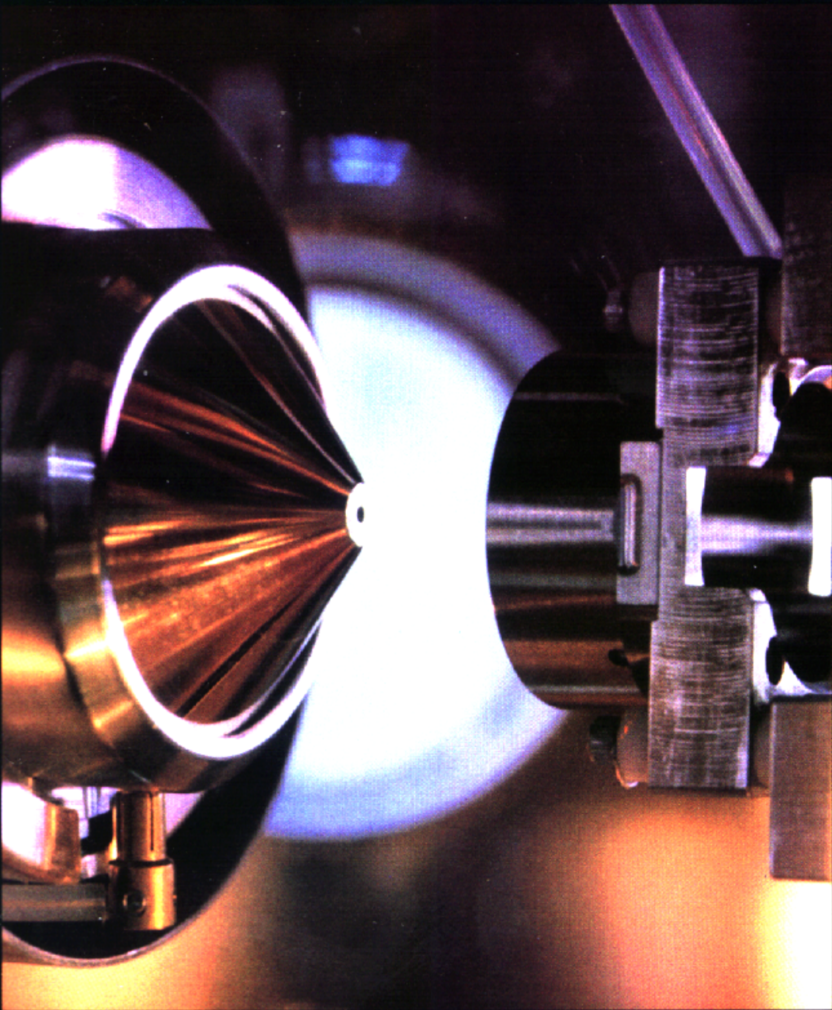
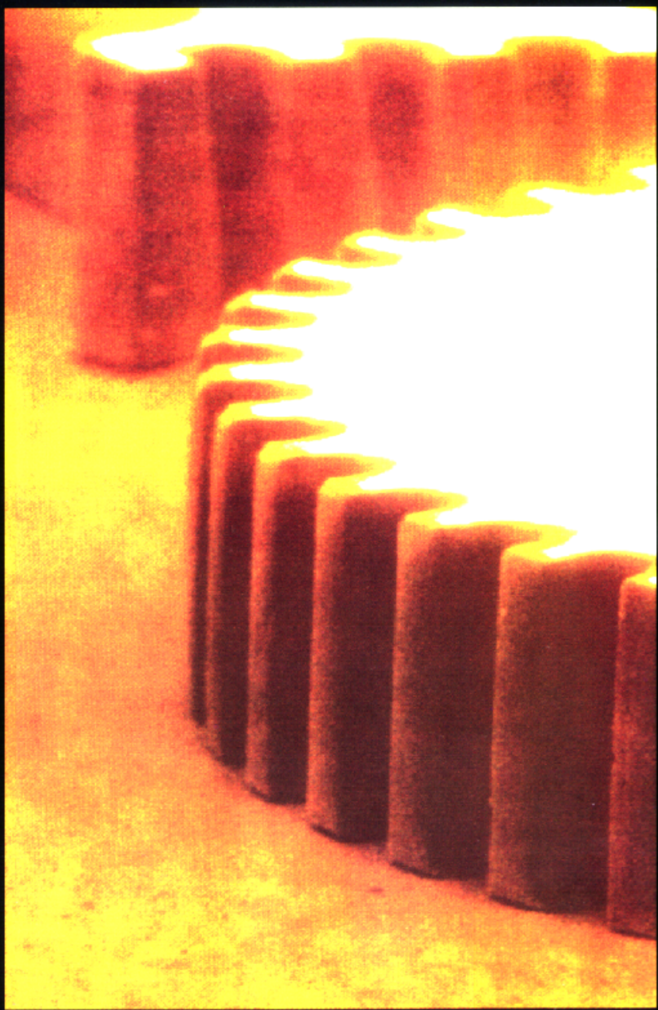
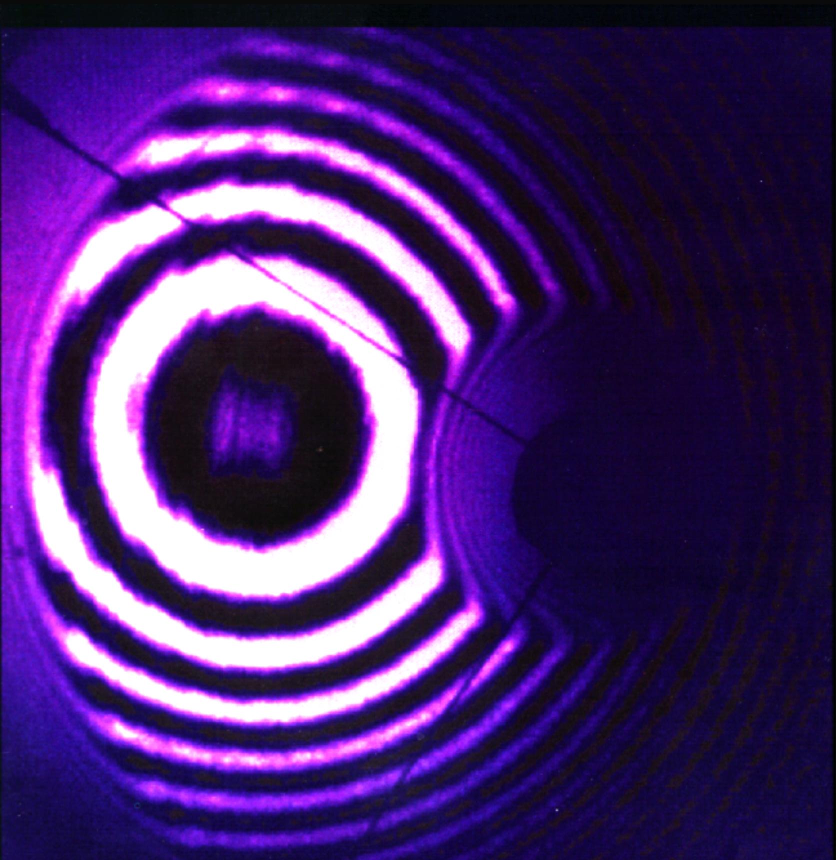
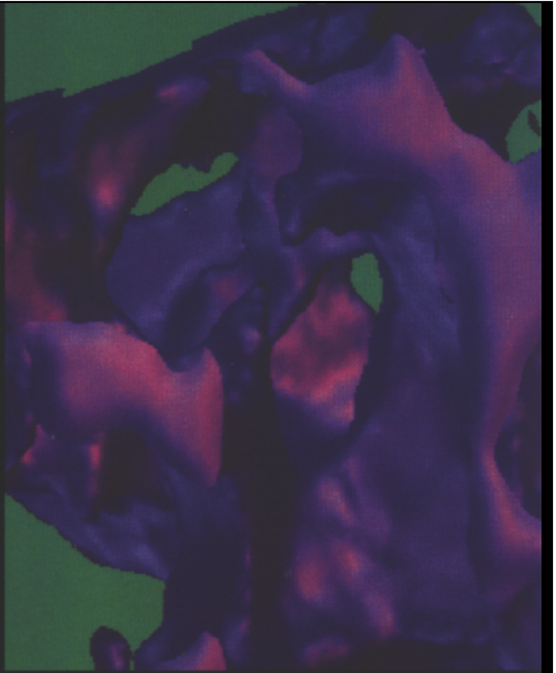




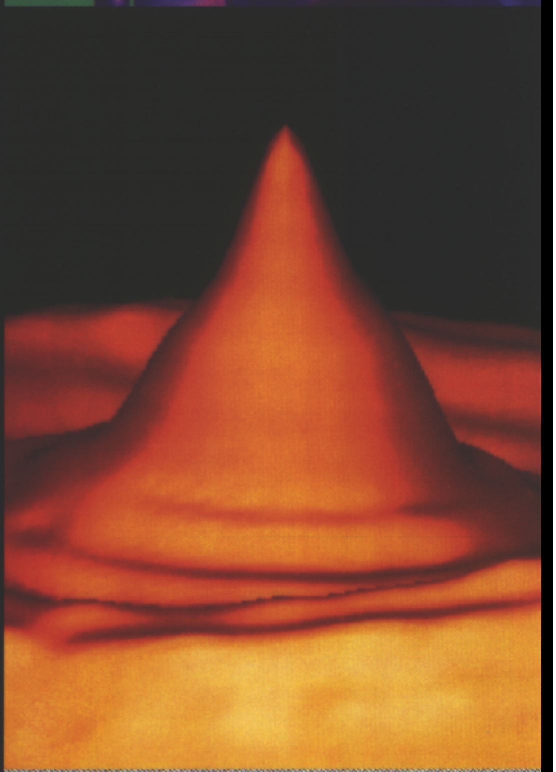
OFFICE OF BASIC ENERGY SCIENCES

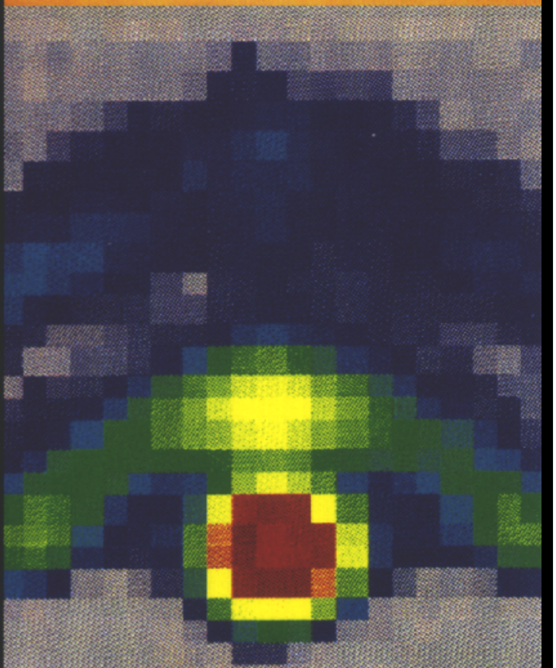
# SCIENTIFIC RESEARCH FACILITIES

## A NATIONAL RESOURCE

OFFICE OF ENERGY RESEARCH
U.S. DEPARTMENT OF ENERGY







# SCIENTIFIC RESEARCH FACILITIES



## *About the Cover*

***At the Advanced Light Source:***

***Interior of a photoelectron microscope (top left) shows the conical electron lens that images photoelectrons, and the sample-mounting area opposite it.***

***Deep-etch lithography [top right) made possible by high-intensity X-rays is used to create miniaturized motors.***

***Analysis of interference patterns in X-ray lenses [bottom left) is part the testing procedure for mirrors and lenses to be used in manufacturing tomorrow's computer chips.***

*Produced for the United States Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, by Argonne National Laboratory, divisions of Public Affairs (OPA) and Information and Publishing (IPD).*

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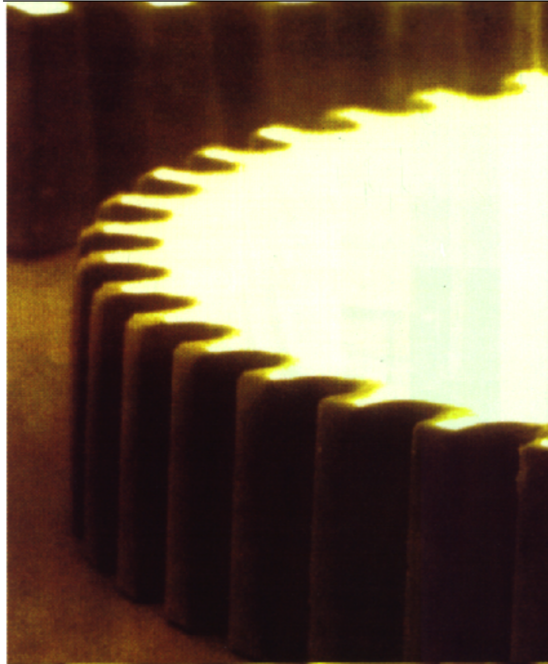
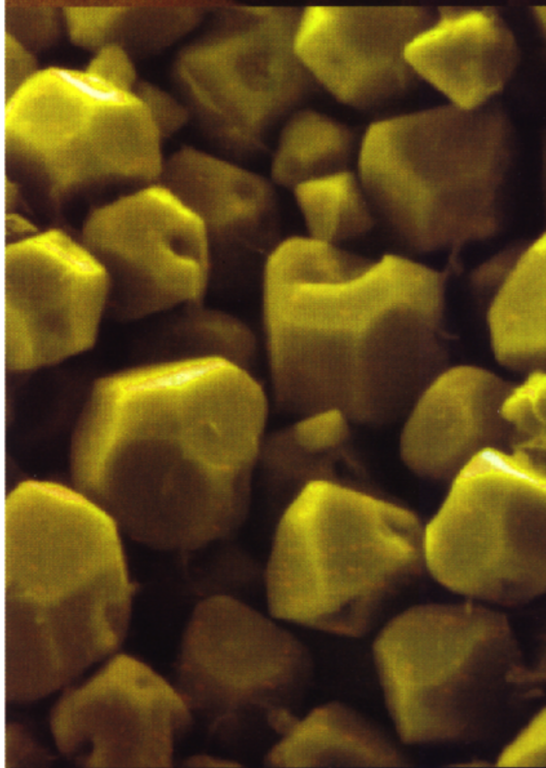
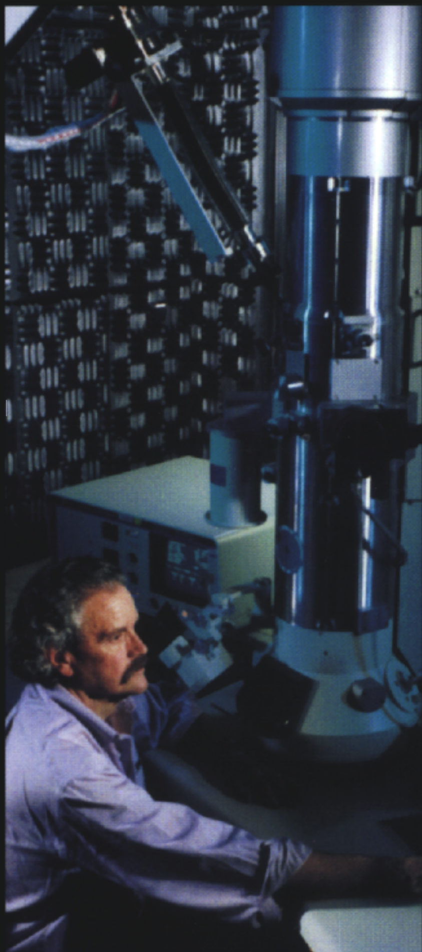




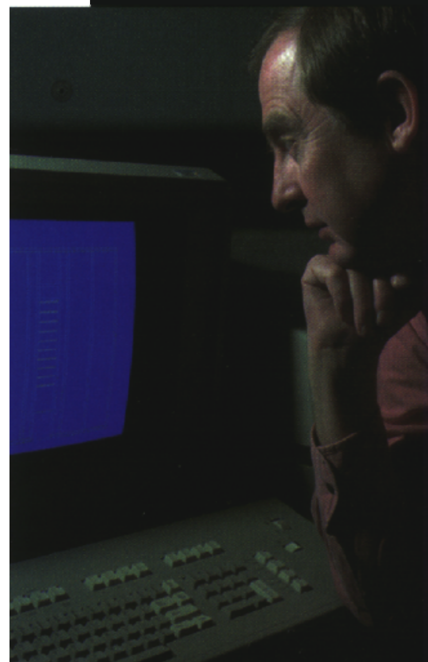


*From the time of the creation of the Land Grant Colleges in the 1860s the United States has fostered scientific and engineering education and research to improve the quality of life for Americans. Today, the Nation's scientific establishment is a robust fabric woven of public and private institutions, large national user facilities, and instrumentation located throughout the country.*

*Synchrotron radiation light sources, high-flux neutron sources, electron-beam microcharacterization centers, and other specialized facilities enable scientists to carry out experiments that could not be done in the laboratories of individuals. Seventeen such facilities, constructed and operated by the Office of Basic Energy Sciences, are described in this booklet. They are part of the Department of Energy laboratory system, the largest of its kind in the world. With origins in the Manhattan Project, this system evolved over 50 years to become a major component of the Nation's commitment to maintain leadership in scientific discovery and knowledge generation.*

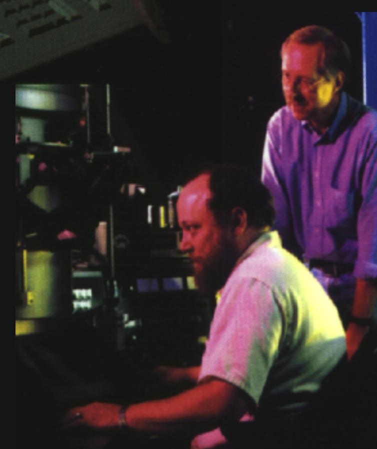
*In a typical year, thousands of researchers and their students from academia, industry, and the federal laboratory system conduct research at these facilities. For approved experiments, operating time is available without charge to those scientists whose intent is to publish their results in the open literature. Proprietary research can be accommodated on a full-cost-recovery basis. The Office of Basic Energy Sciences and the national laboratories continually strive to make these facilities even more accessible and easier for the research community to use.*

*The combination of state-of-the-art, advanced research equipment that exploits the special properties of each facility together with the skills of the staff and scientists who come to use these facilities, has produced a host of important research results over the past two decades. Each year, basic and applied experiments at these facilities embrace the full range of scientific and technological endeavor,*



*including chemistry, physics, geology, materials science, environmental science, biology, and biomedical science.*

*This booklet, then, is more than a description of the services and equipment available at these seventeen collaborative-research centers, It is also a summary of a most effective return on part of our Nation's research investment.*



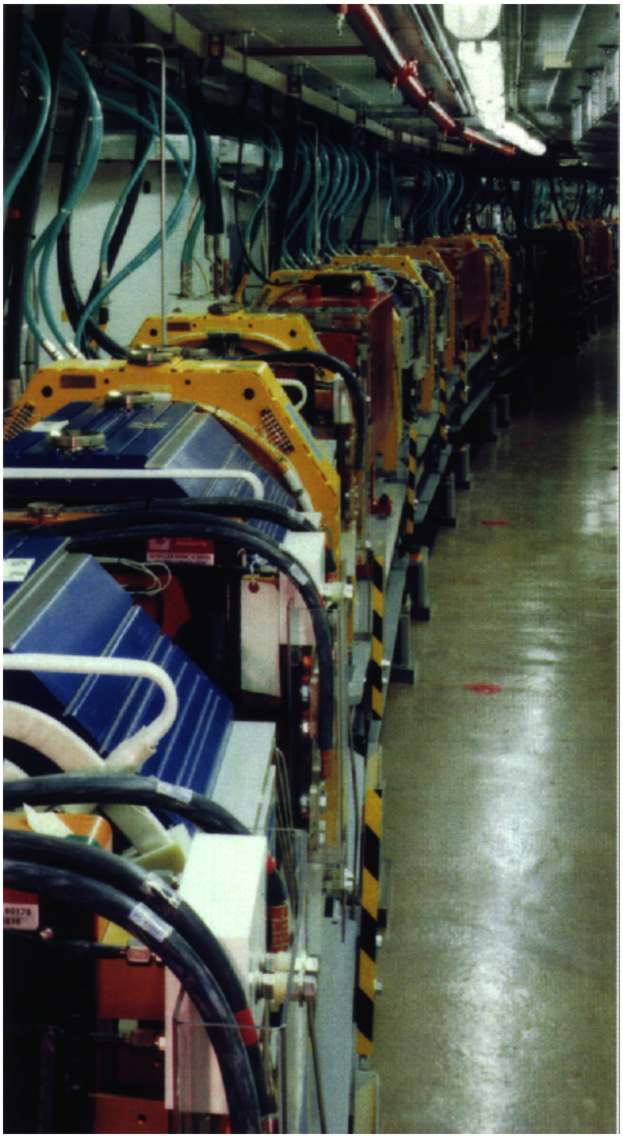
*Iran L. Thomas*
*Deputy Associate Director of Energy Research*
*Office of Basic Energy Sciences*

*Patricia M. Dehmer*
*Associate Director of Energy Research*
*for the Office of Basic Energy Sciences*

# THE RESEARCH

### *Neutron Sources*

- **High Flux Beam Reactor,** *Brookhaven National Laboratory, New York*
- **Intense Pulsed Neutron Source,** *Argonne National Laboratory, Illinois*
- **High Flux Isotope Reactor,** *Oak Ridge National Laboratory, Tennessee*
- *Neutron* **Scattering Center,** *Los Alamos National Laboratory, New Mexico*



Because of their special properties, neutrons have unique applications as probes in many fields of science and technology. Virtually everything we know about the fundamental structure of magnetic materials – which lie at the heart of today's motors and generators, telecommunications, and video and audio technologies – has been learned through neutron scattering. Among other applications are biomolecular structure, polymer science, high-temperature superconductivity, the structure and dynamics of solids and liquids, and the engineering properties of structural materials.

### *Light Sources*

- **Advanced Light Source,** *Lawrence Berkeley National Laboratory, California*
- **National Synchrotron Light Source,** *Brookhaven National Laboratory, New York*
- **Advanced Photon Source,** *Argonne National Laboratory, Illinois*
- **Stanford Synchrotron Radiation Laboratory,** *Stanford Linear Accelerator Center, California*

Together, these complementary facilities help the research community extend basic knowledge and advance technology development in such areas as fiber and composite materials, microscopic machines, high-capacity magnetic data storage, and targeted pharmaceuticals for diagnosis and cure of major diseases. These synchrotron radiation light sources epitomize the contributions of the Office of Basic Energy Sciences research facilities, both to our understanding of fundamental science and to the technological foundations of U.S. industry.

### *Electron Beam Microcharacterization Centers*

- **Center for the Microanalysis of Materials,** *University of Illinois*
- **Electron Microscopy Center,** *Argonne National Laboratory, Illinois*
- **Shared Research Equipment Program (SHaRE),** *Oak Ridge National Laboratory, Tennessee*
- **National Center for** Electron **Microscopy,** *Lawrence Berkeley National Laboratory, California*

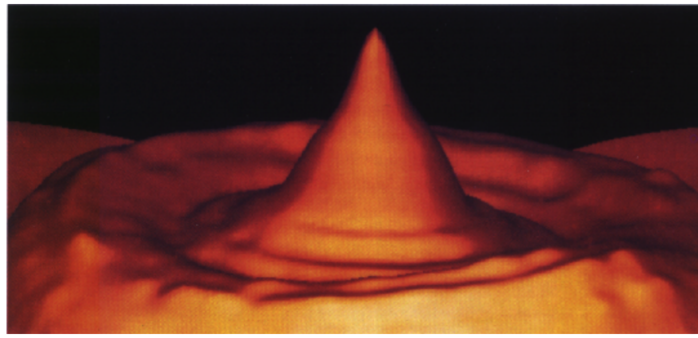
# CENTERS

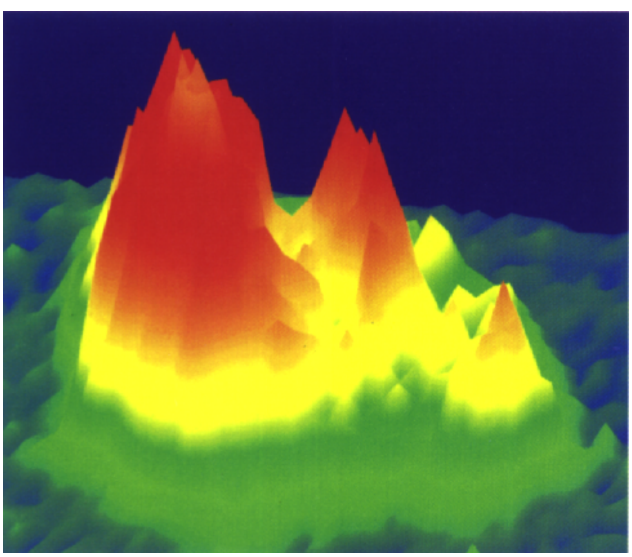
These centers offer researchers access to electron microscopes and other micro-analytical instruments – each dedicated to a different type of structural or chemical analysis, and each with a staff of professional scientists to assist users in choosing and applying appropriate micro-chemical and micro-structural methods.

## OTHER SPECIALIZED CENTERS

- **Surface Modification & Characterization Research Center,** *Oak Ridge National Laboratory, Tennessee*
- **Combustion Research Facility,** *Sandia National Laboratory, California*
- **James R. MacDonald Laboratory,** *Kansas State University, Kansas*
- **Pulse Radiolysis Laboratory,** *University of Notre Dame, Indiana*
- **Materials Preparation Center,** *Ames Laboratory, Iowa*

These specialized research facilities provide unique capabilities for the preparation of unusual materials; for laser spectroscopy of atoms and molecules for understanding combustion processes and chemical dynamics: for ion beam implantation and modification of materials; for the production of highly ionized atoms, or even bare nuclei for atomic physics studies; and for the spectroscopic analysis of intermediate chemical species activated by an 8 MeV electron pulse.





## THE USERS

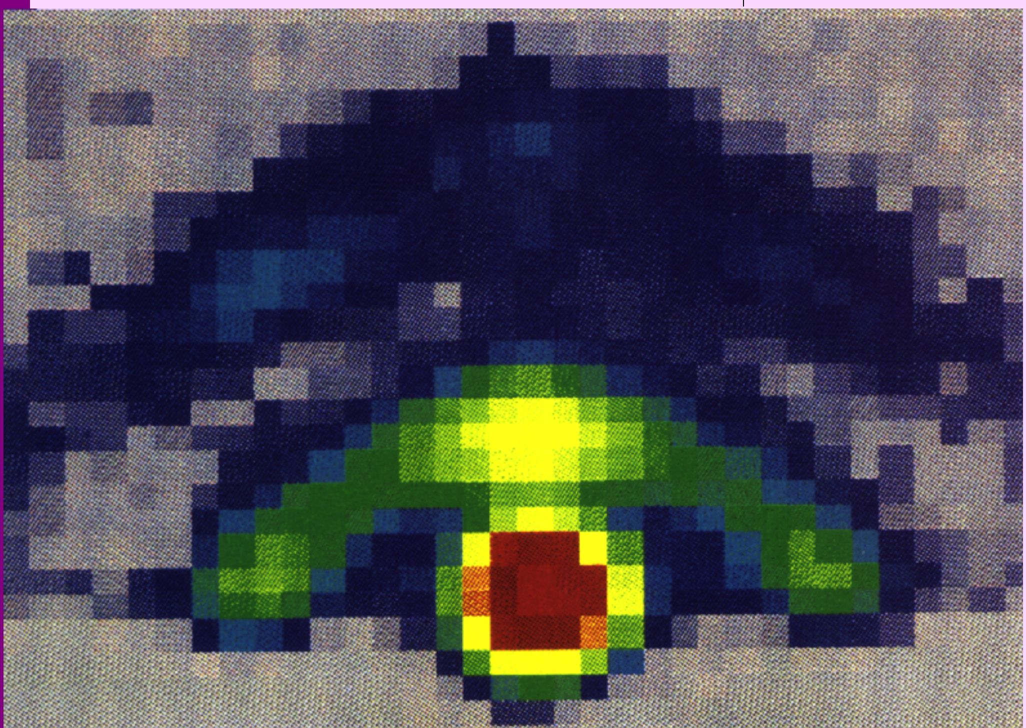
As part of the backbone of the Nation's scientific and technological enterprise, these centers enjoy high and growing user demand. Since 1987 the number of groups conducting research at these facilities has more than tripled. The light sources alone are used by over 3,000 researchers a year for work on semiconductors, polymers, alloys, superconductors, magnetic materials, structural biology, and pharmaceuticals.

Much of the research is broad, producing knowledge that benefits more than one technology, sector, or application. As one example, the products of current research in combustion chemist find use in development of home furnaces, industrial boilers, a new generation of vehicles, and the prevention of toxic wastes.

Beyond scientists and engineers from American industry and government labs, users also include university scientists supported by several Executive Branch research agencies including the National Science Foundation, the National Institutes of Health, the U.S. Department of Agriculture, the Department of Defense, the Environmental Protection Agency, and NASA. Thousands of America's educators and students are users, as well.

# NEUTRON

Neutrons are a unique and effective tool for probing the structure of matter. Neutrons behave as particles which scatter off various objects, but also like quantum-mechanical waves which diffract to form interference patterns. Because the neutron is uncharged electrically, it can penetrate deeply into materials, and give precise information about the positions and motions of individual atoms in the interior of a sample. Neutrons are especially sensitive to the presence of light elements such as hydrogen, carbon, and oxygen which are found in many important hydrocarbon and biological molecules.



Beams of neutrons are particularly well-suited for measurement of the positions as well as the fluctuations in the positions of atoms (phonons), and the structure (position and direction) of atomic magnetic moments in solids as well as the excitations in this magnetic structure (spin waves). Such studies allow physicists to take measurements leading to an understanding of phenomena such as melting, magnetic order, and superconductivity in a variety of solids.

The Office of Basic Energy Sciences operates four neutron sources -two reactor sources (at Brookhaven National Laboratory in New York and at Oak Ridge National Laboratory in Tennessee), and two spallation neutron sources (at Argonne National Laboratory in Illinois and at Los Alamos National Laboratory in New Mexico.)

The High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory produces beams of thermal and sub-thermal neutrons for neutron scattering research. With 15 experimental stations, the HFBR supports research in condensed matter physics, nuclear physics, structural chemistry, biology, and polymer physics. Irradiation thimbles provide access for production of specialty medical isotopes, neutron radiography, and neutron activation analysis.

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory supports 11 experimental stations for neutron scattering research. provides unique materials irradiation facilities, and is the only source of elements heavier than plutonium in the western world. Isotope production at HFIR is critical to medical research. Each year, thousands of patients receive diagnostic testing or cancer therapy using these isotopes. For example, cancer patients are now being treated with brachytherapy using caiifornium-252 produced at HFIR.

# SOURCES

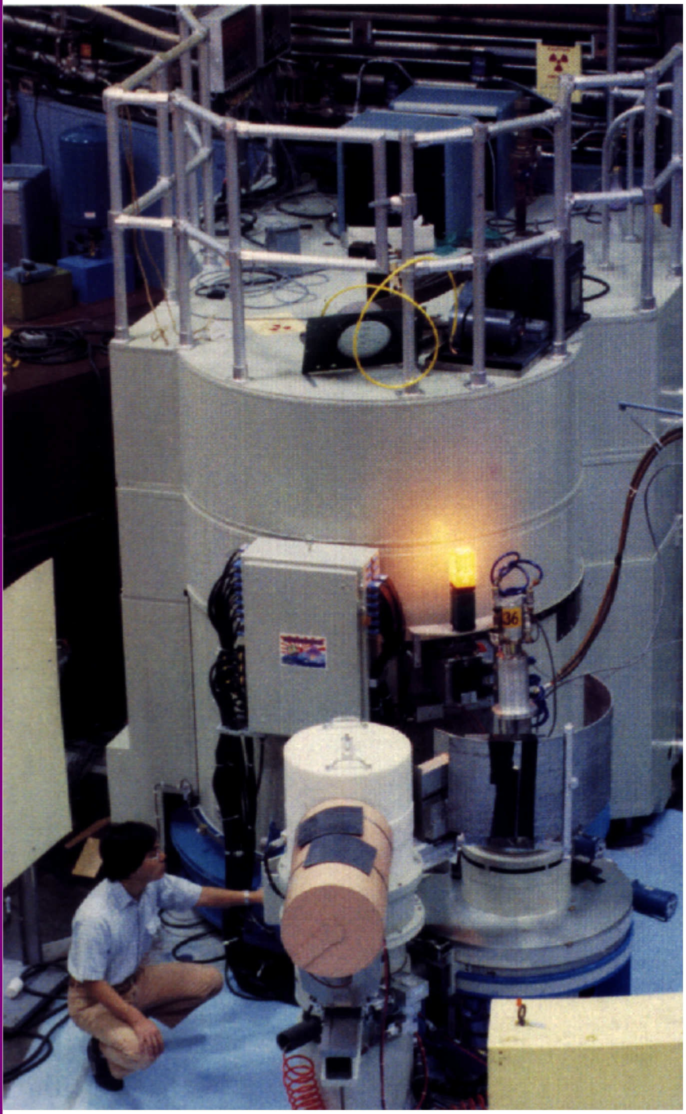
Spallation sources at the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory and the Los Alamos Neutron Science Center (LANSCE) produce neutrons by firing a beam of accelerated protons at a target of heavy metal, such as tungsten or uranium. Because the protons are accelerated in bunches, spallation neutrons are emitted in pulses.

Scientists at IPNS have performed research on the residual stress in composites used in aircraft components, the structure of zeolites used in the petroleum industry, and the adhesion process in polymer layers.

Scientists at LANSCE have used the penetrating ability of neutrons for nondestructive studies of the effects of aging on nuclear weapons components – thus ensuring a safe, secure, and reliable U.S. stockpile without nuclear testing – and to improve the design of materials used in automobile and aerospace applications,

Neutron reflectometry data, *Los Alamos Neutron Science Center*

# H F B R



Institute for Solid State Physics, University of Tokyo, prepares an experiment to determine the structure of a new magnetic material. Neutron structure determinations have resulted in an improved understanding of magnetism and led to the develop ment of new and better magnets.

The High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory supports a range of neutron-based research in solid-state and nuclear physics, chemistry, and structural biology. The Reactor's nine beam tubes deliver neutrons to 15 experimental facilities used by about 250 researchers each year.

The HFBR is equipped with an operating liquid-hydrogen moderator supporting a major program of subthermal neutron investigations. Subthermal neutrons have low energies and are well-suited to determining spatial relationships between atoms in large molecules, such as proteins, viruses, and polymers. Another important capability is the production of polarized neutrons – those that spin in the same direction – which are sensitive probes of magnetic properties of materials.

Studies of crystal vibrations and magnetic fluctuations at near room temperature are performed on HFBR's triple-axis spectrometers. The protein crystallography station allows complete freedom in rotating and orienting crystals under study and provides optimal data on atomic positions in large unit crystals – a material's smallest possible repeating unit.

Two unique small-angle neutron-scattering instruments allow structural study of intermediate-sized molecules, A neutron reflectometer explores the structural properties of surfaces. A high-resolution powder diffractometer allows structural studies of complex polycrystalline materials such as catalysts and advanced ceramic and electronic materials.

Nuclear physics research at HFBR ranges from studies of nuclear reactions, in which atomic nuclei capture incoming neutrons, to studies of gamma radiation emitted from excited nuclei. The major Positron Physics Facility supports studies of the atomic order and electronic characteristics of metal and semiconductor surfaces.

Seven "vertical thimbles" allow material samples to be placed in the Reactor core for direct irradiation at a variety of neutron energies for structural and analytical purposes.

# HIGH FLUX BEAM REACTOR

## MAJOR USERS

- Brandeis University
- Columbia University
- E.I. du Pont de Nemours & Company
- Exxon
- Genentech
- General Motors
- IBM
- Iowa State University
- Lucent Technologies
- Massachusetts Institute of Technology
- SUNY, Stony Brook
- University of Connecticut
- University of Pennsylvania

## ACCOMPLISHMENTS

General Motors scientists used HFBR to understand the structure and behavior of high performance magnets for electric motors.

Industrial scientists use HFBR to probe the structure and function of zeolites, important catalysts in petroleum cracking and refining, and to develop detergents for use as oil additives.

The use of neutron diffraction techniques to study protein structure and function – routinely used today by industrial, academic, and government researchers – was pioneered by experiments at HFBR.

Brookhaven scientists collaborated with university and industrial scientists to study correlations between atoms, and to help unravel the mysteries of high-temperature superconductivity.

Scientists from Brookhaven, Iowa State, and Clark University performed the first detailed studies of the lifetime and decay of zinc-80, a key to understanding how elements are produced in exploding stars.

## HFBR USERS

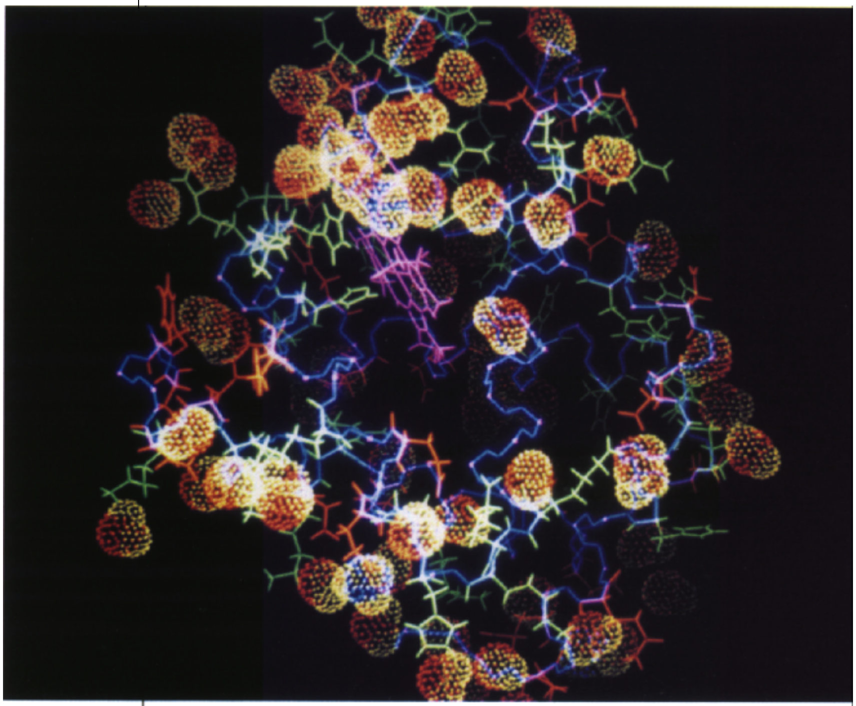
U.S. Universities

U.S. Government Labs

Foreign Labs

U.S. Industry

**A skeletal model of myoglobin, a protein involved in the respiration of oxygen in the lungs. The data, taken at the HFBR, allowed for the first time the accurate determination of weakly bound surface water molecules.**



# IPNS

The Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory allows scientists to study atomic and molecular structure, dynamics of solids and liquids, and materials in high-density neutron environments.

Based on a proton accelerator rather than on a reactor, IPNS produces neutrons by striking a uranium target with a pulsed beam of protons accelerated to 450 million electron-volts. Greater beam intensity allows more experiments to be performed in less time, and permits many specialized instruments to be used with greater precision and in new areas of research.

IPNS researchers examine the structure of high-temperature superconductors, alloys, composites, polymers, catalysts used in oil refining, and materials for advanced energy technologies. Recently developed instruments are used to study properties near the surfaces of magnetic and polymeric materials and to study the structure of liquid and noncrystalline materials.

Accessibility to the facility and its instruments is a high priority. Convenience of use by visiting scientists is further promoted by ancillary equipment and computer facilities. Full-time instrument scientists and scientific assistants and associates help researchers to carry out experiments and to collect and analyze data.

**Jim Jorgensen (left) of Argonne National Laboratory works with Mary Garbauskas and Ron Arendt of General Electric Co. to prepare an experiment to study the structure of bismuth-based high-temperature superconductors at Argonne's Intense Pulsed Neutron Source.**

In recent years, users requested nearly three times as much free experimental time as was available. Additional time is available to industrial researchers interested in performing proprietary research and willing to pay full operating costs for beam time.

## ACOMPLISHMENTS

Small-angle neutron scattering experiments by Amoco scientists are probing the formation and growth of zeolites, important catalysts in petroleum cracking and refining.

Formation and melting studies of bismuth-based, high-temperature superconductors, carried out by General Electric and Argonne scientists, have led to a better understanding the synthesis of these new materials.

Neutron reflection measurements by scientists from IBM, Northwestern University and Argonne on the diffusion of polymers could help the electronics and chemical industries develop improved polymer bonding and welding techniques.

The precise position of oxygen atoms in yttrium-barium-copper-oxide high-temperature superconductors was first determined by Argonne scientists using the Intense Pulsed Neutron Source.

# INTENSE PULSED NEUTRON SOURCE

View along the flight path of a neutron about to enter the new intermediate-angle scattering chamber of the High-Resolution Medium-Energy Chopper Spectrometer (HRMECS) at the Intense Pulsed Neutron Source. At the far end of a total 20-meter flight path is John P. Hammands making t final adjustments to the clusters of detectors.

## INDUSTRIAL USERS

- Alcan
- Allied-Signal Research
- Amoco
- Bell Communications
- B. P. Chemicals
- DuPont
- Exxon
- General Electric
- Hoechst-Celanese Research
- IBM
- Lucent Technologies
- Polaroid Corporation
- Schlumberger-Doll Research
- Texaco

# HFIR

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory produces the Nation's most intense continuous beam of neutrons for materials research and isotope production. About 250 researchers from industrial, academic, and government laboratories perform experiments there each year. HFIR provides state-of-the-art facilities for neutron scattering and materials irradiation and is the world's leading source of elements heavier than plutonium for research, medicine, and industrial applications.

HFIR has four neutron beam tubes with 11 neutron scattering instruments, including several triple-axis spectrometers, a residual stress analysis facility, and a small-angle neutron scattering facility. Facilities are also used for irradiation studies of structural materials for fission and fusion reactors and provide the highest neutron flux available for neutron activation analysis of trace elements in materials.

HFIR is a light-water cooled and moderated reactor with a design power level of 100 megawatts and a normal operating power of 85 megawatts. The flux in the beryllium reflector surrounding the core of highly enriched uranium is about five million-billion ($10^{15}$) neutrons per square centimeter per second. These neutrons produce radioactive elements for more than 800 customers for use in cancer radiation therapy, nondestructive inspection of explosives and aircraft, and as start-up sources for nuclear reactors. HFIR is the western world's sole source of berkelium-249, californium-249 and -252, einsteinium-253 and -254, fermium-257, and high-specific activity cobalt-60 for research and medical use.

## ACCOMPLISHMENTS

Small-angle neutron scattering has been used to test the compatibility of polymer blends by scientists from IBM, Exxon, and Eastman Chemicals. These experiments provide important information on the mixing characteristics of polymers in the 100 million ton per year polymer blend industry.

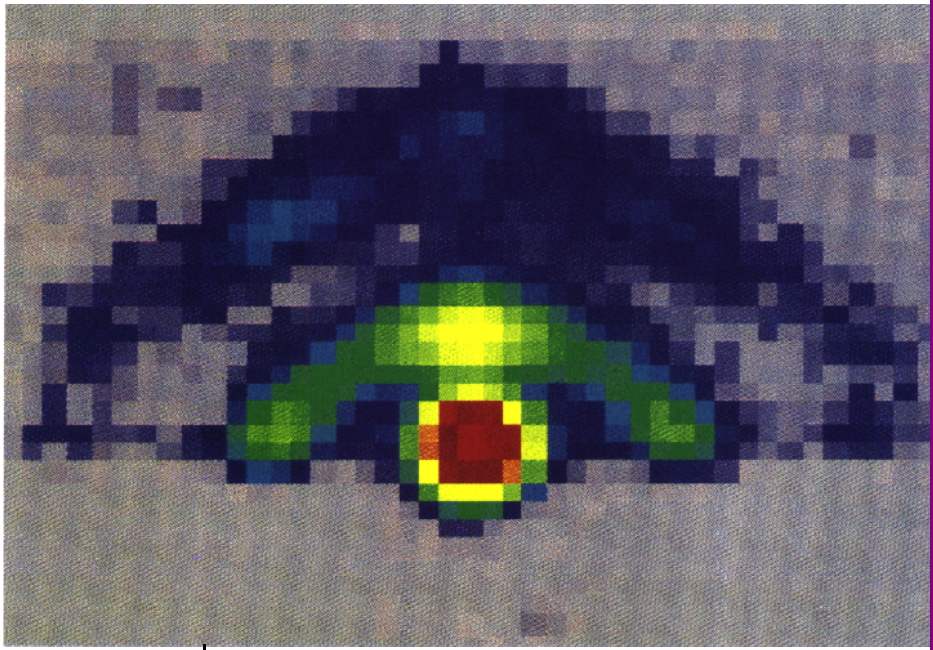
HFIR scientists developed neutron polarization analysis techniques unsurpassed in the thermal neutron region. They have been essential to the study of magnetic fluctuations in high-temperature superconductors in collaboration with AT&T and in measurements of heavy fermion materials in collaboration with the University of California at San Diego.

The structure of complex fluids has been determined by neutron reflectometry and small angle scattering. The hexagonal alignment of normally entangled micelles in viscous solutions under shear has been studied in collaboration with the University of Tennessee and Los Alamos National Laboratory.

**Steve Spooner and Stan David of ORNL examine a welded plate mounted in a residual stress apparatus at HFIR. Neutron residual stress mapping is being used to study stress relief in welds, composite materials, and complex parts. The residual stress facility is jointly sponsored by Basic Energy Sciences and the Office of Energy Efficiency and Renewable Energy.**

# HIGH FLUX ISOTOPE REACTOR

**Researchers from ORNL, the University of Kentucky, the University of Tennessee, and Los Alamos National Laboratory are using small-angle neutron scattering at HFIR to study microscopic order in complex fluids. The two-dimensional scattering pattern reveals hexagonal ordering along the flow direction which greatly reduces viscosity under shear, a desirable property for many complex fluids from shampoos to paint.**



Neutron scattering analysis of residual stresses in materials and components is being used to study the fundamentals of stress relief in welds, composite materials, and complex parts in collaboration with numerous universities and industries.

Scientists from the University of North Carolina are using small angle neutron scattering to study polymer processing in environmentally safe inert gases, a synthesis approach which would greatly decrease the use of ozone-depleting gases in the polymer industry.

## INDUSTRIAL USERS

- Alcoa
- Allied Chemical Corp.
- B&W Nuclear Technologies
- Boeing
- Caterpillar
- Cummins Engine
- Cytec Industries
- Detroit Diesel Corp.
- Doehler-Jarvis
- Eastman Chemical
- Exxon
- Ford Motor Co.
- General Electric
- General Motors
- Grove Engineering
- IBM
- Imperial Chemical Industries
- Lucent Technologies
- Pratt and Whitney
- Procter & Gamble
- Phillips Petroleum
- Phillip Morris
- Raychem Corp.
- Westinghouse

# LANSCE

**Kristin Bennett from the University of California, Berkeley, adjusts valves on the nitrogen cryostat on the neutron powder diffractometer at LANSCE. She is studying texture in shocked ice to understand how ice on Earth and in the outer solar system naturally deforms.**

The Los Alamos Neutron Science Center (LANSCE), which comprises the Manuel Lujan Jr. Neutron Scattering Center and the Weapons Neutron Research facility at Los Alamos National Laboratory, produces pulsed beams of neutrons for experiments that support national security and civilian research.

Neutrons at LANSCE are produced by spallation when high-energy protons strike a tungsten target. LANSCE can provide world-class capabilities to carry out experiments designed to increase understanding of materials. Researchers also use these neutrons to better understand the science underlying aging nuclear weapon components, thus helping predict their safety and reliability without nuclear testing.

In collaboration with U.S. industry, researchers at LANSCE use neutrons to study materials such as polymers, catalysts, and structural composites that are essential for many modern industrial products.

LANSCE offers a range of instruments for probing the structure of materials, facilities for neutron irradiation, and spectrometers for addressing a variety of neutron-scattering issues as well as nuclear physics experiments such as parity violation and fission. There are 10 state-of-the-art instruments – including a powder diffractometer with a higher resolution than any other instrument of its type in the United States and a unique chopper spectrometer and reflectometer.

Scientists from universities use LANSCE facilities for experiments that contribute to a broad range of basic research in disciplines such as materials science, structural biology, solid-state and non-weapon nuclear physics, and chemistry. Many of these experiments are an integral part of the education and training of young American scientists.

Reliability is imperative to the success of an experiment, so LANSCE has begun improvements that will allow the facility to operate at least 85 percent of the time for 8 months a year.

# LOS ALAMOS NEUTRON SCIENCE CENTER

## ACCOMPLISHMENTS

Using neutron reflectometry, scientists from The University of Patris (Greece), Harvey Mudd College (Claremont, California), and researchers from Los Alamos measured the structure of polymers subjected to shear flow, which is important for reducing friction in pipelines.

Proton irradiation research done at Los Alamos has led to improvement in the properties of high-temperature superconductors made by IBM Corporation.

A refined understanding of the structure of carbon black contained in reinforced rubber by scientists from Los Alamos and the Sid Richardson Carbon Company may aid in improving the mechanical properties of tires.

Experiments by Los Alamos and Boston Biomedical Research Institute scientists determined the structure of the molecular switch that helps regulate muscle contraction.

**Besides the mirror-like scattering, this neutron reflectometry data taken by scientists from Los Alamos National Laboratory and IBM's Almaden Research Center also exhibit diffuse scattering, which is characteristic of the rough surfaces between the polymer layers on a silicon wafer.**

**Gary Russell uses sophisticated Monte Carlo codes and high-speed computers as key tools to design spallation target systems.**

Scientists from both Ford Motor Company and Rockwell International have separately used neutron powder diffraction to take strain measurements on composites to obtain information about their mechanical behavior, which leads to improvements in cars and planes.

Los Alamos and Boeing scientists have used neutron irradiation to verify the integrity of electronic systems in modern aircraft such as the Boeing 777.

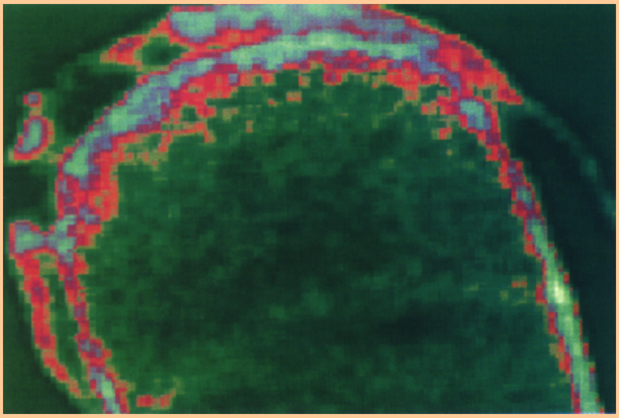
## INDUSTRIAL USERS

- The Boeing Company
- Ciba Vision Corp.
- Dow Chemical
- Exxon
- Ford Motor Company
- Fujitsu Inc.
- IBM Almaden Research Center
- Oak Ridge National Laboratory
- Rockwell International
- Sandia National Laboratories
- Sid Richardson Carbon Company
- Texas Instruments

# SYNCHROTRON

Light is one of the most important tools of science. It is the key to viewing the universe – from distant galaxies to cells, molecules, and even atoms. Visible light, which enables us to see the objects around us, is easy to generate and detect. The sun, electric lamps, and fire produce it; our eyes and photographic film detect it. However, visible light constitutes only a minor fraction of the electromagnetic spectrum. The remainder of the electromagnetic spectrum consists of radiation with longer or shorter wavelengths. On the longer wavelength side are radio waves, microwaves, and infrared radiation; on the shorter wavelength side are ultraviolet radiation, X-rays, and gamma rays. Because radiation throughout the electromagnetic spectrum is necessary to probe matter and fundamental processes, new and improved radiation sources are constantly being sought. During the past two decades, synchrotron radiation light sources have emerged as one of the most important and versatile tools for the production of radiation with wavelengths spanning the infrared to the X-ray regions.

Synchrotron radiation is the name given to light radiated by an electric charge following a curved trajectory-for example, a charged particle under the influence of a magnetic field. Synchrotron radiation is a natural phenomenon that has existed since the Big Bang. It is in the starlight that we see at night, generated by charged particles of matter spiraling through the cosmos. Nearly 100 years ago, theorists postulated the mechanism for the creation of synchrotron radiation. However, a manmade, controllable source of such radiation was not found until the middle of the twentieth century when accelerators for charged particles first appeared. High-energy electron accelerators emerged as viable synchrotron radiation sources because, as electrons approach the speed of light, the synchrotron radiation increasingly is emitted in a narrow, forward-directed cone. Thus, the radiation is concentrated in a small solid angle and can be readily used by researchers.



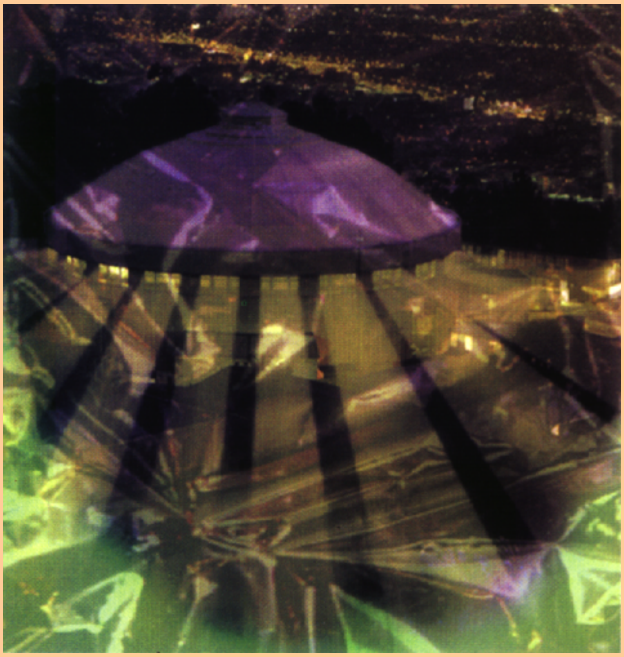
Early synchrotron light sources used photons that were created as the undesirable by-product of electron accelerators operated for high energy physics research. This parasitic use of synchrotron radiation showed such high promise that in the 1980's accelerators were built expressly for the purpose of generating synchrotron radiation. These accelerators, called "second-generation" synchrotron radiation light sources, typically consisted of a number of curved sections, in which the synchrotron radiation was generated, connected by straight sections; together, the curved and straight sections formed a closed, approximately circular orbit.

In the late 1970's, researchers developed devices consisting of periodic arrays designed to produce a series of deflections of the charged particle beam in the place of its straight-line orbit. Such devices are inserted into the straight sections of the storage ring (and hence are called "insertion devices") with one array of magnets above and one array below the charged particle beam path. As the charged particles pass through the alternating field, their deflections produce extremely intense synchrotron radiation: Insertion devices can be configured either as "wigglers" or "undulators" depending upon the effect they are to have on the movement of the charged particle beam. In general, wiggler magnets produce intense, energetic radiation over a wide range of energies, while undulator magnets produce radiation of selected energies (harmonics) at high brilliance. Most synchrotron light sources have several insertion devices, but those designed principally to use insertion devices are termed 'third generation' synchrotron light sources. The two third generation sources in the United States are the Advanced Light Source at Lawrence

# LIGHT SOURCES

Berkeley National Laboratory, optimized to provide radiation in the ultraviolet/soft X-ray region of the spectrum, and the Advanced Photon Source at Argonne National Laboratory, optimized to provide radiation in the hard X-ray region of the spectrum. Both were constructed and are operated by the Office of Basic Energy Sciences.

Researchers use a wide variety of experimental techniques when applying synchrotron radiation to their own problems. Most experiments fall into one of four categories: scattering, spectroscopy, imaging, and time-resolved studies. These relate to the four primary ways in which we describe the physical world: momentum (scattering), energy (spectroscopy), position (imaging), and dynamics (time). Often, forefront experiments will use a combination of these basic approaches, such as time-resolved X-ray scattering or spectrally selected imaging. Today, synchrotron radiation is used for state-of-the-art studies in materials sciences, physical and chemical sciences, geosciences, environmental sciences, biosciences, medical sciences, and pharmaceutical sciences.



The descriptors of synchrotron radiation that determine its properties and range of applicability are ***flux, brightness or brilliance, pulse length, tunability polarization and coherence. Flux,*** and ***brightness or brilliance*** are measures of the intensity of the radiation based on a measure of the number of photons per second in a narrow energy bandwidth (usually 0.1%) per unit solid angle. Flux is a measure of the intensity integrated over all vertical opening angles (above and below the plane of the electron orbit) of the photon beam and is the appropriate measure for experiments that use the entire unfocused X-ray beam. ***Brightness*** is the number of photons emitted per second, per square millimeter of source size, per square milliradian of opening angle, within a given spectral bandwidth (usually 0.1%). ***Brightness*** is a measure of the concentration of the radiation and increases as the size and divergence of the electron beam decrease. Undulators produce the brightest beams of synchrotron radiation. ***Brightness*** is often referred to as ***brilliance. Pulse length*** is the length of time that a burst of X-rays illuminates an experiment. ***Tunability*** is a measure of the useful wavelength range of the synchrotron radiation. ***Polarization*** is a measure of the alignment of the electric field vector of the light. Normally plane polarized, special undulators can alter the polarization to produce variable ellipticity and helicity, which will enable a wide variety of polarization-dependent studies. ***Coherence*** is a measure of the alignment of the phases of the electric field vectors of the light – i.e., a measure of the degree to which the waves are in phase across a light beam at any instant (transverse or spatial coherence) and the degree to which they remain so as the light propagates (longitudinal or temporal coherence). The high spatial and temporal coherence of the light from the ALS and APS undulators facilitates both tight focusing for microscopy and advanced imaging technologies such as holography.

The Office of Basic Energy Sciences operates four synchrotron light sources. In addition to the two third-generation sources mentioned above, there are two second-generation sources – the Stanford Synchrotron Radiation Laboratory (SSRL) and the National Synchrotron Light Source (NSLS).

# ALS

The Advanced Light Source (ALS) at the Lawrence Berkeley National Laboratory (LBNL) is one of the world's brightest sources of soft X-rays and ultraviolet light. ALS is the first U.S. member of a third generation of synchrotron light sources that employ advanced accelerator and magnet technology to produce X-ray beams so bright they resemble the hair-thin beams from lasers. ALS – which began operating in October 1993 – offers unprecedented opportunities for research by American scientists from industrial, academic, and government laboratories.

ALS features an electron storage ring that is about 650 feet in circumference. In it, electrons circulate many hours while they emit synchrotron radiation. The keys to the high brightness of ALS – about one billion times brighter than from conventional X-ray tubes – are the tightly focused beam in the storage ring and the precision-engineered insertion devices that deflect the electrons back and forth many times, thereby dramatically enhancing the emission of synchrotron radiation. Up to 10 insertion-device and 36 conventional beamlines can be arrayed around the storage ring to guide and focus the X-rays simultaneously to some 100 experimental stations.

**The Advanced Light Source at Lawrence Berkeley National Laboratory generates breakthrough results in such fields as atomic and molecular physics, materials and surface sciences, biology, chemistry, and microfabrication.**

Soft X-rays are an ideal tool for probing the secrets of matter at the level of individual atoms and molecules because they can penetrate samples and, according to their wavelength, interact with their atoms and molecules.

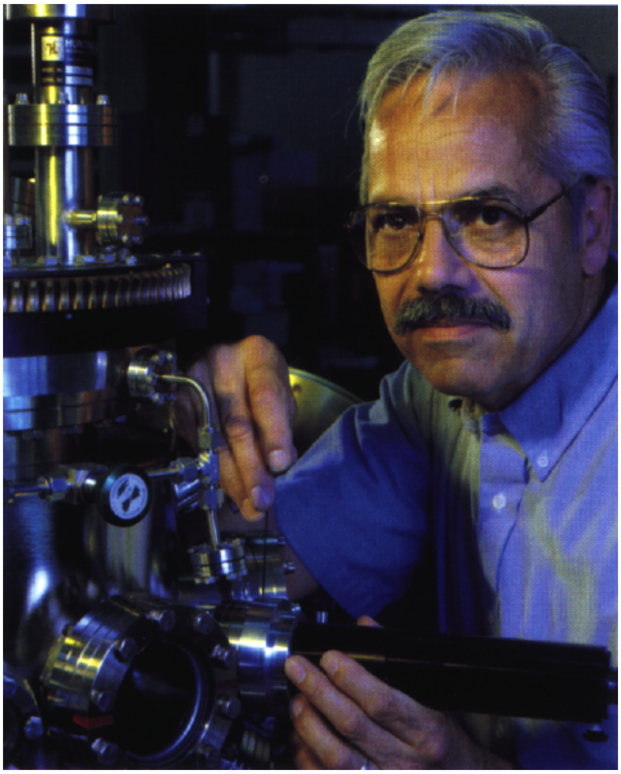
Potentially, research will cover an exceptionally wide range of areas – both fundamental research and new technologies – from semiconductors, the foundation of the electronics revolution, and magnetic materials used in computer-storage disks, to molecules undergoing rapid reactions in combustion and other industrially important processes, and structures within biological cells that determine how well drugs can fight disease-causing agents. such as viruses.

## ACCOMPLISHMENTS

Scientists demonstrated the ability to map the distribution of radioactive isotopes of elements in microsamples with so little radioactivity that they can be handled safely; this could provide a greatly improved way to chemically analyze materials from nuclear waste sites without hazard.

A team of researchers developed an interferometer using extreme ultraviolet light at wavelengths lying between those of ultraviolet radiation and X-rays to test mirrors and lenses that are

# ADVANCED LIGHT SOURCE



George Castro of IBM's Almaden Research Center led the commissioning of a photo-electron microscope at the Advanced Light Source that produces images of solids and their surfaces by means of the electrons emitted when a sample absorbs X-rays.

candidates for use in manufacturing future generations of computer chips.

ALS is collaborating with several Silicon Valley companies to test techniques that combine spectroscopy with microscopy (spectromicroscopy) to monitor computer chips during fabrication for contaminating microparticles, and to analyze failure-causing defects, such as breaks in the current-carrying lines that connect transistors.

Chemists are using the ALS to study in detail the chemical reactions occurring in the combustion processes that are major sources of pollution and in the atmospheric processes that bear on the problem of ozone depletion.

Visiting scientists achieved a world-record spectral resolution in their atomic-physics experiments on helium gas, a well-established test bed for detailed examination of how electrons interact with each other.

Researchers from several institutions are using an X-ray microscope designed at LBNL to image the interior of biological structures, such as the distribution of DNA in the form of chromatin strands in sperm cells, at high resolution without staining or other preparation techniques that can alter the structure before viewing.

- Biotechnology
- Ceramic
- Chemical
- Communications
- Computer data storage
- Energy efficiency
- Environment
- Laser
- Magnetics
- Materials analysis
- Metals and alloys
- Micromachines
- Oil products
- Pharmaceutical
- Polymer
- Semiconductor
- Superconductor
- Synthetic materials
- Transportation
- X-ray lithography

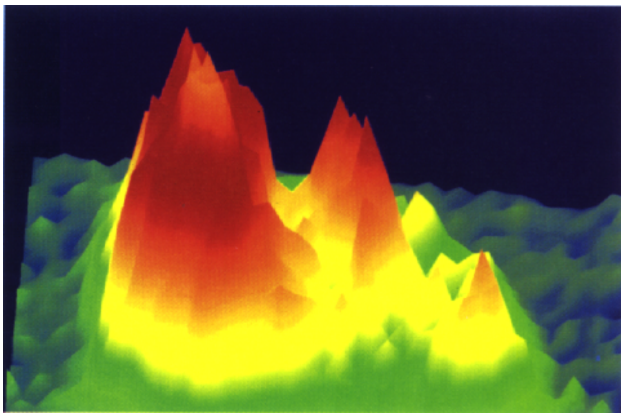


Image of a contaminating chromium particle in sediment from the San Francisco Bay illustrates how the ability of the ALS X-ray microprobe to analyze trace amounts of material with high spatial resolution can contribute to environmental remediation efforts.

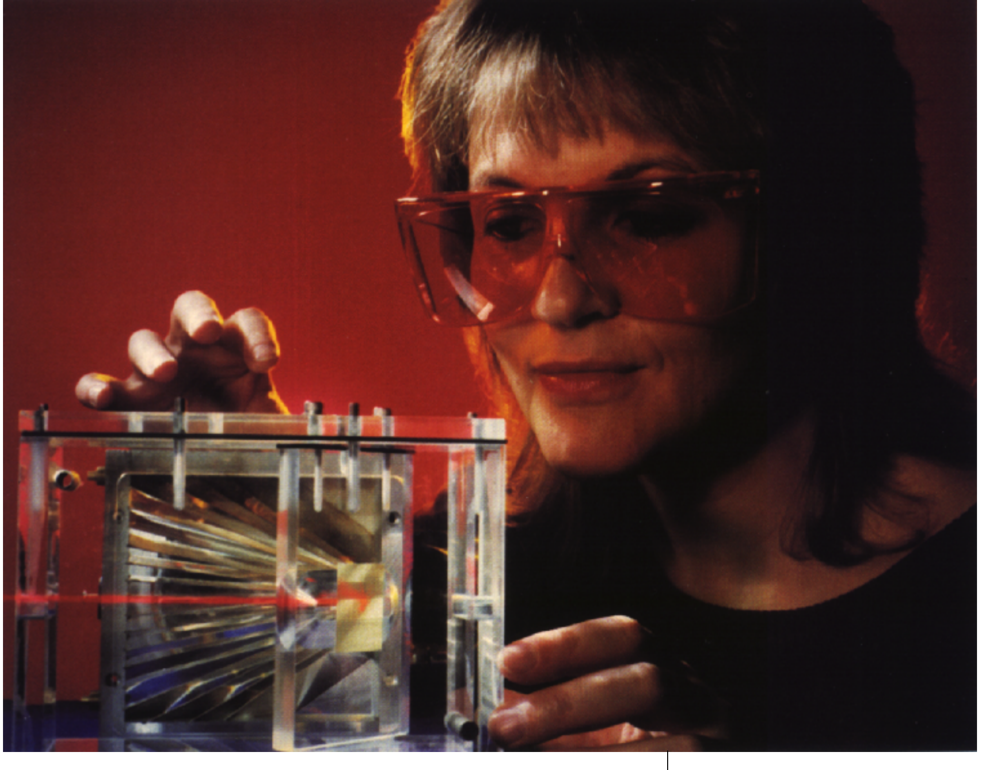
# NSLS

The National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL) is dedicated to the production of synchrotron radiation. Since its construction in the early 1980s the facility has undergone a major four-year upgrade and is continually Improved to take advantage of the latest technology in storage rings, beamline equipment, and insertion devices.

NSLS operates two electron storage rings producing high brightness synchrotron radiation in the infrared, visible, ultraviolet, and X-ray regions of the electromagnetic spectrum. The VUV Ring, with 25 beamlines, supports two insertion devices. The X-ray Ring has a total of 60 beamlines and currently supports five insertion devices. NSLS also has user laboratories and a wide range of research equipment to support basic and applied studies in many scientific disciplines and using a variety of techniques.

A large number of NSLS beamlines have been designed and built by Participating Research Teams (PRTs). These groups are consortia of users, mostly from outside BNL – from industry, universities, and national laboratories -with common research interests and large, long-range research programs. Over the years, PRTs have invested over $126 million and about 1,200 staff-time years of labor to design and install their own experimental equipment, aided by BNL staff. The PRTs have priority access for as much as 75 percent of their beamline’s operational time. The remaining time on PRT beamlines, as well as on NSLS-operated beamlines, is available to outside customers and is allocated on the basis of peer-reviewed research proposals.

Within a single year, 2,228 scientists from over 350 different institutions visited NSLS to perform experiments. Most of the research – for which there is no beamline charge – is published in the open scientific literature. Scientists may also engage in proprietary work, in which case they pay a full-cost-recovery rate. This allows them to take title to any inventions and treat as proprietary all data generated during work at NSLS.



**North Carolina State University scientist Geraldine Lamble collaborates on environmental remediation studies at the National Synchrotron Light Source. Using this detector and a technique called X-ray absorption fine structure, which can be done at NSLS because it delivers highly intense and tunable X-rays, researchers are investigating the behavior and treatment of metal contaminants in soils.**

# NATIONAL SYNCHROTRON LIGHT SOURCE

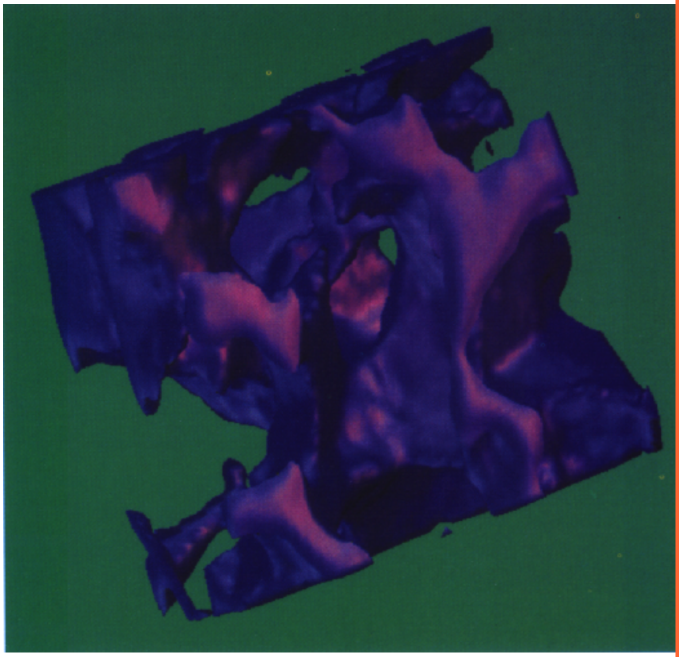
## ACCOMPLISHMENTS

Fundamental advances in surface science have resulted from NSLS studies of the arrangements of atoms and their electrons on boundaries between solids, liquids, gases, or a vacuum.

New materials characterization techniques developed or perfected at NSLS include high resolution infrared spectromicroscopy, new imaging techniques, magnetic scattering, magnetic circular dichroism, and spin polarized photoemission. Materials characterization is also a critical element in the development of new materials, products, and technologies.

Crystallographers from universities, medical foundations, and pharmaceutical companies determined the structure of many biological molecules and how they interact with specially designed drugs. Some of the diseases being studied are arthritis, hypertension, depression, and AIDS.

IBM researchers developed the technique of X-ray lithography to create smaller and faster microchips. Lucent Technologies is extending this technique to extreme ultraviolet projection lithography, creating even smaller features.

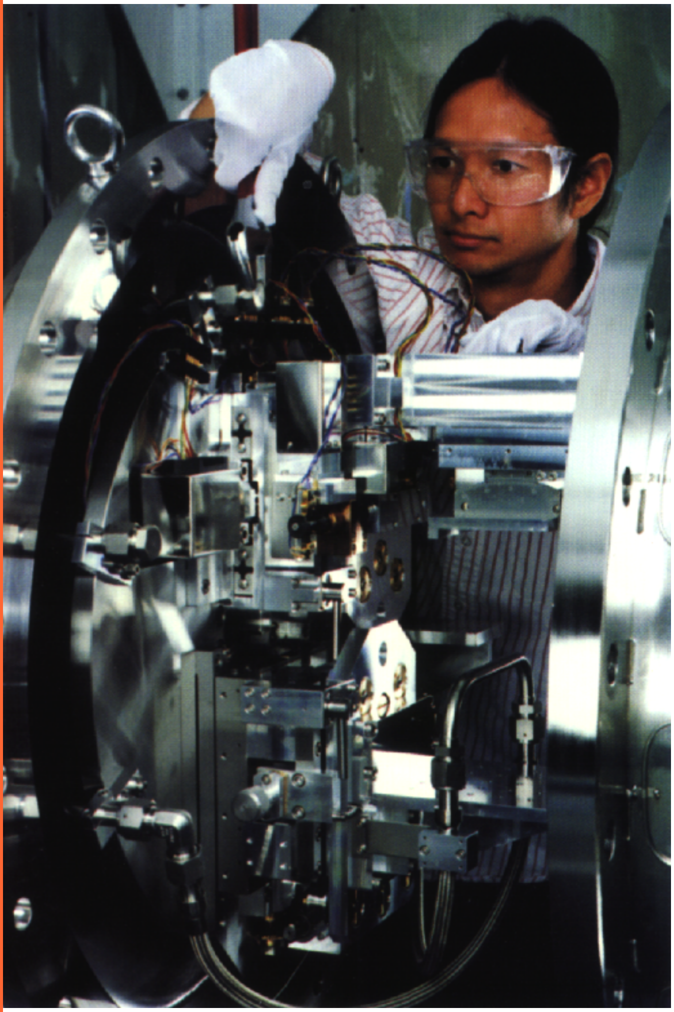


**X-ray tomograph image of a sample of Fontainbleu sandstone showing its pore geometry. This kind of measurement helps Exxon researchers test theories developed to predict fluid flow in the extraction of fossil fuels. Scientists from Kimberly-Clark are also using three-dimensional microtomography, but to analyze the structure of fibrous networks of paper products. The resolution of this technique is 1,000 times greater than using conventional computer-aided tomography.**

## USERS

- Argonne National Laboratory
- Bayer Corporation
- Brandeis University
- Columbia University
- The Dow Chemical Company
- DuPont Merck Pharmaceuticals
- Exxon Research & Engineering Co.
- Harvard University
- Howard Hughes Medical Institute
- IBM Corporation
- Lawrence Berkeley National Laboratory
- Lucent Technologies
- MIT
- Naval Research Laboratory
- National Institute of Standards & Technology
- Polaroid Corporation
- Princeton University
- Rutgers University
- State University of New York
- The Upjohn Company
- University of Pennsylvania
- Yale University

# APS



**Perfect silicon crystals used to monochromatize beams of X-rays generated by the Advanced Photon Source are mounted in these vacuum and mechanical housings. Monochromators are often used at synchrotron light sources as the first optical components to select the energy of the radiation for an experiment. At the APS, these crystals will be subjected to unprecedentedly high heat loads.**

The Advanced Photon Source (APS) at Argonne National Laboratory is a powerful synchrotron X-ray research facility. APS is the source of this nation's most brilliant synchrotron radiation X-ray beams in the energy range from 3 to 300 kilo-electron-volts -the so-called "hard X-ray" portion of the spectrum.

APS design is optimized for special magnet arrays called "insertion devices" which generate highly tunable photon beams. These brilliant X-ray beams probe material structure in greater detail than ever before, opening new vistas of research in materials science, chemistry, physics, biotechnology, medicine, and the environmental, geological, agricultural, and planetary sciences.

Researchers can look at objects thousands of times smaller than can be seen with conventional optical techniques. Exposure times are billionths of a second, fast enough to image chemical and biological molecules as they react, and to make "movies" of catalytic and enzyme reactions.

APS research enhances America's competitiveness in such areas as superconductors, semiconductors, polymers, pharmaceuticals, and catalysts. X-ray optical systems and fast detectors being developed for APS greatly speed the analysis of materials, such as large biological molecules, that deteriorate under prolonged X-ray exposure.

The tremendous brilliance of APS X-ray beams reveals the precise positions of atoms as new materials are formed, and the mechanisms by which atomic changes at these positions give materials new and unusual properties. This knowledge helps create new materials with properties tailored to specific applications. In addition, APS provides a wealth of information about the magnetic and electronic structures of new materials.

APS accelerates positrons to energies of seven billion electron-volts (7 GeV) and stores them in a circular path about two-thirds of a mile in circumference. Insertion devices vibrate the positron beam, causing it to emit an intense, laser-like beam of X-rays. These beams can be tuned to energies up to 40 keV for the highly monochromatic X-rays from undulators and up to 300 keV for the intense, "white-light" X-rays from wigglers.

# ADVANCED PHOTON SOURCE

Up to 70 beam lines will allow 400 researchers to perform experiments at the same time.

## INDUSTRIAL USERS

The Advanced Photon Source stimulates rapid advances in American industrial research. Here are some industries that do or can use the APS for research and development.

- Aerospace
- Agriculture
- Biotechnology
- Ceramic and composite materials
- Chemicals
- Communication
- Computers
- Energy storage
- Environmental technology
- Geology
- Magnetics
- Metal alloys
- Medical imaging
- Microelectronics
- Nuclear energy
- Oil products
- Pharmaceuticals
- Semiconductor materials
- Synthetic fibers
- Transportation
- Waste management

**The Advanced Photon Source opens new realms of research in the structure of materials. Researchers will be able to perform more experiments in less time and gather better data than ever before. The resulting advances in materials and technologies help the nation enhance its lead in technology and science, and stimulate the development of new high-technology industries.**

## USER COMMUNICATIONS

The APS Users' Organization Steering Committee maintains two-way communication between APS management and customers to ensure that customer needs are met. Committee membership includes representatives of:

- Argonne National Laboratory
- Cornell University
- Dow Chemical Company
- DuPont Chemical Company
- Iowa State University
- Los Alamos National Laboratory
- Lucent Technologies
- McGill University
- National Institute of Standards & Technology
- Northwestern University
- Oak Ridge National Laboratory
- University of Chicago
- University of Michigan
- University of Washington

# SSRL

Stanford Synchrotron Radiation Laboratory (SSRL) provides synchrotron radiation and ancillary equipment. The facility, which comprises 25 experimental stations, is used each year by nearly 900 researchers from industry, government laboratories, and universities – including astronomers, biologists, chemical engineers, chemists, electrical engineers, environmental scientists, geologists, materials scientists, and physicists.

Biological sciences, environmental sciences, and studies of materials are major areas of research. Detailed studies of biological structures by corporate and academic scientists are being used to understand disease processes and to develop better drugs for intervention. Recent studies include work on AIDS, diabetes, multiple sclerosis, myasthenia gravis, rheumatoid arthritis, and the flu virus. Other SSRL research has shown how muscles contract and how various genetic defects lead to cancer and Lou Gehrig's disease. Using imaging techniques possible only with synchrotron radiation, the progression of osteoporosis and the effects of various treatments are being studied.

Movement of electrons within superconducting materials is key to their properties. Studies at SSRL have revealed unusual behavior which does not conform to the accepted theories. This work is leading to a more general theoretical understanding of electron movement which will further the development of practical applications.

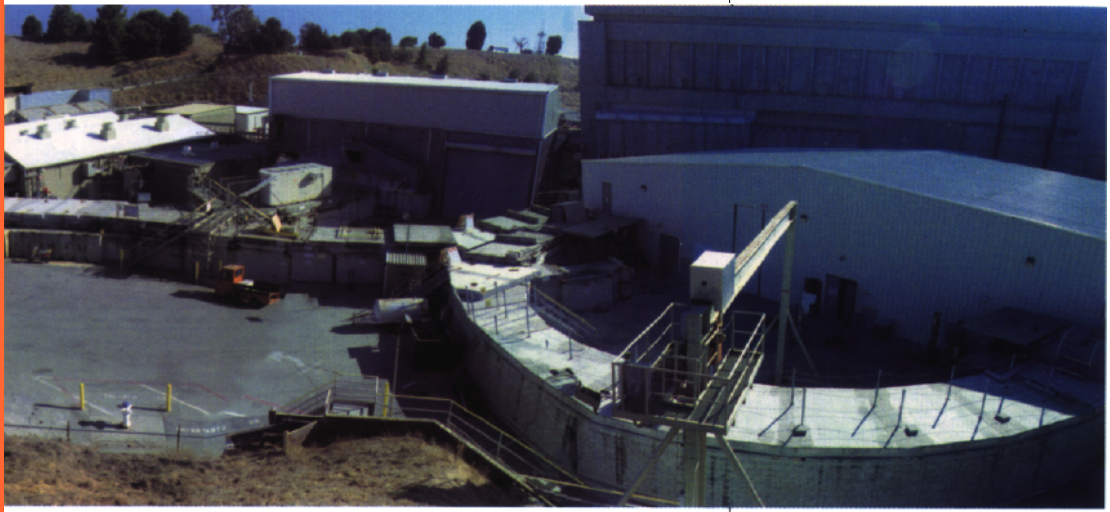
Remediation of toxic environmental sites is limited by insufficient knowledge of how the relevant toxic materials are chemically bound in waste storage or contaminated soils or waters. In a program involving close cooperation of SSRL and four other national laboratories, the intense X-rays at SSRL are being used to study these interactions. Engineers will use these results to more effectively guide strategies for cleanup and long-term waste management. In other environmental studies, DOE and academic scientists are characterizing the nature of selenium contamination in agricultural regions. Studies are being done to develop remediation techniques for lead contamination, and to identify the presence of arsenic in contaminated soils.

Prompted by the semiconductor industry, research is focusing on ways to reduce the metal contamination on silicon wafer surfaces, which can destroy their performance. Synchrotron radiation is being developed as an analytical tool which will allow industry to improve their manufacturing processes for next-generation integrated circuits.

SSRL is currently used by 155 institutions in 35 states and 15 foreign nations. These include 59 universities, 37 private corporations, 18 governmental laboratories, and 41 foreign institutions.

## ACCOMPLISHMENTS

Developed the first wiggler and undulator insertion device magnets as sources of enhanced synchrotron radiation; continued with subsequent



**The Stanford Synchrotron Radiation Laboratory is built around the storage ring SPEAR. The small ring at right is the booster synchrotron and injector. The laboratory's experimental stations are housed in the buildings on the left and rear.**

# STANFORD SYNCHROTRON RADIATION LABORATORY

insertion devices with increased capability including polarization control.

Developed an experimental station with an advanced detector for protein crystallography experiments that is now providing access for hundreds of academic and industrial scientists studying structure of biological materials.

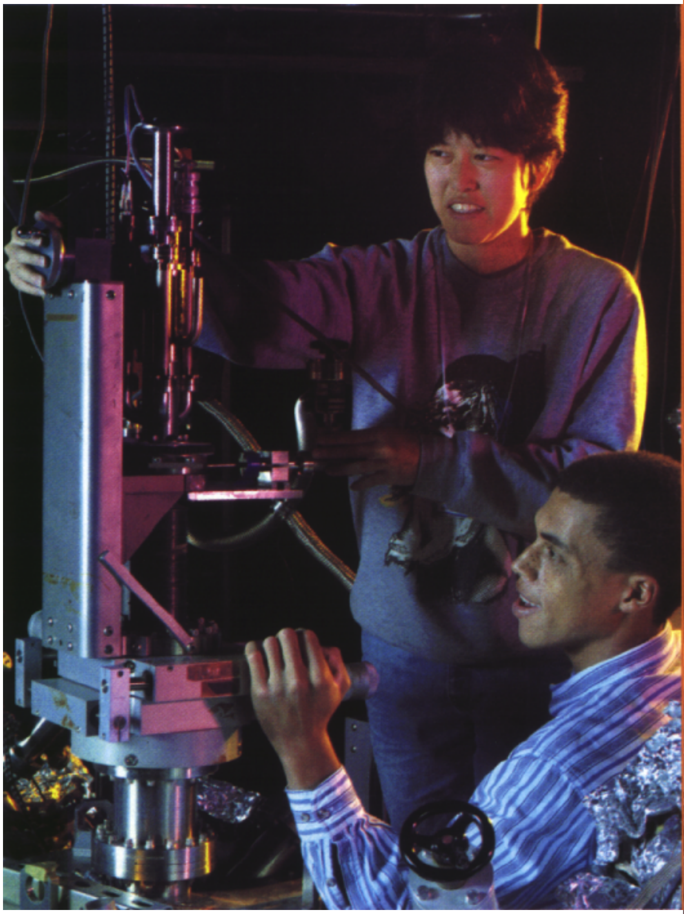
Discovered key properties about the high-temperature superconductors which led to a novel mechanism completely different from conventional superconductors and will further the development of practical applications.

Performed the first dynamic, real-time X-ray study of how semiconductors grow in the commercially important organic-metallic vapor phase epitaxy process.

## INDUSTRIAL USERS

- Adelphi Technology
- Advanced Micro Devices
- Affymax Research Institute
- Alchemist Technologies
- ARACOR
- Bristol-Myers
- Chevron Research & Technical Company
- Conductus, Inc.
- Digital Semiconductor
- Dow Chemical Company
- DuPont-Merck Pharmaceuticals
- Eastman Kodak Company
- E.I. duPont de Nemours and Co., Inc.
- Edge Analytical Inc.
- ESRS Corporation
- Exxon Research & Engineering
- Genentech, Inc.
- General Electric Co.
- Hewlett Packard
- Hirsch Scientific
- IBM Research Laboratory
- Industrial Automation
- Intel Corporation
- Interphases Research
- IBM Technologies
- Lucent Technologies
- Monsanto Company
- Morris Research, Inc.
- Motorola
- Orthologics
- Ovonic Synthetic Materials Co.

**Anne Matsuura and Paul White, Stanford University graduate students, prepare a vacuum chamber which will be placed on the end of an SSRL soft X-ray experimental station. Samples for research on high temperature superconductors will be placed in the chamber for exposure to the synchrotron radiation beam.**



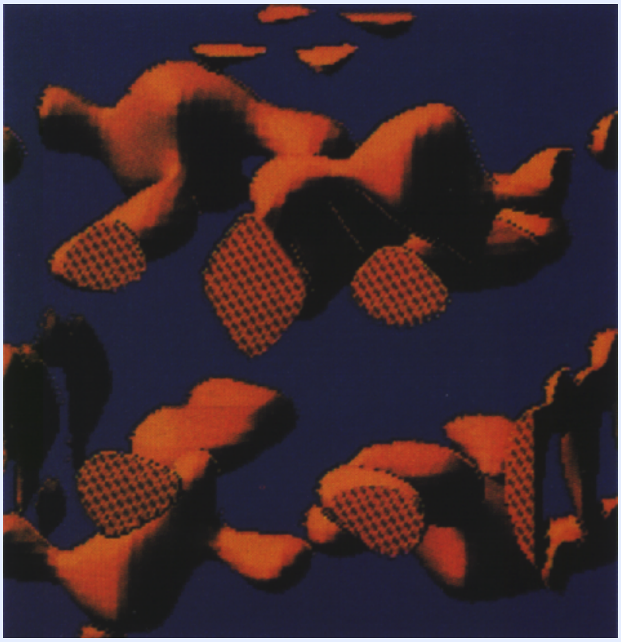
- Siemens
- Squibb Research Institute
- Surface Interface
- Syntex Research
- Texas Instruments, Inc.
- The Dow Chemical Company
- The EXAFS Company
- Wacker-Chemitronic
- X-ray Instrumentation Associates
- Xerox
- Xsirius, Inc.

# CENTERS FOR ELECTRON BEAM


1.6Å Atomic Resolution Microscope. *National Center fir Electron Microscopy*

In microanalysis, information obtained by combining techniques is often more helpful in problem solving than any single technique.

The U.S. Department of Energy's Office of Basic Energy Sciences operates several micro-analysis research centers. Four are equipped with electron microscopes for analysis of the atomic



Atomic structure of staurolite. *National Center for Electron Microscopy*

structure of solid samples, sample-environment interactions, and local chemical composition. All have a variety of micro-analytical instruments, each dedicated to a different type of structural or chemical analysis

A transmission electron microscope uses an electron beam that interacts with, and is transmitted through, the sample; it is directed and focused by electromagnetic lenses. There are three types of transmission electron microscopy.

A high-resolution or atomic-resolution micra scope is used to obtain an image that exhibits

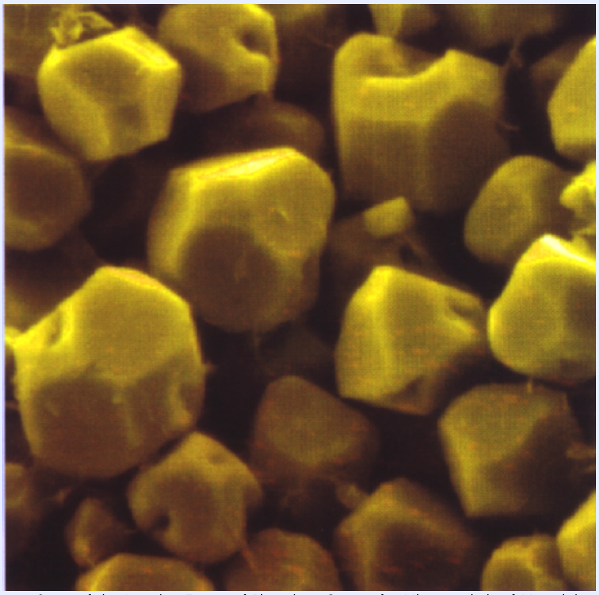
# MICROCHARACTERIZATION

contrast due to the different electron scattering capabilities of atoms or their geometrical arrangements within a material under study.

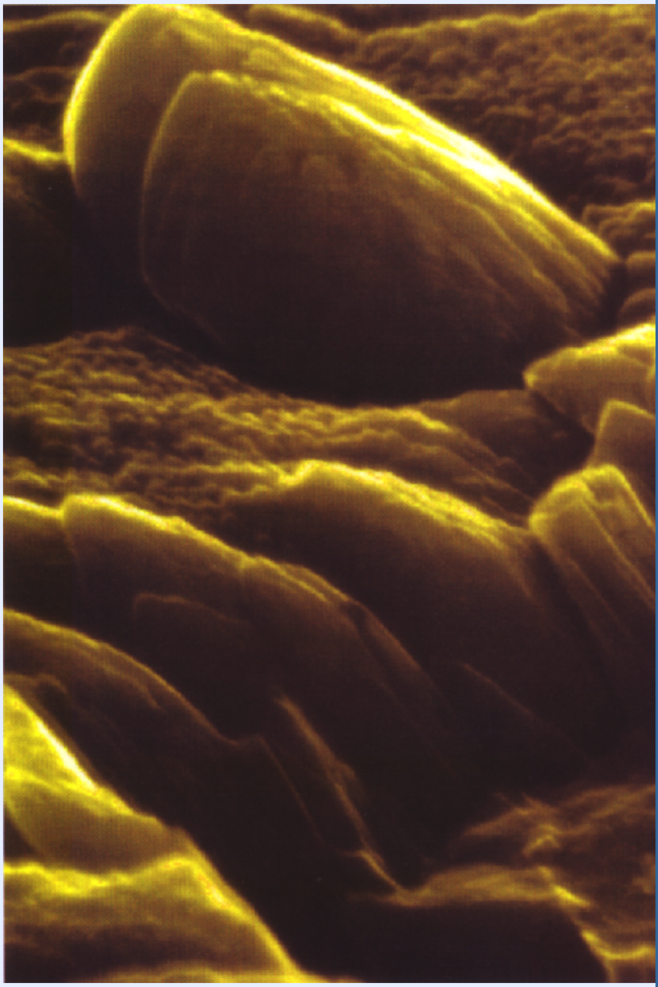
A **high-voltage electron microscope** reveals changes in atomic arrangement in a solid as they occur in real time while reacting with its environment, subjected to a stress, heated, cooled, phase transformed, or irradiated with electrons or ions. This microscope is used to investigate the atomic mechanism of reactions or processes such as corrosion, fracture, film deposition, deformation, sintering, and irradiation effects.

An **analytical electron microscope's** various detectors permit it to perform chemical and crystallographic analysis on the same region of the sample being imaged. Since this region may be a disc that is as small as 2 nanometers, chemical analysis of this type is referred to as elemental microanalysis. Elemental microanalysis is usually carried out by X-ray energy dispersive spectroscopy and/or electron energy loss spectroscopy. Indirect methods of composition analysis based on atomic imaging and microdiffraction are also possible.

Examples of collaborative work at microanalysis research centers include projects at the Shared



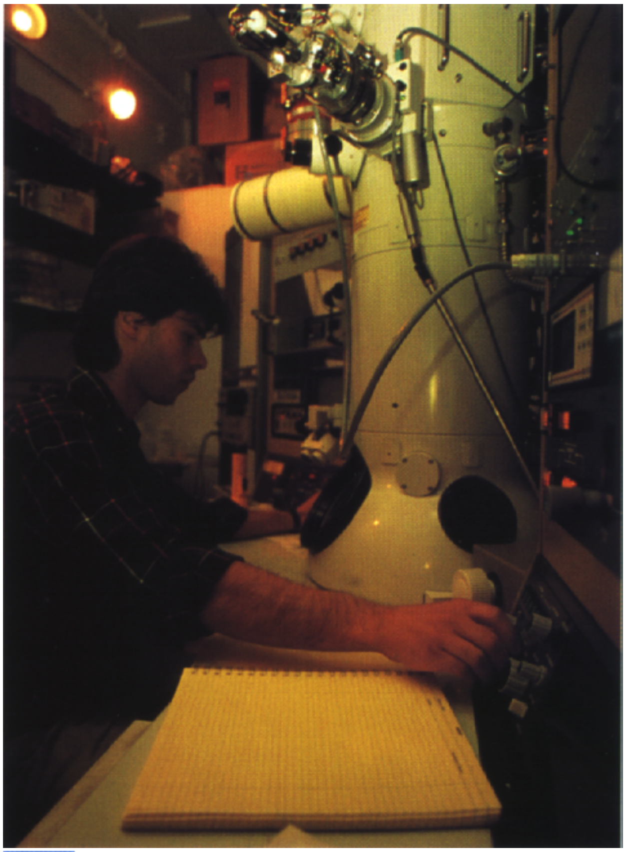
Scan of the Leaning Tower of Pisa clay. *Center for Microanalysis of Materials*



Scan of coating on high-speed steel. *Center for Microanalysis of Materials*

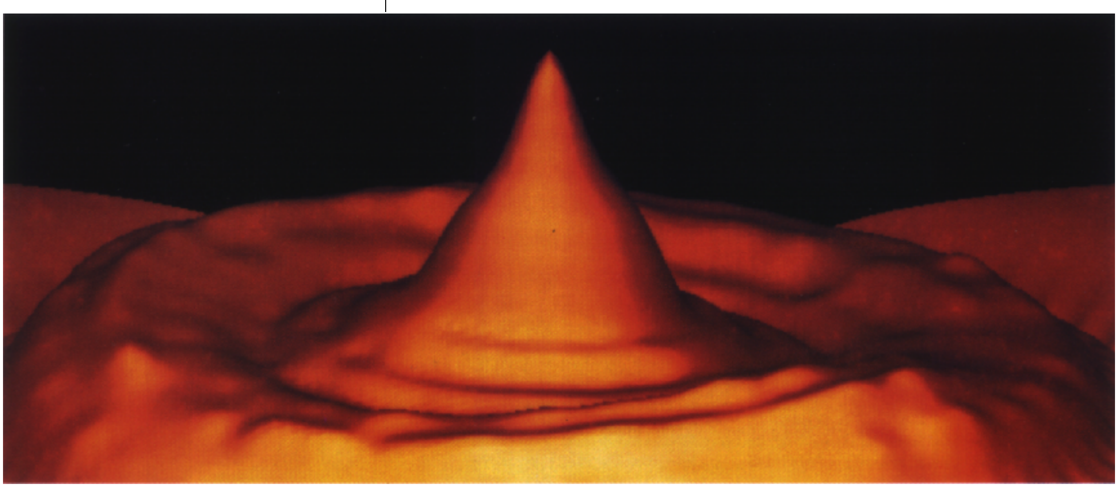
Research Equipment Program that range from improving the performance of turbine blade materials to improving catalytic converters. Another example brings light to the computer industry – a computer that uses light instead of electric currents was brought closer to reality by research at the Center for Microanalysis of Materials.

# CENTER FOR MICROANALYSIS OF MATERIALS



The Center for Microanalysis of Materials at the University of Illinois at Urbana has over 20 major instruments in four areas: electron microscopy, surface microanalysis, X-ray diffraction, and backscattering spectroscopies.

Access to the Center's instruments is easy and flexible. The Center adjusts the way it works to match the needs of each research project. Researchers can be trained to operate the instruments themselves; they can work with Center staff members; the work can be done by staff members directly; or staff can act as consultants. The Center's broad range of techniques ensures that research work will use the optimum method – or the optimum combination of techniques.



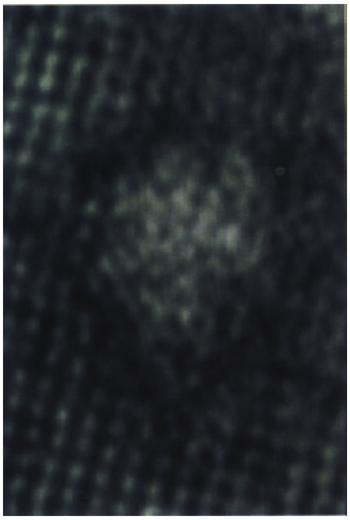
## ACCOMPLISHMENTS

Researchers used several techniques to study the potential of oxide films on gallium arsenide for computer circuitry and to elucidate their structure: transmission electron microscopy, Auger analysis, and secondary ion mass spectroscopy. Together, these techniques led to the discovery that light can be steered around corners in computers.

In many fields of technology, performance is improved if the materials are more finely structured. This makes it hard to investigate the phases, because each region is so small. One important advance in transmission electron microscopy is a technique called convergent-beam diffraction. This technique makes it possible to obtain better information on the crystal structures of materials and to obtain it from smaller regions than earlier techniques. It has important applications in semiconductors, ceramics, steels, rapidly quenched metastable materials, and many others.

The Center developed a unique instrument that permits a sample from an electrochemical cell to be moved directly into an ultra-high vacuum system for surface analysis – without contamination by exposing it to air.

# ELECTRON MICROSCOPY CENTER FOR MATERIALS RESEARCH



**Atomic resolution image of defect in high-temperature superconductor, intentionally produced by ion irradiation to improve the electrical current carrying capacity.**

The Electron Microscopy Center for Materials Research (EMCMR) at Argonne National Laboratory includes the HVEM-Tandem Facility and the Analytical Microscopy Center. The HVEM-Tandem Facility instrumentation includes a 1.2 MeV high voltage electron microscope (HVEM) and a 300 keV intermediate voltage electron microscope (IVEM); both have been modified to permit a specimen under observation to be bombarded simultaneously with ion beams. This allows the irradiation-induced changes in material structure to be observed in situ. It is the only instrumentation of its type in the Western Hemisphere. The facility is open to outside researchers, whether collaborating with Argonne scientists or working independently.

The EMCMR's Analytical Microscopy Center instrumentation includes four transmission electron microscopes (TEM) for conventional TEM, ultra-high resolution, elemental microanalysis, and energy filtered electron diffraction. These instruments are available to outside users collaborating with Argonne scientists.

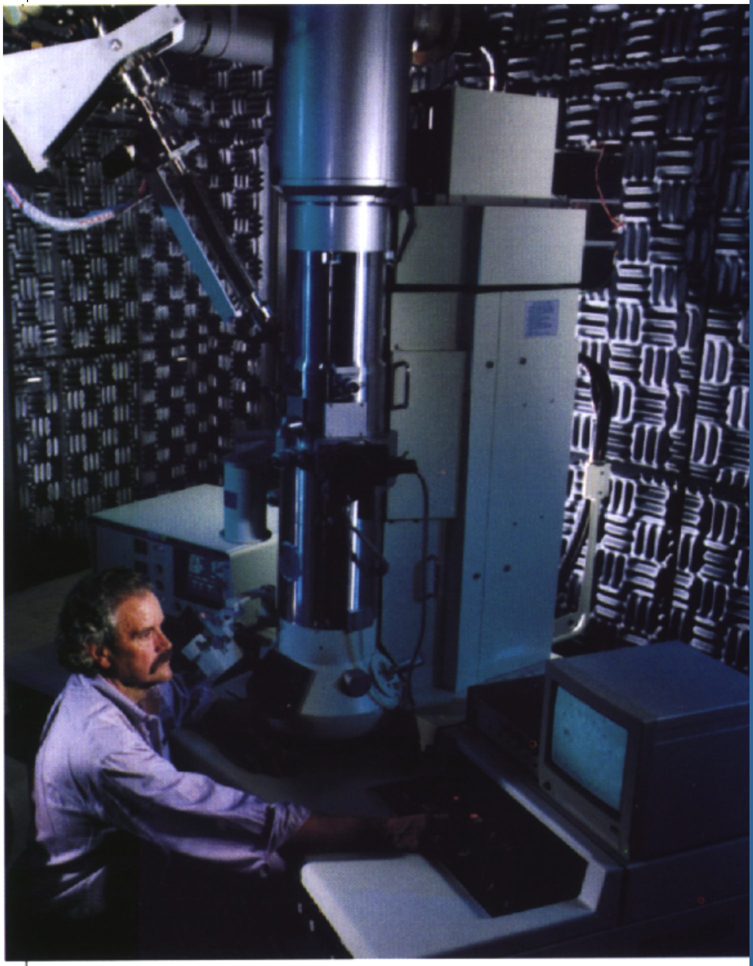
## ACCOMPLISHMENTS

A collaborative effort between IBM and Argonne National Laboratory is examining an ion-irradiation method to induce crystallization of noncrystalline, silicon-based compounds, which could lead to an alternative to existing laser- and thermal-annealing techniques.

Extensive electron microscopy investigations in collaboration with several universities and industries have yielded new understanding of the exciting properties of new high temperature superconductors.

In situ ion-beam irradiations, performed by Argonne scientists for Oak Ridge National Laboratory's Advanced Neutron Source Project, have demonstrated why $U_3Si$ is an unacceptable reactor fuel in certain situations.

**Principal investigator for HVEM-Tandem National User Facility, Charles Allen, operates a newly installed Hitachi Electron Microscope with in situ ion beam irradiation capability.**

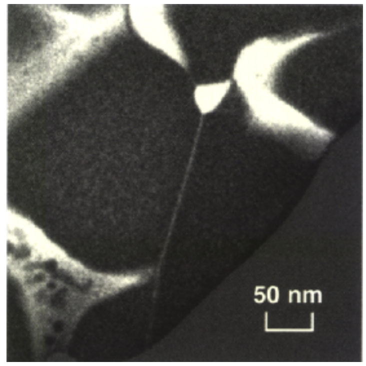


# SHARED RESEARCH EQUIPMENT PROGRAM

The Shared Research Equipment Program (SHaRE) at Oak Ridge National Laboratory (ORNL) provides academic, industrial, and other government researchers access to a singular collecton of instruments that are optimized for the evaluation of structure, chemistry, mechanical properties, and related phenomena in materials on a scale of less than one-millionth of an inch (or nano-scale).

SHaRE provides sophisticated analytical electron microscopes, including one with a special imaging filter and two with field-emission guns. These specialized microscopes can identify and map chemical changes in regions as small as one ten-millionth of an inch in diameter. In addition, SHaRE provides access to a fully analytical field-emission scanning electron microscope that includes an automated capability for texture-mapping.

SHaRE's atom probe field ion microscopes are the ultimate tools for analyzing the structure and chemistry of materials. They can analyze individual atoms appearing in atomic-resolution field-ion images. SHaRE mechanical property microprobes can measure the hardness and stiffness of regions less than a ten-thousandth of an inch across.



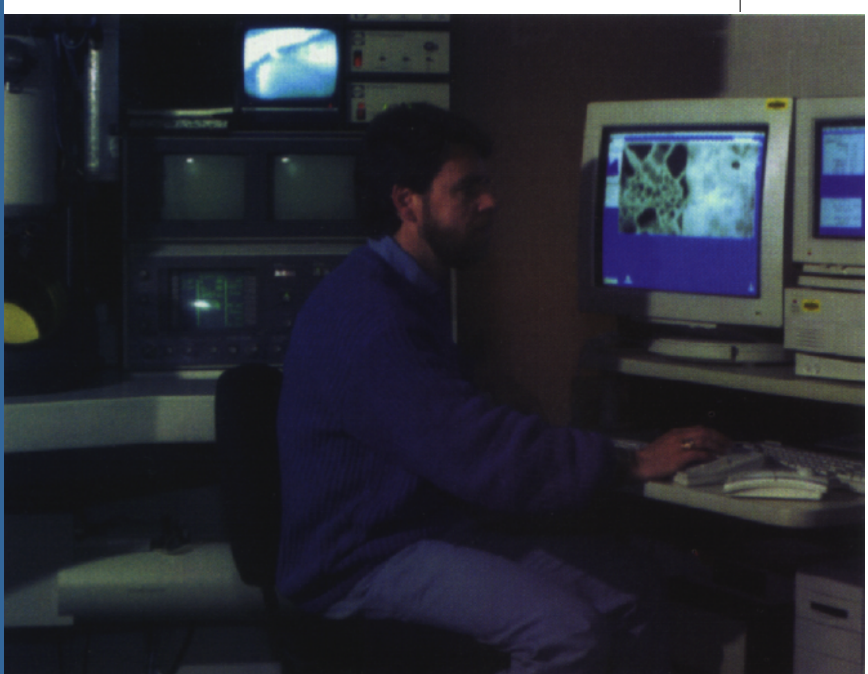

**Images of nickel-based superalloys showing the distribution of chromium (bright regions) as determined by elemental mapping using a specialized energy-filtered imaging technique.**

## ACCOMPLISHMENTS

Metallic materials containing diamond particles which are being developed for cutting and grinding tool applications have been studied in collaboration with researchers from Southern University and Louisiana State University to extend the tool's service life.

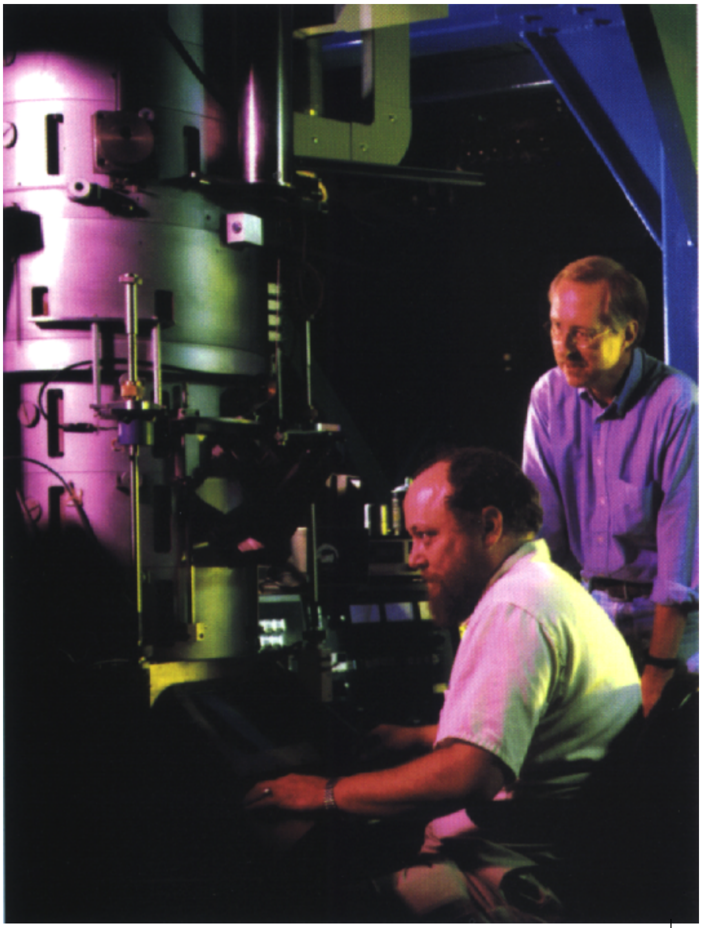
Recent collaborative efforts with Rice University have resulted in the development of an instrumented low-load scratch test for thin films and coatings relevant to the hard disk drive and semiconductor industries.

Collaborations with a variety of industries and universities have focused on the atomic-scale characterization of reactor pressure vessel steels, and have resulted in improved service-life predictions for materials in use in both conventional and nuclear power plants.



**E.L. Hall from General Electric Corporate Research and Development uses a SHaRE analytical electron microscope to investigate nickel-based superalloys used in critical aircraft engine components.**

# NATIONAL CENTER FOR ELECTRON MICROSCOPY



**A development team tests the computer system that has enabled the National Center for Electron Microscopy's 1.5 million-electron-volt high-voltage electron microscope to be used remotely (via the Internet) for in situ experiments by widely-separated collaborators.**

The National Center for Electron Microscopy (NCEM) at Lawrence Berkeley National Laboratory is one of the nation's primary research facilities for the use of high-voltage electron microscopes in the examination of atomic structure of materials.

Of the two high-voltage microscopes, one operates at 1.5 million volts, making it the highest voltage electron microscope in the United States. Its in situ capability allows specimens to be examined while undergoing tensile testing, or while being heated in reducing or oxidizing gases. It is available on-line for remote users.

The second instrument, the Atomic Resolution Microscope, operates at 400,000 volts to one million volts and has a point-to-point resolution of 0.16 nanometers – the highest in the United States. It can distinguish individual atoms in many materials.

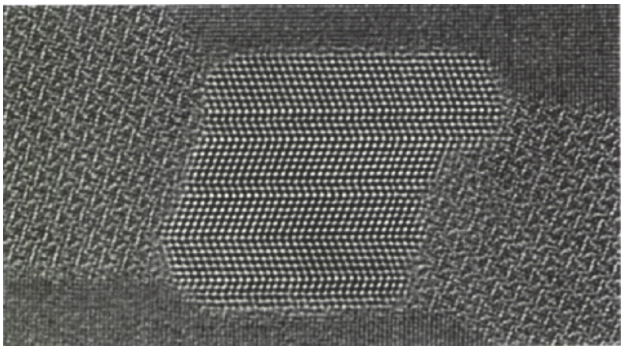
Five additional microscopes operate at 200,000 volts. One has in situ capability allowing the specimen to be examined while being changed by electrical currents, heating, or chemical etching.

## ACCOMPLISHMENTS

Hewlett-Packard's study of defect structures in semiconductors revealed new information on mechanisms by which VLSI memory circuits fail.

Future compact disc players could be improved by IBM Almaden studies of the microstructural properties of multilayer thin films for phase-change optical recording.

NASA/Ames and NCEM researchers determined the structure of minute diamond particles from outer space, using a combination of electron energy loss spectroscopy, high-resolution electron microscopy, and microdiffraction.



**Ultra-high-resolution electron micrograph of a lightweight piston ring alloy, taken on the NCEM ARM, showing a precipitate of twinned silicon (center) and a complex Al-Si-Cu-Mg phase in the aluminum matrix (from a collaboration with GM).**

# OTHER SPECIALIZED CENTERS

The Office of Basic Energy Sciences operates several other user facilities which serve to meet specialized needs of the scientific-community Included among these specialized facilities are:

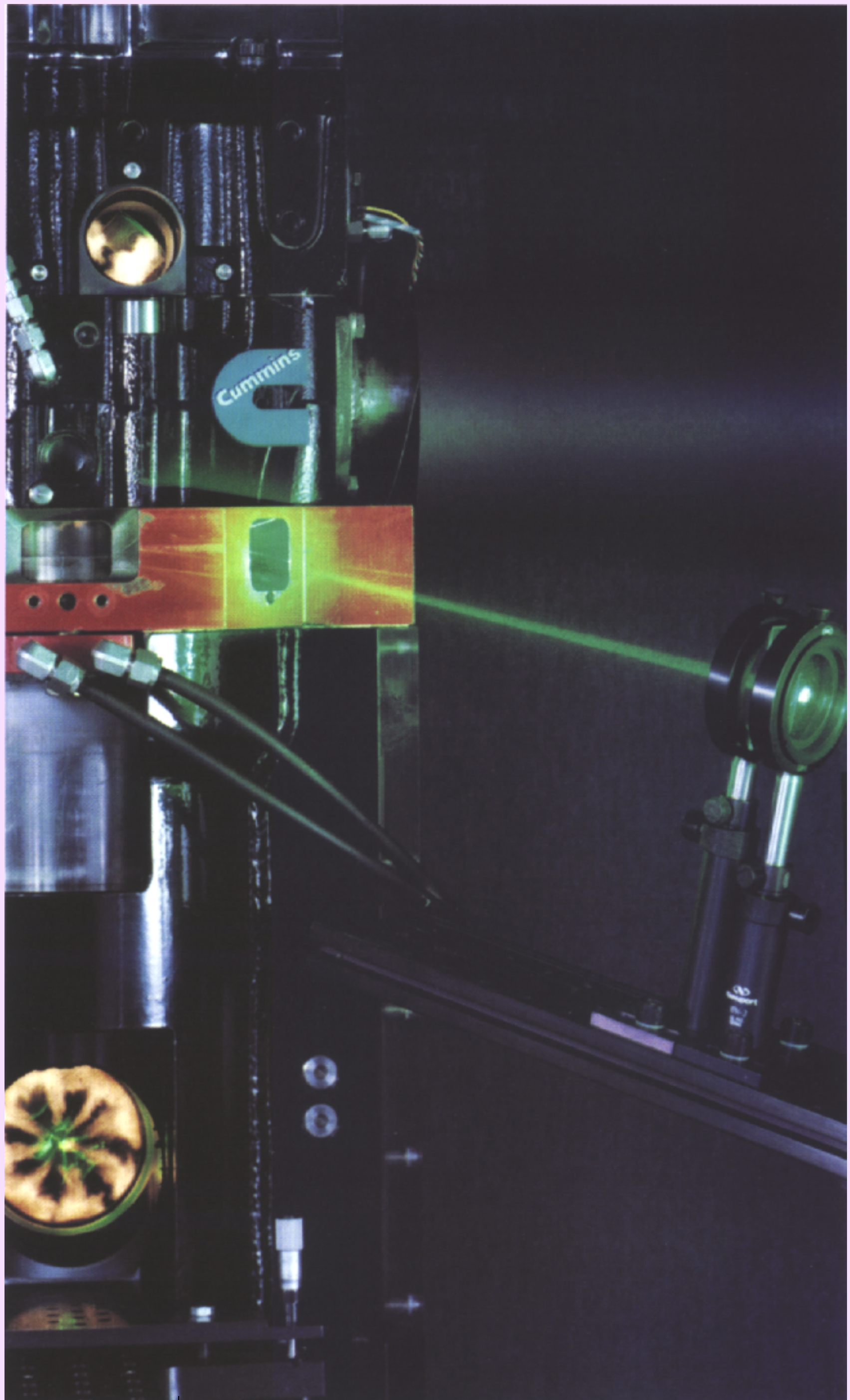
The Combustion Research Facilitv at the Sandia National Laboratory in California, where sophisticated laser techniques are-employed to understand the chemistry and physics of combustion processes.

The Surface Modification and Characterization Research Center at Oak Ridge National Laboratory, which employs ion beam techniques to implant various ionic species in solids, to modify surfaces, and to create certain non-equilibrium materials.

The Materials Preparation Center at the Ames Laboratory, Iowa, which specializes in the preparation, characterization and purification of rare-earth, alkaline-earth, and refractory materials that are not easily available.

The James R. MacDonald Laboratory at Kansas State University, which uses accelerators to create highly charged ions for the study of ion-atom collisions and the atomic and molecular physics of these highly charged atoms.

The Pulse Radiolysis Center at the University of Notre Dame, which provides an intense electron pulse from an accelerator to create a highly excited, short-lived intermediate chemical state to understand various chemical reaction processes.




Lasers measure an operating diesel engine. *Combustion Research Facility*

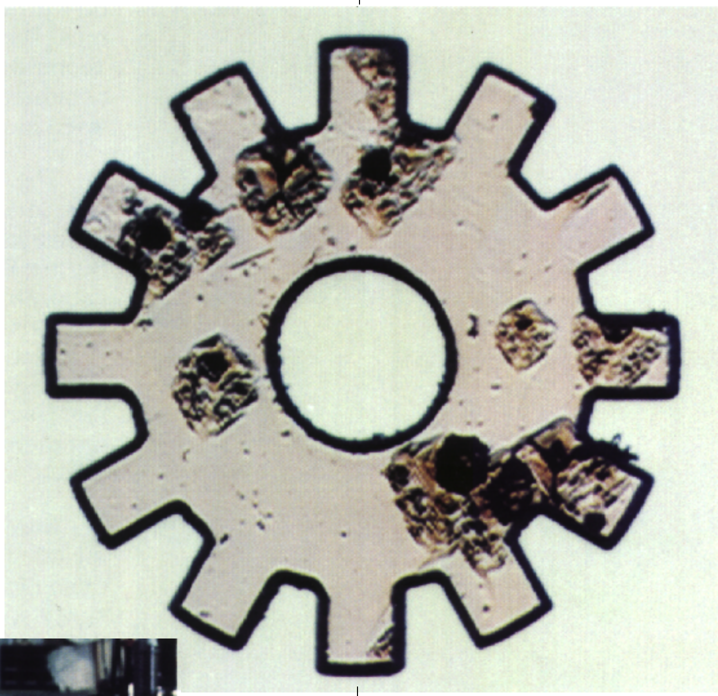
# SURFACE MODIFICATION AND CHARACTERIZATION RESEARCH CENTER

The Surface Modification and Characterization (SMAC) Research Center is a unique facility at Oak Ridge National Laboratory for the alteration and characterization of the near-surface properties of materials.

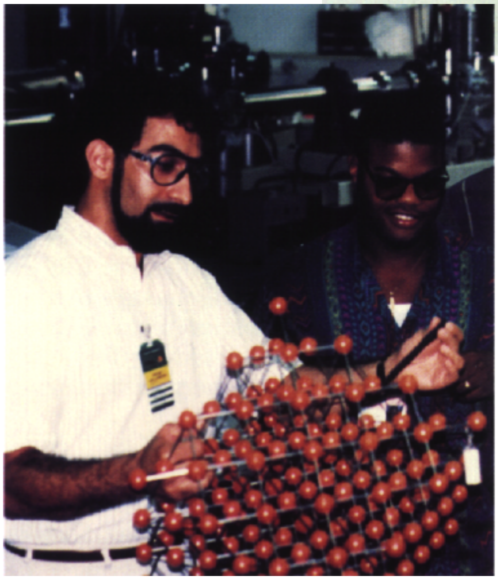
With SMAC equipment, researchers can alter the physical, electrical, and chemical properties of solids to create unique new materials not possible with conventional "equilibrium" processing techniques. Surface modification is achieved using techniques such as ion implantation doping, ion beam mixing, low-energy ion deposition, and ion beam annealing. These ion beam based techniques are suitable for tailoring desired modifications in many different classes of materials, including metals, semiconductors, ceramics, insulators, polymers, and even biological samples.

Changes in surface properties as a result of ion beam processing by these techniques can be characterized at the facility using ion scattering analysis, ion channeling, nuclear reaction analysis, and other surface and bulk-sensitive techniques.

The Center features four ion accelerators that provide a wide range of implantation and ion scattering capabilities. These accelerators are integrated with computer-monitored beam lines, experimental chambers, and data acquisition electronics. Additional capabilities include annealing, thin-film evaporation, optical microscopy, and nanoindentation hardness. Surface analytical equipment, including Auger electron spectroscopy and low-energy electron diffraction, is available on some experimental chambers.



**Micromechanical devices, such as this 400 micron diameter diamond gear, can be easily manufactured using the ion beam liftoff technique developed as a collaborative project in the SMAC facilty.**

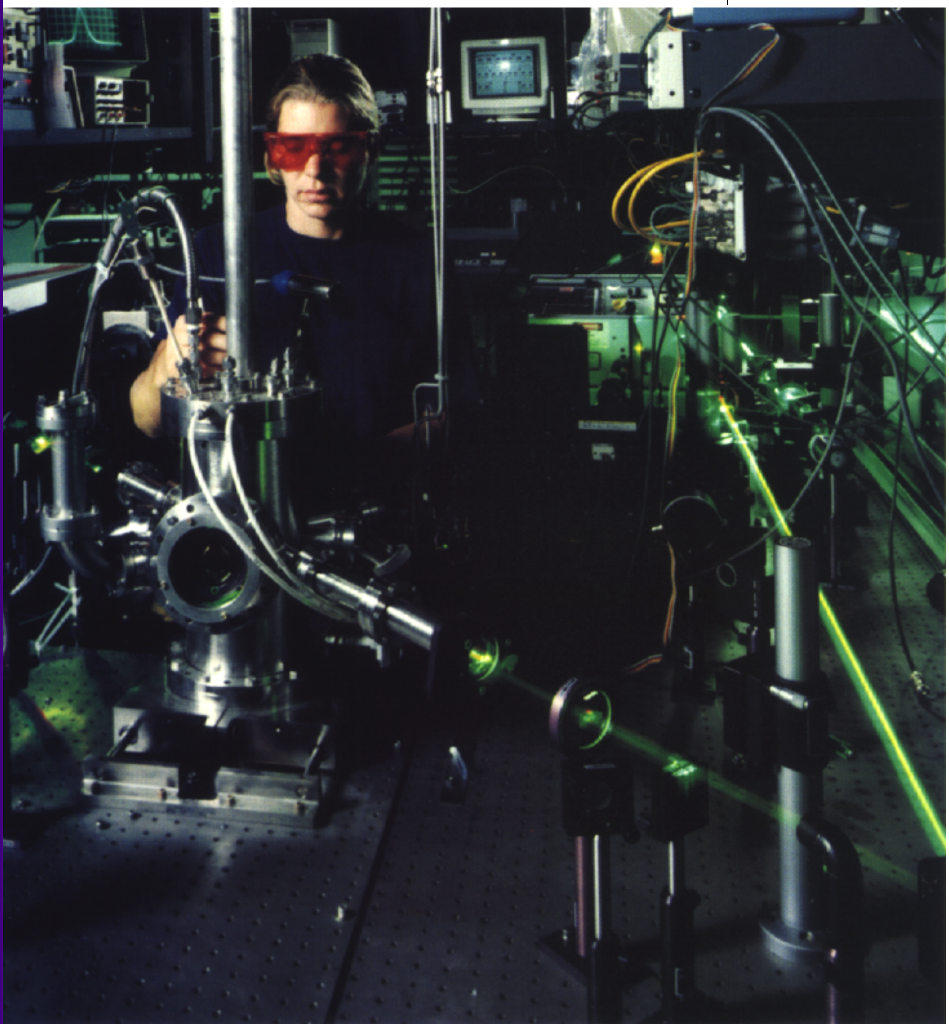


**Alabama A&M Professor Daryush Ila explains to graduate student Melvin Spurlock the concept of ion channeling in a SMAC experiment.**

# CRF

The Combustion Research Facility (CRF) at Sandia National Laboratories is a laboratory-office complex visited by about 1,000 researchers a year. Scientists use the CRF to better understand and control combustion processes. Projects underway range from fundamental studies of combustion generated pollutants, to development of new laser diagnostic techniques, to applied studies of processes in internal combustion engines.

About 25 percent of CRF customers are from American corporations. The other 75 percent come from universities and national laboratories. Research has resulted in the creation of new products and new companies. Technor and Electra-Optics Technologies were created to commercialize products developed at the CRF.



John Garman, a visiting researcher from the University of California at Irvine, adjusts experimental apparatus in the CRF's low-pressure flame laboratory.

The CRF houses 20 laboratories, including the Turbulent Diffusion Flame Facility, the Burner Engineering Research Laboratory, the Multi-fuel Combustor, and the Reaction Product Imaging Laboratory. Laser systems include Diana, a flash-lamp pumped dye laser used remotely for diverse applications throughout the facility.

Numerous other laboratories include facilities for chemical dynamics, chemical kinetics, spray combustion, imaging of turbulent reacting flows, internal combustion engine studies, supercritical water oxidation, and coal research.

Staff collaborate with scientists from industrial, academic, and government laboratories in joint research or to provide technical assistance. In addition, the CRF provides technical management of various combustion technologies programs supported by the Department of Energy Office of Energy Efficiency and Renewable Energy.

The CRF has about 40 resident professionals and 100 long-term visitors doing extensive experimental work. Each year, requests for experimental time at the CRF facilities exceed capacity by about 50 percent.

# COMBUSTION RESEARCH FACILITY

## INDUSTRIAL USERS

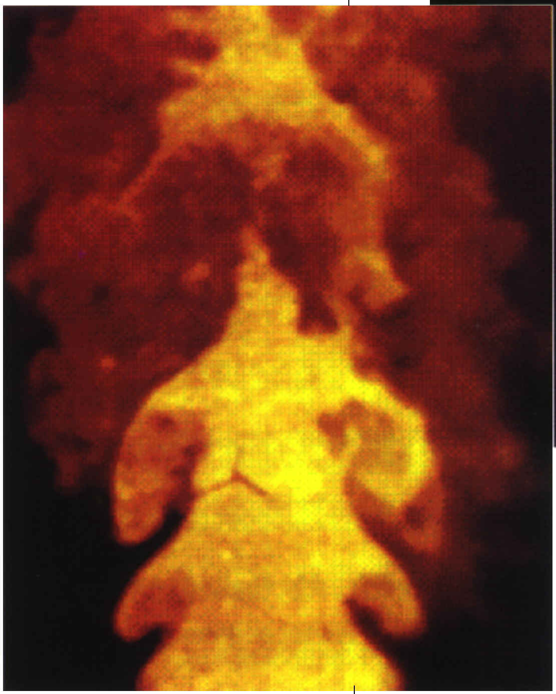
- American Iron and Steel Institute
- Arthur D. Little
- Babcock and Wilcox
- Beckman Instruments
- Chevron
- Chrysler
- Cummins Engine
- Dow Chemical
- Electric Power Research Institute
- Ford
- Gas Research Institute
- General Motors
- Metrolaser
- Mobil
- Petroleum Environmental Research Forum
- Technor
- 3M Corporation
- Unocal
- U.S. Army

## ACCOMPLISHMENTS

Technor, a new company, was started as a result of RAPRENO$_X$, a CRF-discovered process that eliminates nitrogen oxides produced by combustion systems.

Reaction product imaging, a new technique developed at the CRF for investigating the dynamics of chemical reactions, has bee adopted in over a dozen research laboratories throughout the world

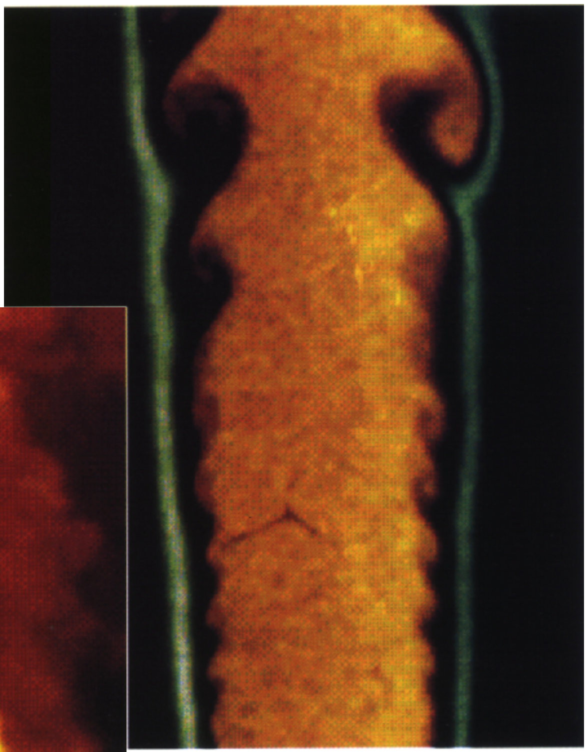
Scientists from Cummins Engine and the CRF applied in sit laser diagnostics to a Cummins diesel engine to study formation mechanisms of particulates. Continuing research at CRF has recently led to a new conceptual model for diesel combustion.



CRF scientists developed and patented a new technique called frequency resolved optical gating, or FROG, for characterizing ultrashort laser pulses. FROG is now licensed to Clark-MXR, Inc. and is an important part of its product line.

CRF researchers developed the ionization probe head gasket as a diagnostic tool for production engines. DSP Technologies is now manufacturing and marketing the gasket.

**Two-dimensional laser-induced fluorescence images show the dramatically different character of flow patterns in nonreacting (left) and reacting turbulent jets.**



# MACDONALD LABORATORY

The James R. MacDonald Laboratory at Kansas State University operates a 7-MeV tandem accelerator, a 9-MeV superconducting linear accelerator (LINAC), and a cryogenie electron beam ion source (CRYEBIS) for the study of ion-atom collisions with highly charged ions. The tandem, with six dedicated beam lines, can operate as a stand-alone accelerator. The LINAC is operated as a booster accelerator to the tandem. The tandem-LINAC combination has four beam lines available. The CRYEBIS is a stand-alone facility for studying collisions with bare ions at low velocity.

The Laboratory has a variety of experimental apparatus for atomic physics research. These include recoil ion sources, Auger electron spectrometers, X-ray spectrometers, and a 45-inch-diameter scattering chamber. The Laboratory is available to researchers who require the unique facilities for atomic collision experiments.

## COLLABORATIVE USE

Users are encouraged to seek a collaborator on the staff or they may submit a brief proposal to the laboratory director.

# PULSE RADIOLYSIS FACILITY

The Pulse Radiolysis Facility (PRF) at the University of Notre Dame is based on a 5-ns electron pulse from an 8-MeV linear accelerator. It is fully instrumented for computerized acquisition of optical and conductivity information on radiation chemical intermediates having lifetimes of 10 ns and longer. An excimer laser/dye laser combination is accessible for double-pulse experiments involving photolysis of radiolytic transients. Energies of -400 mJ at 308 nm and -50 mJ at various near-UV and visible wavelengths are available.

For typical absorption studies, where one produces $10^{-5}$ *M* of intermediates, spectral and kinetic information can be obtained on species having extinction coefficients in excess of 100 $M^{-1}$ $cm^{-1}$. Conductometric methods in aqueous solution cover the pH range of 3 to 11. Data are recorded digitally and stored in magnetically readable form for rapid off-line examination of spectral and kinetic details.

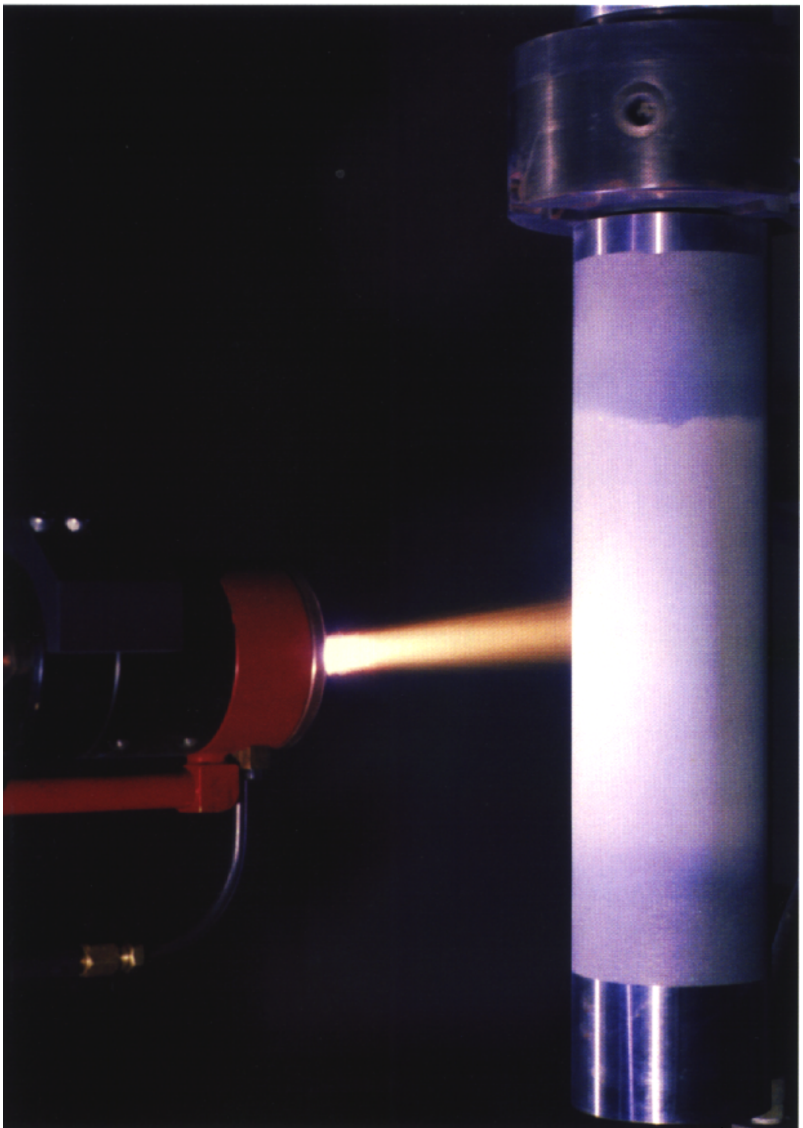
## COLLABORATIVE USE

Experiments may be arranged by proposal to the laboratory director or through collaborations with appropriate staff scientists.

## TECHNICAL DATA

| | |
|---|---|
| **Electron source** | S-MeV linear accelerator |
| **Operating mode** | Single pulse, with signal averaging |
| ***Data collection Workstation DOS/Intel 486)*** | |
| **Pulse width** | *5,* 10, 20, 50 ns |
| **Time resolution (RC)** | *2* ns |
| **Pulse current** | Up to 1 A |
| **Repetition frequency** | **0.2 S-I** |
| ***Optical absorption measurements*** | |
| **Spectral region** | 210 to 750 nm |
| **Sensitivity** | +0.00002 absorbance |
| ***Conductivity*** | |
| **pH range** | *3 to* 11 |
| **Sensitivity** | +5 mhos/cm |

# MATERIALS PREPARATION CENTER



**Plasma arc spray coatings of quasi-crystalline powders have been applied to many types of metal surfaces for improved wear and corrosion resistance. Many potential applications for these high wear resistance coatings are found in transportation and manufacturing industries.**

The Materials Preparation Center (MPC) at the Ames Laboratory, Iowa State University, is known for its unique capabilities for preparation, purification, fabrication, and characterization of pure metals and metal alloys and compounds. Established in 1981, MPC offers engineers and scientists a completely integrated facility for the preparation, characterization, and fabrication of research and prototype quantities of high purity metals, special alloys and compounds in a form and/or purity not available from commercial suppliers.

The Center consists of three sections:

- The Materials Preparation Section for the preparation of high purity rare earth and transition metals and alloys, single crystals, and atomized powdered metals and alloys;
- Chemical and spectrographic analyses using ICP-AES and laser ion mass spectroscopy, among other analytical techniques, are available from the Analytical Section;
- The Materials Referral System and Hotline Section provides requesters with information on the capabilities of U.S. government laboratories and industry to help researchers and engineers obtain materials and services critical to their research and development goals.

## ACCOMPLISHMENTS

Developed plasma arc spraying of a new quasi-crystalline alloy composed of aluminum, copper, and iron for application to the wear surfaces on agricultural, automotive, rubber, and plastics industry components as a hard face coating.

Prepared rare-earth metal alloys for use in hydrogen absorption refrigeration, Ni/metal hydride batteries, and adiabatic nuclear demagnetization refrigeration – all technologies which provide environmentally conscientious alternatives for current environmental problems.

Developed rare-earth intermetallic single crystal magnetostrictive material for application in advanced acoustic devices such as sonar and cryovalves found in space exploration vehicles.

# USER INSTITUTIONS

## A
Adelphi Technology
Advanced Micro Devices
Affymax Research Institute
Agouron Pharmaceuticals, Inc.
Alcan
Alchemist Technologies
Alcoa
Allied Chemical Corporation
AlliedSignal Research
Allison Engine Company
American Iron and Steel Institute
Amoco
AMGEN
Aracor
Arizonal State University
Australian National University
Austria Atominstitut Der Osterreichischen

## B
B. P. Chemicals
B&W Nuclear Technologies
Babcock and Wilcox
Bayer Corporation
Beckman Instruments
Bell Communications
Boeing Company
Brandeis University
Bristol-Myers Squibb Company
Bristol-Myers

## C
California Institute of Technology
California State University
Case Western Reserve University
Catalytica, Inc.
Caterpillar
Center d'Etudes Limeil - Valenton, France
Chalmers University of Technology, Sweden
Chevron Research & Technical Company
Chrysler
Ciba Vision Corp.
Cise S.P.A., Italy
City University of New York
Columbia University
Conductus, Inc.
Cornell University
Cummins Engine
Cytec Industries

## D
Dana Farber Cancer Institute
Dartmouth College
Department of Veterans Affairs Medical Center
Detroit Diesel Corporation
Digital Semiconductor
Doehler-Jarvis Grove Engineering
Dow Chemical Company
Dublin City College, Ireland
Duke University
DuPont Merck Pharmaceuticals

## E
E.I. du Pont de Nemours & Company
Eastern Washington University
Eastman Chemical
Eastman Kodak Company
Edge Analytical Inc.
Electric Power Research Institute
ESRF, France
ESRS Corporation
Exxon Research & Engineering

## F
Ford Motor Company
Forschungszentrum Rossendorf, Germany
Freie Universitat Berlin, Germany
Fritz-Haber-Institut, Germany
Fujitsu Inc.

## G
Garnett McKeen Labs
Gas Research Institute
Genentech, Inc.
General Motors
General Electric Company
Georgia Institute of Technology
Grand Canyon University
GSI, Germany
Gyeong-Sang National University, Korea

## H
Harvard University
Hewlett-Packard
Hirsch Scientific
Hoechst-Celanese Research
Hong Kong University of Science
Howard Hughes Medical Institute

## I
IBM Research Division
Imperial Chemical Industries
Industrial Automation
Institute of Atomic and Molecular Sciences, Taiwan
Institute of Crystallography, Russia
Instituto Cienca de Materiales, Spain
Intel Corporation
Interphases Research
Iowa State University
ISM Technologies

## J
Japan Solar Energy Research Institute
Jet Propulsion Laboratory
Johns Hopkins University

## K
Kansas State University
Kurchatov Institute, Russia

## L
Lab Nazionali di Frascati, Italy
Lawrence Livermore National Laboratory
Lennox Industries
Louisiana State University
Lucent Technologies

## M
Massachusetts Institute of Technology
Max Planck Institute, Germany
McMaster University, Canada
Metrolaser
Mobil
Monsanto Company
Morris Research, Inc.
Motorola
Motorola Orthologics

## N
Nano Instruments
NASA-Marshall Space Flight Center
National Institute of Research Inorganic Metals, Japan
National Institute of Standards & Technology
National Institutes of Health
National Research Council of Canada

Naval Research Laboratory
NEC Corporation, Japan
North Carolina State University
Northern Illinois University
Northwestern University

## O

Ohio State University
Oklahoma State University
Oregon Graduate Institute
Orthologics
Osaka University, Japan
Ovonic Synthetic Materials Company

## P-Q

Pacific Northwest National Laboratory
Paul Scherrer Institute, Switzerland
Pennsylvania State University
Phillip Morris
Phillips Petroleum
Pohang University, Korea
Polaroid Corporation
Pratt and Whitney
Princeton University
Procter & Gamble
Purdue University

## R

Raychem Corporation
Renolds Metals Company
Rensselaer Polytechnic Institute
Rice University
Rockwell International
Royal Institute of Technology, Sweden
Rutgers University

## S

San Jose State University
Savannah River Ecology Laboratory
Schlumberger-Doll Research
Scripps Research Institute
Sid Richardson Carbon Company
Siemens AG, Germany
Siemens Industrial Automation
Simon Fraser University, Canada
SM Technologies
Southern University
Squibb Research Institute
St. Jude Children's Research Hospital
Stanford University
State University of New York
Stevens Institute of Technology
Surface/Interface Inc.
Swedish University of Agricultural Science
Syntex Research

## T

Technor
Terza Universita, Italy
Texaco
Texas A&M University
Texas Instruments, Inc
The EXAFS Company
The Salk Institute
The Upjohn Company
3M Corporation
Tu Munchen, Germany
Tu Wien, Austria
Tulane University

## U-V

US. Geological Survey Water Research
Umea Universitet, Sweden
Unidad Merida, Mexico
Universita degli Studi dell'Aquila, Italy
Universita di Camerino, Italy
Universita di Roma, Italy
Universitat Oortmund, Germany
Universitat Frankfurt, Germany
Universitat Rostock, Germany
Universitat des Saarlandes, Germany
Universite Marne La Vallee, France
Universite de Paris, France
University of Alabama
University of Alberta
University of Arizona
University of Bayreuth, Germany
University of British Columbia
University of California
University of Central Florida
University of Chicago
University of Colorado
University of Connecticut
University of Edinburgh
University of Florida
University of Georgia
University of Hawaii
University of Houston
University of Idaho
University of Illinois
University of Kentucky
University of Maine
University of Maryland
University of Massachusetts
University of Memphis
University of Michigan
University of Minnesota
University of Missouri
University of Nebraska
University of Nevada
University of New Mexico
University of New South Wales
University of Oklahoma
University of Oregon
University of Pennsylvania
University of Southern California
University of Stockholm
University of Sydney
University of Tennessee
University of Texas
University of Trondheim, Norway
University of Utah
University of Virginia
University of Wake Forest
University of Washington
University of Western Ontario
University of Wisconsin
Unocal
Uppsala Universitet, Sweden
Utah State University
Utrecht University, The Netherlands

## W

Wacker-Chemitronic
Washington State University
Weizmann Institute, Israel
Wesleyan University
Western Michigan University
Westinghouse

## X

X-ray Instrumentation Associates
Xerox
Xsirius, Inc.

## Y-Z

Yale University
Yonsei University, Korea

# FOR MORE

*For more information about these facilities, contact them individually at the addresses and numbers below. Or visit the Office of Basic Energy Sciences user facilities homepage on the World Wide Web at: http://www.er.doe.gov/production/bes/dms/facilities/faclhome.html*

## NEUTRON SOURCES

### High Flux Beam Reactor

Contact: Rae Greenberg, High Flux Beam Reactor User Administrator, Brookhaven National Laboratory, Physics Building 510A, Room 1-30, P.O. Box 5000, Upton, NY 11973-5000. Telephone: 516/344-5564. Fax: 516/344-5888. E-mail: greenbel@bnl.gov
World Wide Web: http://neutron.chm.bnl.gov/HFBRJndex.html

### High Flux Isotope Reactor

Contact: Brian Chakoumakos, Neutron Scattering Facilities, Building 7962, Mail Stop 6393, Oak Ridge, TN 37831-6393. Telephone: 423/574-5235. Fax: 423/574-6268. World Wide Web: http://neutrons@ornl.gov
E-mail: kou@ornl.gov

For information about HFIR isotopes, irradiation facilities, and neutron activation analysis, contact: Randy Hobbs, Oak Ridge National Laboratory, P. O. Box 2008, Building 7910, Mail Stop 6387, Oak Ridge, TN 37831-6393. Telephone: 423/574-8789.

### Intense Pulsed Neutron Source

Contact: Beverly Marzec, Intense Pulsed Neutron Source, Building 360, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439. Telephone: 630/252-6600 or 630/252-6485. Fax: 630/252-4163.
E-mail: Marzec@anlpns.anl.gov

### Los Alamos Neutron Science Center

Contact: LANSCE User Program Administrator, Manuel Lujan Jr. Neutron Scattering Center, MS H805, Los Alamos National Laboratory, Los Alamos, NM 87545. Telephone: 505/667-6069. Fax: 505/665-2676.
E-mail: user_program@msmail.lansce.lanl.gov
World Wide Web: http://www.lansce.lanl.gov

## LIGHT SOURCES

### Advanced Light Source

Contact: Elizabeth Saucier, Program Administrator. Advanced Light Source, Lawrence Berkeley National Laboratory, MS 80-101, Berkeley, CA 94720. Telephone: 510/486-6166. Fax: 510/486-4960.
E-mail: ECSaucier@lbl.gov
World Wide Web: http://beanie.lbl.gov:80001/als/als_homepage.html

### Advanced Photon Source

Contact: Susan Barr, User Administrator, Advanced Photon Source, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439. Telephone: 630/252-5981 or 630/252-3098. World Wide Web: http://www.aps.anl.gov/welcome.html

### National Synchrotron Light Source

Contact: Eva Z. Rothman, User Administrator, Brookhaven National Laboratory, National Synchrotron Light Source Building 725B, Upton, NY 11973-5000. Telephone: 516/344-7114. E-mail: ezr@bnl.gov
World Wide Web: http://www.nsls.bnl.gov/

### Stanford Synchrotron Radiation Laboratory

Contact: Suzanne Barrett, Stanford Synchrotron Radiation Laboratory, Stanford Linear Accelerator Center, MS 99, PO Box 4349, Stanford, CA 94309-0210. Telephone: 415/926-3191. Fax: 4151926-3600.
E-mail: barrett@slac.stanford.edu World Wide Web: http://ssrl101.slac.stanford.edu/welcome.html

## MICROCHARACTERIZATION

### Center for Microanalysis of Materials

Contact: Alwyn Eades, Center for Microanalysis of Materials, University of Illinois, 104 S. Goodwin, Urbana, IL. 61801-2985. Telephone: 217/333-8396. Fax: 217/244-2278. E-mail:eades@uimrl7.mrl.uiuc.edu

### Electron Microscopy Center

Contact: C. W. Allen, Materials Science Division, Argonne National Laboratory, Building 212, 9700 South Cass Avenue, Argonne, IL 60439. Telephone: 630/252-4157. Fax: 630/252-4798.
E-mail:allen@aaem.amc.anl.gov

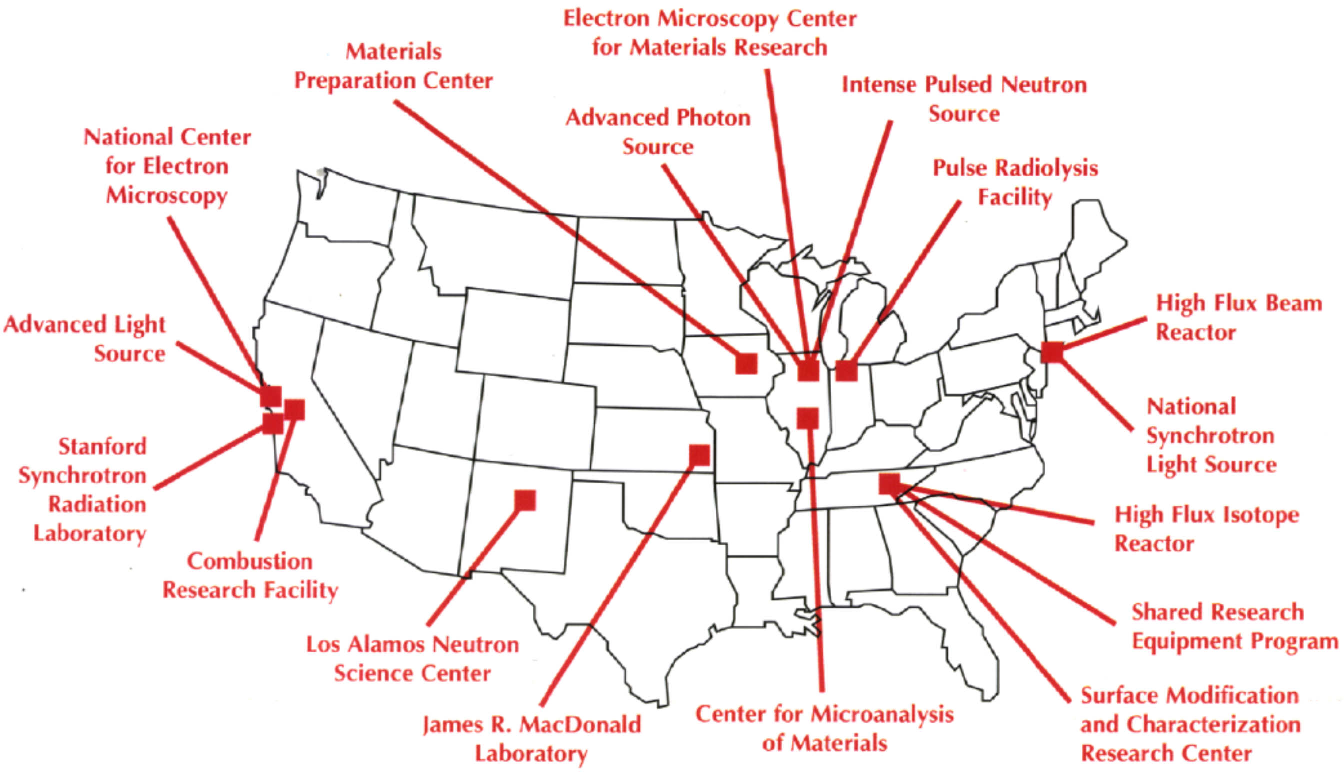
### National Center for Electron Microscopy

Contact: Gretchen Hermes, National Center for Electron Microscopy, Building 72, Lawrence Berkeley National Laboratory, Berkeley, CA 94720. Telephone: 5101486-5006. Fax: 510/486-5888.
World Wide Web: http://ncem.lbl.gov/ncem.html

### Shared Research Equipment Program

Contact: Neal D. Evans or Edward A. Kenik, Shared Research Equipment Program, Oak Ridge National

# INFORMATION




Laboratory, Bldg. 5500, MS-6376, P.O. Box 2008, Oak Ridge, TN 37831-6376. Telephone: 423/576-4427 or 423/574-5066. Fax: 423/574-0641. E-mail: evansnd@ornl.gov or kenikea@ornl.gov

## OTHER SPECIALIZED CENTERS

### *Surface Modification and Characterization Center*

Contact: David B. Poker, Solid State Division, Surface Modification and Characterization Facility, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6048. Telephone: 423/576-8827. Fax: 423/576-6720. E-mail: dbp@ornl.gov
World Wide Web: http://smacserve.ssd.ornl.gov/

### *Combustion Research Facility*

Contact: William J. McLean, Director, Combustion Research Facility, Sandia National Laboratories, MS9054, P.O. Box 969, Livermore, CA 94551-0969. Telephone: 510/294-2687. Fax: 510/294-2276.
E-mail: bill_mclean@Sandia,gov

### *James R. MacDonald Laboratory*

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### *Pulse Radiolysis Facility*

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