one another and change shape. Biological and medical researchers hope these microscopic movies will allow them to see the movements of every atom in an enzyme as it catalyzes a chemical reaction. These studies will not only increase science's knowledge of basic biochemical processes such as photosynthesis, DNA replication and protein synthesis, but they will also help molecular biologists design "smart" pharmaceuticals that can modify the actions of specific enzymes. Researchers from E.I. du Pont de Nemours and Co. plan to study how nylon and other synthetic fibers form during the spinning process. The structure of the fibers determines important properties such as its strength and flexibility and even the way the material takes up dye.

Discoveries made at the APS are expected to enhance the quality of everyday living and impact the nation's economic and technological future. Advances are predicted particularly in biotechnology, polymer and advanced materials, medical diagnostics, digital imaging techniques, semiconductor materials and microelectronic circuits. The focus at APS for the past five years (since groundbreaking in 1990) has been on developing, constructing and implementing the technology to make the machine work. Such bright x-rays have never been produced or controlled to the extent of those at the APS. The beam must be aimed within a tolerance of less than a micron — about one-tenth the thickness of a human hair. Argonne researchers have developed a device that can tell if the beam is on target while



Atop a neighboring building, David E. Moncton, associate laboratory director for the APS, and Laboratory Director Alan Schriesheim survey construction progress.

THE MIGHTY MACHINES

1963

ZPR-6 operational.



Argonne's
Maria Goeppert-Mayer
wins Nobel Prize.

1964

EBR-II completed.



1966

Liquid Hydrogen Bubble
Chamber operational.



1968

Argonne Braille Machine
developed.

1973

First successful test
of superconducting
linear accelerator.

withstanding the searing heat that the x-rays generate. In order to generate a constant intensity x-ray beam for long periods of time, the beam of charged particles must circulate through the storage ring without striking anything — even something as small as a gas molecule — or the positrons will scatter. The storage ring's vacuum system, developed at Argonne, will remove all but one atom out of every trillion present in normal atmosphere.

An intricate network of computers, wires and cables will allow just three or four people to control the entire facility once it is up and running. Computer scientists at Argonne and Los Alamos National Laboratory cooperated to develop the computerized control system that makes this possible. The system is so successful that it has been used to control more than 30 particle accelerators, telescopes and other experimental facilities all over the world. The pieces of the APS have come together on schedule and within budget, a remarkable feat for a seven-year, \$467-million project. As the facility nears completion, however, attention is turning to the real reason for the project: the research scientists will do using the beams. Scientists from 104 universities, 10 medical schools, 16 research laboratories including national labs and 37 industrial companies have formed research teams to use the facility (see page 30). They are eager to improve their old research techniques and develop new ones. The photograph of Bertha Roentgen's hand was only the beginning. The APS is sure to reveal the hidden structure of the world around us in ways William Roentgen and his successors in x-ray research could never have imagined.

HOW APS WILL ILLUMINATE RESEARCH

When the APS is fully operational, electrons will be produced in the electron gun (A) — see diagram on next page. They are injected into the electron linear accelerator (B), where they are boosted to energy levels of 200 million electron-volts and speeds near the speed of light. From there the electrons are aimed at the positron target (C), a thin wafer of tungsten that interacts with the electrons to produce electron-positron pairs. Positrons of appropriate energy levels are selected and injected into the positron linear accelerator (D), which raises their energy levels to 450 million electron-volts.

The positrons are accumulated into a small ring and then injected into the booster synchrotron (E), a circular accelerator in which the positrons are accelerated to an energy of 7 billion electron-volts — in one-third of a second — and then injected into the storage ring (F), located inside the experiment hall. The positrons orbit at 7 GeV around the storage ring, which has a 1,104-meter (7 mile) circumference, 271,739 times each second.

In order to generate a constant intensity x-ray beam for long periods of time, the positron beam must circulate through the storage ring without striking anything — even something as small as a gas molecule — or the positrons may be scattered and lost from the beam. The storage ring's vacuum system will remove all but one atom out of every trillion present in normal atmosphere. The storage ring and





1981
Intense Pulsed Neutron Source operational.

High Voltage Electron Microscope dedicated.

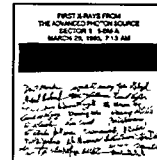
1984
IPNS fires one billionth pulse.

1985
ATLAS, first superconducting accelerator for heavy ions, completed.

1986
Conceptual design for the Advanced Photon Source is completed and approved by DOE.

1990
Ground broken at APS site.

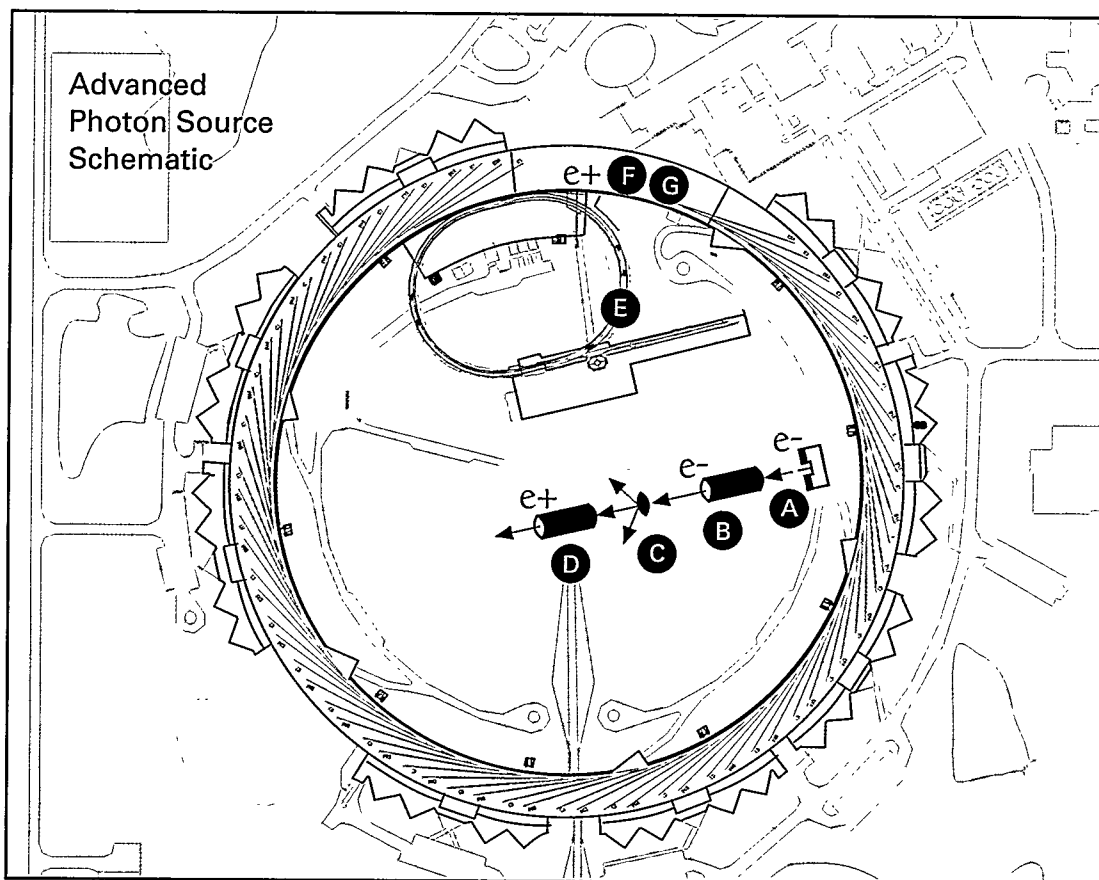
1995
First light shines at APS.



experiment hall are divided into 35 sectors where beamlines originate and research can be performed. Each sector will be managed by the scientists in one of the APS Collaborative Access Teams.

One of the two beamlines in each sector originates at a bending magnet, where positrons emit synchrotron radiation that exhibits a broad distribution of energies. The other beamline in each pair begins at an insertion device (G) – linear arrays of magnets alternating in field direction.

Insertion devices are central to the enhanced capabilities of the APS. They vibrate the positron beam, causing it to emit photons at a certain energy each time the beam is bent back and forth, thereby increasing the brilliance of the x-rays produced. Insertion devices can be configured either as “wiggler” magnets or “undulator” magnets, depending on the degree to which they move the positron beam. Wiggler magnets produce very intense, energetic radiation over a wide range of energies, while undulator magnets yield radiation of selected energy at high brilliance. These tuned x-ray beams are further processed by optical instrumentation before they illuminate the sample being studied.





Northwestern University professor Panayotis Georgopoulos and Argonne technician Cynthia Bresloff prepare for research to begin at Argonne's Advanced Photon Source. Georgopoulos is director of the DuPont-Northwestern-Dow Collaborative Access Team.

APS RESEARCH: A TEAM EFFORT

The Advanced Photon Source (APS) was designed and built as a national research facility. Since 1983, potential users from various scientific disciplines have been helping design the facility to meet their needs. They have provided ideas about important technical and nontechnical issues ranging from the type and quality of the radiation desired to the environment in the experiment hall. While the APS was under construction, hundreds of researchers from companies, universities and research laboratories formed research-specific groups, called Collaborative Access Teams (CATs), to exploit the scientific potential of the brilliant APS x-rays. CATs are responsible for the design, construction, funding and operation of beamlines designed to take radiation from the APS storage ring and tailor it to meet specific experimental needs.

The partnership between the APS and the CATs represents a unique collaboration between the federal government and the scientific community. The U.S. Department of Energy's Office of Basic Energy Sciences funded the \$467 million APS facility at Argonne to produce the radiation; the CATs provide the money — approximately \$180 million initially — to build beamlines and

research instruments. CAT funding comes from several sources, including the U.S. Department of Energy, state legislatures, the Canadian government, the U.S. Department of Agriculture, the National Science Foundation, the National Institutes of Health, the National Institute for Standards and Technology, universities, foundation grants and private companies.

As of fall 1995, 15 CATs (representing 37 industrial companies, 104 universities, 10 medical schools and 16 research laboratories such as national labs and others) had survived a rigorous selection process and were either preparing for or beginning APS beamline construction. Eight CATs were in residence at Argonne. The selection process began in 1990 with the submission of Letters of Intent to form CATs. The letters described the proposed research, with emphasis on the need for the unique qualities of APS radiation; the beamline configuration; and potential funding sources. Thirty-five letters were reviewed by an international scientific panel. Twenty-three prospective CATs were invited to submit full proposals, 21 of which were eventually submitted. Following an extensive, international, peer-reviewed process, 15 proposals were approved. To be approved for beamline construction and operation, each CAT must also obtain funding to build its beamlines, which cost from about \$2 million to \$10 million each. The CAT and the APS then jointly sign a Memorandum of Understanding, which specifically outlines APS and CAT responsibilities. To date, 12 of the 15 CATs have signed these agreements.

The CAT/APS partnerships provide outstanding opportunities for scientists from different institutions, disciplines and career stages to work together. University professors and students will interact daily with colleagues from industry and national laboratories, exchanging ideas both formally and informally through research collaborations, seminars and impromptu discussions. These interactions should pay high dividends in enhanced research quality and scientific productivity.

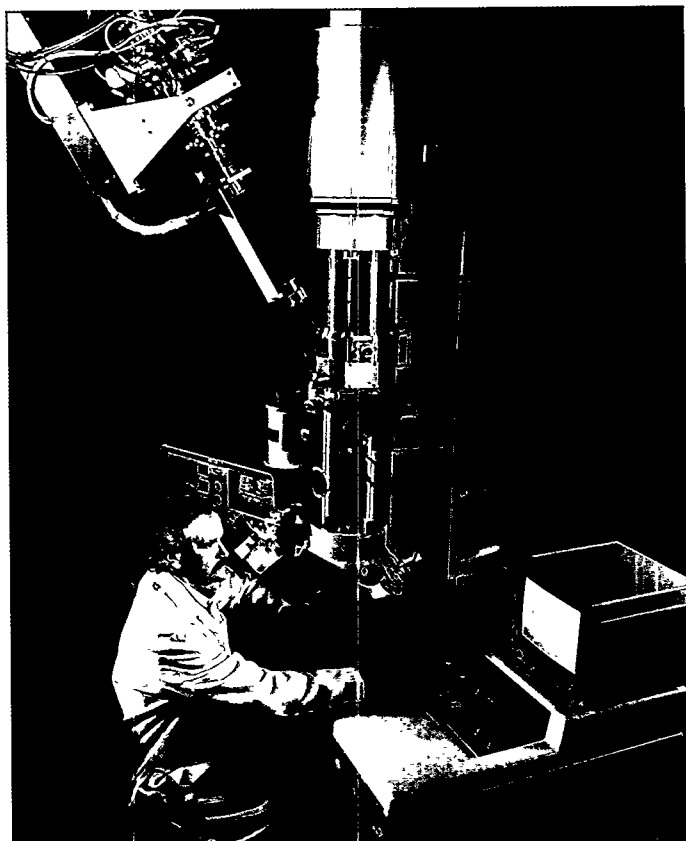


CAT/APS PARTNERSHIPS

- **THE BASIC ENERGY SCIENCES SYNCHROTRON RADIATION CENTER CAT (BESSRC-CAT)**
Plans research in materials science, chemistry, environmental research and atomic physics. Principal partners include the Materials Science, Chemistry and Physics Divisions of Argonne National Laboratory and the Physics Department of Northern Illinois University.
- **THE BIOPHYSICS CAT (BIO-CAT)**
Will study the structure and dynamics of biological systems at the molecular level. The principal institutional member is the Illinois Institute of Technology, but research collaborators come from at least 14 other institutions.
- **THE CONSORTIUM FOR ADVANCED RADIATION SOURCES CAT (CARS-CAT)**
Is a multi-disciplinary group (structural biology, geology, agricultural science, chemistry and materials science) managed by The University of Chicago. This CAT includes more than 140 principal investigators.
- **THE COMPLEX MATERIALS CONSORTIUM CAT (CMC-CAT)**
Focuses on the structural characterization of complex materials including complex fluids, self-assembling systems and heterogeneous materials. Exxon Research and Engineering, Brookhaven National Laboratory, Princeton University, The University of Pennsylvania and Oak Ridge National Laboratory are its major members.
- **THE E.I. DU PONT DE NEMOURS & CO.-NORTHWESTERN UNIVERSITY-
THE DOW CHEMICAL COMPANY CAT (DND-CAT)**
Will deal principally with materials science and engineering and polymer science and technology.
- **THE INDUSTRIAL MACROMOLECULAR CRYSTALLOGRAPHY ASSOCIATION CAT (IMCA-CAT)**
Is a consortium of 11 pharmaceutical companies — Abbott Labs; Bristol-Myers Squibb; Eli Lilly and Company; Glaxo Research Institute; Merck & Company; Miles, Inc.; Monsanto/Searle; Parke-Davis; Procter & Gamble; SmithKline Beecham; and The Upjohn Co. Both fundamental and proprietary research in structural biology will be conducted, with a focus on designing new, improved drugs.
- **THE IBM-MASSACHUSETTS INSTITUTE OF TECHNOLOGY-MCGILL UNIVERSITY CAT (IMM-CAT)**
Will study dynamic phenomena in materials science and physics.
- **THE CENTER FOR REAL-TIME X-RAY STUDIES CAT (MHATT-CAT)**
Plans to study materials under real, dynamic conditions. The University of Michigan, Howard University and AT&T Bell Laboratories are the principal institutional partners.
- **THE MICRO-INVESTIGATION OF COMPOSITION RESEARCH ORGANIZATION CAT (MICRO-CAT)**
Will build a microprobe facility with applications in the fields of materials science, chemistry, geochemistry, environmental science and medicine. The principal investigators are from Oak Ridge, Lawrence Berkeley and Lawrence Livermore national laboratories.
- **THE MATERIALS RESEARCH CAT (MR-CAT)**
Plans several types of studies of materials. Institutional members include the University of Notre Dame, Argonne's Chemical Technology Division, the University of Florida, the Illinois Institute of Technology and Amoco.
- **THE MIDWEST UNIVERSITIES CAT (μ -CAT)**
Will study magnetic x-ray scattering, surface and interface scattering, microdiffraction, and bulk and surface phase transitions. Principal partner institutions include Ames Laboratory, Iowa State University, Kent State University, the University of Missouri at Columbia, Georgia Institute of Technology, the University of Wisconsin at Madison, and Washington University.
- **THE PACIFIC NORTHWEST CONSORTIUM CAT (PNC-CAT)**
Includes scientists from Washington state and Canada who are planning research in environmental analysis, materials and structural biology. Major member institutions are Pacific Northwest Laboratory, the University of Washington, Simon Fraser University, the University of Alberta and the University of Saskatchewan.
- **THE STRUCTURAL BIOLOGY CENTER CAT (SBC-CAT)**
Will operate as a national center for research in the determination of protein structures through macromolecular crystallography. It is managed through Argonne's Center for Mechanistic Biology and Biotechnology.
- **THE SYNCHROTRON RADIATION INSTRUMENTATION CAT (SRI-CAT)**
Focuses on developing new instrumentation and techniques for the synchrotron radiation community. Although the major developers are APS researchers, scientific partners come from other national laboratories, industry and universities.
- **THE UNIVERSITY-NATIONAL LABORATORY-INDUSTRY CAT (UNI-CAT)**
Plans cross-disciplinary studies in materials science, structural crystallography, physics, chemistry, chemical engineering and geology. The University of Illinois is the managing institution; other partners include Oak Ridge National Laboratory, the National Institute of Standards and Technology and UOP Company.

IRRADIATING ATOMS

ELECTRON MICROSCOPES AID STUDY OF IMPROVED MATERIALS



To develop new materials, Charlie Allen uses Argonne's newest electron microscope to fire atomic particles into samples of materials to watch changes as they occur.

Scientists shooting charged atomic "bullets" at their lab samples aren't testing futuristic weapons — they're developing improved materials. In Argonne's High Voltage Electron Microscope (HVEM)-Tandem Accelerator National User Facility, university and industry researchers as well as Argonne scientists and engineers use ion beam accelerators connected to electron microscopes to fire atomic particles into samples in order to see the microscopic changes produced by ion irradiation. Such irradiation may greatly improve or drastically worsen material properties and practical usefulness. As a national resource, the HVEM-Tandem facility allocates more than two-thirds of its experimental time to scientists from universities and industry for studies of various materials, including metals, semiconductors and ceramics.

In 1995, Argonne scientists welcomed a new addition to the facility — an intermediate voltage electron microscope (IVEM) which is also connected to the ion accelerator. These hybrid instruments — the HVEM and the IVEM with the attached ion accelerators — are the only ones of their kind in the Western hemisphere. The IVEM was booked solid for experiments by irradiation

effect scientists from around the world even before the IVEM was fully installed because of its high resolution for imaging. Studies performed with the IVEM could lead to more efficient high temperature superconductors — materials that carry electricity without resistance — and safer storage materials for nuclear waste.

Both the IVEM and the HVEM are connected to a tandem accelerator that shoots charged atoms of varying energies into material samples. Scientists view the material samples through the microscope while the samples are being bombarded with fast ions, a treatment known as in situ irradiation. The IVEM provides an image of the physical consequences of bombardment, which is roughly ten times sharper than the HVEM would provide. With this improved resolution capability, scientists may distinguish even small clusters of atomic defects — similar to distinguishing individual trees in a forest that is hundreds of miles away. To prevent interference due to vibrations, the IVEM room is sound insulated, and the instrumentation is vibration-isolated.

Researchers using the facility might observe the structural phenomena which contribute to the failure of nuclear reactor materials with the bombarding ions playing the role of neutrons. Or, with such

irradiation treatment, the user might watch the sample as it is converted to some completely unnatural state. For example, during this process a metal which is crystalline to begin with might be converted into an amorphous glass. In these experiments scientists control such variables as sample temperature and stress and the energy of the bombarding ions.

The HVEM-Tandem Facility is part of Argonne's Electron Microscopy Center for Materials Research. The center's seven transmission electron microscopes offer a variety of analytical techniques to improve materials such as the metals and semiconductors in today's computers or aircraft composites, as well as to better understand a host of basic phenomena which may find practical application decades from now. In the not-too-distant future, such resources may be operated by university and industrial researchers from their own office work stations via a computer network, eliminating the costs in time and money for travel to such state-of-the-art facilities.

ARGONNE USER FACILITIES

ACOUSTIC LEAK DETECTION LABORATORY	INERT ATMOSPHERE DIAGNOSTIC ANALYSIS FACILITY
ACOUSTIC/ULTRASONIC LABORATORY	INFRARED IMAGING LABORATORY
ADVANCED PHOTON SOURCE	INTENSE PULSED NEUTRON SOURCE
ANALYTICAL CHEMISTRY LABORATORY	LASER APPLICATIONS LABORATORY
AQUEOUS, GASEOUS AND LIQUID METAL CORROSION FACILITY	MAGLEV TEST FACILITY
ARGONNE LIQUID METAL EXPERIMENT (ALEX)	MAGNETIC RESONANCE IMAGING FACILITY
ARGONNE WAKEFIELD ACCELERATOR	MIDWEST AREA DETECTOR
ATLAS HEAVY-ION ACCELERATOR	MILLIMETER-WAVE/MICROWAVE LABORATORY
ATMOSPHERIC FIELD MEASUREMENT FACILITY	MIXING COMPONENTS TEST FACILITY
AUTO SHREDDER RESIDUE LABORATORY	NEUTRON RADIOGRAPHY REACTOR
^{60}Co SOURCE (50,000 CURIES)	PLASTICS/ORGANIC CHEMISTRY LABORATORY
BATTERY AND FUEL CELL USERS TEST FACILITY	PREMIUM COAL SAMPLE FACILITY
BIOPROCESSING AND WASTE TREATMENT LABORATORY	PULSED ELECTRON LINAC
DRY ROOM FABRICATION AND EXAMINATION FACILITY	SLURRY HEAT TRANSFER FACILITY
ELECTROCHEMICAL ENERGY STORAGE ANALYSIS AND DIAGNOSTICS LABORATORY	SMALL CHANNEL FLOW AND HEAT-TRANSFER TEST FACILITY
FACILITY FOR HIGH-SENSITIVITY MAGNETIZATION MEASUREMENTS	STRUCTURAL BIOLOGY CENTER
FLOW-INDUCED VIBRATION TEST FACILITY	SUPERCONDUCTIVE CERAMIC PROCESSING AND APPLICATIONS LABORATORY
HIGH-PERFORMANCE COMPUTING RESEARCH FACILITY	SURFACE ENGINEERING LABORATORY
HIGH-PRESSURE FLUIDIZED BED COMBUSTOR	THERMAL SCIENCE LABORATORY
HIGH-TEMPERATURE FATIGUE, CRACK PROPAGATION AND MECHANICAL PROPERTIES TESTING LABORATORY	TRIBOLOGY LABORATORY
HIGH-VOLTAGE ELECTRON MICROSCOPE-TANDEM FACILITY	UNVENTED WASTE REACTOR
HOT FUEL EXAMINATION FACILITY	3-D MICROFOCUS X-RAY COMPUTED TOMOGRAPHY LABORATORY
	2-MEV VAN DE GRAAF ACCELERATOR
	3-MEV VAN DE GRAAF ACCELERATOR
	5-MV DYNAMITRON FACILITY

ONE-OF-A-KIND

IPNS PROVIDES POWERFUL PARTICLES FOR RESEARCH

A new composite material that could be used to build aircraft that will fly at twice the speed of sound and new ways to improve petroleum recovery in oil fields are only two among many promising areas of study now being pursued at Argonne's Intense Pulsed Neutron Source (IPNS). IPNS is one of the nation's most powerful sources of neutrons for studies of the atomic and molecular structure of liquids and solids. Neutrons, uncharged particles found in the center of most atoms, are special in their ability to penetrate a material and provide information about its structure. Knowing a material's structure helps scientists understand its properties and behavior.

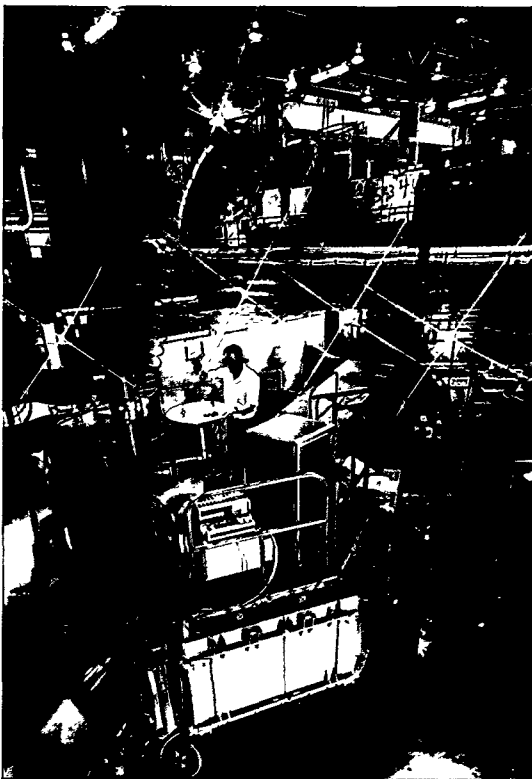


A neutron's-eye view of the interior of the newest IPNS scattering chamber shows John Hammonds at work.

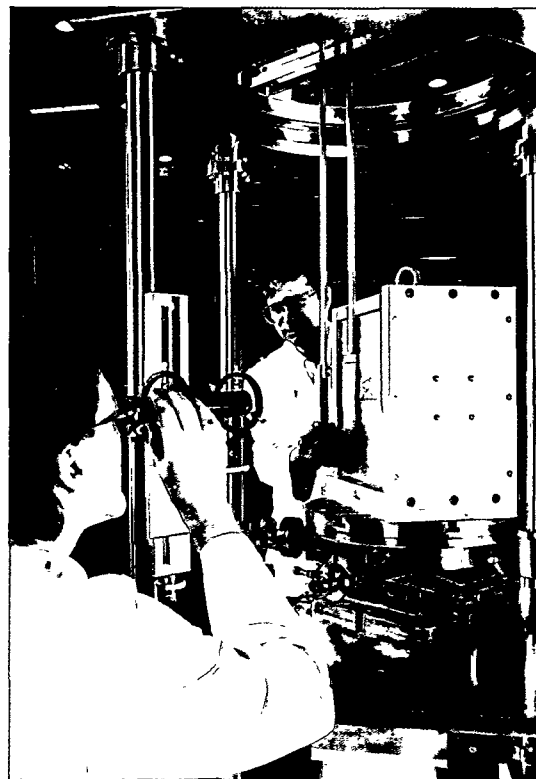
To create the neutrons, protons are fired at a uranium source which boils off neutrons in an intense beam in a process called spallation. The neutron beams are used to study a variety of industrial and biological materials. The IPNS has one-of-a-kind instruments to study glasses, liquids and polymers in new ways never before performed.

For example, the High Speed Civilian Transport, expected to travel at Mach 2.5, would be manufactured using a special composite — ceramic fibers embedded in a metal matrix. This approach makes materials lighter in weight yet able to withstand high temperatures. Neutron diffraction techniques developed at IPNS have been applied to determine residual stresses in these kinds of advanced metal-matrix composites. Capabilities available only at the IPNS are used to measure simultaneously the stress states of the fibers and metal matrix in different orientations. Neutron diffraction is the only nondestructive analytical technique capable of providing the data needed to optimize design and fabrication criteria based on computer models for this type of application.





Argonne's Intense Pulsed Neutron Source is the only operating spallation neutron source in the nation.

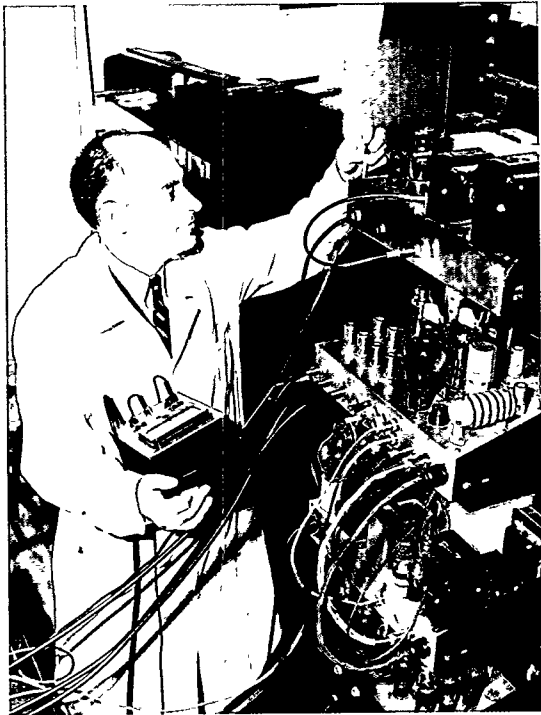


Jim Richardson (left) and Dave Kupperman prepare a section of cladded steel, like that used in nuclear reactor pressure vessels, before testing it in IPNS.

In another example, Argonne is collaborating with Exxon, the University of Pittsburgh and the University of Maryland in research to understand the difference in behavior of liquid mixtures in bulk and in a porous medium — for example, oil embedded in sandstone. The objective is scientific knowledge that may enhance petroleum recovery.

Experiments at the IPNS have examined differences in the phase separation behavior of a mixture of two liquids (water and 2,6-dimethylpyridine), both in bulk and in porous vycor glass which simulate sandstone. These studies clearly showed that the behavior of the two-component liquid in bulk is different from its behavior in nature. This knowledge is laying the foundation for developing new strategies for enhanced oil recovery.

IPNS — the nation's only operating neutron spallation source — is open to researchers around the world. During 1995, 199 scientists performed 242 experiments. Non-Argonne scientists conducting research at IPNS included 12 from industry, 83 from universities, 33 from foreign nations, and 16 from other government laboratories. Over 3,000 experiments have been performed at IPNS since it opened for users in 1981.



(Left) Enrico Fermi tests electronic controls for a neutron chopper device.

(Below) A balloon to test the atmosphere is launched not far from the St. Louis Arch.



(Middle left) A magnet is suspended in midair using a high temperature superconductor held by George Risch.

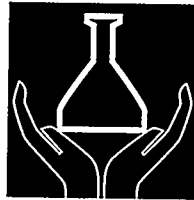
(Middle right) Florence Smith prepares samples for mass spectrometry.



(Bottom) Jugs of pristine coal are examined by Karl Vorres as part of a study to determine cleaner and more efficient coal use.



SCIENTIFIC EXCELLENCE AND LEADERSHIP



1590
Janssen invents
the microscope.



1676
Bacteria described.

1735
Classification of plants
and animals.



1796
Jenner develops
smallpox vaccine.

1842
First use of ether
as anesthesia.



1858
Darwin proposes theory of evolution
and natural selection.

THE BUILDING BLOCKS OF LIFE

INTERNATIONAL PROJECT SEEKS TO DECIPHER THE HUMAN GENOME



Russian biologist Andrei Mirzabekov is developing an efficient method to decipher the human genome at Argonne.

Knowing the sequence of our personal genomes may someday be as common as knowing our blood type, thanks to an international research project now under way at Argonne. Researchers are working at Argonne to develop a new super-efficient biochip that could help scientists decipher nature's code for building and operating all organisms, including humans, animals, plants and bacteria. The chip could lead to a new "holistic" biology that would supersede the current divisions in the study of life. The biological microchip can sequence DNA thousands of times faster than current methods. This "biochip," like an electronic microchip, will analyze the huge amounts of information needed to decipher the human genome.

Researchers at Argonne are working with a team of scientists from the Russian Academy of Sciences' Engelhardt Institute of Molecular Biology to develop ways to produce the devices quickly and efficiently. Biologists, chemists, mathematicians, physicists and engineers from the Engelhardt Institute are working at Argonne

to develop the biochip. The biochip is about the same size and shape as a computer microchip. It is being developed to speed up the process of sequencing the human genome, but can be applied to animals, plants and bacteria as well.

The genome is written in the language of deoxyribonucleic acid, or DNA. DNA is a long and varied sequence of four chemical compounds called adenine, cytosine, guanine and thymine. These compounds, which are organic bases, are denoted by the initials A, C, G and T. This short alphabet encodes thousands of genes that direct the construction of proteins. These proteins, in turn, make up the cells in our bodies and control most biological processes. The human genome project is an international scientific effort to sequence and "map" the huge volume of instructions that control the physiological

1896
X-rays first used for
medical diagnosis.



1941
First practical use
of penicillin.

1951
Watson and Crick discover
structure of DNA.



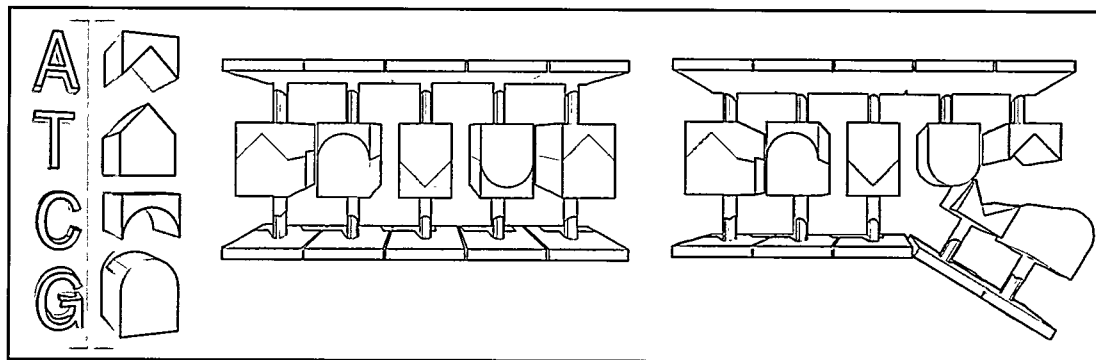
1953
Salk develops
polio vaccine.



1967
First human heart
transplant.

makeup of humans and other organisms. The process of mapping the genes and the traits they control is advancing much more quickly than the process of determining the entire sequence of individual letters. The biochip promises to break through the sequencing bottleneck.

The biochip uses a technique called “sequencing by hybridization” to examine the anatomy of DNA. The four bases, A, G, C and T, form pairs. T always pairs with A while G pairs with C. These base pairs form the twisted ladder that makes up the famous double-helix shape of DNA. A single strand of DNA has a unique match with another strand. For example, GTT can only pair with CAA. TCAA pairs with AGTT. Strands of DNA that pair with each other are complementary strands. When complementary strands attach to each other, it’s called hybridization. Affixed to the glass biochip are many short strands of DNA called oligonucleotides. These short strands are between six and nine base pairs long. They are like a series of words written in the DNA alphabet.



The biochip performs something like a “word search” on longer, unsequenced strands of DNA. Scientists prepare a solution of the DNA to be sequenced and apply a drop to the biochip. The longer strands hybridize wherever there is a complementary oligonucleotide. Then a specially-designed microscope detects where the DNA hybridized. A computer attached to the microscope analyzes the data and in a few seconds can piece the word puzzle together into the correct sequence. The biochip technique uses fluorescent “tags” or stains to indicate where the unknown DNA attached. Most other sequencing procedures use radioactive tags or labels. The fluorescent tags provide enough sensitivity for this procedure and are easier and safer for scientists and technicians to use.

Combining DNA sequencing research with Argonne’s Structural Biology Center — used to determine the structure of proteins — will permit researchers to compare information from the structure of the protein to the genome. They may soon be able to quickly tell from the DNA sequence what shape the proteins will take and how they function. This would permit the study of biology from a holistic approach instead of from its current elemental approach, allowing scientists to predict the structure of proteins, cells and organisms from the structure of genes.

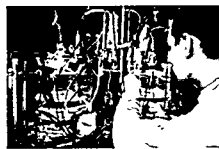
1969

Argonne's Center for Human Radiobiology opens, assigned to "find, follow and study persons who may have been exposed to radioactive materials in the U.S."



1982

Argonne biologist Charles Ehret develops a "feast-fast" diet to help reduce physical effects from jet lag and shiftwork.



1992

Argonne scientists develop "biochip" to sequence genome.



STRUCTURAL BIOLOGY

PROVIDING CLUES TO VIRAL, BACTERIAL AND MOLECULAR FUNCTION

Biological research took two giant steps forward in 1995 as a result of major developments at Argonne's Structural Biology Center (SBC). SBC researchers installed a dramatically new x-ray detector at existing SBC facilities at Brookhaven National Laboratory in New York, and work was started on SBC's new experimental facilities at Argonne's Advanced Photon Source (APS). The SBC provides advanced instrumentation for crystallographic research to all qualified biologists through peer-reviewed proposals. These researchers use SBC facilities to find all of the thousands of atoms that make up viruses, proteins, enzymes and other large biological molecules important to human health. Such knowledge is now leading to cures for many diseases. The center is used for applied research into medicine, industrial enzymes and other biotechnology products, and for basic research in structural and molecular biology.



Circadian Rhythm

In August 1954, a three-part spectrograph — carbon arc light source, reflector mirror and diffracting grating — was designed at Argonne. It was the largest and most versatile of its type in the country. On it, light was separated into various wavelengths to produce a full band of color from the invisible ultraviolet to the invisible infrared. Data on the interaction of radiant energy with proto-plasm was now possible.

The spectrograph was an important research tool for Argonne's innovative studies on circadian rhythms, the clock-like cycles in cells that regulate basic life functions.

In 1973, Argonne biologists demonstrated for the first time the existence of a biological clock in single protozoan cells. They also showed that this clock could be unset and reset by light. This breakthrough

discovery led to the 1982 design and development of Argonne's Anti-Jet Lag Diet and regimen to ease the effects of trans-continental travel and shiftwork rotation.

The Argonne Anti-Jet Lag Diet continues to be widely used by frequent fliers, and the lab receives thousands of requests a year for copies of this helpful traveler's aid.



Using a technique called protein crystallography, scientists grow crystals of viruses or bacterial proteins the size of a salt grain and then bounce, or diffract, x-rays off the crystals. The x-rays are detected in two dimensions, as with film, and converted instantly into a computer-readable form for rapid processing. Computers transform x-ray diffraction patterns into three-dimensional figures revealing details about molecular structure at atomic resolution and providing clues to viral, bacterial and molecular function. Such knowledge at a molecular level allows the design of better enzymes and molecular processes and allows pharmaceutical development to combat viral and bacterial disease. At SBC's Brookhaven facility, a powerful new x-ray crystallography detector was installed in the winter of 1995. It is three times larger than any previous electronic detector and can capture complete two-dimensional data files in four-tenths of a second. Crystal data that previously took from 10 to 24 hours to gather, now take only one hour. And, the data from the detector are automatically entered into the computer.

SBC staff moved into the new \$15 million Structural Biology Center at Argonne's APS in June of 1995 to begin assembling and installing their equipment. When the facility is completed in 1996, it promises to be the world's leading research center for structural biology in terms both of speed and accuracy for x-ray diffraction data. The new facility is being built at the APS, a new \$467-million super-powerful x-ray machine (see page 24). When the SBC opens, about 250 biological and medical researchers will be able to use the facility each year. The SBC facility is run by Argonne's Structural Biology Center Collaborative Access Team (SBC-CAT), an organization funded by the USDOE/Office of Health and Environmental Research to develop, build and operate research facilities for the nation's structural biology community. Argonne's SBC-CAT receives scientific oversight and governance from a board of directors which includes many of the world's leading molecular biologists. The team includes Argonne researchers and an industrial consortium of 12 pharmaceutical companies



HEAT-LOVING ORGANISMS

Organisms that thrive in extremes of temperatures and acidity are the interest of biologist Jonathan Trent. These organisms, called thermophilic (heat-loving) archea, look like bacteria but are not. They live in volcanic hot springs and certain areas within the Earth's crust, where conditions are reminiscent of the primitive Earth. In fact, it is believed that these organisms are similar to some of the earliest life on this planet. The proteins inside thermophilic archea have adapted to the harsh environment they call home. Argonne scientists are studying these proteins to discover new industrial and biotechnological processes and to identify uses in forensic medicine and cancer therapies.

called the Industrial Macromolecular Crystallography Association. Members of the association are Abbott Laboratories, Bristol-Meyers Squibb, Du Pont, Eli Lilly, Glaxo, Merck Sharp and Dohme, Miles Laboratories, Monsanto, Procter & Gamble, SmithKlein Beecham, Sterling and Upjohn.



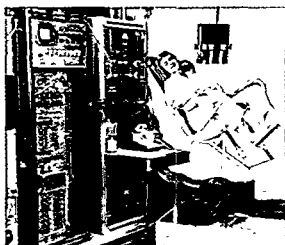
Biology: Living Organisms and Their Rhythms

At Argonne National Laboratory, research in the biological sciences has always been an interdisciplinary effort. Teams of nuclear and molecular

physicists and chemists work with life scientists to study the causes and potential cures of cancer and the effects of radiation on biological systems.

In fact, scientists at the Metallurgical Laboratory, and then at Argonne, pioneered radiation research.

Creating a New Area of Research



Argonne's first facility for measuring radioactivity in humans was an "iron room."
1950s

One unusually important phenomenon at the MetLab was radiation — never before had so many people been assembled to work with radioactive materials. By mid-1942, an all-out research effort was underway on the effects of radiation on animals — and the term "health physics" was coined.

Argonne continued that trail-blazing work. Early studies with transuranic elements, fission products and other radioisotopes led to international radiation standards for the protection of humans exposed to these new materials and to the current methods for removing radiation from the body. It is now rare to see human beings with substantial amounts of radioactivity in their bodies. In earlier decades, however, significant numbers of people ingested radium on-the-job.

Among the groups of people studied by Argonne were

painters of luminous watch dials who used their lips to point radium-laden brushes; they experienced an unusually high rate of bone cancer. These and many other people with body burdens from radiation exposure received before radiation dangers were understood were enlisted in Argonne's pioneering studies to determine the maximum permissible levels of radioactive substances in the human body.

Argonne's first facility for measuring radioactivity in humans was an "iron room" where during the 1950s, the nation's most sensitive and accurate radiation assays of humans were conducted. These tests allowed scientists to determine the amounts, locations and identities of extremely small quantities of radioactive materials in the body — as little as one-billionth of a gram of radium. Similar facilities were later used throughout the world.

Attempts to modify the effects of radiation led to development of the first successful protective agent against x-rays, to techniques for removing radioactive metals from the body, and to in-depth studies of tissue transplants and the immune system. Cell transformation systems were used to study the carcinogenic processes following

exposure to either promoter or inhibitory chemical agents. A chemo-prevention research program was developed to reduce cancer risk to patients receiving radiation treatments.

Argonne also took a lead role in photobiology, especially in lethal and mutagenic effects of near-ultraviolet radiation

in bacteria. Argonne scientists were the first to conduct in-depth examinations of the genetic effects of exposure to near-ultraviolet radiation. The findings were critical to assessing effects of exposure to the sun and the risks of exposure to artificial light used in medicine and industry.

Finding Causes and Origins of Cancer

The search for a bone cancer virus was undertaken by a team of biologists which, in 1965, found a filterable agent that produced cancerous tumors in mice. This discovery added a new tumor to the lexicon of known virus-produced malignancies, as well as a strong suggestion of a viral origin in all cancers. In 1975, the team isolated two bone tumor viruses further strengthening the hypothesis that viruses may play a role in the formation of cancerous bone tumors.

Meanwhile, other cancer studies were achieving pace-setting advances. In 1962, Argonne biologists discovered that white corpuscles in the blood stream represent only a minute portion of those manufactured in the bone marrow, an important clue to understanding leukemia. In 1969, two related abnormal blood and urinary proteins from a bone cancer patient were isolated and crystallized. It was the first time this had happened in the same person. Characterized as an important

breakthrough, this unusual demonstration greatly increased understanding of the human immune response at the molecular level. Argonne biologists were the first to demonstrate a minothiolo mediated – or “early” – gene expression and its effects on DNA synthesis. This led to current work on a revolutionary technique to speed up by thousands of times the process of decoding DNA – the hereditary blueprints stored in every living cell.



Early studies led to international radiation standards for the protection of humans exposed to these new materials.

Argonne studied radium dial painters. As a group, the painters had high rates of bone cancer.

1800
Herschel discovers
infrared radiation.

1801
Ritter discovers invisible
ultraviolet radiation.



1840
Becquerel finds
magnetic property
of liquid oxygen.

1869
Mendeleev develops
periodic table.



REFORMING HYDROGEN

A NEW DEVICE ENABLES FUEL CELLS TO POWER ELECTRIC CARS



Researcher Shabbir Ahmed readies an experiment to test the performance of Argonne's methanol reformer.

Fuel cells are like batteries with fuel tanks. Unlike batteries, they produce electricity as long as they have fuel, and they never need recharging. Fuel cells are also more efficient and less polluting than internal combustion engines. For these and other reasons, the Department of Energy (DOE) is looking into fuel cells as possible power sources for electric vehicles.

A major problem in using fuel cells to power electric cars, however, is that they are fueled by hydrogen, a very light gas that is hard to store. Currently available hydrogen-storage technologies are so heavy and bulky that they would limit the driving range of any car that used them. Argonne researchers have tackled this problem by inventing a new device that could bring electric cars a step closer to practical use for daily driving. The device, called an "on-board methanol reformer," releases the hydrogen bound up in methanol (methyl alcohol). Because it is more compact than other reformers, it could enable fuel cells to power an electric car by reforming methanol from the fuel tank and feeding the hydrogen into a fuel cell.

The Argonne device is less than one-half the size of a car's fuel tank. This makes it the first fuel reformer small enough to fit under the hood of a compact car beside a 50-kilowatt polymer-electrolyte-membrane fuel cell, DOE's top candidate for an electric-vehicle fuel cell.

Argonne's reformer would combine methanol with oxygen from the air to produce a hydrogen-rich mixture of gases that would be injected into the fuel cell. Compared to other reformers, Argonne's is lightweight, compact and energy-efficient. In addition, it is flexible enough to respond well to frequent startups and shutdowns and to the rapidly changing engine demands of daily stop-and-go driving.



1895

Lorentz determines structure of atoms.



1898

The Curies isolate radium and polonium.

1926

Dirac advances theory of submicroscopic phenomena.



1931

Urey discovers hydrogen isotope.

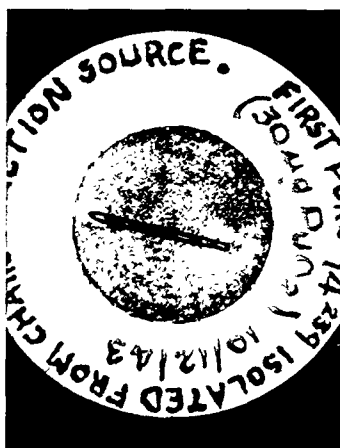


The design is simple and inexpensive to manufacture. The device is a cylinder packed with a common and inexpensive catalyst. In addition to hydrogen, the reformer produces carbon dioxide and carbon monoxide. A small on-board chemical reactor would convert the carbon monoxide into carbon dioxide. Development of Argonne's on-board fuel reformer was funded by the Department of Energy's Office of Transportation Technologies.



Innovation and Serendipity

The role of chemists at the Metallurgical Laboratory was critical to achieving a chain reaction. Production of transuranic elements was in its infancy in the early 1940s. MetLab chemists had the seemingly impossible task of separating plutonium from uranium in the race to harness an awesome new energy. That early record of innovation continues through today.



MetLab chemists had the seemingly impossible task of separating plutonium from uranium in the race to harness an awesome new energy.

The first reactor-produced plutonium.

Argonne chemists moved beyond production of transuranium elements to transplutonium elements and participated in their discovery. In the 1950s, laboratory chemists co-discovered the man-made elements 99 and

100 (einsteinium and fermium) and 102. Element 102 was an international effort. Discovered in early 1957 at the Nobel Institute, element 102 was produced by bombarding curium with carbon ions

accelerated in a cyclotron. Argonne chemists also made unique contributions to the production, separation and characterization of these elements and their isotopes.

1962

Argonne chemists produce xenon tetrafluoride.



1963

Argonne chemist Edwin Hart discovers the "Hart electron," a breakthrough in radiation chemistry.

1966

Argonne chemists measure the radioactive element of astatine, one of the halogens never before measured.

REDUCING RECYCLING RATES

NEW PROCESS SAVES BIG MONEY FOR SMALL BUSINESSES



Solutions used by Ken Nash recycle copper out of waste from printed circuit board manufacturing.

Electroplating does more than just make jewelry shine. The printed circuit boards found inside computers and microwave ovens need a shiny, electroplated coat of copper. But this copper-electroplating process creates waste; and until now, many small electroplating operations could barely afford the high costs of waste disposal and recycling. Argonne researchers tackled that problem and came up with an inexpensive way to reduce and recycle metal wastes while saving small electroplators big money. The method uses commercially available chemicals to recover metals such as copper from aqueous solutions generated during electroplating operations. The environmentally friendly process will not eliminate wastes entirely, but it will significantly reduce their volume. It is expected to be more than 99-percent efficient in recovering metals.

During the extraction process, the metal-containing aqueous solution is contacted with an oily solvent which selectively pulls the metal out of the aqueous medium. The metals are later released to a fresh aqueous solution in a more concentrated form. This concentrated solution can be recycled within the system or sent off-site for further refining if required. The oily solvent is recycled after it is scrubbed to remove impurities. With this extraction process, the typical small electroplating company could save up to \$200,000 a year in waste disposal costs.

Two Chicago-area businesses — Wayne Circuits, an electroplator, and Eichrom Industries, Inc., a metals separations technology company — are working with Argonne to develop and operate a pilot-scale system that will allow on-site metals recycling. The Argonne-developed technology for the separations process has been in existence for several years, but this is the first time it has been adapted for use by a small business. Eichrom is designing a compact system for the electroplator that will extract metals and recycle water, dramatically decreasing water use. Wayne Circuits expects its liquid wastes to drop from about 200,000 gallons a year to only 16,000.



Noble Gases

In 1962, three Argonne scientists made a chemical reaction previously thought impossible. They combined the “noble gas” xenon, thought to be inert and non-reactive, with the highly reactive element fluorine to

produce xenon tetrafluoride. It was an important discovery and opened a whole new research area in chemical bonding.

Chemists at the laboratory also determined that radon, another noble gas, is capable of produc-

ing chemical compounds. With these breakthroughs in the chemistry of the noble gases, the laboratory was preeminent in the field. In April 1963, Argonne held the first-ever conference on the chemistry of rare gases.

Hydrated Electron

In early 1963, a “new” ion — the hydrated electron — was discovered by an Argonne chemist and a British colleague. It was a major breakthrough because it elucidated previously unexplained chemistry.

Its discovery, however, was serendipitous. The Argonne researcher said they were not looking for the hydrated electron. They were doing research on pulsed radiation of water when, unexpectedly, the spectrograph they were using indicated a blue absorption band — it was the new hydrated



The discovery and analyses of the roles of short-lived fragments have led to a better understanding of radiation chemistry.

Argonne chemist Edwin Hart found the hydrated electron.

electron. The discovery and analyses of the roles of the hydrated electron and other

short-lived fragments have led to a better understanding of radiation chemistry.

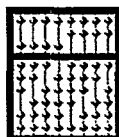
Organic Compounds and Proteins

Other pioneering research was done on “isotopic substitution” in organic compounds, including the first complete substitutions of deuterium (heavy hydrogen) for ordinary hydrogen in living organisms, both plant and animal cells. Argonne scientists were the first to demonstrate the origin of the

triplet state in primary charge separation in photosynthesis. This phenomenon and its associated radical pair serve as the definitive “fingerprint signatures” of both natural and artificial photosynthesis. The second crystal structure of a membrane-bound protein was obtained by Argonne chemists.

This demonstrated to the scientific world that crystallization of membrane proteins was generally feasible; it also confirmed the work of German chemists who obtained the first membrane protein crystal structure, for which they received the Nobel Prize

3000 B.C.
First calculating device,
the abacus, invented.



1636
Fermat advances modern
theory of numbers.

1642
Pascal invents a simple
mathematics machine.

1833
Babbage proposes
digital calculator.

1888
Burroughs patents
adding machine.



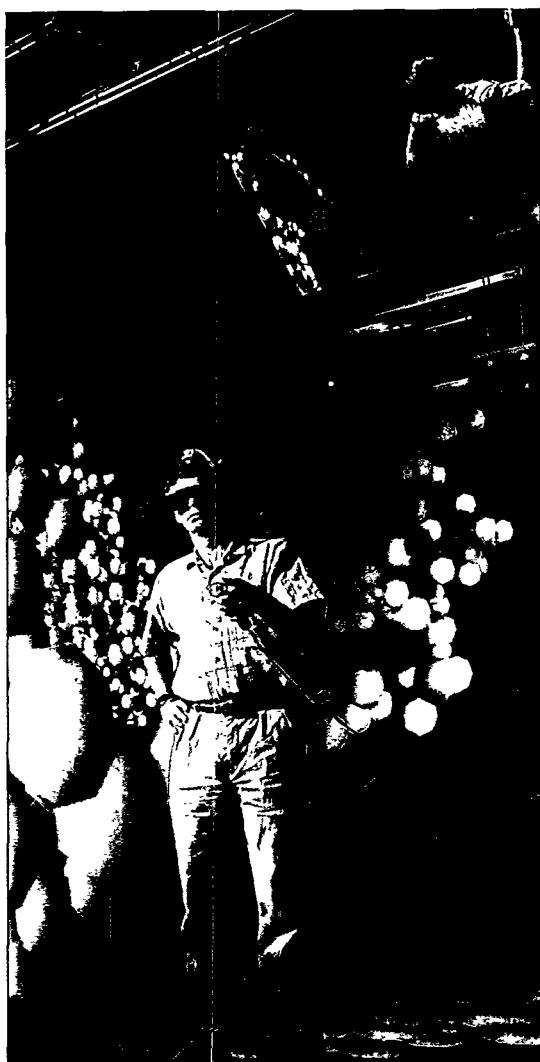
1925
Vannevar Bush develops
first analog computer.

1942
First operating computer
with binary numbers.

Data storage tape
invented.

3-D SCIENCE SCENE

SCIENTISTS IMMERSE THEMSELVES IN DATA FOR IMPROVED UNDERSTANDING



Modern-day caveman and computer scientist David Levine studies the relationships between nucleic acids (the spheres) in a ribosome (shown as cylinders). A ribosome is a molecule that synthesizes protein in the body.

In the popular TV series "Star Trek: The Next Generation," the crew finds relaxation and entertainment on their starship's "HoloDeck" — a walk-in theater where interactive 3-D holograms create the illusion of strolling through a lush tropical forest, or sailing over the Bounding Main aboard an 18th-century schooner. Not to be outdone by science fiction, Argonne scientists today can pick up a headset and control wand and enter their own version of a HoloDeck — a three-dimensional virtual reality environment that lets them immerse themselves in visual representations of complex chemical, industrial and medical data.

Argonne's Cave Automatic Virtual Environment (CAVE), one of four such sophisticated virtual reality facilities in the world, lets scientists see, touch, hear and manipulate data. Designers can use the facility for activities such as creating and testing models of commercial boilers and visualizing a photon (light) beam as it travels through and is influenced by high-powered magnets. The CAVE is a 10-foot-square room composed of projection screens. In a darkened lab, projectors and mirrors overlap two images on each screen. Inside the CAVE, researchers wear stereoscopic glasses to turn the projections into hologram-like images. Six to ten people can stand in the CAVE and view the projection, while one person with a headset and joystick-like computer wand controls the simulation's perspective. The CAVE was developed by the Electronic Visualization Lab at the University of Illinois at Chicago.



1953

AVIDAC built, first electronic digital computer.



1957

GEORGE computer completed.

1993

SP1, world's largest parallel processing supercomputer, installed at Argonne.



1995

CAVE — a virtual reality environment — operational at Argonne.



Argonne's CAVE is outfitted for scientific research in "real time." Argonne's powerful IBM SP POWERparallel computer system works in tandem with a sophisticated Silicon Graphics SGI computer to generate the CAVE's realistic images. The SP can perform the calculations — sometimes millions of them — necessary for each step of the simulation as it is needed. As an experiment produces data, the SGI immediately translates the information into images for projection in the CAVE. The two systems communicate up to 20 times per second. Argonne researchers develop their own CAVE applications and work with industry and university researchers.

CURRENT CAVE APPLICATIONS INCLUDE:

- Molecular-level drug design, simulating the docking of a drug molecule to its biological receptor to minimize drug side effects and speed the development of new pharmaceuticals.
- Foundry casting visualizations, which can improve the casting process for car and aircraft parts (in collaboration with Caterpillar Inc.).
- A grinding simulation with a block and wheel that lets researchers see how temperature and stress affect material properties and rotational speed. Surface Finishes Co. is collaborating.
- Visualization of parallel computer operations, with Northwestern University researchers, using maps and molecular dynamics models.
- Volume visualization of both medical data — computed tomography scans of lungs, abdomens and colons — and astrophysics data.
- Studying the operation of wigglers, an array of magnets used in Argonne's Advanced Photon Source. The configuration of magnets and electromagnets controls the path of the machine's charged particles and causes the "wiggles" that produce extremely high-energy x-rays (see page 24).
- Modeling weather conditions. The images produced in the CAVE allow researchers to interpret huge amounts of data quickly.

In December 1995 Argonne researchers demonstrated that CAVEs across the country can be linked. By 1996 Argonne researchers hope to link CAVEs at different sites and perform joint visualization research over a high-speed communications network (see page 52). When the system is in place, whatever Argonne CAVE researchers are doing will also be seen at the CAVEs at the University of Illinois at Chicago and the University of Illinois at Urbana-Champaign — and vice versa. In other words, CAVE researchers will be able to stay in their labs and work together on the same experiments at the same time — no Transporter necessary.



Computers: AVIDAC to Virtual Reality



AVIDAC



PACE



CDC 294A

Since the early days, lab researchers have used and developed exotic machines known to few and used by even fewer.

Today, Argonne scientists can solve computational problems once considered unsolvable. They can “walk into” experiments in a computerized virtual reality environment where they can see, hear and manipulate information with a mouse-like control wand. The computer’s development — as with reactor

technology — was sped by defense needs during World War II. ENIAC, containing 18,000 vacuum tubes, was built at the University of Pennsylvania in 1946 and was soon used by Argonne researchers to solve ballistic trajectory problems. Two years later, the discovery of the transistor inaugurated

an industrial revolution and made possible construction of powerful computers. It was not until 1951, however, that the first commercial transistor-driven computer, UNIVAC, was introduced for use in business and science.

Digital to Analog

Argonne physicists encountered mathematical problems of enormous complexity. In 1949, since there were no computers available commercially, the researchers built their own. The laboratory’s first electronic digital computer, referred to as an “electronic brain,” began operation in January 1953. It was named AVIDAC and was used in reactor engineering and

theoretical physics research. Several months later, it was followed by ORACLE, a larger computer system. Increasingly, almost exponentially, the need for better and quicker handling of scientific data grew as the laboratory expanded. Advanced computer facilities became a necessity. In 1957, Argonne scientists built GEORGE, a large-scale digital computer

that operated around the clock. A digital IBM-704, then one of the world’s largest computers, was installed. The next year, PACE (Precision Analog Computing Equipment) was purchased. PACE, unlike the digital computers, measured and simulated experimental conditions.

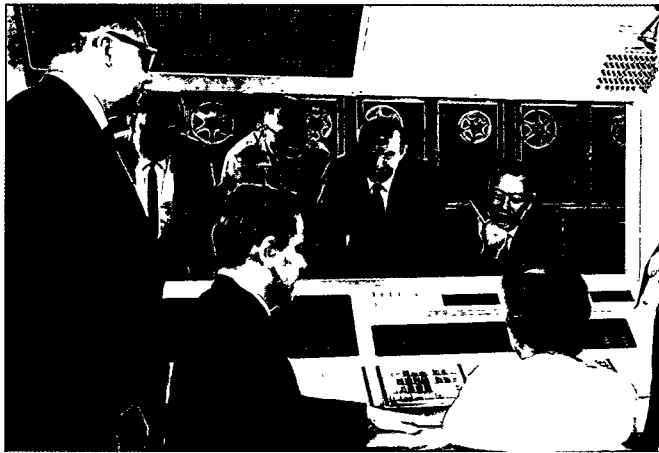
High-Speed Machines

By the early 1960s, Argonne was one of the biggest computing centers in the Midwest. Its high-speed computers were being used for design calculations to help determine reactor design and for data analysis to interpret experiments by measuring physical properties — important, for example, in determining the effects of small amounts of radiation in the human body. The computers allowed physi-

cists, biologists and chemists to compare experimental results and test them against the validity of theoretical models.

Difficulty keeping up with the demand for state-of-the-art computer technology led to new and expanded programs. In 1963, construction began on a new mathematical and computer facility, staffing in the Applied Mathematics division was

increased by 50 percent, and one of the world's most advanced electronic computers, the CDC 3600, was purchased. In addition, GEORGE got a new, and tripled, memory, and other upgrades including a floating index point (FLIP) that let GEORGE automatically handle numbers of widely varying sizes. It would later "become" GUS (GEORGE Unified System) as part of the trend toward "linking" computers; GUS provided memory for up to seven computers operating at the same time. Throughout the decade, Argonne added new computer resources. Of particular note was the design and development of a series of computer systems called CHLOE, POLLY and ALICE. These systems were capable of analyzed data on photographic film and were used in scanning spark chamber data for physics research and fingerprint patterns.



GUS

Algorithms and Software

Software engineering was established as a laboratory discipline during the 1970s and 1980s. PACKs, the first truly high-quality collections of mathematical software, were designed and implemented under Argonne leadership. EISPACK, in particular, set a new standard for reliability, efficiency and accuracy.

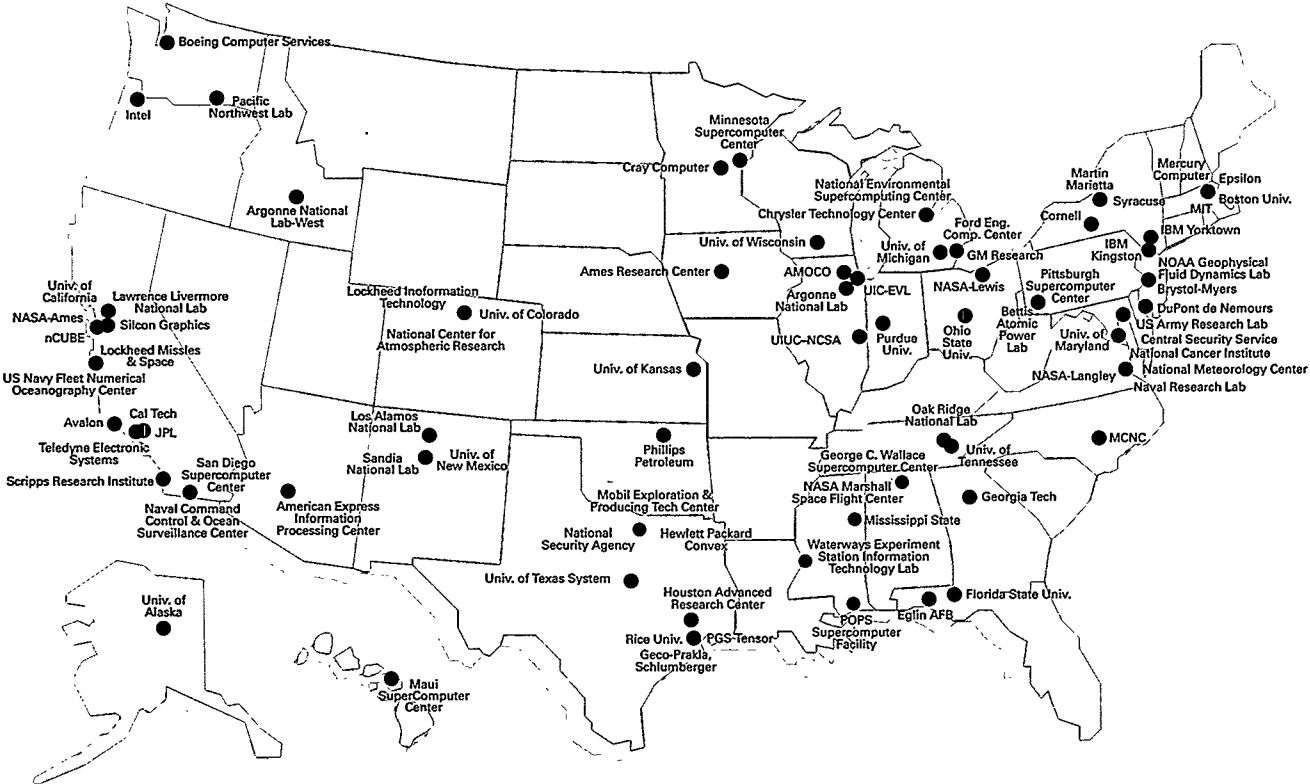
LINPACK, developed shortly thereafter, remains today in great demand by industry and the scientific community and is widely used throughout the world to evaluate new computer performance. By the early 1980s, Argonne was internationally recognized as a world leader, not only in numerical software, but in symbolic computation.

Researchers at the laboratory introduced into the field a theorem proving new strategies that enabled programs to "reason." Such programs, called "automated reasoning programs," today are being used to design circuits, verify computer codes, solve puzzles and prove theorems from mathematics and logic.

THE I-WAY NETWORK

BUILDING A BRIDGE TO THE NEXT GENERATION INTERNET

While most of us are still clamoring to get on the current Internet — that electronic gateway to the information world— researchers at Argonne are building the bridge to the next generation Internet. Researchers from across the nation have built an experimental high-speed network, called the I-WAY, to link the country's fastest supercomputers and advanced visualization environments.



THE NETWORK

The network will be used as a state-of-the-art testbed for at least two years to determine potential problems to be overcome when the proposed information superhighway, or National Information Infrastructure, is built. The I-WAY network lets sites link up to share high quality video, data, images and voice. Researchers are connecting many different computers together to perform calculations not previously possible on one large computer. Argonne leads two critical components of the I-WAY experiment — assembling the advanced network and developing software that enables all of the different machines to communicate and share work. Computer scientists will also run experiments over the I-WAY, especially performing shared virtual environment research in high-temperature superconductivity and interactive molecular modeling.

The backbone of the I-WAY is an experimental Asynchronous Transfer Mode (ATM) network. ATM is an emerging telecommunications technology capable of simultaneously passing high-quality video, data, image and voice traffic hundreds of times faster than conventional technology. ATM uses short data



cells that can be quickly switched through local, regional and international networks. Current data technologies send information in variable-sized packets. In order to maintain quality, audio and video feeds must currently be sent over separate networks, or the calls get choppy. For reasons of efficiency and cost, data is typically sent on totally separate network infrastructures. However, ATM supports all of the media simultaneously through one network. ATM uses small cells to mix data, voice and video. The ATM cells allow a large amount of data to be sent by packing concurrent cells. Audio and video cells can maintain the desired sample rate.

Telecommunication providers including AT&T, MCI and Sprint and equipment vendors are participating in the research at an unprecedented level. Each provider owns different parts of the national communication network and is donating connections. Other computer equipment vendors are also participating, donating substantial equipment and software resources. Participating vendors have the opportunity to develop and test new products on the I-WAY, and these products could end up in the mainstream commercial market.

Argonne developed the software that ties the supercomputers into one large machine. To keep the I-WAY running as one computer requires volunteers from all of the supercomputing sites. Much of the funding for this research is provided by the Department of Energy, the National Science Foundation, Advanced Research Projects Administration and Supercomputing '95, the annual supercomputing conference. The first full I-WAY demonstration was performed at the 1995 conference in San Diego, Calif.

In May, 1995, the I-WAY concept was demonstrated with a transcontinental virtual field trip. Using an ATM network, an oceanographer performing an experiment underwater in Monterey Bay, off the coast of California, used two-way audio and video signals to discuss her experiment with students in high schools in Pender, N. C. and Chicago, Ill. The field trip, coordinated by Argonne, required joint services from Ameritech, AT&T, Bell Atlantic, Bell South, Pacific Bell and Sprint. Switching was provided by Fore Systems and Newbridge Networks.

Parallel Computing

Anticipating the growing importance of parallel computing, Argonne established the Advanced Computing Research Facility in 1984. For almost a decade, the facility supported collaborative research with universities, laboratories and industry on a variety of experimental parallel machines including hypercubes and a locally developed shared-memory machine nicknamed

the Lemur. More recently, the laboratory established a High-Performance Computing Research Facility featuring a massively parallel IBM Scalable POWERparallel SP system. Researchers use the SP for a range of collaborative studies from high-energy physics, propulsion, and data imaging to automotive research and environmental restoration. To support such research, labora-

tory scientists are developing toolkits for portable parallel programming. Argonne computer scientists also spearheaded efforts to promote the use of MPI, a standard interface for message passing on distributed-memory, shared-memory, and networked computers. MPI permits supercomputer programs to be quickly converted for easy use on parallel processing computers.

1752
Ben Franklin invents a conductor for lightning.

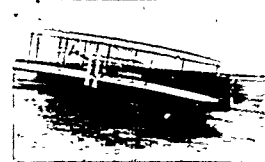


1801
Robert Fulton builds first submarine.

1824
Isomers discovered.



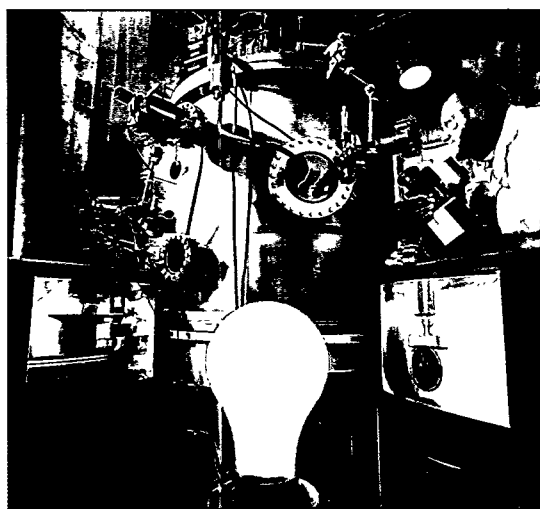
1880
Thomas Edison invents electric lighting.



1903
Orville and Wilbur Wright fly the first airplane.

SUPERCONDUCTIVITY

LIGHTING THE PATH TO THE FUTURE WITH VIRTUALLY NO RESISTANCE



Energy to light the future may come from electricity stored efficiently in a superconducting flywheel Argonne is developing with Commonwealth Edison.

In 1879, Thomas Edison flipped a switch and illuminated his workroom with the first electric light, launching the age of bright lights and big cities. More than a century later Argonne scientists are devising high-temperature superconductors that could provide cleaner, cheaper power than from the conventional electrical systems in use since Edison's time. In 1995, Argonne researchers developed new methods to measure the properties of superconducting materials; produced improved superconducting materials; and transferred this technology to the marketplace. As the home of the nation's largest publicly funded high-temperature superconductor program, Argonne continues to set records and generate breakthroughs in superconductor research.

High-temperature superconductors are ceramic materials that carry direct electrical current without resistance. They lose their electrical resistance when they are submerged in liquid nitrogen to minus 321 degrees Fahrenheit (77 Kelvins). More powerful and compact motors and transmission lines can be built with superconductors. Using superconducting material in electrical wires, generators and storage systems offers the potential to power industrial plants and cities without the inefficient loss of electrical energy. New methods were developed by Argonne scientists to understand energy loss in superconductors. Numerical computer simulations demonstrated the motion of individual vortices, the swirling clouds of electrons which control the energy loss. Accurate measurements of the behavior of electrons in superconducting materials supported the importance of a technique called "single crystal alignment" to prevent energy loss inside these materials.

Argonne researchers not only have increased their understanding of the mechanisms of superconductivity, but they can now "map" the exact location of electrical flow interruptions. Argonne developed the first instrument to precisely image electrical flow through superconductors (see Flux Imaging System, page 57). This technology could be key to the development of materials that carry current ten times greater than previously possible.



1911

Heike Kamerlingh-Onnes
discovers superconductivity.

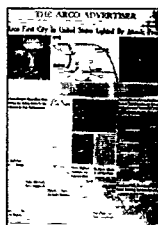
1933

Superconducting
Meissner effect
discovered.



1951

Argonne's EBR-1
produces first usable
nuclear electricity.



1955

Arco, Idaho becomes first
town lighted entirely by
nuclear power.

1957

Theory of superconductivity
formulated.

1986

Oxide that superconducts
at 35 Kelvins created.

The current-carrying capacity and length of superconducting materials continues to improve. Researchers increased the current-carrying capacity of silver tapes used to transmit electrical current, setting a record. Previous silver tapes could carry 80,000 amperes per square centimeter of conductor; now they can carry 100,000 amperes per square centimeter. Argonne scientists have also helped companies to develop the technology to create superconducting wires nearly one kilometer long. These accomplishments are closing the gap between research and the marketplace.

In collaboration with industry, Argonne designed high-temperature superconducting leads for energy storage systems. The leads connect to a magnetic electric storage device comprised of low-temperature superconductor windings that operate in liquid helium at very cold temperatures — minus 452 degrees F (4 K). The high-temperature superconducting leads operate between minus 452 degrees F (4 K) and minus 321 degrees F (77 K) and complete the link to utility systems running at room temperature. Using copper leads to carry electricity between room and liquid helium temperatures would create heat and cause the liquid helium used to cool the energy storage device to evaporate. Replacing copper leads with superconductor leads provides an energy-efficient link to the extremely cold temperatures. The American Superconductor Corporation uses such leads for utility systems. The company plans to put the leads inside an energy storage device being built for an Alaskan utility company. Understanding the mechanisms of superconductivity and improving materials for commercial use will enable Argonne to help bring the world closer to a future powered by superconductor technology.



Student John Ulanday prepares to test high-temperature superconducting bars used to link utility systems operating at room temperature to systems operating at liquid nitrogen temperatures.

1987

Argonne is only national laboratory in the four-member National Science Foundation Center for Superconductor Applications.



1987

Argonne develops world's first flexible ceramic superconducting wire.



1989

Powerful ceramic superconductor created.

FASTER THAN A SPEEDING BULLET

The flywheel doesn't fly like Superman, but it does spin — and fast. Argonne is testing flywheels that in the future will reach rim speeds greater than 2,000 miles an hour — faster than a speeding bullet, and about three times the speed of sound. The flywheel rotor is a rapidly spinning disk attached to a permanent magnet ring that floats above high-temperature superconducting material. The superconductor generates a magnetic field “cushion” when it is cooled to minus 321 degrees F (77 K). This cushion allows the flywheel rotor to hover above the superconductor without touching it. The entire assembly — a high speed rotor with this superconducting magnetic bearing combined with an efficient motor/generator — is called a Flywheel Energy Storage System.

Researchers from Argonne and Chicago's Commonwealth Edison utility are jointly developing the flywheel system. When the system lights a simple electric bulb, it illuminates the possibility of a future powered by superconductors. Argonne is developing a prototype system that will generate about one kilowatt hour of power, the equivalent of powering ten, 100-watt light bulbs for one hour.

Larger energy storage systems are planned. With further development, this system could dramatically change the way energy is produced and supplied to consumers. During the day the spinning flywheel would release energy to meet the increased demands of electricity, and at night, the disk would act as a storage system. It would provide a consistent stream of electricity, avoiding the usual peaks and valleys of electrical demand during a 24-hour period. Commonwealth Edison also plans to use the system as a backup energy supply during power outages.

Reduced frictional drag is the key to the efficiency of the flywheel energy storage system. The flywheel is contained in a vacuum chamber, to eliminate air friction. Because the magnetic bearing floats above the superconductor, frictional drag is one-tenth that of any conventional bearing system. Argonne continues to hold the world record for least friction created in a magnetic bearing. This low-friction system is under continuous improvement, using larger rotors, greater speeds and improved superconducting materials.

ROLLER-COASTER ELECTRON RIDE

New measurements demonstrate that electrons in high critical temperature superconducting materials behave like bonded “buddies” on an electrical roller-coaster ride. Using “photoemission” measurements that shoot photons at single superconducting crystals, Argonne researchers pinpointed exactly where electron pairs are broken and concluded that electron pairs rotate around each other along a pathway that takes them on high climbs and low dips. This roller-coaster movement makes electron pairs difficult to break up in some directions, and easy to tear apart in others. Their degree of “bondedness”

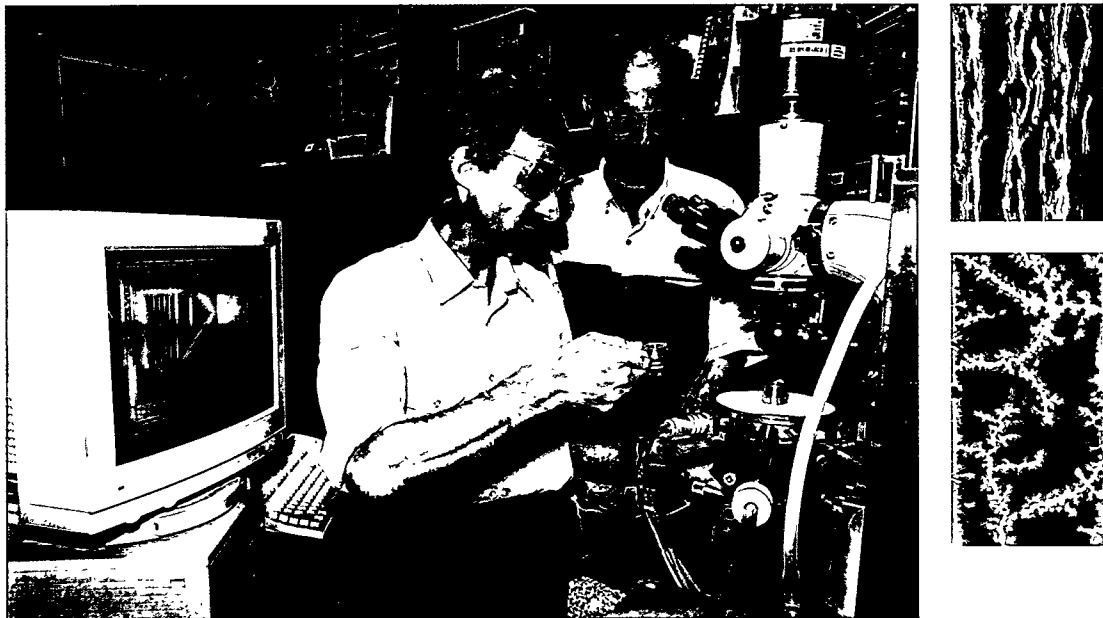
depends on the symmetry of the pair. A simple twist or turn of the roller coaster path and the binding forces for electrons may be stronger or weaker, greatly affecting the efficiency of electrical flow through superconducting material.

Earlier research suggested a more homogenous electron setup in which a twist of the electron path, or roller coaster, had no significant effect. The new measurements paint a more accurate picture of electron behavior, providing researchers with additional information to investigate the best recipes for superconducting materials. Understanding the true symmetry of superconducting pairs is an important step in developing improved superconducting materials with an uninterrupted flow of electrical energy.

ELECTRICAL ROADMAPS

Scientists can see the "roadblocks" that interrupt electrical current flow in superconducting materials using an imaging system developed at Argonne. The system takes a snapshot (shown below right) of the electrical flow using a special indicator film developed by a research institute in the former Soviet Union. The image clearly shows the path taken by the electrical current from point A to point B, including interruptions to the flow. The system includes an optical microscope, a polarizing filter, the special indicator film, a stage to place the superconducting sample and a computer to image the results. The technique, called "flux imaging," constructs a picture of magnetic fields. These magnetic fields are the natural result of electrical current flow. The pictures show variations and defects in the superconducting materials and how the electrical current reacts to these defects.

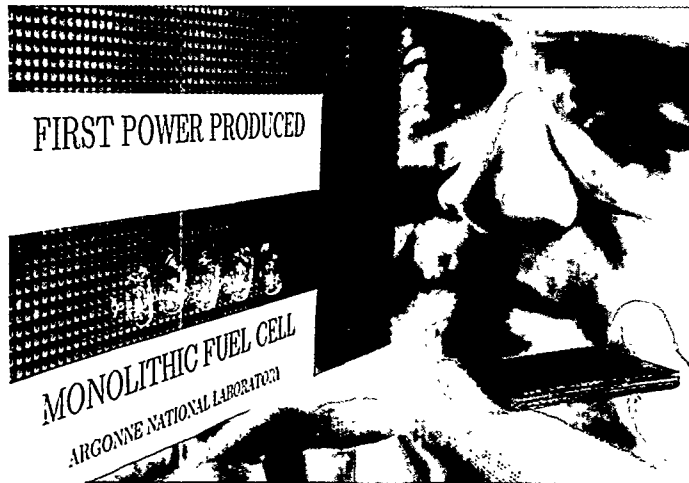
Identifying the precise location of interruptions in the electrical current flow in superconductors is crucial to understanding why current flow stops. Now that researchers can see the roadblocks, they can experiment with different superconducting samples to make the best pathway for the electrical current. The new imaging technique is already being used as a tool to improve the performance of commercial wires. It will be marketed by Phase Metrics, a San Diego-based company.



This flux imaging system is the first to "map" electric current flow in superconducting materials. The monitor shows a "map" of a single superconducting crystal. At right are images of electrical flow in superconductors.



New Materials for Future Energy: A National Center



Materials research began with the need to know the physical and chemical properties of fuels and structural materials used in operating early reactors.

Argonne developed the first monolithic fuel cell.

Argonne's preeminence in determining material performance and reliability, critical to developing new energy systems, is based on a tradition of excellence that dates back to MetLab days. Materials research began with the need to know the physical and chemical properties of fuels and structural materials — graphite, uranium, plutonium — used in operating early reactors.

After the second world war, Argonne was the first laboratory devoted to civilian use of nuclear energy. During the energy crises of the 1970s, its programs were expanded to include alternate energy sources. By developing new materials and modifying existing ones, materials research provides superior mechanical, electrical, thermal, nuclear, corrosion and wear properties.

For example, Argonne's 1967 discovery of radiation-induced voids in metals was an important factor in the design of fast breeder reactor cores. By the mid-1980s, in addition to focusing on work in fission and fusion, there was also a commitment to exploring new ways to deliver efficient energy — tribology, aqueous corrosion, amorphous alloys, superconductors and ceramics.

Conducting Superconductivity Research

Superconductivity, the conduction of electricity virtually without resistance, was discovered in 1911. It was limited, however, because the phenomenon could only be achieved at extremely cold temperatures. The field was

revolutionized in 1986 when two Swiss researchers developed compounds that were superconducting at high temperatures. This Nobel Prize-winning work spurred Argonne scientists to ever more inventiveness. Argonne's superconductivity

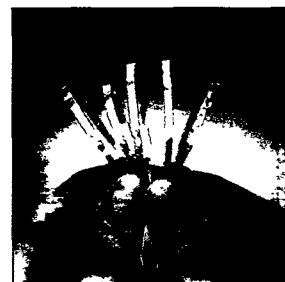
research was aided by the ability to quickly study new materials at the lab's Intense Pulsed Neutron Source (see page 34) and to provide rapid suggestions for modifications in synthesis. In 1987, Argonne scientists made the first electric

motor, the Meissner motor, based on high-temperature superconducting properties. That same year, the laboratory was named a national center for the study of high-temperature superconductivity applications.

In the first four years since the 1986 discovery of high-temperature superconductivity, Argonne scientists reported 18 superconducting inventions, including: determination of the precise position of oxygen atoms in high-temperature superconducting ceramics; production of high-temperature superconducting bearings that hold the world's record for lowest losses; extrusion of wire from high-temperature superconducting materials — the first laboratory in the world to do so. They later grew single crystals of the material and discovered that current is carried primarily through chains of copper and oxygen in the crystals. They also determined the crystal structure of the first high temperature superconductor — yttrium barium copper oxide. In 1990, Argonne chemists surpassed their own world's record for the highest transition temperature for an organic superconductor. The following year, scientists from Argonne and Northwestern University discovered a new family of high-temperature superconductors made of a compound of oxygen, copper, gallium, strontium and yttrium.

Argonne's designation as one of three Superconducting Pilot Centers in the country attracted

the interest and participation of private industry. More benchmark successes were achieved. A private superconductivity company, Illinois Superconductor Corp., was founded in 1990. It is the first superconductivity company to be formed as part of a joint cooperative program among state and federal government, private industry and academia. It had the first high-temperature superconducting commercial product on the market — a liquid nitrogen depth sensor used in hospital equipment. In 1990, Argonne and Westinghouse Science and Technology Center developed an electrical lead that achieved a world record for current carried by a practical high-temperature superconductor device. Three years later, Commonwealth Edison and Argonne developed the world's most efficient superconducting magnetic bearing. It could revolutionize the way electricity is stored and how it



A "super coil" of flexible superconducting tape loses all resistance to electricity when cooled by liquid nitrogen.

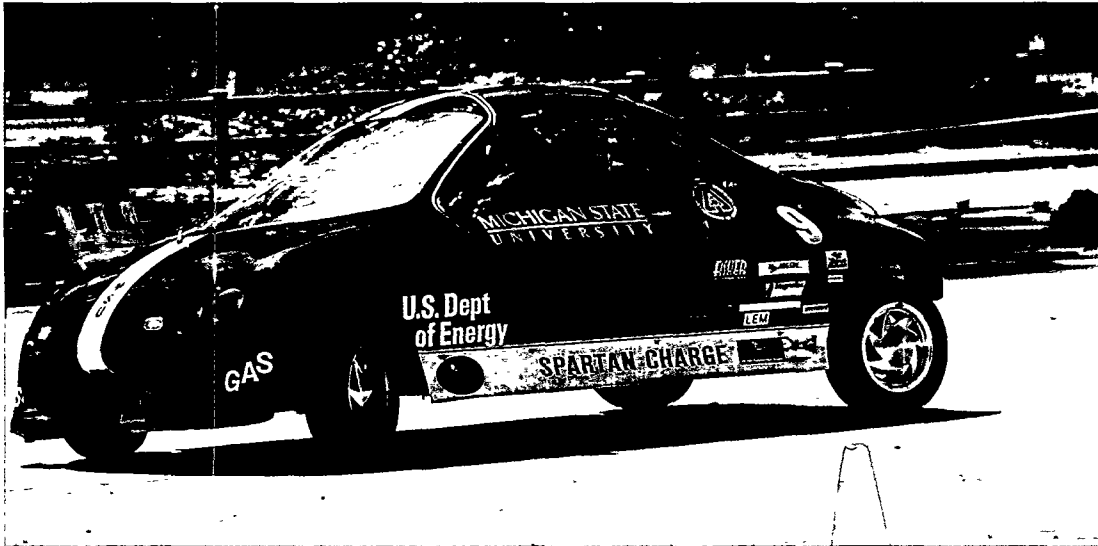
is supplied to consumers. Teamwork between scientists from Argonne and Intermagnetics General Corp. produced the strongest magnetic field ever generated by a coil of high-temperature superconducting wire — an important innovation for motors and generators. In January 1994, they would set an even stronger record.



Superconductors are tested by Bogdan Dabrowski in a high-pressure synthesis chamber.



Balu Balachandran stretches a silver-clad high-temperature superconductor wire.



The Spartan Charge leads the way in a collegiate car competition. Argonne organizes the competitions to harness the creativity of college students to develop innovative alternatives to gasoline-powered autos.

TOMORROW'S AUTOMOBILE

CREATING CLEANER CARS FOR A CLEARER FUTURE

Cars are part of the American dream. And like other changing parts of our way of life, the cars we buy are influenced by our concern for clean air and conservation of our natural resources.

ARGONNE RESEARCHERS ARE FINDING SOLUTIONS TO SOME OF THESE CONCERNS BY:

- Testing currently available alternative-fuel vehicles;
- Spurring designs of innovative cars powered by electricity, alternative fuels or a combination of the two;
- Developing cleaner-burning engines;
- Creating high-energy-density batteries for electric vehicles and high power-density batteries for hybrid-electric vehicles; and
- Researching ways to recycle all parts of cars.

Scientists, staff and secretaries at the lab drive around the site in alternative fuel vehicles as they go to meetings or run errands. Argonne operates the largest federal fleet of alternative fuel vehicles in the nation, with 60 sedans, minivans and full-sized vans operating on methanol fuel (M85), ethanol (E85) and compressed natural gas (CNG). Data are collected on the fleet vehicles, compiled monthly and sent to the Alternative Fuels Data Center. The information there is available to researchers as well as the public. In addition to dedicated vehicles, researchers are also working with flexible fuel Chrysler Intrepids, Ford Tauruses and variable-fueled Chevrolet Luminas, which run on any mixture of gasoline and alcohol fuels. Argonne also tests five CNG Dodge Minivans that have been certified as ultra-low-emission vehicles, meaning that they meet the most stringent standards proposed in the Clean Air Act.



Student vehicle competitions, organized by Argonne for the U.S. Department of Energy, provide innovative alternatives to gasoline-powered autos. Hybrid electric vehicles — cars that can run on electricity around town to lower emissions, but also have a fuel tank for highway trips — are the focus of college car competitions. Manufacturers donate new cars to college teams who convert them from gasoline to hybrid operation and compete in the HEV Challenge for best energy economy and lowest emissions, longest driving range, best handling and acceleration, and overall performance. Some student innovations are making their way into patented designs for autos.

Argonne engineers are studying several technologies for advanced emissions control. One is a cold-start-only variation of the oxygen-enrichment technology Argonne developed to increase energy power density and reduce particulate and smoke pollution from diesel engines. This new concept uses a small separation membrane that is activated only during cold starts on spark-ignition engines to reduce hydrocarbons and carbon monoxide emissions during the first one to two minutes of engine operation before the catalytic converter becomes hot enough to efficiently reduce emissions. Another research project is focused on a novel method for controlling nitrogen oxides. The same separation membrane used for oxygen enrichment can also provide a separate stream of nearly pure nitrogen. By passing that nitrogen through a sparkplug-like device, a nitrogen plasma can be created. The single atoms of nitrogen that form in this plasma rapidly combine with most of the nitrogen oxides to form nitrogen and oxygen — the basic constituents of air.

Boosting the acceleration and driving range of electric cars would make them more desirable. Argonne researchers developed the first rechargeable bipolar lithium metal sulfide battery. It runs about 250 miles before needing a recharge and lasts 100,000 miles. And the battery's design permits acceleration from zero to 60 miles per hour in eight seconds. Argonne's battery provides up to five times as much energy per pound as current battery technology and lasts ten times longer. Electrical current travels through the Argonne battery stack unimpeded like water flows through a hose. This cuts the physical resistance in half when compared to traditional battery current flow, permitting the power surges necessary for quick acceleration. Argonne battery research is funded by the Department of Energy's Office of Energy Efficiency and the U.S. Advanced Battery Consortium (USABC), a partnership of Chrysler Corp., Ford Motor Co. and General Motors Corp. with the Electric Power Research Institute.

An alternative source for electric cars is a fuel cell. Argonne researchers have developed an on-board methanol reformer that may make fuel cells practical. Fuel cells are like batteries with fuel tanks — they



Argonne is home to the largest federal alternative fuel fleet in the nation.



Students rebuild cars from the ground up for Argonne-run collegiate competitions.

produce electricity as long as they have fuel, and they never need recharging. Fuel cells are powered by hydrogen, a very light gas that is difficult to store, but Argonne's compact device that releases the hydrogen bound up in methanol could fit under the hood of a car along with the fuel cell (see page 44).

As new cars and engines are developed and replace older automobiles, the old cars go to dismantlers for recovery of useful body parts and other components for remanufacturing. Remanufacturable items include engines, transmissions, alternators, starters, water and steering pumps, and running gear. Ultimately, the obsolete shell of the auto is sent to a shredder, where almost 100 percent of the metal content and 75 percent of the total weight of the car is easily recycled. Working with the United States Council for Automotive Research, Argonne researchers are finding ways to recycle the remaining nonmetallic 25 percent, as well as to extend the useful life of auto components through disassembly and remanufacturing.

With Argonne processes, the plastic foam from your car seats may be recovered for use as carpet padding, the brass from your radiator may be recast into plumbing fixtures, the dust from auto shredders may be in the cement highway you drive on, and the plastic foam from an old dashboard may be used to make the dashboard in your new car. Argonne's development efforts are making dismantling more efficient, remanufactured components more reliable and the nonmetallic content of obsolete autos more easily recyclable.

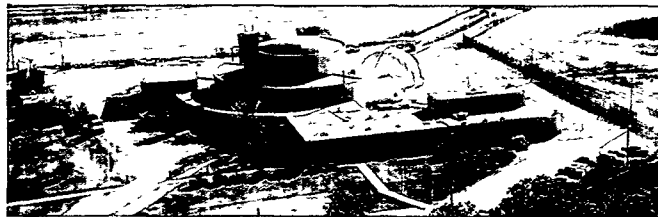
Tools to Create New Materials

The development of fuels and structural materials for nuclear reactors was facilitated by Argonne irradiation facilities such as Chicago Pile-5 and Experimental Breeder Reactor-II. Irradiated materials continue to be examined in the Alpha Gamma Hot Cell Facility.

Significant expansion in materials research was made possible by Argonne's Intense Pulsed Neutron Source (IPNS). The IPNS, based on a proton accelerator rather than on a reactor, allows scientists to study atomic and molecular structure, dynamics of solids and liquids, and materials under various environments.

Argonne's High Voltage Electron Microscope-Tandem Accelerator, dedicated in 1981, permits researchers to study real-time structural changes in materials subjected to ionic bombardment with a resolution close to the atomic level. The special microscope produces radiation damage by bombarding materials with particles

from a 300-kilovolt or two-million-volt particle accelerator. This allows study of radiation damage and deformation that may lead to new materials for nuclear reactors and energy storage and transfer. It is the only research facility in the world that lets scientists "watch" the effect of radiation damage to materials as it occurs.



An aerial view of the CP-5 facility.

EXTRACTING O₂ FROM AIR

ARGONNE/AMOCO RESEARCH BOOSTS NATURAL GAS-BASED FUELS



Joe Dusek examines a ceramic membrane that can be used to cleanly convert natural gas into a clean diesel fuel alternative. The membrane was jointly developed by Argonne and Amoco.

In many ways, natural gas is an ideal energy source: clean-burning, versatile, and plentiful. Until now, however, tapping into remote natural gas reserves for energy has been a difficult and costly undertaking. But Argonne material scientists, working with researchers from the Amoco Research Center, may have come up with a way to use the world's 7,000 trillion cubic feet of known natural gas reserves to economically produce a clean-burning alternative fuel for diesel engines. An additional benefit of the research is that it could provide a low-cost source of pure oxygen for a variety of uses.

The Argonne and Amoco researchers developed an inexpensive ceramic membrane that selectively extracts pure oxygen from air, which contains only about 20 percent oxygen. By providing oxygen at low cost, the membrane promises to reduce by 30 percent the cost of converting natural gas to synthesis gas, or syngas,

a mixture of hydrogen and carbon monoxide. For the development, researchers won a 1995 "R&D 100 Award." Each year *R&D* magazine recognizes the 100 most important technological achievements of the year with these awards. Amoco plans to use this ceramic membrane to convert remote natural gas reserves into syngas and use syngas to produce a clean alternative to diesel fuel. Other gas and oil companies are also possible customers for the technology. The membrane could also eliminate the burning of fossil fuel now required to convert natural gas to syngas. The ceramic membrane is estimated to save the oil and gas industry millions of dollars a year.

Syngas is an important feedstock for producing easily transportable liquid fuels, pollution-fighting fuel additives and many other industrial chemicals. Argonne and Amoco have used the membrane in natural-gas conversion processes, achieving conversion efficiencies of more than 98 percent. During the process, the membrane performed for more than 1,000 hours at temperatures as high as 1,560 degrees Fahrenheit (about 850 degrees Celsius) without failing.

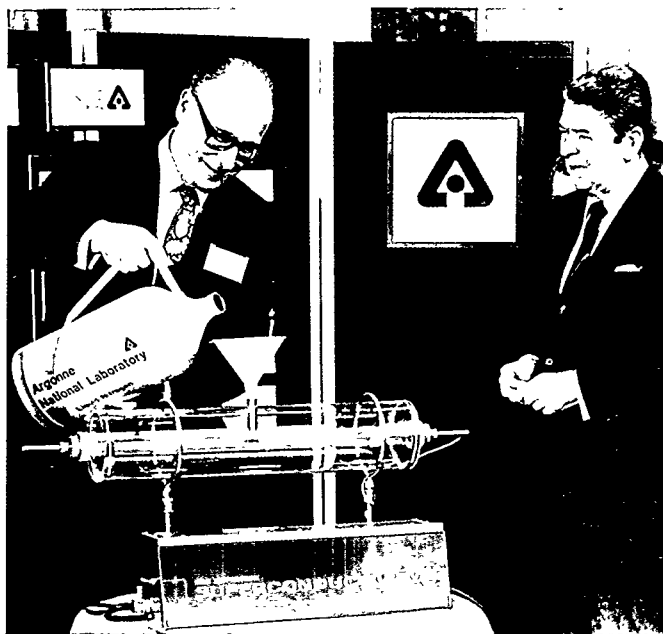
The ceramic is a strontium-iron-cobalt oxide. The keys to its success are its stability in the hostile syngas-reactor environment and its ability to conduct both electrons and ions — electrically charged atoms. In a typical syngas reactor, the membrane would separate air on one side from natural gas on the other. Electrons in the membrane combine with oxygen in the air to create negatively charged oxygen ions. The ions migrate through the membrane, from the air side to the natural gas side. At the natural-gas side, the electrons are stripped from the ions, converting them into oxygen atoms, which combine with methane, the main constituent of natural gas, to form syngas. Meanwhile, the freed electrons migrate back to the air side of the membrane, create fresh oxygen ions, and the process continues.



New Materials Research

Benchmark work by Argonne scientists produced many breakthroughs in materials research. For example, they discovered one-third of all organic superconducting materials. Materials with record-breaking magnetoresistive effects in metallic layered materials were unknown until Argonne researchers found them. Other discoveries include:

- Radiation-induced segregation as an important microstructural process in metals.
- Alloys for thermonuclear fusion reactor applications that limit erosion, provide self-sustaining protective coating to minimize energy loss, and inhibit transfer of impurities.
- Uranium silicide fuels for research and test reactors which require only low-enrichment and are therefore proliferation-resistant.
- Synthesis of new organic superconducting materials and structure-property relationships; record high superconducting transition temperatures for these materials were also established.
- New ceramic compounds for high energy density fuel cells, and for oxygen-permeable membranes used in converting methane to liquid fuels.



Alan Schriesheim demonstrates high-temperature superconductivity to President Ronald Reagan at a 1987 superconductor applications meeting.

- New solid lubricants based on boric acid compounds.
- Synthesis of high-quality nanocrystalline diamond film that is exceptionally smooth and has superior tribological properties.

Among other major accomplishments, Argonne scientists were able to: determine the mechanisms of irradiation-induced swelling of materials; predict the behavior of fuel elements in reactor cores; investigate and clarify the coexistence of superconductivity and magnetism in single crystals; develop inelastic

neutron scattering techniques to provide unique information on dynamics of solids and liquids; determine the structural, thermodynamics and phase relationships of many transuranium compounds; elucidate the depth of origin of sputtered atoms and the mechanisms of sputtered cluster emission (this was important for applications in many fields including geochemistry, cosmochemistry, and the superconducting industry). Also developed was neutron radiography and other nondestructive testing techniques that are used throughout the world.

Energy for the Future

By the 1980s, Argonne's mission in energy-related research was broadened to include fossil fuels, fusion, solar energy and energy storage systems. For example, work on molten salt and liquid metal chemistry led to the development of the LiAl-FeS battery.

Another example is "solar-cell-on-a-roll" technology that incorporates photo-active molecules developed at Argonne with electrically conductive stretched film.

By the 1980s, Argonne's mission in energy-related research was broadened to include fossil fuels, fusion, solar energy, and energy storage systems.

In 1991, the Department of Energy authorized a Proton-Exchange Membrane (PEM)

fuel cell program to develop the technology for energy-efficient electric vehicles. Argonne is responsible for its technical management.

Electrochemical materials research included development of improved cell chemistry, in situ electro-chemical overcharge tolerance, and metal-to-ceramic seal technologies that led to the successful demonstration of a rechargeable bipolar lithium/metal sulfide battery.



The rechargeable bipolar lithium/metal sulfide battery is used in electric cars.



Nanophase materials have extraordinary tribological properties.



X-ray diffractometry studies show material change as a function of temperature.

This technology enhanced the power and energy densities of long-life batteries for electric and hybrid vehicles—lasting up to 100,000 miles and running 250 miles before recharging.

Argonne scientists also directed the development of a phosphoric-acid fuel cell propulsion

system which led to the first successful demonstration of a methanol-fueled urban bus.

The laboratory's work on fuel cell technology could make electric cars a common sight on the street scene. Much more efficient and less polluting than current automobiles, the

fuel cells produce electricity, and they never need recharging.

Argonne has developed a device that may enhance the performance of the fuel cell — an on-board methanol reformer that is small enough to fit under a car's hood along with the fuel cell.

1953

The first of 1 million pine trees is planted at the Argonne site, part of a project to convert farmland to forest.



1962

Rachel Carson's *Silent Spring* is published, launching the environmental movement in the U.S.



1970

The first Earth Day is celebrated.

1988

The worst drought in 50 years hits the U.S. Half of the nation's farmland is designated disaster areas. Fires destroy 4 million acres of forest land.



Argonne, the U.S. Department of Energy's leading nuclear reactor lab throughout its 50-year history, is now taking the lead in developing new technologies and techniques to help the nation deal with two nuclear-related problems: how to dispose of spent nuclear fuel, and what to do with decommissioned nuclear plants.

ELECTROREFINING

A PROMISING TECHNOLOGY FOR TREATING SPENT FUELS

One of the problems, for both government and industry, created by the first generation of nuclear facilities has been the disposition of spent nuclear fuel — the material left after fuel rods have been burned in a reactor. Currently, about 3,000 tons of spent fuel are stored at various Department of Energy sites around the nation. This spent fuel comes from more than 40 years of nuclear-reactor research and includes more than 150 different fuel types. Some of it cannot be disposed of safely until it is treated to form a stable waste package that can stand up to long-term storage in a nuclear-waste repository. The DOE inventory includes fuel that is seriously degraded, highly enriched with fissionable or chemically reactive materials, and lacking the structural integrity to remain stable during long-term storage.

Argonne's nuclear technology program demonstrated a nuclear-fuel electrorefining process in 1995 that could save taxpayers billions of dollars in disposing of much of this spent nuclear fuel. A National Research Council committee reported in a preliminary finding that Argonne's electrorefining technology represents "a sufficiently promising technology for treating a variety of DOE spent fuels" to warrant continued research. In its current stage of development, Argonne's electrorefining process can treat more than 90 percent of DOE's spent-fuel inventory, converting it into a common waste form suitable for treatment and long-term storage. By providing a single process for this task, Argonne could save taxpayers billions of dollars compared to the alternative of developing dozens of processes to treat dozens of different fuel types. Argonne's electrorefining system is compact and fast. It was originally developed to treat small amounts of spent fuel from Experimental Breeder Reactor-II (EBR-II), an experimental reactor Argonne operated for 30 years in Idaho. Tests completed in early 1995 indicate that a unit about the size of a bathtub could process a ton of spent DOE fuel a day. If continued development is successful, small, standardized electrorefiners could be built at the sites around the country where DOE stores its spent fuel.

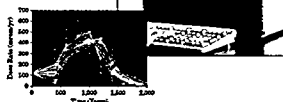
Electrorefining removes and separates the two major types of waste found in spent fuel: the short-lived radioactive by-products of uranium fission, such as cesium and strontium, and the long-lived





1989
Eleven million gallons of oil are spilled in Alaska's Prince William Sound.

1989
Argonne scientists develop RESRAD, a computer model for developing residual radioactive material guidelines.



1992
Argonne scientists develop a process to recycle auto "fluff," the non-metallic materials from junked automobiles.



transuranic elements, such as plutonium and other heavy, man-made elements. Long-lived wastes emerge from the process in a mixed form that cannot be used directly to make nuclear weapons. At the same time, the long-lived waste form is more compact and can be stored in a smaller space. The electrorefiner is made up of positively charged electrodes, called anodes, and negatively charged electrodes, called cathodes. When current is run between the electrodes, the transuranics collect on the cathode, while the short-lived, radioactive wastes stay behind in a concentrated form that can receive special handling and disposal.

Argonne engineers are now designing a 500-pound-per-day prototype. By 1997, they expect to be ready to demonstrate it at Argonne's Idaho site. As work progresses, Argonne hopes to develop a larger unit with a one-ton-per-day capacity for installation at various DOE sites. A ton-a-day system, which could be composed of a single unit or a number of smaller units, could be in operation by the turn of the century.



A History of Providing Environmental Solutions

Argonne has been involved in environmental programs since its earliest days. The Atomic Energy Commission was concerned about the fate and transport of radionuclides due to nuclear testing in the early 1950s. As a result, early atmospheric modeling, plant uptake and human health physics programs were established.

Environmental programs have been expanded since the late 1960s in response to national

needs. Even before the United States Environmental Protection Agency (U.S. EPA) was established, Argonne scientists and engineers were performing air quality evaluations throughout the greater Chicago area.

Following the creation of U.S. EPA and the passage of the National Environmental Policy Act, there was considerable debate over the need for a new kind of document —

the Environmental Impact Statement.

Argonne scientists, starting in 1973, began developing these statements for the Atomic Energy Commission, and later, the Nuclear Regulatory Commission and the U.S. Department of Energy. This work has continued until the present, with Argonne recognized as the preeminent laboratory for this activity.

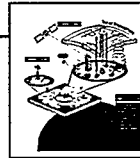


1992

Argonne scientists develop RISKIND, a computer program for calculating the radiological consequences and health risks from the transportation of spent nuclear fuels.

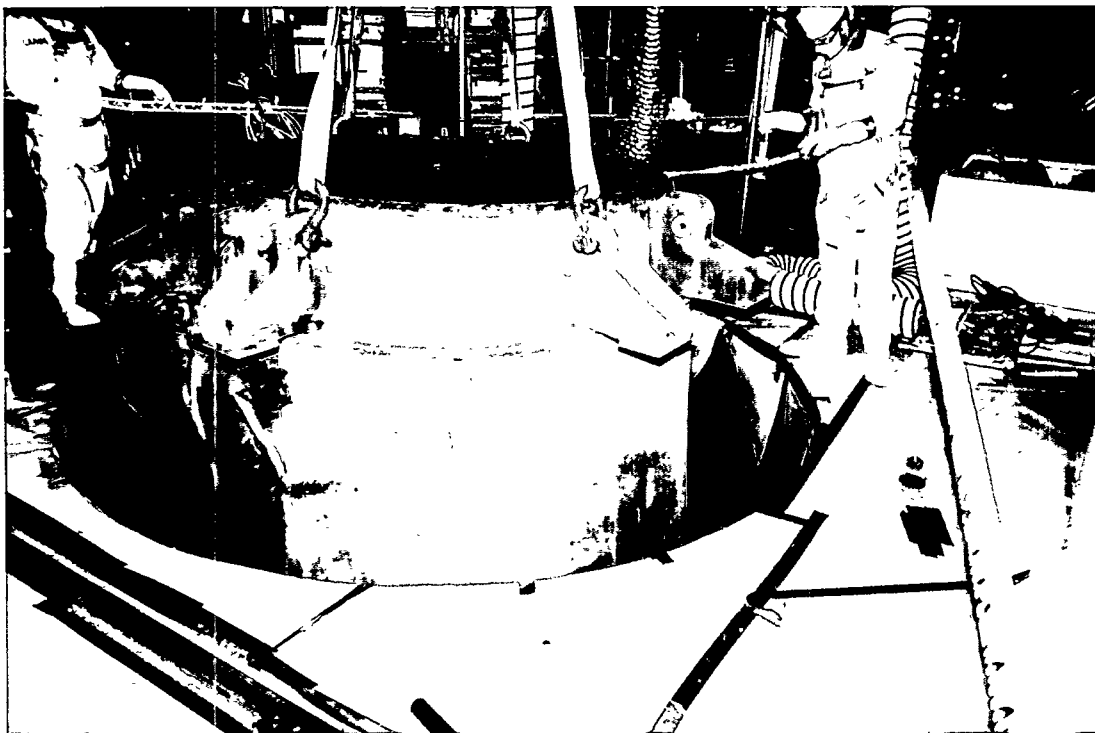
1993

ARM, a project to monitor climate data around the world, begins its first monitoring efforts at an Argonne-run site in central Oklahoma.



RETIRING REACTORS

NEW PROCESSES SAFELY CLEAN UP AGING FACILITIES



D & D technicians hoist a section of the Experimental Boiling Water Reactor. EBWR operated from 1956 to 1967.

A new Argonne program will help the U.S. Department of Energy find ways to safely retire aging facilities used in the development of nuclear power. New technologies are being developed and tested for decontaminating and decommissioning (D&D) radioactive components of old reactors and associated facilities, and dismantling and preparing for safe storage components that cannot be readily decontaminated. These techniques could help reduce the mounting costs of monitoring the facilities and make it possible to safely transfer many of them to other uses, such as storing reactor wastes or as sites for new reactor-related facilities.

Argonne's work in the D&D field could help strengthen the capabilities of American industry to meet an international need that is expected to grow in importance. In the next few decades, the domestic and international market for D&D services is expected to gross hundreds of billions of dollars. Thousands of DOE facilities now need decontamination and decommissioning, and the costs have been estimated in



the billions of dollars. A long list of nuclear facilities owned and operated by electric utilities will need decontamination and decommissioning in the foreseeable future. As DOE's leading reactor-development laboratory, Argonne has expertise in many key D&D areas and has already developed a number of relevant technologies. Argonne is developing plans to decontaminate and decommission two of its existing reactors and expects to perform D&D on three other Argonne reactors in the next few years. In addition, D&D is scheduled for a number of the laboratory's gloveboxes, hot cells, caves, fuel storage pits and particle accelerators. These projects all provide practical opportunities to test newly developed D&D technologies.

The Argonne reactors funded for D&D are the Experimental Boiling Water Reactor (EBWR) and Chicago Pile 5 (CP-5). Decontamination and decommissioning is already under way on the EBWR. Operated from 1956 to 1967, it was the nation's first reactor built solely for research on generating nuclear electricity. From 1954 to 1979, CP-5 provided neutrons for hundreds of experiments that probed the structure of solids and liquids. It was a direct descendant of CP-1, the University of Chicago reactor that produced history's first controlled self-sustaining nuclear chain reaction on December 2, 1942 (see page 6).

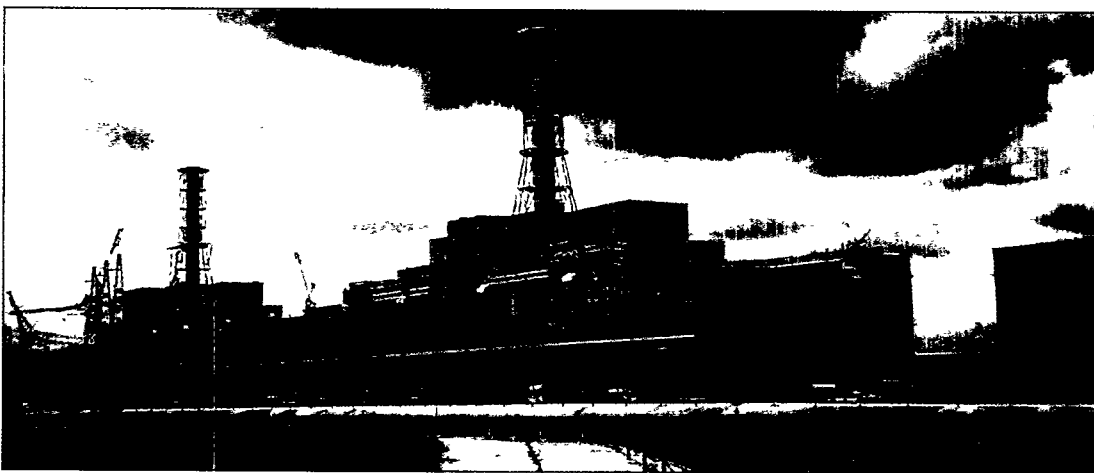
An important part of Argonne's program will center on developing D&D methods for EBR-II. The reactor was shut down in September 1994. EBR-II has a core of metal-alloy fuel, which sits in a cooling bath of thousands of gallons of liquid sodium. Liquid-metal cooling is unusual for a reactor in the United States, but France, Germany, England, Japan and Russia all have experience with liquid-metal reactors. D&D of EBR-II offers valuable learning opportunities for other nations. At the same time, EBR-II will provide lessons that apply to all reactor D&D. For example, a number of designs are being evaluated for remote viewing and other equipment that should prove valuable for inspection and diagnostics during D&D of most reactors.

ARGONNE'S NEW D&D PROGRAM HAS BEEN UNDER WAY ONLY SINCE OCTOBER 1994, BUT SIGNIFICANT TECHNICAL PROGRESS HAS BEEN MADE IN SEVERAL AREAS:

- An experimental program is measuring airborne particles generated from a variety of cutting devices used to dismantle nuclear power-plant components. These particles could harm workers who accidentally breathe them. A computational tool is being developed to help design ventilation systems that capture and remove particles from the air inside cutting chambers.
- A novel system is being developed that captures radon, a radioactive gas that sometimes contaminates gloveboxes and other nuclear facilities and interferes with the detection of long-lived radioactive elements, such as americium and neptunium, during D&D operations. If tests of Argonne's radon-capture system prove successful, it could lead to commercial products for removing natural radon from commercial and residential buildings.
- Experiments are using components from commercial reactors to test the effectiveness of an Argonne-patented decontamination process.
- Work is under way to improve the fiber-optics system that delivers a cutting beam from a neodymium YAG laser used during D&D to cut apart reactor components.
- An experiment is being prepared to assess the ability of membrane filters to remove radioactive contaminants from chemical waste streams produced during decontamination. Once captured, the contaminants can be disposed of safely.

SAFE REACTORS FOR ALL

SHARING ARGONNE'S EXPERTISE WITH THE INTERNATIONAL COMMUNITY



Argonne-developed safety standards will be used in foreign reactors such as this unit at Kursk in Russia.

As the tragic 1986 accident at Chernobyl demonstrated, many of the Soviet-designed nuclear reactors in the former Soviet Union and Central and Eastern Europe do not measure up to modern Western safety standards. The nations that operate them often lack the safety culture, regulatory processes and technical support that make Western reactors safe. Nevertheless, many of these reactors must continue operating because local economies badly need the electricity they provide. Accordingly, Argonne is working with the U.S. Department of Energy to provide scientific and technological resources to help improve the safety of Soviet-designed nuclear reactors in cooperation with concerned governments and international agencies. Much of this effort will involve cooperative East-West research.

One long-term goal is to provide a centralized resource of major computer codes, data and expertise to provide a fast response when international reactor-safety issues arise. Started in late 1994, this effort is developing a safety database on foreign reactors. Discussions are under way to develop collaborative programs between Argonne and various institutes conducting reactor-safety research in Russia.

Argonne has also made significant progress in modifying existing computer programs, created for

Western reactors, to better predict the behavior of Soviet-designed reactors. Teams of Argonne scientists and engineers have collected safety-analysis data on Soviet-designed reactors and are at work determining ways in which accident management developed for U.S. reactors can be applied to Soviet-designed reactors.

Another key mission for Argonne's reactor-safety programs focuses on light-water reactors — the world's most common type of commercial nuclear power plant. Argonne's goals are to apply advanced technology to maintaining safety and reducing operating costs at nuclear power plants. This work will also provide DOE with technical resources to aid safety analysis and experiments in support of existing and advanced light-water reactors. One major accomplishment in 1994-95 was testing a gas-tagging technique

OTHER ACCOMPLISHMENTS INCLUDE:

- Developing a way to use existing computer codes and advanced computing techniques to simulate light-water-reactor operations and diagnose possible safety problems.
- Gathering data from flowmeters and pressure transmitters at an operating pressurized-water reactor and demonstrating techniques for detecting failures of these instruments.



that pinpoints the location of failed fuel in pressurized-water reactors. This method involves loading a mixture of inert gases, such as xenon and krypton, into reactor fuel pins when they are made. These gases come in many isotopes, atoms that are chemically identical but have different atomic masses. During manufacture, each fuel pin is loaded with a different, but known mixture of isotopes. If a pin should fail later, it can be identified by the isotopic composition of inert gases that leak out.

RISKY BUSINESS

RISK ASSESSMENT PLAYS GROWING ROLE IN POLICY-MAKING

Determining the true levels of potential risk to human health and the environment has become a key consideration in the development of federal, state and local environmental policies and decisions. And while "risk assessment" has only recently become a buzzword in congressional debate on environmental laws, it is not a new concept to scientists at Argonne. As risk-based decision-making and cost-benefit analysis of environmental laws become standard procedure, Argonne's risk assessment expertise will increasingly be in demand.

For years, environmental scientists at the laboratory have been using Argonne-developed, integrated computer approaches for conducting risk analyses. "Risk" refers to a broad spectrum of undesirable consequences, including those that affect human health and safety, the environment, facilities, and measures of economic and social well-being. Risk assessment computationally evaluates the likelihood that these undesirable circumstances would occur. Risk computer programs can investigate the hazards or sources of risk; the mechanisms by which sensitive human, ecological or other systems become exposed; and the consequences of exposure.

Key to Argonne's approach to risk analysis is the development of sophisticated environmental pathway analysis models — or computer codes — to predict environmental and human health risks of specific actions. One such computer code, Residual Radioactivity (RESRAD), was developed by Argonne for the U.S. Department of Energy to guide environmental cleanup activities at radioactively contaminated sites. The only such code authorized for use by DOE, RESRAD is being extended to investigate risks from chemical contaminants. RESRAD has been used to determine site-specific guidelines for cleanup activities at more than 30 sites across the country, including the Weldon Spring site near St. Louis, Mo. Weldon Spring was chemically and radioactively contaminated between the 1940s and 1960s as a result of processing and disposal activities. Site remediation alternatives required Argonne's integrated study of current radiological, chemical, ecological and transportation risks. Argonne also developed and evaluated alternatives for reducing risks and managing hazardous materials at the site.

Using its risk analysis programs, Argonne scientists have provided risk-based evaluations to help develop guidelines for recycling radioactive scrap metal from dismantled nuclear facilities. The risk assessment analysis considered recycling alternatives and identified parameters that could be used for general regulatory guidance. Researchers also identified conditions under which using recycled scrap metal from the nuclear facilities would pose less overall health risk to workers and the general public than using new steel produced from raw materials. Argonne provides training in risk assessment methodology, as well as conducting critical analyses on issues including spent nuclear fuel conditioning; treatment, storage, disposal and transport of radioactive and hazardous materials; and facility accident analysis.

RELYING ON THE EXPERTS

ARGONNE PROCESS SPEEDS HAZARDOUS WASTE CHARACTERIZATION



Using PLUME, soil samples are surveyed at Argonne for quick feedback.

In 1995, when Argonne needed to determine the extent of contamination at a site used for storage and disposal of laboratory wastes for nearly 50 years, the lab turned to the national experts in the field — its own environmental researchers. Scientists at Argonne had designed and were already using a site characterization, or mapping, program called PLUME™. PLUME is a decision support program that uses a technique called “adaptive sampling strategy” to determine the best locations for collecting soil samples.

Argonne now ships all of its hazardous waste off-site, but in the lab's early years, some wastes were disposed of on-site, using procedures that were standard at the time. In the 1980s, a number of hazardous organic compounds were found in the soil and groundwater around a radioactive waste handling area and storage facility at Argonne's Illinois site. During the mid-1950s, liquid chemical wastes (such as spent solvents, cutting oils and machine coolants) had been poured into a gravel-filled trench and were absorbed into the soil. Recent characterization studies revealed that the chemicals were still in the soil and groundwater at high concentrations very close to where they were discharged. To fully characterize the nature and extent of this contamination, an outside contractor proposed a soil probe study to locate the original trench structure and to determine the size of the contaminated region. Soil samples

would be collected along a sampling grid consisting of more than 200 locations. To save money and improve the study's effectiveness, Argonne turned instead to its own environmental research experts. Using the newly-developed PLUME tool, scientists created an alternative study plan. The plan called for only 77 sampling locations instead of the contractor's proposed 200 — a 62 percent reduction.

PLUME uses geostatistical data analysis, based on prior knowledge of the site and new information developed in the field, to determine the most efficient placement of sample locations. Researchers analyzed samples as they were pulled in the field and quickly fed the data into PLUME for an almost instantaneous analysis and graphical presentation of the information. The program compared the new data with previously known information about the site and recommended locations for the next set of samples. Having this information available while the sampling crew was still in the field enabled the sampling program to proceed with a clearer focus and greater efficiency than would have been possible with the traditional grid pattern system of characterization and later analysis. As a result, this phase of the investigation was completed twice as fast as expected at about half the cost. In addition, the information gathered with PLUME is more valuable than the results from conventional characterization.

PLUME is suitable for many types of site studies involving the identification of contaminated areas. The PLUME program was designed to work in conjunction with a commercial data management and visualization program called SitePlanner™, marketed by ConSolve, Inc.

Hazardous Waste Cleanup

Argonne has been a leader in addressing hazardous waste site problems for all federal agencies since 1983 — the time of Love Canal. Laboratory researchers have developed a number of innovative separations techniques for radioactive wastes. The 1990 discovery of the Transuranic Extraction (TRUEX) process, a method for separation of transuranics from radioactive wastes, was followed by the development of a process for separating strontium-90 from liquid nuclear wastes. More recently, Diphonix, a chelating ion exchange resin, was developed to treat hazardous and radioactive wastes.

A number of fate and transport waste programs were developed to address site remediation issues. RESRAD is an environmental pathway and health risk model used for deriving soil clean-up guidelines. Developed at Argonne, along with RISKIND for examining issues associated with transportation of wastes, these decision models are now used at many U.S. Department of Energy facilities.

Methods of rapidly assessing and characterizing sites have also been developed at Argonne. Argonne was one of the first organizations to develop expedited site characterization processes and methodologies. These techniques, first developed at Department of Interior and Department of Agriculture



Argonne was one of the first organizations to develop expedited site characterization processes and methodologies.

A chemical additive based on ferrous iron and a common food additive was developed by Argonne researchers to remove most nitrogen oxides from coal-burning steam plants.

sites, have gained wide acceptance from regulators and are now being used by DOE, leading to significant cost and time savings. Other modeling and decision tools have been developed by Argonne, including PLUME™ (see page 72) which was the first Cooperative Research and Development Agreement to produce royalties in the environmental arena. This system, successfully used at DOE and U.S. Air Force locations, is designed to reduce sampling requirements based on modeling projections.

Starting in the late 1970s, the National Acid Precipitation Assessment Program was designed to examine the causes and impacts associated with acid rain. This program, as practiced at Argonne, successfully combined research

activities in ecology, meteorology and atmospheric physics with the development of atmospheric transport models which were used for public policy evaluations and recommendations.

Work in this area has continued under the overall umbrella of global climate change activities. Argonne is a leader in the Atmospheric Radiation Measurement (ARM) program. The laboratory currently runs the only fully instrumental Cloud and Radiation Testbed (CART) site in the country. At the site on the Kansas-Oklahoma border, measurements of solar radiation, greenhouse gases, aerosols, clouds and their effect on atmospheric heat and temperature are taken and studied by scientists.



Geologists examine soil samples recovered during sonic drilling at the Pantex Plant near Amarillo, Texas.

HAZARDOUS WASTE CLEANUP

ARGONNE-DEVELOPED PROCESS SAVES TIME AND MONEY

Cleaning up the nation's legacy of hazardous waste sites is a time-consuming, expensive job that is expected to last well into the next century. To accelerate the cleanup, Argonne scientists have developed a new characterization method that is saving both time and money. The Argonne process uses seismic and magnetic imaging and on-the-spot chemical analysis to determine the locations of water and its path at a contaminated site. Field investigators can then locate and identify contaminants without resorting to the use of costly monitoring wells. The Argonne Expedited Site Characterization (ESC) process is now being used at a number of hazardous waste sites, including the U.S. Department of Energy's Pantex Plant near Amarillo, Texas. Formerly a nuclear weapons production facility, Pantex is contaminated with explosives, organic solvents and heavy metals. Argonne's task is to characterize, or map, a perched aquifer — similar to a bowl of water underground, surrounded by relatively impermeable material — under one 280-acre site. Once the nature of the contaminants is determined, detailed cleanup plans can be made.

Scientists are working to determine the aquifer's size, its connection to other bodies of water and the direction the water is flowing. They are also mapping out the area's geochemical and geological makeup. A team of environmental scientists uses a combination of geological, geophysical and chemical diagnostic procedures to identify and characterize contaminated areas. The procedures minimize the need for installing monitoring wells, saving time and money over traditional methods. In the ESC process, researchers use advanced drilling techniques to map and sample soil and ground water without installing wells. Seismic and electromagnetic devices produce images of the subsurface, much like medical imaging. A portable, sophisticated chemical laboratory is often set up at the site to provide precise information on the types and quantities of contaminants in water, soil and vegetation.

This process is in sharp contrast to traditional methods of site characterization, which rely heavily on costly monitoring wells to map the distribution of contaminants. The Argonne characterization

process not only increases the accuracy of the site characterization, but it can also dramatically reduce costs, by up to 90 percent, and field time by as much as 95 percent. These savings can greatly accelerate the environmental cleanup programs of government agencies and private industries. Thanks to the Expedited Site Characterization process, managers of the Pantex project estimate that they will finish four years ahead of schedule at a cost savings of \$4 million. The ESC process was also demonstrated successfully in New Mexico, where Argonne scientists characterized landfills thought to contain hazardous waste.

York, Neb., is the setting of yet another success story. At an abandoned U.S. Department of Agriculture grain elevator site, carbon tetrachloride used to fumigate stored grain in the 1950s and 1960s had leached into the soil. Using the Argonne process, scientists completed characterization of the site in 15 field days at a fraction of the cost of traditional characterization techniques, helping to speed the return of clean water to surrounding communities.

Scrubbing the Atmosphere

During the early and mid-1970s, Argonne scientists were also "pushing the envelope" in developing new instrumentation for measuring anthropogenic — caused by humans — pollution in the atmosphere. For example, techniques developed then reduced the time for analysis of atmospheric particulates from several hours to 20 minutes.

Argonne chemists have been active since the 1950s in addressing needs associated with separation and treatment of radionuclides in waste. Early breakthroughs included the development of methods for separation of xenon and radon from contaminated atmospheres in 1973.

The energy crisis of the mid-1970s led to new integrated assessment programs seeking



Testing provided insight into atmospheric pollution transport.

to develop indigenous energy resources. With the formation of the U.S. Department of Energy, it was recognized that there could be severe environmental impacts associated with the development of resources such

as coal, oil shale, uranium, and materials required for solar and renewable technologies. Two programs, the National Coal Utilization Assessment and the Regional Studies Program, were developed, and major portions were led by laboratory scientists and engineers. These programs were enhanced by expertise developed in other programs, such as water quality studies for the Corps of Engineers, the land reclamation program for DOE which examined the re-use of surface coal-mined lands, and atmospheric modeling activities developed for predicting the transport of atmospheric pollutants. By the late 1970s, Argonne was positioned to address practically any scientific or engineering issue related to energy and the environment.



Soil scientists run field tests in a TNT-contaminated field. Their "path" is so highly contaminated with TNT that plants will not grow there.

EXPLOSIVE PLANT GROWTH

FIRST-EVER FIELD STUDIES CONDUCTED ON CONTAMINATED CROPS

As they produced weapons during and after World War II, the nation's munitions factories used the standard practices of the time for handling waste. Waste streams were frequently discharged directly into lagoons or fields, and solid waste was often burned. Over time, residues of TNT and other explosives accumulated in these disposal areas. Depending on the types and concentrations of explosives waste, the disposal sites now are either barren or covered with plants. Citizens and government agencies have become concerned about possible environmental and human health risks from these contaminated fields. Could the explosives, their by-products and the products of their degradation be entering animal and human food chains through vegetation and crops growing on explosives-contaminated soils?



Analytical chemist Nancy Tomczyk performs tests in the field for instantaneous results.

Argonne soil scientists and agronomists set out to answer this question by undertaking studies at two U.S. Army ammunition plants. Previous studies had indicated that explosives and/or their degradation products may be taken up by plants grown under greenhouse and hydroponic conditions; but no data were available for plants grown in the field. The results of the Argonne study are in, and the news is mixed. The good news is that crops grown on the former munitions fields are not being contaminated with TNT. Contamination by other explosives, however, may pose a health problem.

Argonne, a pioneer in studying agent-contaminated soils, looked not only at the extent to which explosives are brought up by plants from the soil, but also at the possible influence of organic additions to the soil on the uptake. Soils and existing plants collected at the former ammunition plants, located in Iowa and Illinois, were analyzed for explosives and degradation products to determine a baseline. At one site, oat and rye grass were planted on TNT (2,4,6-trinitrotoluene) contaminated soils with added ground grass hay. Extractable TNT concentrations in soils were monitored for 328 days. Crop growth improved as more ground hay was added, but TNT uptake was not affected in any above-ground crops. In fact, neither TNT nor its degradation products were found in above-ground-plant tissues of existing vegetation at either ammunition plant.

The study's results suggest that vegetation grown on TNT-contaminated soils is not a health hazard. Soil and plant roots may, however, contain TNT degradation products that could be toxic and their consumption is not advised. There was also some evidence that hay additions may reduce extractable TNT concentration in soils, but more research is needed.

On the other hand, at all sites where the explosive RDX (1,3,5-trinitro-1,3,5-triazine) was manufactured, RDX was found in tops and roots of plants growing on RDX-contaminated soils. RDX is not a listed carcinogen, but several of its potential degradation products may be carcinogenic. For this reason, the consumption of any plants growing on RDX-contaminated sites should be considered a potential health hazard. Argonne researchers are also studying more highly contaminated areas across the country to develop techniques to clean the soil.

Controlling Pollution and Contamination

Argonne is a leader in pollution control systems for fossil-fired power plants. Some of this expertise has evolved into new areas related to pollution prevention, waste minimization and recycling. The lab's nuclear, chemical and biotechnical engineering expertise and experience permits Argonne to play an increasing role in Department of Energy and other federal agency waste management activities. Some activities include development of vitrification technologies, use of separations technologies for reducing radioactive waste volume, use of biotechnology

for remediation of TNT-contaminated soils, and the use of technologies and experience developed as part of the Integral Fast Reactor program. In the last use, instrumentation, facilities and pyroprocessing R&D are being used to address DOE's spent nuclear fuel issue (see page 66). Argonne has been a contributor to environmental research and technology development since the early 1950s. As national needs and priorities have grown in this area, Argonne experience and capabilities have also grown to meet these needs and address priorities. Argonne's environ-

mental programs are carried out in the national interest.



William Penrose tests the toxic gas detector developed at Argonne. The detector can identify 40 hazardous gases almost instantly.

1800

Herschel discovers infrared radiation.

1801

Ritter discovers ultraviolet radiation.

1869

Maxwell proposes laws of electromagnetism.



1888

Hertz produces first radio waves.

1889

Rutherford discovers alpha rays and beta rays.



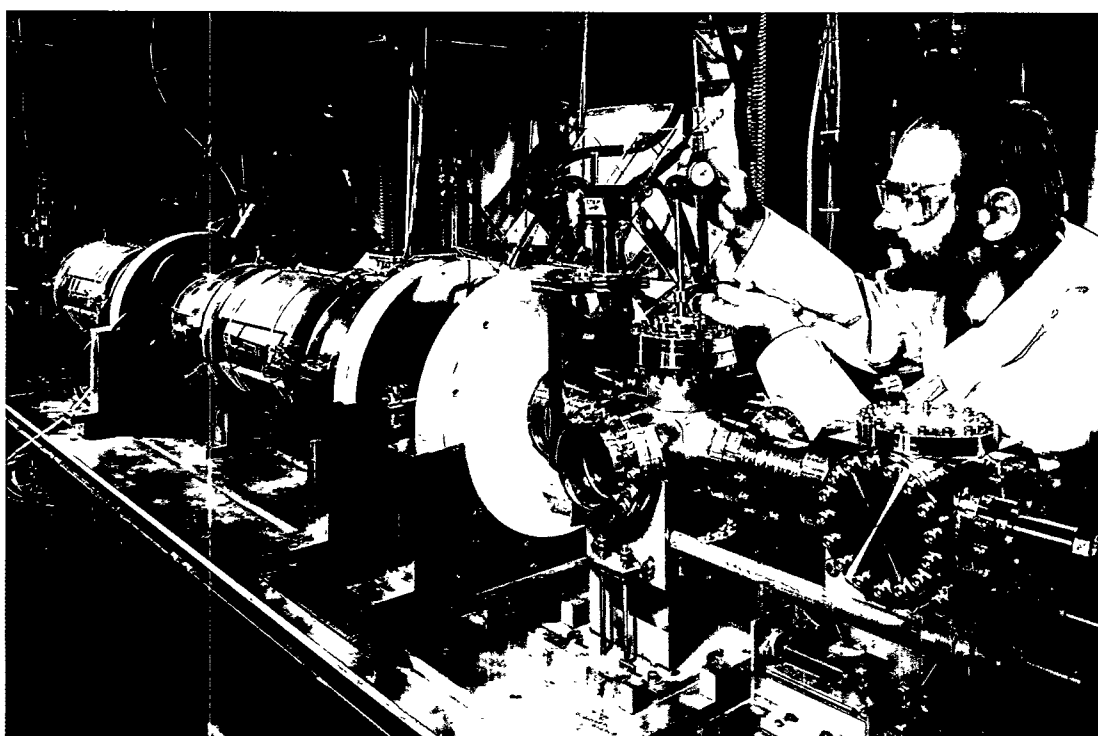
1895

Roentgen discovers x-rays.



"SURFING" PARTICLES

SCIENTISTS SEEK TO UNDERSTAND MATTER'S BASIC BUILDING BLOCKS



Dick Konecny prepares for an experiment in the Argonne Wakefield Accelerator, in which particles surf through an electron beam wave.

If a new technology being developed at Argonne lives up to its promise, the next generation of high-energy particle accelerators may be very different from the giant, sprawling, expensive machines presently being used. Argonne researchers have built and successfully tested a key component of a revolutionary new way to accelerate subatomic particles using a technique called the wakefield effect.

The Argonne Wakefield Accelerator could lead to smaller, more cost-effective accelerators for the complex machines used by physicists to explore the basic structure of matter, as well as for medical and industrial applications. The Argonne wakefield device, expected to begin operation by the year 2000, will accelerate particles, such as electrons, at a rate many times faster than conventional accelerators. While conventional accelerators supply about 25 million volts of acceleration in each meter of length, one using wakefield technology could supply up to 200 million volts in the same distance. A wakefield





1897
Thomson discovers
the electron.



1900
Rutherford discovers
gamma rays.

1913
W.D. Coolidge invents
x-ray tube.

1917
Millikan measures
electron charge.



1923
Arthur Holly Compton
concentrates x-rays using
lenses and mirrors.

accelerator uses the energy of a special, relatively low-power electron beam to produce wakefields on which other particles “surf,” riding along on an electric field wave in much the same way a surfer can build momentum by riding along a speedboat’s wake. The accumulated effect can accelerate these “surfing” particles to very high energies in short distances.

In high energy physics experiments, the beams are collided “head on” with other beams. The collisions produce particles which previously existed for only a short time after the “Big Bang,” the cataclysmic birth of the universe. Studying the properties of these particles helps scientists understand the most basic building blocks of matter.

A source for the drive electron beam has been tested at Argonne. The specially designed linear accelerator system which makes up the source produces intense electron bunches, each containing up to 500 billion electrons traveling near the speed of light. Each bunch is less than 40 picoseconds long, about the time it takes light to travel one-half inch. In order to reach extremely high accelerating strengths, the wakefields produced by the drive bunches will be compressed by special ceramic “transformer” devices. Transformer tests began in 1995. However, the new drive linear accelerator alone is a useful tool for developing and testing other accelerator ideas and other uses. For example, Argonne chemists believe they can take advantage of the very short pulses of electrons to investigate how chemical processes are initiated and how they may be controlled in those initial picoseconds. This basic chemical research may lead to new industrial applications in the production of polymers. Argonne scientists plan to demonstrate a 1-billion-electron-volt linear accelerator based on this technology by the end of the decade.



Physics: Beginnings

Much of the understanding of nuclear fission came from the work of physicists at the Metallurgical Laboratory and at Argonne. Argonne scientists led the country’s basic research

effort in support of reactors. They also developed and built two novel accelerators — the Zero Gradient Synchrotron and the Argonne-Tandem Linear Accelerator System, the world’s

first superconducting accelerator of heavy nuclei, which is now the country’s premier research tool for studying the structure and dynamics of heavy nuclei.

1925
Rutherford discovers the proton.

1957
ARGONAUT completed.



1960
Juggernaut built.



1934
First instruments for high-resolution measurements of absorption and emissions of x-rays in solids developed at Cornell University.

1962
Van de Graaf accelerator operational.

ATLAS ADVANCEMENTS

NEW ION SOURCE INJECTOR PROVIDES UNIQUE RESEARCH RESOURCE



Iain Tilbrook keeps an eye on ATLAS. Ions are accelerated 24 hours a day, seven days a week.

The Argonne Tandem Linear Accelerator System (ATLAS) will soon provide researchers with beams of heavy ions five times more intense than is now possible, thanks to a new “injector” ion source now under construction. The ion source strips electrons from atoms, giving them a positive charge used to propel them at high energies into targets of various materials. The impacts produce gamma rays and particles which contain valuable information about nuclear structure and reactions. ATLAS is the first heavy-ion accelerator in the world in which superconducting devices provide all of the acceleration as well as the beam-focusing elements. Superconducting metals, which conduct electricity with very little resistance, allow the beam to operate continuously without generating excess heat. The complex machine is almost 500 feet (150 meters) long.

The accelerator’s flexibility is a strong attraction for researchers interested in low-energy nuclear physics. The device offers hundreds of possible choices of beam particles and energies. Using the existing injector, the heaviest natural element, uranium-238, can now be accelerated up to energies

1963

ZPR-6 operational.



Argonne's
Maria Goeppert-Mayer
wins Nobel Prize.

1966

Liquid Hydrogen Bubble
Chamber operational.

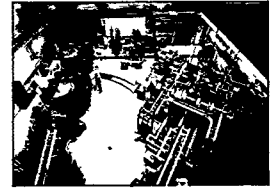


1968

Argonne Braille Machine
developed.

1973

First successful test of
superconducting linear
accelerator.



1985

ATLAS, first superconducting
accelerator for heavy ions, completed.

of 1.9 billion electron-volts (Gev), which permits study of atomic nuclei in an extreme state of excitation and provides new insights into nuclear forces. This high energy also permits a large number of electrons to be stripped from heavy atoms, allowing high-precision atomic physics studies on these stripped ions. The advanced design of the new injector ion source makes possible increased beam energies for uranium up to 2.2 Gev. Having two positive-ion sources also reduces setup time between experiments, as one injector can be readied for operation while the other is in use.

The ATLAS building is being expanded to house the new injector, and many of the device's components are already fabricated. Testing should begin in the spring of 1996, with beams for research expected by the end of the year. ATLAS is open to visitors from around the world. In 1995, 161 scientists from 22 American universities, five national laboratories and 16 foreign institutions performed research at ATLAS. Other ATLAS upgrades include a new "wet-engine" system, which has increased the efficiency of ATLAS' cryogenic system by almost 30 percent. The system cools the machine's superconducting components. The heart of ATLAS is 63 superconducting resonators — each operating as an independent miniature particle accelerator. Three liquid helium refrigerators cool the resonators and other parts of the machine, currently using about a megawatt of power when going at full tilt. In addition to lowering ATLAS's electricity bills, the system makes additional refrigeration available for special applications such as accelerating heavy ions like uranium to peak energies.

Accelerating All Nuclei



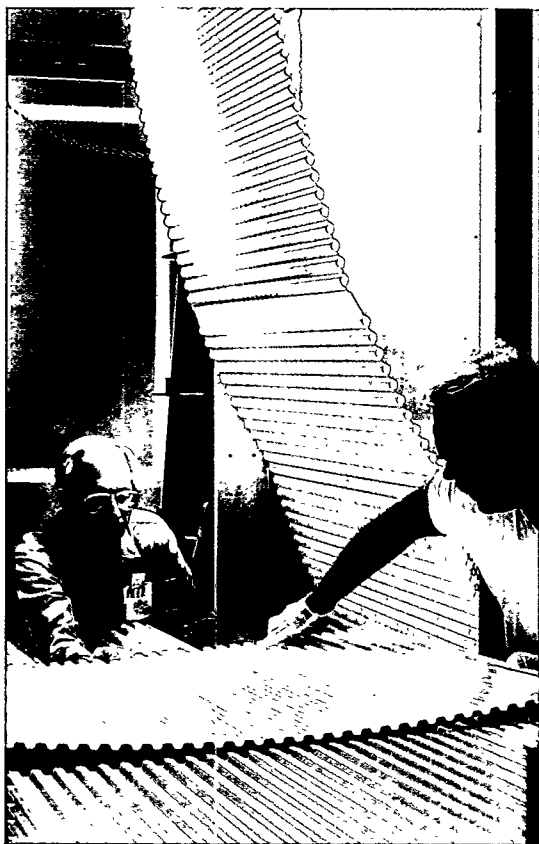
ATLAS Split-Ring Resonator

Argonne's Tandem-Linear Accelerator System (ATLAS) was dedicated in 1985, one week after accelerating its first ion beam. The world's first superconducting linear accelerator for nuclear research was a major advance in accelerator technology. Acceleration is provided by superconducting resonators. This makes possible

high-quality ion beams over a broad range of projectile energy and mass, spanning the energy domains in which nuclear structure effects are particularly important. Its beam intensity was increased 100-fold in 1988 which permitted acceleration of ions as heavy as uranium to energies as high as 1.9 billion electron volts.

DO PROTONS DECAY?

MINE OBSERVATORY SEEKS CLUES TO UNIVERSE'S FATE



The Soudan 2 detector modules were constructed from layers of corrugated iron.

Many of the canoeists and fishing buffs on their way to northern Minnesota's Boundary Waters won't realize it, but almost a half-mile below the region's rolling hills and pike-packed lakes, scientists are trying to determine the ultimate fate of the universe. In an old iron mine 2,340 feet below the town of Soudan, Minn., researchers from Argonne and other institutions are now monitoring the thousand-ton Soudan 2 proton decay detector to determine whether protons — the positively charged particles that make up part of every nucleus in every atom of the universe — will eventually decay into other particles. The project is a collaborative effort by Argonne's High Energy Physics Division, the University of Minnesota, Tufts University and England's Rutherford Appleton Laboratory and Oxford University.

A free proton's half-life (the period in which it has a 50-50 chance of decaying into other particles) may be longer than 10^{31} years — that's a one with 31 zeroes after it, or 10,000 octillion years. Since that's too long for even the most patient scientist to wait, the Soudan 2 detector contains more than 10^{31} protons in the form of iron sheets, which

are monitored by sensitive particle detectors listening for a single proton's death rattle. The electronic signature of a proton's demise would contribute to a better understanding of three of the universe's four fundamental forces: electromagnetism and the strong and weak nuclear forces that bind matter together (the fourth is gravity).

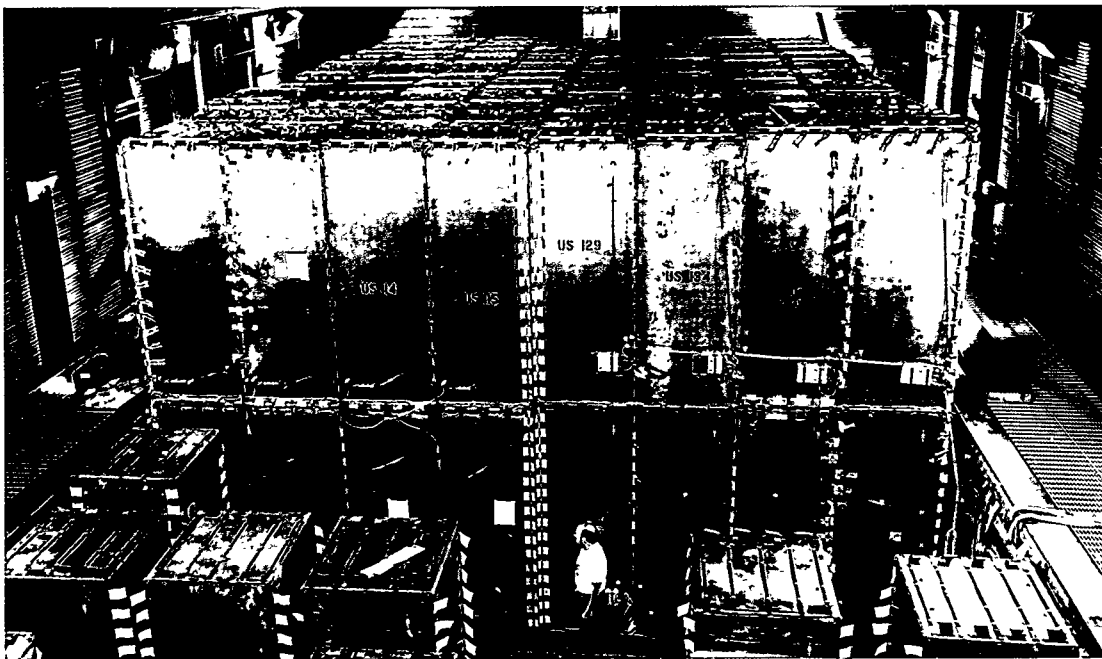
The vision of such a great physics payoff has kept the Soudan experimenters working in such an inconvenient location for all these years. The experiment began taking data in 1988 with 275 of the detector's 963 tons in operation. Observing the types and energies of particles released from a disintegrating proton — the "decay mode" — would help physicists to choose from among theories that explain how the fundamental forces were unified in the early history of the universe, then later separated as the "Big Bang" cooled. Observing how protons decay would also tell physicists about the physics of a new type of fundamental interaction that has never been observed before. About half the anticipated data sample has been collected and is now being analyzed.

Another important clue to the nature of the universe will be sought at Soudan in a new experiment to learn more about the ghostlike subatomic particles called neutrinos. The project, now in the design and approval process, will take advantage of the Soudan 2 detector and a major upgrade of the accelerator at

Fermi National Accelerator Laboratory (Fermilab) at Batavia, Ill. Neutrinos have no electric charge and interact only rarely with matter. The particles' mass is known to be very small — if they have any mass at all. Observing these particles in accelerator experiments requires massive particle detectors and intense beams of neutrinos to produce even a few thousand interaction “events.”

Data about cosmic-ray neutrinos from other underground particle detectors have hinted at a phenomenon known as “neutrino oscillation”: neutrinos may spontaneously change from one type to another as they travel. Such oscillations, if confirmed, would be definitive proof that neutrinos do have mass. Soudan 2 already detects cosmic-ray neutrinos that travel through the 2,340 feet of rock above the instrument — and through the 8,000 miles of planet Earth beneath it. The detector will soon have enough data to check the reports of neutrino oscillations from earlier experiments, which used different and less sophisticated detection techniques.

For the new “long baseline” experiment, Fermilab’s “Main Injector,” now under construction, would be used to generate a beam of nearly pure “muon” neutrinos aimed into the ground at a three-degree angle toward the north-northwest. The neutrinos would arrive at the Soudan underground observatory an instant later, after passing unhindered through 730 kilometers (453 miles) of solid rock. Neutrino interactions would be recorded by Soudan 2 and a proposed new 10,000-ton detector at Soudan.



Deep beneath the surface in an old iron mine, these detectors seek proton decay. Whether or not they see it will provide physicists with a clearer picture of the beginning — and perhaps the end — of the universe.

The new detector, called MINOS for Main Injector Neutrino Oscillation Search, has been proposed by a collaboration of 18 institutions from the United States, Britain and Russia. A proposal for the \$100-million project is currently undergoing an intensive review by the U.S. Department of Energy. If neutrinos do oscillate, the beam arriving at the underground physics laboratory will contain a significant number of “tau” neutrinos, which produce a different signal than their muon cousins. The observation of a distinctive tau neutrino signal would be a sure sign that muon neutrinos had oscillated during their journey from Batavia to Soudan, providing an important new piece in the particle physics puzzle and another clue to the nature and origin of the universe.

Determining Nuclear Structure

In 1948, an Argonne scientist reasoned that the atomic nucleus consisted of protons and neutrons arranged in a shell. Her invention of the nuclear shell model provided

a working theoretical infrastructure for studying the properties of atomic nuclei and earned her a share of the Nobel Prize in Physics in 1963. Other Argonne scientists developed

and extended the shell model to make it applicable to a wide range of nuclei. In the process they introduced modern electronic computing to nuclear physics.



The conservation of parity principle was challenged by Argonne researchers.

University of Chicago and Argonne researchers expanded nuclear science knowledge significantly.

Argonne scientists have also provided understanding of the nuclei through experiments in nuclear spectroscopy, in particular of the very heaviest of nuclei — those beyond uranium.

In 1956, the conservation of parity principle, posited by Eugene Wigner in 1936, was challenged. Wigner's original formula showed that atoms can fluctuate between two atomic states; that the laws of nature made no distinction between left and right. The challengers, who received a Nobel Prize for their efforts, demonstrated that the principle did not apply to all nuclear reactions and that parity was not preserved in weak interactions. In 1957, Argonne and University of

Chicago physicists proved that the principle did not hold for complex nuclei or mesons. They later demonstrated, using a beam of slow neutrons, that parity conservation also does not apply in the radioactive decay of neutrons. These findings expanded knowledge in nuclear science significantly.

The Mössbauer effect, first demonstrated by a German physicist in 1958, presented the world with a new way of studying a wide variety of phenomena at a vastly enhanced level of precision by making use of the absorption x-rays at sharply defined energies in special nuclei and under special conditions. Argonne scientists almost immediately found a particular

nucleus (iron-57) for which the Mössbauer effect could then be used as a practical tool under many conditions. Since then more than 90 percent of all research using Mössbauer effect has been done with iron-57. Argonne researchers were among the leaders in using Mössbauer effect for fundamental studies in nuclear physics, hot-atom chemistry, materials science and general relativity experiments.

Argonne, capitalizing on the synergy between the lab's basic research and its fission reactor development, has from the outset been a leader in the use of slow neutrons to study nuclear physics, materials science, chemistry and biology. Among the achievements in physics

Nobelist Maria Goeppert-Mayer 1906 ~ 1972

Argonne's tradition of excellence is reflected in the achievements of MetLab and Argonne scientists that have led to many prestigious national and international awards. Among the Nobel Prize winners was an Argonne physicist who shared the 1963 Nobel Prize for Physics.



Maria Goeppert-Mayer, on Argonne's staff for 15 years, studied theoretical physics under Nobel Laureate Max Born at Göttingen University in Germany. She came to the United States in 1939 with her American husband, chemical physicist Joseph Mayer. They both joined the faculty at Columbia University — she, because of anti-nepotism rules, as an unpaid “voluntary” teacher — and became associates of Enrico Fermi. Goeppert-Mayer would not hold a paying, full university professorship until she was 53.

When Fermi left Columbia to direct the MetLab project, Goeppert-Mayer took over his courses and worked with Harold Urey on separating uranium isotopes as part of the Manhattan Project. The

Mayers did follow Fermi to The University of Chicago in 1945 to continue research at the Institute of Nuclear Studies. Her position remained an unpaid “voluntary” one.

One of her former students at Johns Hopkins, Robert Sachs, brought her to Argonne at “a nice consulting salary.” Sachs would later become Argonne's director. While there, she learned most of her nuclear theory and set up a system of “magic” numbers to represent the numbers of protons and neutrons, arranged in shells, in the atom's nucleus. While collecting data to support nuclear shells, she was at first unable to marshal a theoretical explanation. During a discussion of the problem with Fermi, he casually asked:

“Incidentally, is there any evidence of spin-orbit coupling?” Goeppert-Mayer was stunned. She recalled: “When he said it, it all fell into place. In 10 minutes I knew... I finished my computations that night. Fermi taught it to his class the next week.” Goeppert-Mayer's 1948 theory explained why some nuclei were more stable than others and why some elements were rich in isotopes.

The following year, J. Hans Daniel Jensen independently advanced the same theory. They collaborated on *Elementary Theory of Nuclear Shell Structure*, published in 1955. Goeppert-Mayer and Jensen received the 1963 Nobel Prize for Physics for their work on nucleic structure. They shared the prize with Eugene Wigner who was honored for his elucidation of the mechanics of proton-neutron interaction — Wigner, one of the MetLab team members, designed the Chicago Pile-3 reactor. In 1960, Goeppert-Mayer and her husband moved to the University of California at San Diego. She remained there until her death.

were: systematic investigation of the interactions of slow neutrons with nuclei; the invention of magnetic neutron

mirrors that enabled neutrons to be used as a surrogate for x-rays in investigating properties of matter for which x-rays were

not useful; and basic data on some properties of the universal weak interaction, one of the four fundamental forces of nature.

Accelerating Protons and Spallating Neutrons

In the early 1960s, Argonne scientists designed and built the 12.5 GeV Zero Gradient Synchrotron (ZGS), then the world's leading weak-focusing proton accelerator. Its program of polarized target development and exploitation led to greater understanding of the spin dependence of strongly interacting particles and, coupled with the later success in accelerating polarized protons in the ZGS, opened up a new area of high-energy physics.

Most synchrotrons are of the alternating gradient design — the magnetic field keeps the circulating beams of particles focused. The ZGS had no field gradient, relying on edge-focusing to confine the

particles to the beam orbit. By developing the highly efficient window-frame magnets used in the ZGS, the lab earned a reputation for working at the frontier in magnet technology.

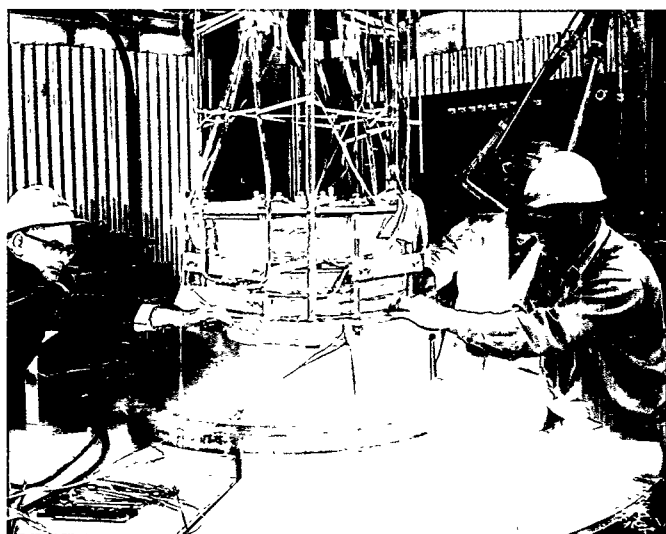
Experimental facilities developed for use at the ZGS improved its scientific performance tremendously. Scientists built and incorporated the world's largest (12-foot) bubble chamber for high-energy physics research. Another important achievement was the use of a superconducting magnet in conjunction with this huge chamber. In November 1970, a neutrino interaction was observed in the bubble chamber — the first time one had ever been seen in a liquid hydrogen

chamber. The lab was a world leader in cryogenics and superconducting magnet development in the 1960s and 1970s.

On July 11, 1973, measurements taken at the ZGS proved it was possible to inject polarized protons and accelerate them to high energy while retaining their polarization. This has made possible the study of previously inaccessible aspects of the high energy proton-proton interactions.

When the Zero Gradient Synchrotron shut down in 1979, its parts were recycled for inclusion in further state-of-the-art facilities. The 107-ton superconducting magnet from the 12-foot bubble chamber was incorporated into the High Resolution Spectrometer at the Stanford Linear Accelerator Center's PEP collider. The detector was built and operated by Argonne scientists, in collaboration with several university groups. In 1983, the detector discovered a new decay mode of the tau lepton and made the most accurate measurement of the tau neutrino mass at that time.

The Intense Pulsed Neutron Source (IPNS), completed in 1981, also incorporated elements from the old ZGS. It is the country's most productive source of spallation neutrons (see page 34). Based on a proton



In 1970, a neutrino interaction was observed in the bubble chamber — the first time one had ever been seen in a liquid hydrogen chamber.

accelerator rather than on a reactor, it produces neutrons by firing a beam of accelerated protons at a uranium target; neutrons then boil off through a process known as spallation. Designed and built at Argonne, IPNS was enhanced by labora-

tory scientists in 1985 — the year after it had fired its one-billionth pulse. The beam intensity was increased by an enriched uranium target — from less than one percent uranium-235 to 77 percent. Scientists could now gather data faster,

carry out difficult experiments more easily, use smaller samples, and heighten the precision of specialized instruments. In 1995, IPNS was approaching a world record 5 billionth pulse.

Wakes and Explosions

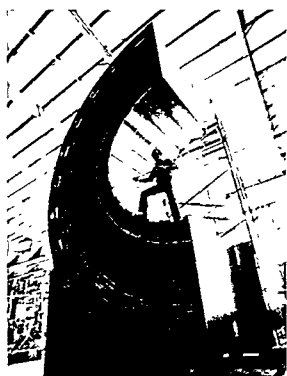
In 1987, the first ever demonstration of wakefield acceleration in structures and in plasmas was demonstrated at Argonne's pioneering Accelerator Test Facility, which was based on the Chemistry Division's electron linear accelerator. The wakefield concept promises to accelerate subatomic particles to higher energies in substantially shorter distances than are possible by conventional techniques (see

page 78). Wakefield acceleration is accomplished by firing a relatively low energy electron pulse through plasma or special dielectric loaded radio frequency waveguides to create an electromagnetic "wake." The strong electric fields in the wake can be used to accelerate a second, trailing pulse of particles. If this second pulse is properly timed relative to the first, it can ride the wake of the first pulse gaining energy as it

travels like a surfer behind a motor boat.

Argonne invented the Coulomb explosion technique now used at other nuclear accelerator laboratories worldwide. The technique, which is based on accelerating molecules and breaking them up in thin foils, provides greater sensitivity to measuring the geometric structures of molecular ions.

Chasing the Top Quark

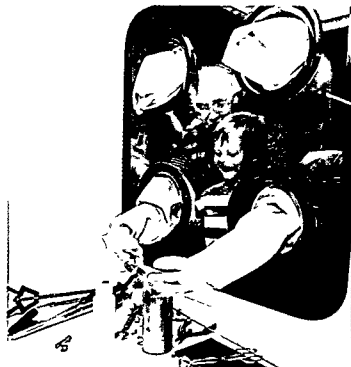
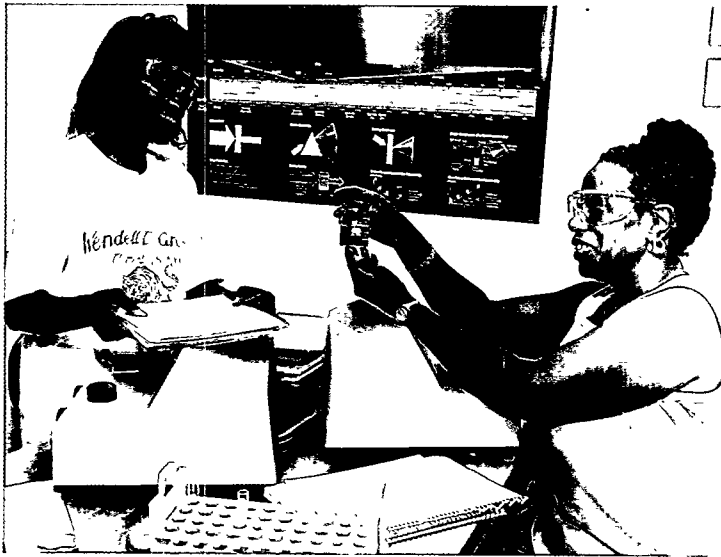


Argonne built this 190-ton detector for the Collider Detector at Fermi National Accelerator Laboratory.

Major discoveries during the 1980s included: super deformation in heavy nuclei; new proton emitters; short-range correlations in nuclei through meson-exchange models for threshold meson production; and high-density laser, polarized hydrogen particles, including isotopes of deuterium

and tritium. In 1993, Argonne scientists discovered the meson containing both bottom and strange quarks. Two years later, they topped that achievement by assisting in the discovery of the elusive top quark at Fermi National Accelerator Laboratory in nearby Batavia, Ill

During the 1990s, scientists discovered the bottom quark, the strange quark and the elusive top quark.



(Top left) Chicago-area teachers are trained to use laboratory instruments which they later borrow for use in their classrooms.

(Top right) From its beginning the lab has worked with graduate students.

(Middle left) Argonne researchers worked in Nepal to help that country overcome its deforestation problems. Planting fast-growing trees helps the country meet its food, fodder and fuel needs.

(Middle right) At the 1994 Open House, this glove box was on display for visitors to experience how researchers are protected when they work with hazardous material.

(Bottom) Using its induction furnace and microscopes, Argonne tested Magneco/Metrel, Inc.'s new refractory materials which can be pumped into place to better hold molten metal.



SERVING THE REGION



TEACHING TEACHERS

HELPING EDUCATORS KEEP UP WITH CHANGING TECHNOLOGY



Chicago-area teachers learn to use laboratory instruments such as the light microscope. When the trained teachers return to their schools, they are allowed to borrow the instruments for use in their classrooms.

Virtual reality; communicating in cyberspace; faster, smarter computers — changes in science and technology happen almost faster than they can be reported. Keeping up with these developments is challenging for all of us, but especially so for teachers trying to prepare their students to function in an ever more technologically complex world. Scientists at Argonne are helping teachers meet this challenge by giving them hands-on experience with new technologies and innovative teaching methods that will take their classrooms into the 21st Century.

One of the most important developments in science education will be the use of telecommunications. Accordingly, Argonne's Division of Educational Programs has launched an initiative to help teachers harness this powerful resource. Early in 1995, the laboratory helped establish the Educational Networking Consortium (ENC) — a program that will give 55 percent of Illinois teachers access to the information superhighway and all its resources for the price of a local phone

call. The ENC is a collaboration between Argonne, Chicago's Adler Planetarium, the Illinois Institute of Technology - Rice Campus, the Illinois Math and Science Academy and a number of Chicago-area school districts.

Argonne has been training teachers on the Internet for nearly two years, and will continue to do so as part of the consortium. These teachers then return to their school districts to train even more teachers. As a result, hundreds of thousands of Illinois students will benefit from the Internet's resources in their science studies. The promise of the Internet for classroom teaching is a radical expansion of the dimensions of the classroom itself. With telecommunications, it is possible to gain access to experts, other teachers and students around the world, as well as databases, computer-based activities for learning and documents from a wide variety of sources. While navigating the Internet, students also learn computer and telecommunications skills that will be fundamental requirements of most jobs in the future.

Another way Argonne helps teachers to communicate electronically is through NEWTON, a computer bulletin board system available to users around the world on the Internet. The bulletin board is open free to anyone who teaches or studies science, computer science, mathematics or technology at any level. Nearly half a million people have logged on to NEWTON to ask questions of scientists, discuss teaching methods and share ideas for experiments. NEWTON can be accessed on the Internet via telnet at "newton.dep.anl.gov"; on the World Wide Web at "http://www.newton.dep.anl.gov/"; or by modem at (708) 252-8241.

Teacher programs at Argonne also aim to show teachers what science is and what it is not, how to do it, and how to teach it. Participants in Argonne's National Science and Technology Council Summer Teacher Enhancement program return to their students in the fall with a richer perspective on the practical applications of science and science careers. About 25 junior high and 25 high school science teachers spend four weeks at Argonne learning to use scientific equipment and how to incorporate the technology into classroom studies. These teachers may then borrow equipment from the lab's Educational Outreach Vehicle — a mobile laboratory of state-of-the-art equipment — for their students to use. Last summer, the teachers studied forensics and returned to their classrooms to teach their students about DNA testing. Argonne's advanced equipment — including spectrophotometers, microscopes and superconductivity probes — helped give the students a "real world" perspective on their experiments and sparked their interest and enthusiasm for science. Co-sponsored by the National Science Foundation's Science and Technology Center for Superconductivity, the program gave more than 11,000 students the opportunity to gain hands-on experience with the sophisticated equipment during the 1994-95 school year.

A HEAD START FOR FUTURE SCIENTISTS

There's more to science education than teaching science. Argonne's educational programs are also working to develop the country's next generation of scientists. An important goal of the laboratory's Division of Educational Programs is encouraging students to consider technical or scientific careers. Student interns come to the laboratory from throughout the nation and play important roles in the laboratory's scientific research. Working side by side with Argonne scientists and researchers, they get hands-on experience with state-of-the-art technologies — experience they can put to work in a future scientific career.



Education: The Effort Is Global

Before World War II, international cooperation among scientists was free and open. The war changed all that. The race for the bomb cultivated a scientific atmosphere of secrecy.

On December 8, 1952, President Eisenhower, in an effort to restore international scientific cooperation, proposed an Atoms for Peace program in

which the United States would help other nations to harness the power of nuclear energy for peaceful uses.

Two years later, Argonne established its International School of Nuclear Science and Engineering. Its first session began on March 14, 1955. In attendance were 40 students from 20 countries, all from

industry. President Eisenhower told the group, "You represent a positive accomplishment in the free world's efforts to mobilize its atomic resources for peaceful uses and the benefit of mankind." At the school, seven-month courses covered unclassified theory and technology of reactors.



Sam Bowen (right) leads a lively question-and-answer session at a monthly West Garfield Park Explorers meeting.

Argonne has been training undergraduates for decades. Many of these students have gone on to pursue careers based on the experience they gained through programs such as Summer Research Participation, Science and Engineering Research Semester and Laboratory Graduate Program. During the summer of 1995, for example, a professor from Tuskegee University brought computer science students to the laboratory to work on a faster design implementation for superconductor modeling. The student interns' task was to find a new or modified design which would provide better performance and to find a way to obtain direct, instantaneous display of a data file. Students from local community colleges and technical institutes have worked with scientists and engineers on real problems encountered at the lab, gaining a better understanding of their classroom studies. One group helped to prepare scientific demonstrations on telecommunications and other current topics for students at local colleges.

To encourage these young people to pursue graduate studies in science, Argonne also has developed programs that provide them with opportunities to share their research with other students and faculty members. One such opportunity is the Argonne Symposium for Undergraduates in Science, Engineering and Mathematics. In 1995 at the sixth annual symposium, more than 150 students talked about their research in front of an audience of scientists, faculty and other students. Often, this is the first time the students present their research to an audience of experts. The symposium encourages undergraduates to pursue research careers and helps them to build confidence in themselves and their work. Partnerships between universities and laboratory scientists and engineers also are common.

Argonne takes great pride in its long-standing involvement in consortia with colleges and universities. One of these is the Associated Colleges of the Chicago Area, made up of 14 local colleges. Through this consortium the Division of Educational Programs hosts a series of seminars in such fields as chemistry and computer science at Argonne. The Central States Universities Inc., a consortium made up of universities in the Midwest, co-hosts a major conference each year, focusing on a current scientific topic. The Regional Instrumentation Sharing Program offers access to the laboratory's many research facilities to students and faculty from regional high schools, colleges and universities and minority institutions throughout the country. Access is not only to equipment but also to the scientific expertise of Argonne scientists who work closely with the visitors. Reaching thousands of students each year, Argonne's educational programs continue to be a catalyst and long-term partner with educational organizations to meet the needs of the future. Its broad spectrum of opportunities are an effective way to foster interest in science and to encourage young people to "think science" when choosing a career.

Education: A Foundation for Excellence

In 1956, a low-cost training and research reactor — Argonaut — was designed based on a series of multiplication experiments. It became critical in 1957 and was a key training facility in Argonne's International School. By 1959, Argonne had trained 420 students from 41 countries, including the United States. When the school closed in 1965, 800 students from throughout the Free World had participated in the training program.

In 1968, the Argonne Center for Educational Affairs was established. Within this center, training courses in nuclear technology began in 1976, with sponsorship by the U.S. Department of State in cooperation with the International Atomic Energy Agency. All educational activities were consolidated into the Division of Educational Programs in 1980. Today, more than 2,000 participants from

foreign countries have completed training offered by the division in radiation protection, nuclear safety and energy planning.

Argonne's excellent training and educational enrichment reputation is neither confined to the international sector nor to a particular period. The lab's educational division has been called by many the "flagship" among the science education programs offered at U.S. Department of Energy national laboratories. For example, the lab conducts the largest DOE-sponsored undergraduate research participation program in the nation. Each year, hundreds of students are mentored by Argonne scientists and engineers. The program, which encourages young people to enter technical careers, has been very successful. Argonne has played a lead role in establishing this program as

well as others such as the Science Bowl; Community College and Technical Institutes Initiative; Science and Engineering Research Semester; and Industry/Argonne Internship. In focusing on females, Argonne established in 1990 the conference series Science Careers in Search of Women. Each year nearly 500 young women and teachers interact with Argonne scientists to explore career opportunities in the sciences.

Argonne provides learning experiences for pre-college students and teachers. From the Argonne-developed Science Explorers Program, which has had an impact on more than 100,000 students throughout the nation, to more recent programs like the telecommunications training courses for teachers, the laboratory makes major contributions to the nation's educational systems.



A Commitment to Education

The 60,000th Chicago Science Explorer student was awarded a T-shirt in 1992 by Secretary of Energy James Watkins (left) and Bill Kurtis (right).

Argonne developed a study guide program to accompany Kurtis' Public Broadcasting System science show. The Science Explorers program is now in use across the nation.

BETHEL NEW LIFE

A PARTNERSHIP WITH AN URBAN COMMUNITY



Annette Wilson demonstrates her newly acquired word processing skills as Pat Kulzer, the Argonne trainer, and other interns look on.

Can a national laboratory and an urban community development corporation combine their expertise to revitalize a deteriorating inner-city neighborhood? Can such a partnership serve as a model for restoring other urban communities? These are the questions Argonne and a Chicago organization called Bethel New Life Inc. are tackling in a joint project called "Towards a Healthy Sustainable Community" — a community economic initiative focused on redeveloping Chicago's West Garfield Park neighborhood. One sign that the three-year-old partnership will answer these questions affirmatively is the national recognition it received in 1995 when it earned a "Partnership" award from the U.S. Department of Energy's Pollution Prevention Awards Program. Also in 1995, Bethel New Life received the Robert Rodale Environmental

Achievement Award from Renew America, a nonprofit organization that promotes successful environmental initiatives. The award is presented to an organization that embodies the quest for better public health and heightened environmental responsibility. Bringing together Argonne's expertise in science and technology and Bethel's skills in community economic development, the partnership focuses on four main areas:

INDUSTRIAL SITE RECLAMATION AND RETENTION: More than 40 vacant or abandoned industrial buildings clustered near Bethel's headquarters provide mute testimony to the community's industrial and environmental devastation. Besides creating environmental and safety risks, these buildings prevent new industry from moving in because companies purchasing the property could be liable for any required environmental cleanup. To help the neighborhood reclaim these valuable properties, Argonne scientists are identifying contaminants and appropriate clean-up methods. Additionally, Argonne is transferring this technology to community-based businesses to perform these analyses, thus equipping residents with the skills to reclaim still more sites.

RECYCLING SPIN-OFFS: Argonne is helping Bethel find ways to increase the value of recycled materials. The laboratory will send its waste paper to Bethel's recycling center and is working to expand the center's output and to create new markets for material recycled at the plant. Potential projects are numerous. Staff from both organizations are exploring ways of converting waste plastics into new plastics suitable for molding into new products.

ENERGY-EFFICIENT HOUSING REHABILITATION: Finding affordable, energy-efficient housing is a growing problem in many urban areas. In West Garfield Park, the best solution may be rehabilitation, or "rehabbing." This can spur local economic development, improve the environment and save money by eliminating the costly demolition of buildings. Argonne and Bethel are applying energy-efficient



Argonne's Jennifer McHenry works with environmental waste management interns and West Garfield Park residents Chris Garner (center) and Kevin Hammock (right) to characterize an Argonne solid waste stream. They will use their knowledge in their neighborhood's recycling program.

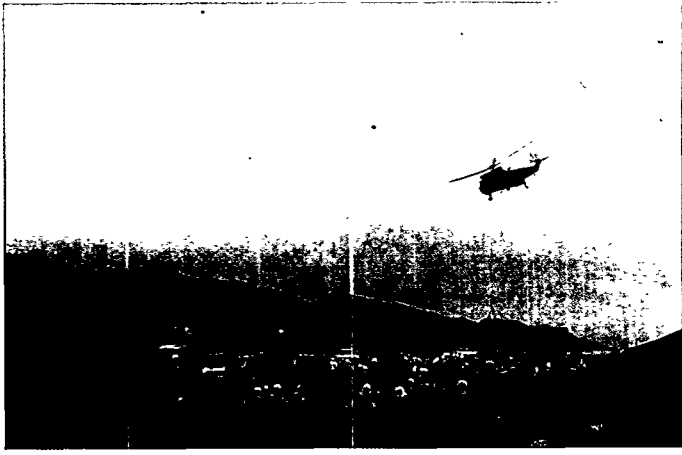
materials and construction techniques to rehab apartments so that the annual operating costs (for electricity and gas) can be kept under \$1,000. They are also investigating building components — windows, doors, lighting fixtures — that can be produced and demonstrated in West Garfield Park, which would create local jobs.

EDUCATION AND TRAINING: Employment is a powerful force for battling urban decay. Chicago's West Side currently faces an unemployment rate as high as 30 percent, which makes job creation a priority issue. Together, Argonne and Bethel have established a job training initiative which includes: assisting residents who participate in a course offered by the Midwest Environmental and Industrial Health Training Center at the University of Illinois at Chicago; offering a 40-hour course that certifies residents as Occupational Safety and Health Administration (OSHA) approved hazardous-materials handlers or environmental assessment technicians; and, offering internships in general office procedures and word processing skills at Argonne for individuals who successfully complete training at Bethel.

In addition, the Urban Engineering Program — funded by the U.S. Department of Energy — works to inspire disadvantaged urban students to pursue careers in science and engineering. It also provides students, teachers and parents with information on how to enter college and pursue an engineering degree. It is hoped that these students will return to their neighborhoods to use their scientific and engineering expertise to rebuild the community. By bringing people and technologies together, the partnership between Argonne and Bethel hopes to give West Garfield Park residents a better life while offering other communities a successful model for urban renewal.

WELCOME RELIEF

COMPUTER MODEL HELPS BRING AID TO WAR, FAMINE VICTIMS



Technology has a human side that is often overlooked. To Kurdish refugees in Iraq and to the famine-stricken citizens of Somalia, sophisticated computer models developed at Argonne meant that U.S. military personnel could analyze options for providing relief more quickly and efficiently. The Argonne Distribution Feasibility Estimator (DFE) computer model helps planners analyze logistics to determine the feasibility of moving large quantities of equipment and supplies while considering the complications unique to each situation.



Using data on available roads, transportation vehicles, airports, personnel and the amount of supplies needed, the DFE predicts which method of transportation — land, air, or sea — or combination of methods will deliver the maximum amount of supplies in the least amount of time. Operation Provide Comfort brought relief supplies to Kurds from Northern Iraq. Argonne scientists used the DFE to study the area's transportation infrastructure and to decide how to best use the limited transportation available. For Operation Restore Hope in Somalia, planners had to address the lack of seaways, airways and roadways for Southern Somalia. There are only three, one-lane roads out of the port of Mogadishu. Argonne staff helped military personnel determine how many aircraft and trucks could be used productively given the area's limited accessibility. Also added to the equation was the need to move and support military personnel and equipment as well as relief supplies.



An Argonne computer model aided the U.S. Army mission to provide food and shelter to Kurdish refugees during Operation Provide Comfort. The Argonne model provided transportation infrastructure information critical to bringing in relief workers and supplies to Zakho, Iraq. PHOTOS BY SERGEANT FIRST CLASS STEVEN DUTCH.

Using the DFE model is a welcome relief from calculating logistics manually — a tedious process that doesn't allow for the investigation of as many options with subtle variables and constraints. DFE allows almost instant analysis of alternative courses of action and is helpful for planning ahead, anticipating problems and dealing with them before they occur.





Technology Transfer: Innovations Aiding Society

Argonne has a tradition of working with industry ever since its MetLab days. Results of research that lead to everyday, practical “spin-off” inventions — just as in space technology — have produced benefits for the public at large. For example, in 1968 scientists designed and developed a braille machine — the size of a portable typewriter — that reduced the bulk and complexity of braille reading for the blind. Another lab-to-patient innovation was a small and inexpensive hemodialyzer — artificial kidney — developed for kidney failure patients. Today, as part of the Department of Energy’s mission to help industry develop solutions for public policy issues, Argonne is a leader in transferring technology from the lab to private industry. Together with The University of Chicago, Argonne formed a not-for-profit subsidiary, the ARCH Development Corporation, in 1986. Its purpose is to speed commercialization of research innovation. This is done by vigorously pursuing patent licensing agreements, forming new companies, and developing joint ventures with existing organizations. The emphasis is on creating new companies to market inventions.

By 1995, 13 companies had been created and the number of



Braille Machine



Artificial Kidney Machine

annual patents filed increased ten-fold — from 15 to 150. Some examples of start-up companies include two in Darien, Ill., a small town of 18,000. Eichrom Industries, Inc., makes plastic resins used to separate radioactive materials and heavy metals from hazardous wastes, a technology developed at Argonne. Its 1993 sales were \$1 million, and revenues had doubled over the previous year.

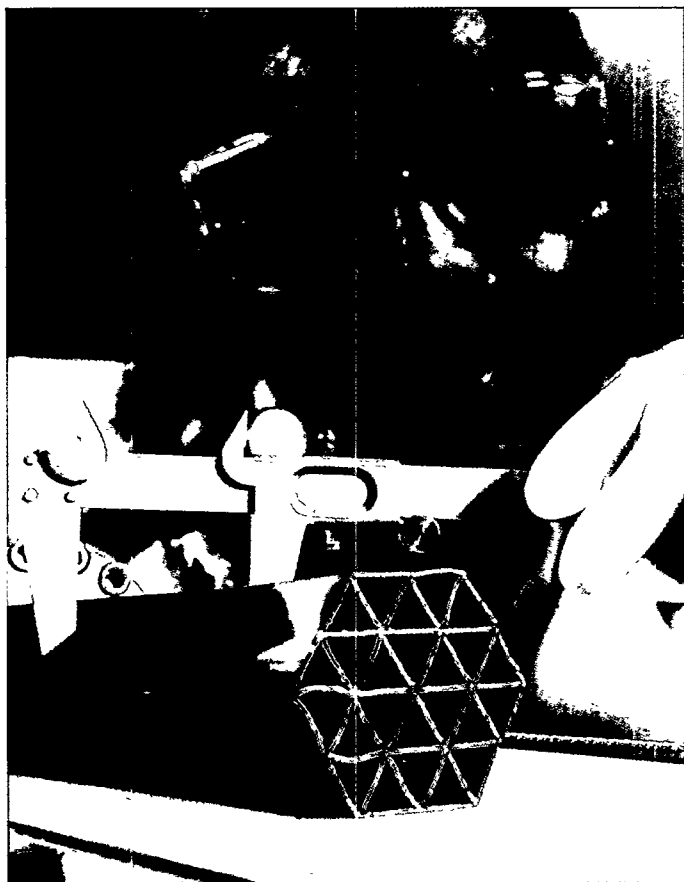
Nanophase Technologies Corporation, also in Darien, perfected a cheap way to mass-produce pure, ultrafine powders made from ceramic or metal compounds — from one gram a day to one pound an hour; from a cost of half a million dollars a pound to just ten dollars. Their technology could revolutionize the makeup of many everyday products, from suntan lotion

to diesel engines. One of its customers is Caterpillar, Inc., in Peoria. Together they are developing molded engine parts, rather than machined ones, that will run at high temperatures without breaking.

The five-year-old Illinois Superconductor Corporation in Evanston, Ill. is a special success. The company uses liquid-nitrogen-cooled ceramic technology developed at Argonne that eliminates resistance in electrical devices. For example, it has developed a highly efficient electronic filter to increase the capacity of cellular phone systems. The company went public in 1993 and has a market value of approximately \$40 million. Plans are underway to move production facilities to Mount Prospect, Ill.

COST-SHARED PARTNERSHIPS

WORKING WITH INDUSTRY TO SUPPORT RESEARCH GOALS



Researcher Balu Balachandran examines a ceramic material that could lead to reduced energy consumption and costs in the oil and gas industry. Argonne and Amoco cooperated on the R&D 100 Award-winning research (see page 63).

Since the laboratory's beginning 50 years ago, Argonne researchers have earned their living solving tough scientific challenges – from designing nuclear reactors and nuclear fuel to building state-of-the-art particle accelerators. Many new technologies have resulted in the course of supporting the nation's energy-related research missions. Working with industry through cost-shared partnerships, this research is being translated into new products and processes, and in some cases, new companies. Examples can be found throughout this report.

Argonne works with industrial partners through cost-shared agreements and full-cost-recovery agreements. Over the past five years, Argonne has had agreements of both types with more than 300 companies in 31 states. Most cost-shared research currently is carried out under Cooperative Research and Development Agreements (CRADAs). In 1995, Argonne reached a landmark when it signed its 100th CRADA. The CRADAs signed through mid-1995 are valued at more than \$24 million; the total value of the partnerships over the past five years is \$113 million. Another \$26 million of cost-shared research is being conducted through the High Temperature Superconductivity Center, bringing the laboratory's total for cost-shared research to well over \$139 million.

While joint research partnerships have benefited U.S. industry, they also have greatly enhanced Argonne's mission-oriented research and development, from energy conservation to advanced materials development. A substantial portion of the laboratory's efforts in these projects has been supported with funding provided by industrial partners. One example of these mutually beneficial partnerships is the lab's work with Modine Manufacturing of Racine, Wis. Working together, researchers are developing an efficient heat exchanger for smaller and lighter-weight automotive air conditioning systems. More efficient auto air conditioners could protect the environment by helping the auto industry switch to refrigerants that do not attack the earth's ozone layer. Smaller-size units could help improve gasoline mileage by allowing manufacturers to build cars with more aerodynamic profiles.

This CRADA supports a major research goal of the Department of Energy's Thermal Sciences Program to expand the use of compact heat exchangers in energy-intensive process industries. And it has helped guide industry in developing automotive air conditioning system condensers that are smaller and

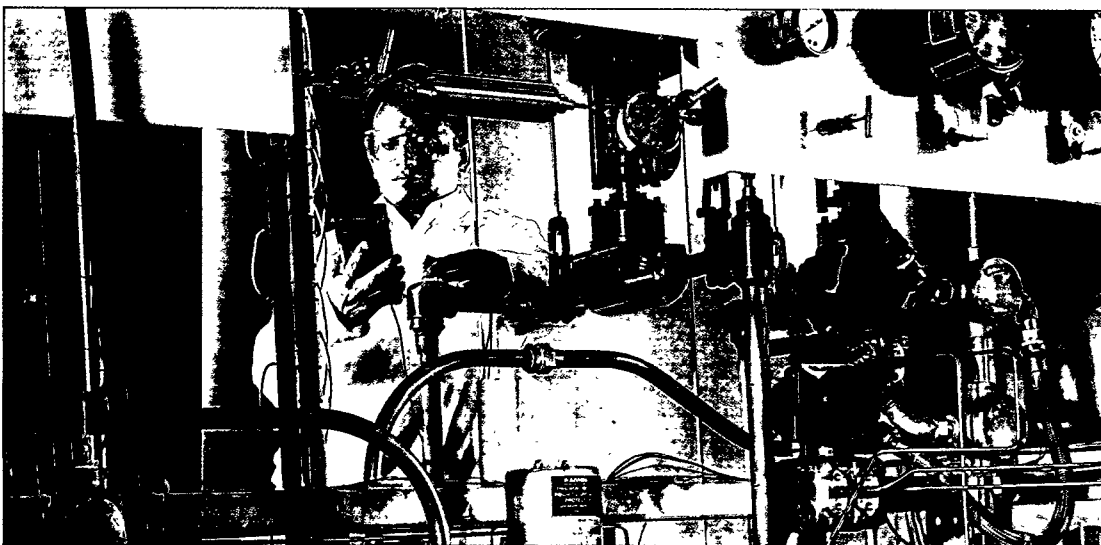
lighter-weight, with less refrigerant. The cost-shared project used less public funding than would have otherwise been needed.

The research has benefited Modine as well. The company can now optimize the design of its air-conditioning condenser relative to the best size and shape of heat exchanger tubes carrying the refrigerant. Smaller size, lighter-weight condensers in auto air-conditioners lead to improved gasoline mileage, with direct energy savings and reduced refrigerant need, which saves the energy associated with refrigerant production. Modine plans to incorporate the CRADA-identified heat exchanger in future models of its new compact, high-performance air conditioning condenser.

Argonne also uses its expertise to aid industry under full-cost-recovery agreements (termed "Work for Others"). In one such arrangement, McDonald's Corp. contracted with Argonne to study the fundamental characteristics of fryer equipment and heat transfer during food frying in an effort to speed cooking and deliver consistent food quality. The research led to the invention of several new frying baskets, including a patented Chicken McNugget Fry Basket now used in 13,000 McDonald's restaurants. Argonne researchers study heat transfer in many different research programs.

100TH CRADA

In 1995, Argonne signed its 100th Cooperative Research and Development Agreement (CRADA). The 100th agreement is with Shell Development Company. CRADAs are projects jointly funded by industry and the U.S. Department of Energy to combine funding for mutual research benefits. Working together, Argonne and Shell will identify the major causes of fouling in heat exchange equipment and develop techniques to alter conditions and increase the effectiveness of chemical additives. At a typical refinery with a 100,000 barrel-per-day capacity, the fouling-related costs are \$20 million per year — half of this for added energy. Shell will learn how to save energy in refinery operations, and Argonne will gain a better understanding of heat-exchanger fouling that may be applicable to other energy-intensive industries. Argonne's portion of this research is supported by DOE's Office of Energy Efficiency and Renewable Energy.



C.B. Panchal tests an improved field-fouling unit for monitoring heat exchangers in refineries, which could lead to increased refinery production.

HONORS AND AWARDS

The University of Chicago Vice President for Argonne National Laboratory Arthur M. Sussman (rear left center) and Argonne National Laboratory Director Alan Schriesheim (rear right center) presented Argonne Board of Governors and University of Chicago Awards for 1995.



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Awards were presented to: (seated) Allen Carbaugh, Rosalie Bottino, (standing) Raymond Wolson, Eileen Graff.



THE UNIV. OF CHICAGO DISTINGUISHED PERFORMANCE AWARDS
Awards were presented to: (seated) Larry Curtiss (left), William Perry (right), (standing) Edward Fujita (left), John Hull (right).

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