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NBS Research Reports

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Cover photo: The scanning electron microscope with polarization analysis (SEMPA) enables researchers to see how the magnetic ordering of a surface is influenced by its physical structure. Such information can be used, for example, to design denser recording media and lighter, more efficient motors. Shown here is a typical magnetization image produced using SEMPA. **See page 5.**

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FREE ELECTRON LASER FACILITY TO BE BUILT

A national free-electron laser (FEL) facility for research in physics, materials science, and biomedicine will be constructed at NBS. A proposal to build the new facility, submitted jointly by NBS and the Naval Research Laboratory, has been recommended for funding by the Office of Naval Research and the Air Force Office of Scientific Research. The two agencies jointly manage the FEL research program for the Strategic Defense Initiative Organization, which would provide $4.9 million to build the facility.

The FEL, to be constructed in the accelerator complex at the NBS laboratories in Gaithersburg, Md., will be driven by the Bureau's 185-MeV continuous wave (cw) racetrack microtron currently nearing completion. The microtron, being built in collaboration with Los Alamos National Laboratory, will be one of the world's most powerful high-current cw accelerators.

A free-electron laser is an exotic light source in which the gases, liquids, or crystals normally used to produce the laser effect are replaced by bunches of electrons traveling through a periodically varying magnetic field. Such lasers are capable of very short, intense bursts of light that can be tuned very finely across a broad range of frequencies.

The unique properties of the FEL, including broad wavelength tunability, high peak and average power, and extremely short pulse lengths, open up a broad range of exciting new research opportunities in such diverse areas as atomic and molecular physics, surface science, photochemistry, biophysics, and biomedicine. Plans for the facility call for close collaboration with the medical and materials science communities, including the Uniformed Services University of the Health Services, the Food and Drug Administration, the Center for Advanced Research in Biotechnology, and a number of universities in the Washington, D.C., metropolitan area.

BIOTECHNOLOGY RESEARCH CENTER UNDER CONSTRUCTION

Construction is under way for the nation's first biotechnology research center involving academia and government at the federal, state, and local levels. The one-of-a-kind center, established by The University of Maryland, NBS, and Montgomery County, Md., will be located at the county's Shady Grove Life Sciences Center. Biotechnology companies are expected to join in research at the Center for Advanced Research in Biotechnology (CARB).

Focusing on protein engineering and rational drug design, CARB now is putting together multidisciplinary teams of scientists and engineers with state-of-the-art facilities. The organization has been housed at NBS, where researchers from the Bureau and The University of Maryland have undertaken several research projects taking advantage of specialized NBS laboratories. When the new CARB building is ready in spring 1988, it is expected to accommodate 100 researchers. Up to one-third of CARB's research staff will be visiting industrial fellows. Both cooperative and proprietary research will be possible at CARB.

WATTHOUR METER CALIBRATION FACILITY IMPROVES ACCURACY

NBS has begun operation of a watthour meter calibration facility that offers a fivefold improvement in accuracy over the previous Bureau calibration system. The facility, incorporating digital technology, will help ensure the accuracy of watthour meters used in standards laboratories operated by utilities and meter manufacturers. These meters are calibrated at NBS and subsequently used as secondary standards to check the operation of watthour meters such as those found on customers' houses or businesses. Some $150 billion per year in electricity is billed to users based on readings from watthour meters. Domestic meter manufacturers also need accurate products to compete better in the international marketplace with meter producers from other industrialized nations. The 5 million new watthour meters manufactured yearly in the United States are referenced to NBS for accuracy. The NBS facility now enables routine calibrations to be made with a 0.01 percent accuracy. Previously, typical Bureau calibrations were in the 0.05 percent accuracy range.

COMPUTER ACCURACY AND SECURITY IN VOTE-TALLYING

The NBS Institute for Computer Sciences and Technology recently received $215,000 for a 3-year project to study the use of computers in vote-tallying. The funding is from the John and Mary R. Markle Foundation, a private, nonprofit organization in New York. NBS computer scientist Roy Saltman will review computerized vote-tallying methods currently being used and will evaluate problems that have been encountered. He also will recommend methods which election administrators can use to assure that computerized vote-tallying systems are accurate and secure. The study should give election officials a better understanding of the use of computer technology in vote-tallying and improved technical tools to assure public confidence in the reported outcomes. The project will continue a previous study conducted by Saltman for the Office of Federal Elections, U.S. General Accounting Office, on computerized vote-tallying.

SPACE-MADE EDUCATION TOOL, MEASUREMENT STANDARD ON SALE

The first commercial product made in space is available on a microscopic slide as an education tool for teachers and students and as a standard to calibrate microscopes for small particle measurements. Standard Reference Material (SRM) 1965 contains material produced aboard a National Aeronautics and Space Administration (NASA) space shuttle using a chemical process developed for NASA by Lehigh University. The standard is a glass slide with only a few thousand microspheres permanently sealed in an air chamber on the surface of the slide. The spheres are arranged in two different groupings on the slide so that students in high schools and colleges can carry out a series of laboratory experiments that are a part of the new SRM package. SRM 1965, Microsphere Slide, 10-Micrometer Polystyrene Spheres, is available for $77 from the Office of Standard Reference Materials, B311 Chemistry Building, NBS, Gaithersburg, MD 20899, 301/975-OSRM (6776).

NEW NVLAP PROGRAM FOR CONSTRUCTION TESTING SERVICES

NBS has established a new laboratory accreditation program (LAP) for organizations that perform construction testing services on concrete, aggregates, cement, soil, rock, asphalt, and geotextiles. The program, which was established at the request of industry under the procedures of the National Voluntary Laboratory Accreditation Program (NVLAP), will be particularly useful to laboratories testing construction materials for export. NVLAP-accredited laboratories are recognized as being equivalent to those of foreign laboratory systems that have international agreements with NBS, and test data reports issued by one accredited laboratory will be recognized on the same basis by other national accreditation systems.

NBS was requested to establish the new construction testing services program because many engineering decisions are made solely on the basis of laboratory test data. The new program will help the buyers of private and public buildings, both here and abroad, to more easily determine if the products in structures meet specific national building codes and insurance requirements. For information on the new construction testing services program, contact: Harvey W. Berger, A531 Administration Building, NBS, Gaithersburg, MD 20899, 301/975-4016.

DIRECT OBSERVATION OF VIBRATIONAL BREAKDOWN OF MOLECULES

In a unique laser experiment to observe molecules on a picosecond (0.000 000 000 001 s) time scale, NBS chemists have made direct measurements of the decomposition of simple, vibrationally excited molecules. Vibrational excitation, as by heating, is a common method of breaking down weak (van der Waals) molecular bonds, those responsible for the physical properties of many solids and liquids and for the shape of biomolecules. Even simple molecules have several possible modes of vibration, and the flow of energy from one mode to another occurs so quickly that previously it has been difficult or impossible to study this process directly.

Using a state-of-the-art laser apparatus which produces ultra-short light pulses, the NBS team was able to excite selectively two different vibration modes in the nitric oxide dimer (O-N-N-O) and observe the breakdown of isolated molecules—an event that occurs in less than 1 billionth of a second. A very important finding that runs counter to intuition (and theory) is that the higher energy excitation is less efficient than the lower in breaking down the molecule.

NONDESTRUCTIVE METHOD DETECTS FLAWS IN CERAMIC POWDERS

A new ultrasonic method for detecting flaws in compacted ceramic powders has been developed by scientists at NBS. It is the first nondestructive evaluation technique to permit ceramic producers to fully automate the inspection of compacted powders while the material is in the mold. The system provides producers with information on the uniformity and density of materials at almost any stage of compaction. It will help manufacturers to screen out defective parts before costly processing takes place.

The ultrasonic sensor method was developed at the Bureau by Johns Hopkins University materials science graduate student Martin P. Jones and NBS physicist Gerald V. Blessing. Blessing says, "The ultrasonic system offers producers a way to control the quality of ceramic powders without having to handle the very fragile materials in their green or unfired state. A ceramic part does not have to be removed from its mold for testing, prior to the firing or sintering stage." The new ultrasonic sensor method has been developed as a part of the NBS effort to apply nondestructive evaluation to materials for in-line monitoring and process control during manufacturing.

DOSIMETER PROCESSORS MUST BE ACCREDITED SAYS NRC

The Nuclear Regulatory Commission (NRC) has amended regulations to require all NRC-licensed organizations to have their personnel radiation dosimetry device readings performed by a processor that is accredited by the NBS National Voluntary Laboratory Accreditation Program (NVLAP). The NVLAP dosimetry program, which provides for periodic evaluations of dosimeter processors, was established in 1984 at NRC request to improve the accuracy of measurements on ionizing radiation that may be received by workers. Under the personnel dosimetry program, accreditation is limited to personnel services for types or models of dosimeters that document whole body and skin-dose radiation. All participating organizations are required to demonstrate that they are able to process each dosimeter type in accordance with ANSI N13.11, *Criteria for Testing Personnel Dosimetry Performance*. Currently, the NVLAP program has 45 accredited processors with evaluations under way for an additional 13.

NEW STEAM TURBINE TECHNOLOGY: LARGE ENERGY-SAVING POTENTIAL

Electric utilities could save up to $200 million annually in generating costs by using a new packing ring designed to reduce leakage in steam turbines, according to the Department of Energy (DOE). The improved ring was developed by Ronald Brandon of Schenectady, N.Y., with partial funding from a grant by DOE, after NBS reviewed and recommended Brandon's proposal to DOE. Packing rings, located on the turbine drive shaft of an electric generator, typically become worn from vibration during start-up and shut-down, allowing steam to escape and wasting energy. The new ring reduces wear and allows a tighter seal. It was tested recently at a power plant in Maryland. NBS evaluates, free of charge, ideas for energy-saving inventions. To date, nearly 400 promising ideas have been recommended to DOE for possible support.

FIRST RESULTS FROM NBS BEAMLINE AT NSLS

The first year of experiments using the NBS X-24A beamline at the Brookhaven National Synchrotron Light Source (NSLS) confirms that this facility will be an important national resource for x-ray spectroscopy. X rays can be tuned through the energy range from 500 to 5000 eV to a bandwidth of 0.2 to 0.5 eV, two to five times better than competing sources, and focused to a 1- by 2-mm spot at the sample chamber. Flux at the sample chamber is 10^9 to 10^{13} x rays/second. Current studies of argon, methyl chloride, various freons, and sulfur hexafluoride demonstrate that the instrumentation is sufficiently precise to separate x-ray spectral features due to multiple electron effects from those due to specific bond orbitals, long a stumbling block in such research.

NATIONAL PROGRAM FOR RADIATION INSTRUMENT CALIBRATIONS

NBS and the Health Physics Society (HPS) have begun a national program to accredit laboratories that calibrate instruments used to measure ionizing radiation. Under their agreement, NBS will continue to be the primary standards laboratory for these instruments, such as Geiger counters, which are regularly used in industry to protect radiation workers by making on-the-spot measurements of radiation levels. HPS will provide a service to accredit secondary- and tertiary-level calibration laboratories using procedures and technical criteria developed by the society in cooperation with the NBS Office of Radiation Measurements. This program will provide professionals in occupational radiation protection greatly expanded access to the national standards maintained by NBS. HPS says this will result in improved uniformity, accuracy, and traceability of ionizing radiation measurements. There are more than 1.3 million industrial radiation workers in the United States who could be affected by the new program.

SEM LINEWIDTH MEASUREMENTS UNDER STUDY

NBS and EDAX International, Inc., have agreed to a joint research program to help develop techniques for making precision measurements of the dimensions of integrated circuit features using the scanning electron microscope (SEM). The dimensions of integrated-circuit structures are important in their manufacture and must be carefully controlled. At present, the most accurate measurements are made on photomasks by optical microscopes, using methods developed at NBS. However the ability to measure small dimensions of features on actual circuits by optical microscopy is limited by the wavelength of light and the thickness of the features, so manufacturers look to the SEM to measure feature dimensions below 1 micrometer—the dimensional region of the newest generation of dense integrated circuits.

EDAX, a manufacturer of SEM peripherals, will supply NBS researchers with equipment and programming support to help develop the new techniques necessary to make precise and accurate feature-size measurements using SEM's, and to facilitate comparisons between the custom SEM used by NBS and commercial equipment. Richard Holton of EDAX International will work as a research associate with the NBS Center for Manufacturing Engineering.

INFRARED SYSTEMS DEVELOPED TO TEST GALLIUM ARSENIDE WAFERS

Detecting flaws in gallium arsenide (GaAs) semiconductor materials should be easier with two polarized infrared light systems developed by NBS Semiconductor Electronics Division researchers. Both are nondestructive methods wafer manufacturers can use to screen materials before marketing. One system can examine an entire wafer, while the other employs a 75- to 600-X microscope to view isolated wafer portions. Both systems allow digital storage of images and the use of false-color graphics to represent wafer characteristics such as variations in the transmitted infrared intensity, which could indicate potential problems. GaAs wafer applications in high-speed electronic and optoelectronic devices are growing rapidly, but production of the near-perfect GaAs crystals needed for optimum performance is not as advanced as the older silicon technology. The two NBS systems can aid in production control by pinpointing wafer flaws and inhomogeneities. Bureau researchers are using the infrared techniques in-house, but will also assist industries in setting up their own systems. ■

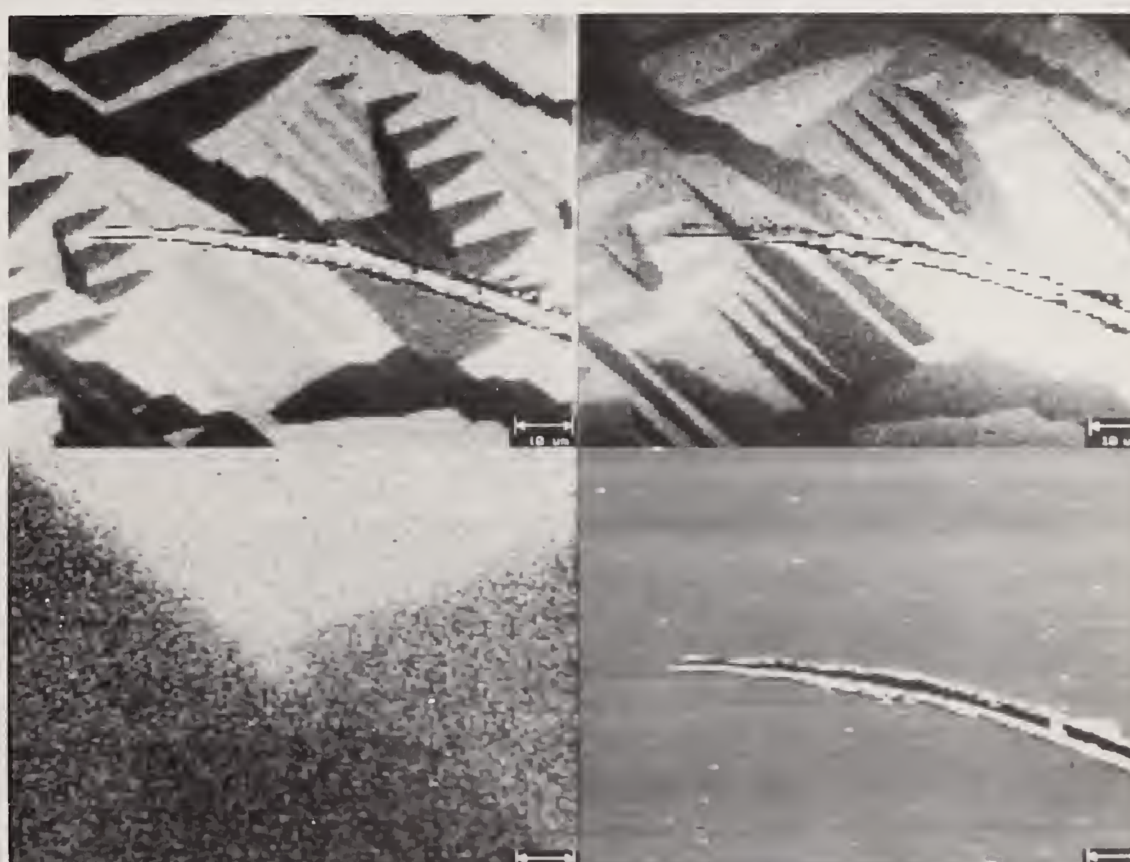
Surface Science: Thin is In

Superficial interests? Hardly. Researchers who confine their studies to the surface—the first few atomic layers of materials—believe the seeds of technological advances in fields as diverse as medicine, chemical catalysis, nuclear fusion, atmospheric science, materials science, and electronics lie in that curious ultrathin region.

One need only look at advances in electronics to find striking evidence of how technologically fertile the surface is. In the electronics field, where thin is in and smaller is better, the ability to engineer the surfaces of semiconducting silicon chips has resulted in ever faster and more powerful computers. But now scientists and engineers are up against a formidable obstacle, the so-called "micron barrier." The next truly significant advance in computing power hinges on the ability of researchers to develop methods for packing chips with transistors and other electronic components that are smaller than the current size limit of 1 micron (one-millionth of a meter).

"The push is for very small devices, but you can't just scale down the size of the components," explains Dr. Robert Celotta, head of the electron physics group in the NBS Center for Radiation Research. "Inevitably, once you get down to a certain level, things no longer work."

Adds Dr. Ted Madey, head of the surface structure and kinetics group in the Center for Chemical Physics at the Bureau, past surface-engineering developments that spawned scores of technolo-



Used to view the magnetic microstructure of surfaces, SEMPA (scanning electron microscope with polarization analysis) has a spatial resolution up to 100 times better than the best optical methods now available. The top two magnetization images shown here were obtained by using SEMPA to measure two in-plane components of the polarization in a Fe-3%Si single crystal. At the lower right is an intensity image showing the surface topography of the same area. The image at the lower left is a small region of the image at the upper left magnified 50 times.

gies have been primarily "guided by empiricism"—experiments and observations—and even intuition. But extending these developments and creating new surface-engineering applications, Madey and others believe, require fundamental understanding of the chemical and physical properties of surfaces and interfaces—the thin boundary regions between two substances—and how these properties affect reactions in the critically important regions.

Strictly defined, the surface is the outermost layer—or, at most, the first few layers—of atoms that lies on top of a solid or liquid. By virtue of their location, these layers, with a thickness of a few to tens of angstroms (one angstrom is one ten-thousandth of a micron), are substantially different from the bulk of the substance below.

"The arrangement of atoms in the surface layer is typically different from the bulk solid," explains Dr. Cedric Powell, chief of the Surface Science Division. "The electronic structure of atoms in the surface is also different, so the chemical and physical properties of the surface differ from the corresponding properties in the bulk."

"Most people tend to think there are only three states of matter—solid, gas, and liquid," says Madey, who has been studying surfaces for more than two decades. "But surfaces constitute yet another state of matter." To study this complex and unusual form of matter with the necessary sensitivity, scientists and engineers have developed an arsenal of analytical tools.

The proliferation of techniques testifies to the complexities of the research task and the many different surface properties to be measured, including elemental composition, chemical state, atomic arrangement, structural defects, electronic structure, topography, diffusion, and surface reaction.

"Ideally, a single technique would measure a particular property of the surface," Powell explains. The commonly used techniques for measuring surface composition, however, differ in sensitivity, specificity, spatial resolution, and ability to identify chemical state. The limitations of these techniques, such as electrostatic charging of insulating specimens and damage to the specimen during analysis, vary as well. Because most scientists need to determine a number of surface characteristics, they frequently combine instruments and techniques to obtain the best data for a given task.

"The arrangement of atoms in the surface layer is typically different from the bulk solid."

The rapid growth of surface science and its applications has led to increased awareness of the need for standards. For example, ASTM, a voluntary standards organization, has established a committee that is active in this area, and the Versailles Project on Advanced Materials and Standards, a new international group, has recently formed a surface analysis working party. NBS scientists are working closely with these and other standards-writing groups to help improve the accuracy and reliability of surface science measurements.

For the techniques most widely used to measure surface composition, Auger-electron spectroscopy and x-ray photoelectron spectroscopy, researchers in the Surface Science Division are providing calibration data for the instruments and reference data on materials to make the analyses more accurate. They are also developing reference materials to allow accurate measurements of composition versus depth.

As part of a joint U.S./Yugoslavia program, researchers developed a Standard Reference Material, SRM 2135, with thin layers of known thickness, which is sold through the NBS Office of Standard Reference Materials. Currently, analysts remove surface material by ion sputtering and then measure the instantaneous surface composition versus sputtering time. By using this SRM, researchers will be able to convert the sputtering time to a depth measurement more accurately. In addition, NBS scientists are working with the ASTM Committee E-42 on Surface Analysis to develop reference procedures that will improve the reliability and efficiency of surface analyses.

Powell points out that standards will enhance the usefulness of the instruments and, in the process, push the field ahead. "Most of the commercial instruments used today only became available within the past 15 to 20 years," he says. "We're using them in a qualitative fashion, but there is a growing need for quantitative analyses with improved accuracy."

The biggest boost to the field will come from more detailed understanding of the composition and properties of surfaces and interfaces and from unifying theories that describe how surface structure influences chemical behavior.

Ejected Ions Reveal Surface Geometry

One of the basic tenets of chemistry is that structure—shape and composition—determines function. Two molecules may consist of the same atoms in the same proportions, but if the atoms are arranged differently, one molecule may react strongly with neighboring substances while the other stands idly by.

To get a glimpse of the atomic geometry of solid surfaces, Madey and his colleagues had to build their own instrument, a combination of probes that allows them to determine shape and composition of molecules on surfaces. The novelty of the instrument is that it provides "a rather direct way to determine how atoms and molecules are bonded to the surface," Madey explains.

The method, called electron stimulated desorption ion angular distribution (ESDIAD), capitalizes on what had been considered to be a hazard of the trade—surface damage caused by incident beams of electrons used as probes. When the electron beam strikes the surface, it imparts some of its energy to surface molecules, exciting the bonds that hold the molecules together. If excited sufficiently, the bonds break, the molecules fall apart, and ions are ejected from the surface of the specimen.

NBS scientists are working closely with these and other standards-writing groups to help improve the accuracy and reliability of surface science measurements.

"It turns out that the ions fly off in the direction of the broken bonds, in highly directed patterns," Madey says. With the help of an ion detector and a sophisticated computer system, Madey and his colleagues can determine the original orientation of the molecules on the surface. With other equipment on the device, including a mass spectrometer, the researchers can also determine the number and composition of the ejected ions, and they can make judgments about the motion and internal energy of the original bonds.

Put all the information together and the NBS team has a three-dimensional snapshot of a specimen's surface. For example, Madey has determined that the position a carbon monoxide molecule assumes on a surface depends on its environment. On nickel and ruthenium, carbon monoxide stands up, perpendicular to the surface, but on chromium, the molecule lies down. And on palladium, the bond is tilted.

Odder still, they have learned that surface molecules can be "pushed around" by impurity atoms. For example, a two-dimensional layer of water molecules on a silver surface is badly disordered. When the surface has a few foreign atoms on it, such as oxygen or bromine, the water molecules immediately rearrange to form well-ordered local structures attached to the foreign atoms.

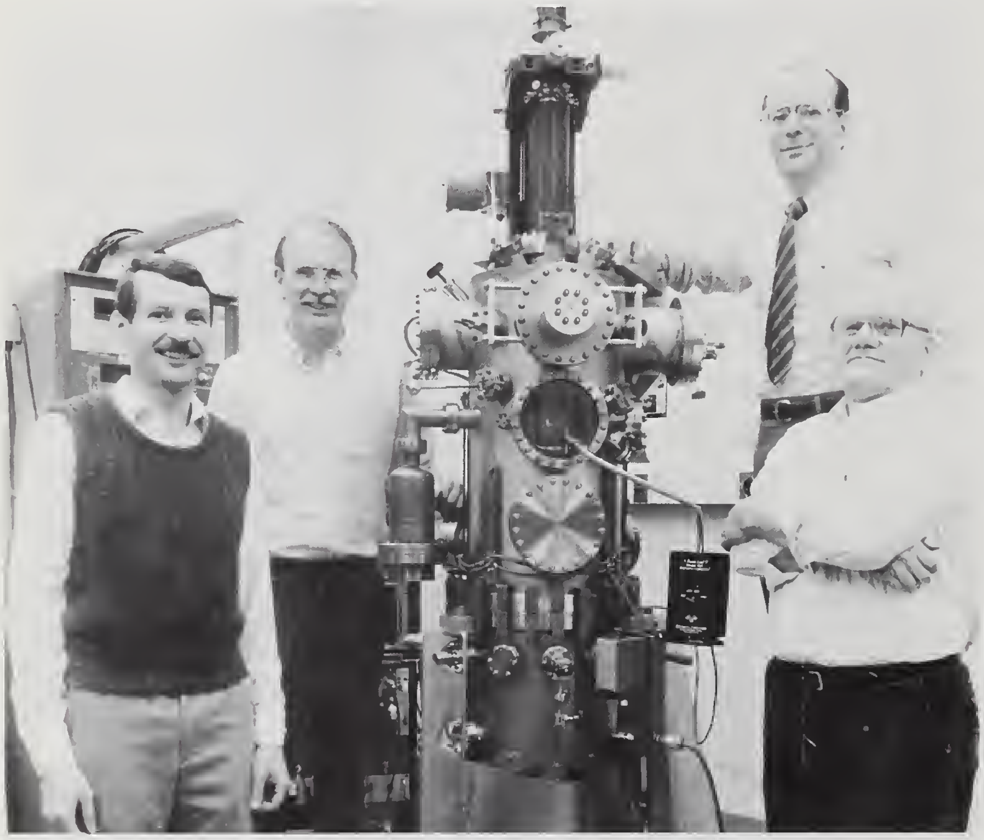
Madey and his team have used ESDIAD to chart the surface landscape of several noble metal catalysts and to study the structure of surface defects on single-crystal oxides. They also have studied the bonding of water to the surface of silicon, yielding insights into how the contaminant alters the electronic properties of the semiconductor. Other investigations have focused on the mechanisms of radiation-induced damage to surfaces.

Worldwide, researchers at ten institutions, including five in the United States, have built instruments based on the NBS ESDIAD apparatus. These researchers also are extending the applications of the technique.

But are ESDIAD studies, which probe single-crystal specimens in a high-vacuum environment, relevant to the surface characteristics of a material exposed to less-than-ideal conditions, such as a metal catalyst in a chemical reactor or an electrode in an electrochemical cell? Madey believes so.

Drs. Ted Madey and Allen Johnson use electron stimulated desorption ion angular distribution to determine how atoms and molecules are bonded to the surface.

"Guided intuition has taken chemists an amazingly long way," he says. But analyses of the detailed information gained with ESDIAD and comparable techniques that use photon beams as probes can reveal the fundamental structural and electronic mechanisms that govern chemical reactions. The insights that evolve from this understanding will aid efforts to develop computer models of chemical reactions at surfaces. With these models, scientists may be able to fabricate "designer catalysts," customized mixed-metal compounds that are superior to the catalysts that nature supplies.



With a scanning tunneling microscope, Drs. Robert Dragoset, Daniel Pierce, Robert Celotta, and Stanley Mielczarek (left to right) study the structure of surfaces and interfaces to determine how changes affect their properties.

New Views of the Atomic Microstructure of Surfaces

Over in the NBS Center for Radiation Research, there's a scientific instrument that, as physicist Celotta describes it, "looks like a bird cage inside a bird cage." But the instrument, which stems in part from pioneering research conducted by retired NBS scientist Dr. Russell Young during the 1960's, is for scientists, not bird fanciers. With the instrument—a scanning tunneling microscope (STM)—scientists can "see" the surface in previously unattainable detail, an atom-by-atom view of the contour of surfaces and interfaces.

Modeled after the STM built by the IBM Zurich Research Laboratory, where the first such microscope was built, the NBS instrument has a vertical resolution of one-tenth of an angstrom—less than the size of an atom—and a horizontal resolution of 6 angstroms, according to Celotta. This precision stems from the STM's ability to exploit the wavelike properties of electrons.

Celotta explains that the microscope gets its name from the propensity of electrons to extend beyond the surface of materials. The ability of electrons to jump between materials that are very close, but not touching, is known as tunneling. In scanning tunneling microscopy, a needle-like probe is moved to within far less than a hair's breadth of the surface of the specimen. When the distance between probe and specimen is less than 10 angstroms, the cloud of a single electron emanating from the metal tip of the probe intersects with an electron cloud floating above the surface. Applying a voltage to the probe generates a tunneling current that flows between the tip and the surface.

As the tip sweeps across the surface in a series of parallel lines, a computerized feedback mechanism maintains the probe at a constant height above the surface. In effect, the probe traces the atomic topography, which appears as a series of peaks and valleys on a computer screen. The computerized data can be fashioned into a topographic map or a three-dimensional rendering. And because the tunneling current depends on the voltage applied to the electronic structure of the surface, variations in the current yield details about the electronic behavior of the surface atoms.

NBS researchers plan to use the instrument to investigate such things as the structure of biological molecules, the growth of single layers of atoms and molecules on surfaces, and the structure of finely machined surfaces.

Celotta's group intends to study "multilayer epitaxial growth," a technique for growing a crystalline film on the surface of an underlying crystal. Although the atomic arrangement of the deposited film is assumed to conform with that of the substrate crystal, Celotta suspects that slight deviations arise at the interface.

"There might be defects and maybe something happens at the defects," he says. "In the transition region between the crystal layer on the top and the crystal on the bottom, the lattices could become stretched or strained." Because of these changes, atoms may behave in ways that defy current understanding, creating what Celotta calls a "crack in the periodic table." Once understood, the atomic rearrangements would allow for strategic manipulation of surface properties. Changes measured on the order of angstroms could yield new surface properties that greatly enhance the performance of such devices as transistors, lasers, and magnetic recording materials.

Into the Magnetic Domain

The STM is not the only new addition to the arsenal of research instruments capable of measuring the microstructure of surfaces. Another, developed at NBS by Celotta, Dr. John Unguris, Dr. Daniel Pierce, and Gary Hembree, brings the magnetic microstructure of surfaces into view. Known as SEMPA, for scanning electron microscope with polarization analysis, the device has a spatial resolution of 100 angstroms, or up to 100 times better than the best optical methods now available. With it, researchers can actually see what is happening on the heads of a tape recorder, on a floppy disk—two of many types of magnetic storage media—or on the surface of a magnet in an electric motor.

First built in 1982, SEMPA quickly captured the interest of companies that manufacture products with magnetic components, including General Motors, Kodak, Control Data, and Westinghouse. These companies and six others are exploring the possibility of establishing a collaborative research program with the NBS team. Another gauge of interest in the measurement technique is the fact Perkin Elmer, the scientific equipment manufacturer, intends to introduce a commercial version of SEMPA within the next year or two, according to Celotta.

The key feature of SEMPA is a compact "spin polarization detector" built by the NBS researchers. A cube measuring about 6 centimeters on a side, the detector can be appended to an ultrahigh vacuum scanning electron microscope, where it counts the polarized secondary electrons ejected from the surface of a specimen by the microscope's electron beam probe.

As determined in an important discovery at NBS by Unguris, Celotta, Pierce, and Annija Galejs, the spins of the secondary electrons are identical to those of the electrons in the specimen. This finding made it possible to develop a means to characterize the local magnetic structure of surfaces.

Each atom has a "magnetic moment," the product of its spinning electrons. In nonmagnetic materials, the magnetic moments of the constituent atoms are randomly oriented and cancel each other. Magnetic materials, in contrast, contain more electrons spinning in one direction than they have electrons with opposite spins, resulting in a net magnetic field. But ferromagnetic atoms tend to be "clannish," isolating themselves in separate domains. On the surface

Once understood, the atomic rearrangements would allow for strategic manipulation of surface properties.

of a material, a domain of atoms with magnetic moments aligned in one direction may be located next to a domain of atoms that has a different preferred orientation of their magnetic moments.

Secondary electrons basically tell the NBS scientists the magnetic direction of the domain they are from. For example, if electrons ejected by the microscope beam at a specific site are polarized—spinning in the same direction—then a measurement of this polarization gives both the strength and the direction of the magnetization at that spot. After scanning the entire surface of a specimen, the researchers have two computerized images—one of the topography of the surface and one of its magnetic microstructure. Because of SEMPA's high resolution, they can actually "see" inside individual magnetic domains.

From the view that emerges, the researchers can see exactly how the magnetic ordering of a surface is influenced by its physical structure. They can determine how, for example, an impurity, a stress, or "miniaturization" alters the arrangement and distribution of surface domains. They can also chart changes in the shape and location of domain walls, the partitions that cordon off domains. According to Celotta, the shape of the domain walls is a critical variable in high-density magnetic recording media because it influences how many bits of information can be stored in a given area.

The timing of SEMPA's arrival couldn't be better, as demonstrated by the short span between its development at NBS and its approaching commercial introduction. As is true for the semiconductor industry, international competition in the magnetics field is intense. The drive is to develop smaller and better products—denser recording media and a lighter, more efficient motor, for example. With SEMPA, researchers have a new tool to guide their efforts.

by Mark Bello
Washington, D.C.-area Science Writer

Mapping Microstructures: A Quest for the 'Smoking Gun'

During the 1960's, a bridge over the Ohio River collapsed. NBS researchers eventually determined that the technological calamity had its origins in a material defect so small that it would have evaded detection by the unaided eye.

The bridge collapse and the subsequent NBS study preceded Dr. Dale Newbury's arrival in the NBS Center of Analytical Chemistry, but he is familiar with the details because they demonstrate the importance of the compositional mapping program he directs.

"Our interest arises," Newbury says, "because a large number of physical, biological, and technological processes are controlled by compositional events that occur on a micrometer or submicrometer basis."

Dr. Dale Newbury uses compositional mapping techniques to chart small changes in the atomic composition of materials.

Put another way, that statement means big events start as small changes in the atomic composition of materials. With the tools in the compositional mapping program, Newbury and his colleagues can chart those changes in intricate detail, at the level of a micrometer (one-millionth of a meter) or less.

"Strictly speaking, we are not surface scientists," Newbury says. "Our probes take us a micrometer—a few thousand atomic layers—deep. But the term 'surface' is a relative one. To many surface scientists, it may mean a few atomic layers. To geologists, the surface is a region 50 to 100 miles thick."

The power of the techniques used in the program is their high-spatial resolution. Microanalytical techniques, some of which were developed at NBS, allow Newbury and his colleagues to determine the atoms present at sites 1 micrometer apart. For example, an electron scan across a human hair—about 70 micrometers across—would yield 70 different compositional analyses.

While even better spatial resolution is achieved with some of the program's instruments, the micrometer seems to be an especially important unit in nature and in technology. Organelles, the specialized cellular factories that perform tasks such as assembling proteins from instructions encoded in genetic material, for example, are only a few micrometers in size. In the drive to cram more electronic components on computer chips, the micrometer represents the limit of current chip-manufacturing technology.

The NBS researchers have now greatly advanced their methods by designing computer programs that allow them to determine the number and type of atoms in a given sample mass. By moving the beam in a regular pattern (scan) and repeating the quantitative analysis at many thousands of points, they can develop a complete "compositional image." The product of years of work, the compositional mapping program does the "number crunching" for the group's primary instrument—a combination of a scanning electron microscope and x-ray microanalyzer.

The compositional maps are actually two pictures in one. Color-enhanced pictures allow viewers to see changes in the concentration and distribution of different types of atoms in a specimen; overlaying graphs show the actual concentrations that correspond to the features depicted in the images.

"With the combination of pictures and numbers you get a much better feel for what's happening in a material," Newbury says. In effect, the quantitative images provide researchers with what Newbury calls "the smoking gun"—direct evidence of microstructural changes.

A natural application for the tool is in the design of new alloys and advanced composite materials. When researchers change the mixture of atoms in an experimental material, they will be able to see the resulting changes in distribution and concentration. They also will be able to relate these compositional changes to the macroscopic properties of a material. In addition, the ability to track microstructural changes will aid efforts to understand destructive processes, such as corrosion, and how slight defects can ultimately lead to structural failures.

The potential uses of the NBS compositional mapping techniques are not confined to the province of materials science. As Newbury says, "They can be applied to an incredibly wide variety of fields." M.B.

Parallel Processing Research: Turning Supercomputing Promise Into Practice

Almost overnight, in the relative timeframe of technology, a new generation of computers is dawning. Known as parallel or multiprocessors, their difference is that they use more than one processor to simultaneously solve many pieces of a problem. Their promise is to make practical the glamorous, ambitious aspirations of computing such as artificial intelligence and image and speech recognition. But, there are many hurdles to overcome before these aspirations become reality.

The idea behind parallel processing is to get supercomputing speed for a fraction of the cost. To achieve this higher performance, the algorithm—mathematical recipes, programming language, and hardware architecture must be perfectly matched to the application. The only way to know whether a particular combination is successful is through reliable measurements.

But the state of the art in computer performance measurement is poor for computers with one processor and much worse for multiprocessors, says Dr. Stuart Katzke, of the NBS Institute for Computer Sciences and Technology.

By developing new techniques and tools to measure the performance of these new computer architectures, researchers at NBS are evaluating how different configurations of processors solve particular types of problems.

"You can't measure computer performance in terms of length, or watts, or joules," explains electronic engineer Robert Carpenter, head of the parallel processing group at NBS, "and existing measurements such as 'instructions per second' or 'logical inferences per second' do not adequately express the performance of these novel architectures."

Adds Katzke, "If we know what to measure and how to measure it then it will be easier to evaluate and compare machines, 'tune' current designs, or improve future designs."

Along the way, the NBS researchers will be studying many aspects of parallel processors. "Before we can develop techniques to measure their performance, we have to understand many factors, such as which languages are best, how these machines can be programmed and used, and how different architectures work," says Carpenter.

"If we know what to measure and how to measure it then it will be easier to evaluate and compare machines, 'tune' current designs, or improve future designs."

Serial vs. Parallel Processing

Conventional computers, sometimes called serial or Von Neumann, have one processor to perform operations, such as addition, on data. (John Von Neumann is often credited with the general design upon which most of today's computers are based.) Even today's fastest serial computers solve a problem one step at a time, just as they have since the 1940's.

But one-step-at-a-time computers are already beginning to approach speed limits, largely because of basic physical limitations that exist in today's electronic circuitry.

Unlike serial computers, parallel processors use more than one processor to simultaneously solve many pieces of the problem. Theoretically, they can comprise two processors connected by a simple link or tens of thousands—even millions—of processors connected by a complex communications network.

Von Neumann and others of the time saw the appeal of putting multiple processors to work on a problem. But the high cost and low reliability of early computer components made the idea impractical even into the early 1970's. The advent of microprocessors, which provide inexpensive, compact, and reliable processing power on a single silicon chip, made parallel processing possible.

Of course, adds Katzke, having the capability does not mean the technology is well understood.

Bottlenecks

While parallel processors can speed the processing of data, they pose a different set of problems for users, including uneven flow of information and increased likelihood of communications bottlenecks.

Robert Carpenter (rear), head of the NBS parallel processing group, and computer scientist Gordon Lyon are developing special hardware to help solve problems such as communications bottlenecks.

In parallel processing, memory either is shared by many processors through some common access network, or each processor is given its own memory with the network passing messages and information from processor to processor. "Both forms need just the right amount of data flow or some processors will sit idle while others choke on too much data," explains NBS computer scientist Dr. Gordon Lyon.

The NBS team is developing special hardware to determine what the computer is doing and where the problems such as bottlenecks are. "Our goal is to develop measurement hardware that can be used with a wide range of parallel-processor architectures," says Katzke. "The hardware will help find out where the machine is getting hung up and where it's doing most of the work. With this information, designers and manufacturers can change the architecture to become more efficient."

Languages and Programming

Another key to making these machines run more efficiently is understanding how to program them. "But," says Katzke, "we don't have a very good handle on programming parallel processors.

The NBS team is developing special hardware to determine what the computer is doing and where the problems such as bottlenecks are.

Having more than one processor drastically changes how you should instruct a machine via a programming language to perform some task. But we don't fully understand how." He adds, "Programming languages are still oriented to serial or Von Neumann machines. But if a problem is treated sequentially then you are not going to get any increase in productivity out of a parallel machine."

Either the language must provide a way for the programmer to decompose the problem so that it can be executed in parallel, or the compiler has to be smart enough to recognize the best approach to partitioning the computational problem, explains Katzke. (A compiler translates a higher level programming language into instructions the machine can understand.)

Benchmarks

While each computer architecture represents a new opportunity for solving problems, according to Katzke it is often difficult to know which architecture is best for which application.

To help compare the performance of machines with different parallel-processing architectures, the NBS scientists are creating, collecting, and evaluating a wide range of test software known as benchmarks. The benchmarks will represent a variety of applications which could be run on multiprocessors.

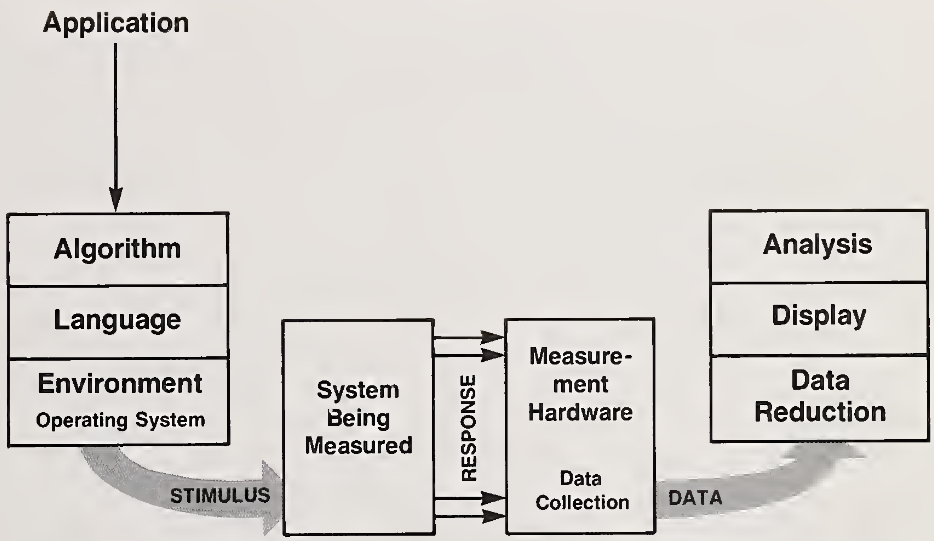
Most benchmarks available today, such as the Linpack codes (a package of about 400 Fortran subroutines for solving dense systems of linear equations), measure performance for only a particular class of problems and were not specifically developed with parallel processing in mind.

The NBS collection so far contains a number of programs aimed at measuring a computer's performance in areas that include fluid dynamics, artificial intelligence, image processing, and general scientific computing.

To help compare the performance of machines with different parallel processing architectures, the NBS scientists are creating, collecting, and evaluating a wide range of test software known as benchmarks.

The NBS researchers will make the routines available at no charge over networks such as the Defense Department's Arpanet.* "This should help users decide which machines might be best for a given application," says Carpenter, "because it will offer benchmark programs characteristic of a variety of problems."

*For information, write or call Robert Carpenter, B364 Materials Building, NBS, Gaithersburg, MD 20899, 301/975-5677.



To achieve the higher performance promised by parallel processors, the algorithm, programming language, and hardware architecture must be perfectly matched to the application. The only way to know whether a particular combination is successful is through reliable measurements. NBS researchers are developing new tools and techniques to measure the performance of parallel processors.

DARPA

The Defense Advanced Research Projects Agency—known as DARPA—is interested in the NBS research for its strategic computing project. Steven Squires, assistant director for information science and technology at DARPA, says the agency's project is taking advantage of the fact that "we can take a fairly simple technology and create a revolution in computing through careful engineering."

Squires adds, "These machines are very hard to characterize. NBS will be learning what you can measure and developing the technology to do it. By getting NBS in at the beginning we are planning for technology transition of this new generation of computers."

The Best Machine?

"Just as no one car is best for everyone, no single design of a parallel processor is best for all problems," says Katzke. "We will never come up with a standard for the 'best' parallel processor. But over the next several years, we will be developing ways to measure the performance of these machines, so when someone asks, 'Given my requirements, what should I look for?' they may be able to find an answer."

by Jan Kosko
NBS Public Affairs Specialist

Cancer Prevention Research Examines Micronutrient Levels in the Body

Can supplemental doses of certain vitamins and minerals reduce cancer risks?

Researchers from the National Bureau of Standards are helping to answer this question by contributing to a larger government program that is examining the cancer preventive properties of micronutrients. These are compounds such as vitamins A, C, and E, which may help prevent some tumors in persons at high risk due to lifestyle or occupational exposure, or in those who have had cancer but now are free of the disease.

Sponsored by the Chemoprevention Branch of the National Cancer Institute (NCI), the larger study requires accurate measurements of micronutrient levels in body fluids such as blood serum because these values will be correlated with the occurrence or recurrence of cancer in populations being studied. Earlier studies have indicated in many cases that low nutrient levels in the diet or in the body are related to a higher risk of cancer. The hypothesis now being tested is whether increasing nutrient levels might be related to a lower risk of disease occurrence.

Clinical trials, in which several thousand individuals are taking supplements for several years, are testing this theory scientifically. About 100,000 volunteers at 50 medical facilities worldwide are participating in the studies.

At NBS, scientists have established a quality assurance program to help NCI-sponsored laboratories make reliable analytical measurements of the micronutrients. Before any conclusions can be drawn, participating labs must have comparable data. But preliminary lab testing has shown a wide variety of results when portions of the same sample were sent to different laboratories for analysis. So NCI asked the Bureau to join the project and lend its chemical measurement expertise to develop standards that will improve interlaboratory measurement quality.

NBS plans to continue these round robin tests and follow-up consultations until all the labs show they can make measurements at acceptable levels of accuracy. If a lab's results are biased, Bureau researchers will suggest ways to make improvements.

"We may recommend that a lab modify techniques or use an entirely different analytical method," says Dr. Willie E. May, who heads the NBS Organic Analytical Research Division. "Other times problems might be remedied by improving equipment calibration procedures."

...study requires accurate measurements of micronutrient levels in body fluids...because these values will be correlated with the occurrence or recurrence of cancer in populations being studied.

About 20 laboratories are participating in the NBS portion of the program. These labs are either directly involved in the project or are striving to improve the quality of their measurements of the micronutrients under study.

NCI has stressed the importance of measurement science. "It is easy, of course, to know how much of a compound is being administered," says Dr. Winfred Malone, chief of NCI's Chemoprevention Branch. "But an important factor in a chemoprevention study is the level of the agent in body fluids and how much is being absorbed into tissues. Too little might not be effective, and too much could prove toxic over an extended time period."

The NCI studies are presently focused on the types of cancer that earlier research has indicated might be responsive to preventive interventions: skin, cervical, colon, mammary, and lung. NCI project leaders hope the study will reveal ways some cancers can be headed off before they become what Malone calls "full-blown malignancies." At several cancer sites, scientists now can identify "premalignant" cells which may be midway in the cancer development process. This is one of several points where NCI believes tumor chemoprevention may be possible.

For example, persons with colonic polyps are often at higher risk of developing cancer. Giving individuals whose polyps have been surgically removed oral supplements such as beta-carotene or calcium carbonate—two of the chemopreventive agents NCI is studying—might head off subsequent cancer development. Both of these compounds have shown preventive promise in human epidemiological and animal model studies.

It also may be possible to interrupt the transformation of normal cells to cancer cells through these interventions with chemopreventive agents. "Even a small delay in the process of transforming initiated cells (those exposed to carcinogens) could drastically reduce cancer incidence," Malone says. Since this promotional phase of cancer induction usually lasts for a number of years, it may be amenable to cancer prevention by agents that could block or interrupt this second step.

While NBS scientists are currently involved in measuring and examining the cancer prevention properties of beta-carotene, retinol (vitamin A), ascorbic acid (vitamin C), alpha-tocopherol (vitamin E), and selenium, NCI has targeted some 500 additional compounds it suspects of possessing chemopreventive qualities for further testing. NBS will likely become involved in developing measurement methods for many of these compounds, which include naturally occurring substances found in vegetables such as members of the cabbage and onion families.

Additionally, NBS is serving as a reference laboratory to a concurrent NCI study in which blood samples of atomic bomb survivors in Hiroshima and Nagasaki who now have cancer are being measured for nutrient levels. Under the auspices of NCI's Epidemiology and Biostatistics Program, the study is evaluating the effects of ionizing radiation on cancer risk.

The program is determining serum levels of beta-carotene, retinol, alpha-tocopherol, selenium, and zinc in Japanese donors who were exposed to various doses of radiation and subsequently developed cancer. This information from NBS will help researchers elsewhere, who hope to relate amounts of the various nutrients found in the samples to occurrence of different types of cancer.

Comparing NBS analytical methods with Japanese methods may help pinpoint potential inaccuracies or measurement biases. Early NBS evaluations have resulted in the recommendation that one analytical technique be modified for vitamin measurements. NBS found that the method was subject to a 40 to 50 percent bias.

NBS also is investigating procedures for long-term storage of blood serum samples. If conditions can be established where samples remain stable over long periods of time, this will open the door to applying the principles of "specimen banking." That is, samples can be deposited periodically and kept frozen until interest in a particular sample prompts withdrawal and analysis. A serum sample, if proven stable, could be withdrawn from a specimen bank years later and the resulting analysis would reflect the sample's chemical composition at the time of deposit. This is especially valuable as analytical technology becomes increasingly sophisticated and new possibilities open for detecting different compounds and smaller concentrations of chemicals more accurately.

by John Henkel
NBS Public Affairs Specialist

Chemist Jeanice Brown-Thomas prepares to analyze a blood serum sample for vitamin A, vitamin E, and beta-carotene using high-performance liquid chromatography. The research will be used to help determine if these nutrients play a role in preventing cancer.

Manufacturing Technology for the Second Industrial Revolution

Computer scientist Albert Wavering monitors the performance of a robot at the horizontal machining center in the AMRF.

When you think of automation, you probably think of automobile plants, and for good reason. The automobile is perhaps the ultimate symbol of the Industrial Revolution. Massive factories turn out millions of cars every year, a feat made possible by careful measurements and the use of thousands of interchangeable parts.

While the innovations of the first Industrial Revolution brought about mass production, small-scale production remains one of the most important segments of American industry. Small-scale or small-batch manufacturing accounts for up to 75 percent of U.S. trade in manufactured goods. Small-scale manufacturing is primarily done by small companies—only one in 10 employs more than 50 people. These companies need the economies produced by automation to survive, but they can't use the techniques of mass production.

The second Industrial Revolution is for them. And the recently completed Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards is at the frontier of that revolution. The AMRF has been designed as a proving ground for the technology of America's factories in the 21st century. Research at the facility is helping manufacturers that must turn out comparatively low numbers of individual parts. These manufacturers include key suppliers to aerospace, automotive, electronics, and home appliance industries.

Although the AMRF looks like a machine shop, it is actually a unique engineering laboratory where NBS researchers work with their colleagues from industry and universities to learn how modern computer technology can provide the small manufacturer with more efficient techniques and better quality control. According to NBS researchers, this laboratory was designed to study standard methods for linking different computerized machines. It also is used to help manufacturers improve quality control by experimenting with efficient and reliable methods for monitoring the performance of automated machinery.

NBS, as the nation's primary laboratory for measurement science and engineering, has two principal goals for its automated manufacturing program: to supply American industry with a radically new way of making precisely machined parts—with dimensions that can be referenced to national measurement standards maintained by NBS—and to encourage the modernization of American manufacturing by providing the technical information necessary to develop standardized interfaces between various types of equipment.

NBS also is using this facility as a testbed for research on the next generation of "knowledge-based" manufacturing systems—automation systems that incorporate artificial intelligence capabilities.

Government, Industry, University Cooperation

The AMRF is one of the largest cooperative research programs at the Bureau. The Navy's Manufacturing Technology Program is a major partner in the facility, and the Navy RAMP project, the Air Force Intelligent Task Automation Project, and other government agencies also have sponsored specific parts of the AMRF effort. More than $4.6 million worth of equipment and software has been loaned or donated by private companies, part of industry's extensive cooperation in this project. Since 1983, about 35 private companies—large and small—have contributed to AMRF research by sponsoring more than 50 of their employees to work at NBS with Bureau researchers. In addition, a number of universities have contributed to the project by loaning guest researchers.

Innovative Production of Precise Parts

Historically, manufacture and measurement have always been two separate processes. A machinist would cut a part on a milling machine and stop periodically to check dimensions with calipers and gauges. As manufacturing techniques became more and more efficient, the measurement portion of the operation consumed an ever-greater percentage of the total work required to produce a part. The development of automated coordinate-measuring machines (CMM's) in the 1970's helped somewhat, but measurement still used up about 50 percent of the total time required to produce a precision part.

It would be many times more efficient if the machining process could be made to produce accurate parts without being interrupted by the measuring process. Not only would it take less time, but fewer parts would have to be scrapped for being out of tolerance. (Some surveys have shown that in the United States one-third of the work force in manufacturing industries is engaged in rework—correcting out-of-tolerance parts made by the other two-thirds.)

NBS research suggests that this problem can be solved by use of today's computer-controlled machine tools, because the position of the cutting edge of the tool is known and controlled at all times, at least in theory, by the computer. The computer can be programmed to compensate for known errors in the machine's movement, using sensors that feed back information on the machine's condition.

This concept of feedback and process control is well known in some industries, such as oil refining and chemical production. In discrete parts manufacturing, however, it will require the development of a whole new generation of sensors and control systems.

This isn't all just theory. NBS researchers have already applied some of these ideas to commercial machine tools and improved their performance in terms of accuracy and control five- to tenfold. Some of this research already is finding its way into the marketplace in new industrial machine controllers.

One important issue to be studied in the AMRF: You can no longer calibrate a measurement process that is deeply embedded in the manufacturing process, one that depends on the interaction of a machine tool with its environment and with one or more computers. How then do you ensure that the dimensions of the finished parts can be shown to be in agreement with national standards of measurement?

Importance of Standardized Interfaces

The automated "factory of the future" offers American industry an important weapon in the highly competitive world marketplace, but even for the largest firms the lack of agreed-upon standards for "interfacing" complex equipment is a difficult—and costly—problem.

For close to 90 percent of the small-batch manufacturers—about 100,000 firms—the problem is worse. These are much smaller companies (fewer than 50 employees) without great financial resources. These smaller companies need to be able to buy automated machinery in stages, one or two machines at a time, and slowly build up to an integrated system.

They need the flexibility to buy from different manufacturers at different times with the assurance that the machines they buy will work together properly without a lot of expensive, custom-designed interfaces. They need the same flexibility that one can now find when buying the parts of a home stereo system from several different manufacturers, knowing that they will all plug together.

These firms also need a system flexible enough to switch from the production of one part to another quickly and without expensive reprogramming.

Most of these problems are problems of standardization—standard procedures, standard protocols, standard interfaces. The challenge is to develop standards which support current technology and still encourage equipment manufacturers to develop new and innovative products. These are problems that NBS is studying in the AMRF.

NBS is not a regulatory agency, and does not set standards, at least in the legal sense. However, NBS has a long history of working as a neutral, third party, providing technical knowledge and leadership and encouraging the establishment of standards. NBS research has become the basis for many standards adopted by private industry on a voluntary basis.

Three industrial standards have already been developed based on NBS automation research. For example, a standard method for exchanging graphics data between otherwise incompatible computer-aided design (CAD) systems, developed by a government-industry coalition led by NBS, was adopted by the American National Standards Institute (ANSI), a private voluntary standards organization. The standard now is supported by all U.S. CAD vendors which have at least a 1 percent market share.

AMRF research also has led to standards for the characterization of computerized coordinate measurement machines and for a method of surface texture measurement. Seven other potential standards are now being considered by various industrial standards groups.

Unique Features of the AMRF

Several things make the AMRF unique including:

☐ Its location at the National Bureau of Standards. As an open federal laboratory with no commercial interests, NBS can make this facility accessible to private firms interested in automation research—firms that individually could not afford such a complex research facility. NBS has a long history of working with private firms and organizations to develop standards and measurement and test methods that benefit the entire industry.

☐ The active participation in the AMRF by industry, universities, and other government agencies. The AMRF has become a focal point for interactions among all American researchers in automated manufacturing.

☐ The use of a wide variety of commercially available machine tools and robots. This is a direct result of the NBS decision to study the most practical, incremental route to automation for the small- to medium-sized firm; it is an approach that has never been used before.

☐ The flexibility of the system. One of the goals of the AMRF is to create a facility that is, in the jargon of the researchers, "data driven"—the actions of the various machines and robots should be determined primarily, or solely, by a computerized description of the part to be manufactured. This stands in contrast to modern "flexible manufacturing" cells which are truly flexible only for a limited "family" of parts for which the machine tools are programmed.

In the AMRF scheme, the programs which actually control the machine tools should not make any assumptions about the part to be produced. That information will be kept in a separate database system, and control programs will look up the description of the desired part and take the necessary steps to produce it. The production of a part could then be changed simply by changing its description in the database, without needing to reprogram the machines.

☐ Sensory interaction. The AMRF makes use of an unusually versatile robot control system in which sensory information from, for example, the NBS robot vision system is fed back to the controller to provide a basis for its decisions. This is important because it enables the system to react to its environment, eliminating the need for a lot of rigid programming.

☐ The scope of the facility. Research at the AMRF covers everything from the preparation of data on a new part to final automated inspection.

The AMRF Control System

The AMRF has a total of six workstations which include several types of modern automated machine tools, such as numerical control milling machines and lathes, automated materials-handling equipment (to move parts, tools, and raw materials from one workstation to another), and a variety of industrial robots to tend the machine tools.

At the heart of the facility is the AMRF control system—one of the most important innovations. It is flexible and can be adapted easily to new machines and new technology, works in the split-second real-time world of factory processes, and is "modular," allowing today's manual or partially automated factories to evolve into "factories of the future" incrementally, adding one or two modules at a time.

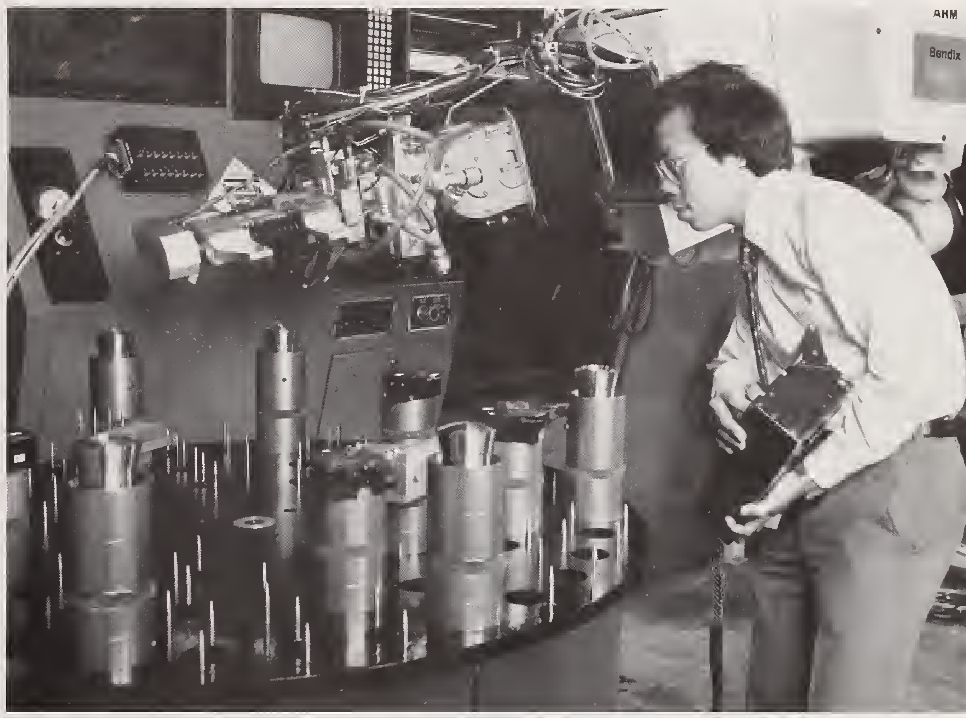
Several elements of the AMRF control system are being considered as possible factory automation standards by national and international standards organizations.

Among the key features of the control system are: hierarchical control, the cell control system, and the computer emulation system. The activities in a manufacturing facility, like those of most complex organizations, fall neatly into a hierarchical framework. NBS pioneered the use of hierarchical control in the design of a sophisticated robot control system a decade ago. This work led to the development of a five-layer, hierarchical control model for an entire factory. Commands go into the hierarchy at the highest level, where a complex set of instructions is initiated. At each lower level, the instructions are broken down into successively simpler instructions.

The AMRF represents what is probably a unique level of complexity in multilevel control systems. The modular, hierarchical software developed by NBS for this facility is the most flexible, most advanced control system ever used in such an application.

The cell control system is the highest implemented level of the AMRF hierarchy. It receives orders for parts from an operator terminal, determines the necessary resources, and then schedules, coordinates, and monitors the activities of the workstations required to manufacture the parts.

The AMRF hierarchical control system emulator (HCSE) is a tool for testing the effects of new systems before they are actually linked into the existing factory system. This testing must confirm not only that the new system has no internal errors, but also that its addition will cause no unexpected problems in synchronization.



Research engineer Kang Lee at work at the AMRF turning center workstation. Computer control techniques developed at this facility make it possible to operate this machine tool at five to ten times its normal accuracy.

The HCSE provides the programmer with a convenient framework for creating modeling programs to take the place of any element in the AMRF. To the rest of the control system, the computer emulation "looks the same" as whatever it replaces. So when research needs dictate, any piece of equipment or group of machines or subsystem can be taken out of action and replaced by the appropriate emulation. Potentially risky changes to the control system can be tested without endangering expensive equipment. Versions of the HCSE are already being used commercially to study new automated manufacturing facilities.

Data Preparation and Handling

In a very real sense, the cornerstone of the "factory of the future" will be information. The hardware of the AMRF—robots, machine tools, and sensors—is very visible, but the ability to generate, store, retrieve, and transfer information accurately and on time will be just as important as any hardware.

Such a facility requires a number of important advances in computer software, including the development of standard techniques to "interface" different types of computer systems and software and the development of standard methods for handling data in an automated factory.

The interface problem in the AMRF is complex. At least nine different computer systems are in common use, ranging from large minicomputer systems to advanced microcomputers. At least eight different computer languages are used throughout the AMRF control system. Special features of the AMRF data-handling system include the use of distributed databases and a specially designed data communications system.

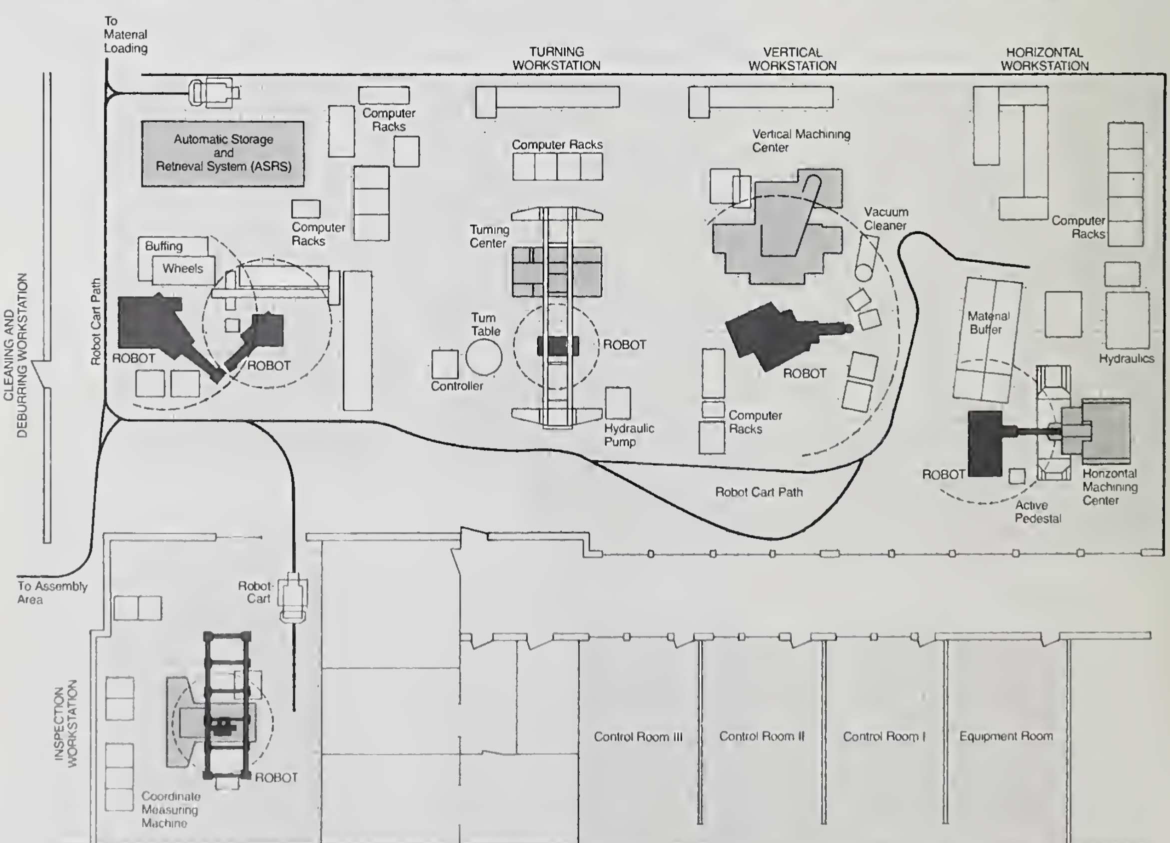
An equally important task is data preparation, transforming the customer's requirements for a particular part into the production control data needed to manufacture that part. These tasks include designing the part, determining what materials and tools are necessary to produce the part, developing the process plans that detail how the part is to be made, and generating the programs that instruct the robots and machine tools that actually make and inspect the part. Also vital is the ability to verify these plans—to make sure that they don't instruct the machines to do something dangerous or impossible.

A common thread through all of these tasks is the need for standardized methods of handling the data. At the AMRF, research is under way to determine exactly what types of data are required by a factory's manufacturing and inspection systems, and how these data can be generated automatically by the various data preparation systems in use in the facility.

Research at the Workstations

Research projects at the horizontal workstation, focus on basic studies of generic, real-time control systems, methods of programming such systems, and the handling of data and materials in an automated workstation. This workstation features: a real-time control system, materials buffer, the automated fixturing system, tool changing, the sensory-interactive robot control system, the NBS robot vision system, the Quick-Change robot wrist, the active pedestal, and the "Watchdog" safety computer.

The vertical machining workstation features an advanced, automated process-planning system tied to its workstation controller, equip-



This floor diagram shows the arrangement of workstations and equipment in the Bureau's Automated Manufacturing Research Facility.

ment controller, machining center, robot grippers, pallet system, vise, and the chip removal system.

A major factor in the economics of automation for the small-batch manufacturer is whether or not the system can be left to run unsupervised for fairly long periods, such as the overnight shifts. One of the research efforts at the turning workstation has been the study of the sensors and process control systems needed for untended operation.

The turning workstation includes a malfunction detector—a microprocessor-based device which uses a vibration sensor mounted on the tool holder in the tuning center to compare the vibration levels to a "catalog" of acceptable levels for different machining operations. Unacceptable levels trigger an error message to the workstation controller.

Research in the cleaning and deburring workstation focuses on the investigation of robotic deburring techniques. These techniques would more closely emulate the actions taken by a human in deburring a part and would permit a much more specialized treatment of a given part than would the current mass deburring methods.

Gaining this additional flexibility in robotic deburring will require advances in several areas of robotic control and sensing systems. A major research topic at this workstation is the use of CAD data—the computerized description of the part—to guide the robot through a trajectory that is sufficiently accurate for deburring work. Other research topics include: developing remote measurements of the robot's position to enhance its positional accuracy; investigating high-speed feedback control systems using force sensors; and developing control methods for coordinating the cooperative actions of two or more robots.

In the materials-handling workstation researchers study the movement of part blanks, raw materials, tools, and finished parts in and out of storage and between the other workstations.

One of the key ideas behind the AMRF states that sufficiently good process control will one day eliminate the need for final inspection to assure the accuracy of manufactured parts. The role of inspection will evolve from simply sorting good and bad parts to ultimately providing the process control over the most complex sources of error in part manufacturing.

The inspection workstation represents the first step in developing this advanced process control capability for the AMRF. This workstation, which includes CAD-direct inspection and surface-roughness measurement, is isolated from the rest of the shop floor and temperature-controlled—important factors in the performance of coordinate-measuring machines.

A Working Research Laboratory

The AMRF, however, is not a prototype of the "factory of the future." It is extremely unlikely that any actual factory would resemble the AMRF, at least physically. The AMRF is a laboratory for studying factory automation.

The AMRF is not a demonstration project. Although it does demonstrate several new and potentially important techniques for machine control and the integration of diverse systems, the completed AMRF is not be a museum piece but rather a working research laboratory.

In the coming year, researchers in the AMRF will concentrate on aggressively transferring the technology they have learned about, as well as continuing research on manufacturing data preparation and precision manufacturing.

by Michael A. Baum
NBS Public Affairs Specialist

A robot at the AMRF inspection workstation presents a newly machined part to a device that uses optical techniques to measure surface finish.

New Values Recommended for the Fundamental Physical Constants

Chemists, physicists, engineers, and others in science and technology have a new, more accurate set of values for the fundamental constants now that work is completed on the *1986 Adjustment of the Fundamental Physical Constants.* These are the basic quantities used in physics and chemistry worldwide for scientific investigations.

The 1986 adjusted values are recommended by the Committee on Data for Science and Technology (CODATA), an interdisciplinary, scientific committee of the International Council of Scientific Unions with headquarters in Paris. Dr. David R. Lide, Jr., CODATA president and director of the Office of Standard Reference Data at the National Bureau of Standards says, "The new set of adjusted values for the fundamental physical constants will contribute to improved data in nearly all fields of scientific research."

NBS works through CODATA to ensure the international coordination of scientific information used by laboratories throughout the world.

The 1986 CODATA report, which gives the new set of recommended values, is the first revision to the 1973 CODATA report that established the first internationally adopted set of values. The revised version of the fundamental constants takes into account the significant advances in metrology that have occurred since the 1973 analysis.

The new set was developed over a 5-year period under CODATA sponsorship by physicists Dr. E. Richard Cohen at Rockwell International Science Center and Dr. Barry N. Taylor at NBS. The scientists received guidance on their work from other members of the CODATA Task Group on Fundamental Constants that includes representatives from Canada, France, Japan, West Germany, the Soviet Union, and the United Kingdom.

The adjustment includes the new definition of the meter in terms of the distance traveled by light in a given time, measurements linking atomic lattice spacings to optical wavelengths that make possible significant improvement in the determination of the Avogadro constant, and measurements of the quantization of the electrical conductance in certain semiconductor devices—the quantum Hall effect—discovered by Nobel laureate Klaus von Klitzing in 1980.

"The new set of adjusted values for the fundamental physical constants will contribute to improved data in nearly all fields of scientific research."

While there are changes in all of the 1973 recommended values, the major ones include decreased values for the Planck constant, the elementary charge, and the electron mass and increased values for the Avogadro constant, the Faraday constant, and the Josephson frequency-voltage ratio. Most importantly, throughout the 1986 set of recommended numerical values, the uncertainties are now typically about 10 times smaller than those in the 1973 set.

Although the data represent different physical quantities, they must be expressed so that coherent comparisons can be made of their uncertainties. As part of their review, Cohen and Taylor examined each originally assigned uncertainty and modified it, if necessary, to ensure that all uncertainties were expressed consistently in terms of a variance.

Taylor points out that while the 1973 CODATA report provided the first internationally adopted set of values for the fundamental constants, the recommended values were almost immediately challenged by several new measurements. He says, "Because new and better data are continually becoming available, it is always difficult to establish an optimal time for making a change in the recommended values of the constants. We finally decided to consider all the data that was available up to January 1, 1986, in this revision."

CODATA was established in 1966 to promote, on a worldwide basis, the compilation, evaluation, and dissemination of numerical data in all fields of science. Its membership includes 18 nations and 15 international unions. The member countries include the United States, the Soviet Union, Japan, China, the major industrialized European nations, and several developing countries.

Copies of the *1986 Adjustment of the Fundamental Physical Constants,* CODATA Bulletin 63, may be purchased in North America for $15 prepaid from Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, NY 10523. Elsewhere, the bulletin may be obtained from Pergamon Press Ltd., Headington Hill Hall, Oxford OX3 OBW, United Kingdom.

by Roger Rensberger
NBS Public Affairs Specialist

Quantity	Symbol	Value	Units	Relative Uncertainty (ppm)
speed of light in vacuum	c	299 792 458	$\mathrm{m\,s^{-1}}$	(exact)
permeability of vacuum	μ_0	$4\pi \times 10^{-7}$	$\mathrm{N\,A^{-2}}$	
		$=12.566\,370\,614\ldots$	$10^{-7}\,\mathrm{N\,A^{-2}}$	(exact)
permittivity of vacuum	ϵ_0	$1/\mu_0 c^2$		
		$=8.854\,187\,817\ldots$	$10^{-12}\,\mathrm{F\,m^{-1}}$	(exact)
Newtonian constant of gravitation	G	6.672 59(85)	$10^{-11}\,\mathrm{m^3\,kg^{-1}\,s^{-2}}$	128
Planck constant	h	6.626 0755(40)	$10^{-34}\,\mathrm{J\,s}$	0.60
$h/2\pi$	$\hbar$	1.054 572 66(63)	$10^{-34}\,\mathrm{J\,s}$	0.60
elementary charge	e	1.602 177 33(49)	$10^{-19}\,\mathrm{C}$	0.30
magnetic flux quantum, $h/2e$	Φ_0	2.067 834 61(61)	$10^{-15}\,\mathrm{Wb}$	0.30
Josephson frequency–voltage ratio	$2e/h$	4.835 9767(14)	$10^{14}\,\mathrm{Hz\,V^{-1}}$	0.30
electron mass	m_e	9.109 3897(54)	$10^{-31}\,\mathrm{kg}$	0.59
proton mass	m_p	1.672 6231(10)	$10^{-27}\,\mathrm{kg}$	0.59
proton-electron mass ratio	m_p/m_e	1836.152 701(37)		0.020
fine-structure constant, $\mu_0 ce^2/2h$	α	7.297 353 08(33)	10^{-3}	0.045
inverse fine-structure constant	α^{-1}	137.035 9895(61)		0.045
Rydberg constant, $m_e c\alpha^2/2h$	R_∞	10 973 731.534(13)	$\mathrm{m^{-1}}$	0.0012
Avogadro constant	N_A, L	6.022 1367(36)	$10^{23}\,\mathrm{mol^{-1}}$	0.59
Faraday constant, $N_A e$	F	96 485.309(29)	$\mathrm{C\,mol^{-1}}$	0.30
molar gas constant	R	8.314 510(70)	$\mathrm{J\,mol^{-1}K^{-1}}$	8.4
Boltzmann constant, R/N_A	k	1.380 658(12)	$10^{-23}\,\mathrm{J\,K^{-1}}$	8.5
Stefan–Boltzmann constant, $(\pi^2/60)k^4/\hbar^3c^2$	σ	5.670 51(19)	$10^{-8}\mathrm{W\,m^{-2}\,K^{-4}}$	34
		Non-SI units used with SI		
electron volt, $(e/\mathrm{C})\,\mathrm{J} = \{e\}\,\mathrm{J}$	eV	1.602 177 33(49)	$10^{-19}\,\mathrm{J}$	0.30
(unified) atomic mass unit, $1\ \mathrm{u} = m_u = \frac{1}{12}m(^{12}\mathrm{C})$	u	1.660 5402(10)	$10^{-27}\,\mathrm{kg}$	0.59

This table is an abbreviated list of the 1986 recommended values of the fundamental physical constants, which are based on a least-squares adjustment with 17 degrees of freedom. The digits in parentheses are the one-standard-deviation uncertainty in the last digits of the given value. Since the uncertainties of many of these entries are correlated, the full covariance matrix must be used in evaluating the uncertainties of quantities computed from them.

Equations and Models Used to Investigate Hotel Fire

The following article is adapted from a statement made by Dr. Jack E. Snell, director of the NBS Center for Fire Research, before the House Committee on Science, Space, and Technology, Subcommittee on Science, Research and Technology, March 5, 1987.*

In the late afternoon of the last day of 1986, a fire of devastating intensity swept through the lower floors of the Dupont Plaza Hotel in Puerto Rico, killing 96 people. Other major hotel fires in just this past decade include the MGM Grand in Las Vegas which was followed closely by the Las Vegas Hilton fire, the Westchase Hilton Fire in Dallas, and the Stouffers Inn in New York. The United States continues to post one of the worst fire death records in the world, and hotels and motels represent just the tip of the iceberg of the U.S. fire problem, accounting for only 1.3 percent of the total fire deaths according to the National Fire Protection Association.

Hotel fire safety is of concern for a number of important reasons. The public perceives and expects hotels to be safe. Hotels present a large number of potential sources of fire—laundries, kitchens and storage rooms, restaurants, night clubs, convention centers, shops, and commercial spaces, as well as occupant rooms. Large concentrations of people are exposed to any fire incident that may occur in them. Hotels are often the targets of negligence, carelessness, arson, and, increasingly, terrorist attack. Finally, hotels are important because new fire safety practices and technologies introduced in hotels ultimately find their way into homes. Lessons learned about hotel fire safety can profoundly affect the rest of the fire problem.

Too many people still think they are safe in buildings made of noncombustible construction materials. Fire investigation reports frequently cite the victim's apparent lack of knowledge of escape routes as a significant factor in loss of life. We need to do a better job of communicating fire safety information.

While the fire hazards of highly combustible interior finishes have been greatly reduced in recent years, the fire hazards of hotel contents may in fact be even greater now because of the relatively high energy-release rates of many modern materials used in them. Highly combustible contents clearly contributed to the magnitude of loss in each of these major hotel fires. Reduction of the hazards of combustible contents remains a major piece of unfinished business in improving hotel and home fire safety.

The United States continues to post one of the worst fire death records in the world....

It is not always easy or obvious to tell whether a building is "fire safe." Fire safety depends on many factors, including, of course, the vast number of fire scenarios that are possible. What is needed is a means to evaluate a hotel (or any building) for the many types of fire it may be subjected to as well as the likely behavior, and fate of, the occupants. More precise means are needed for determining the sequences of events that occur in a fire.

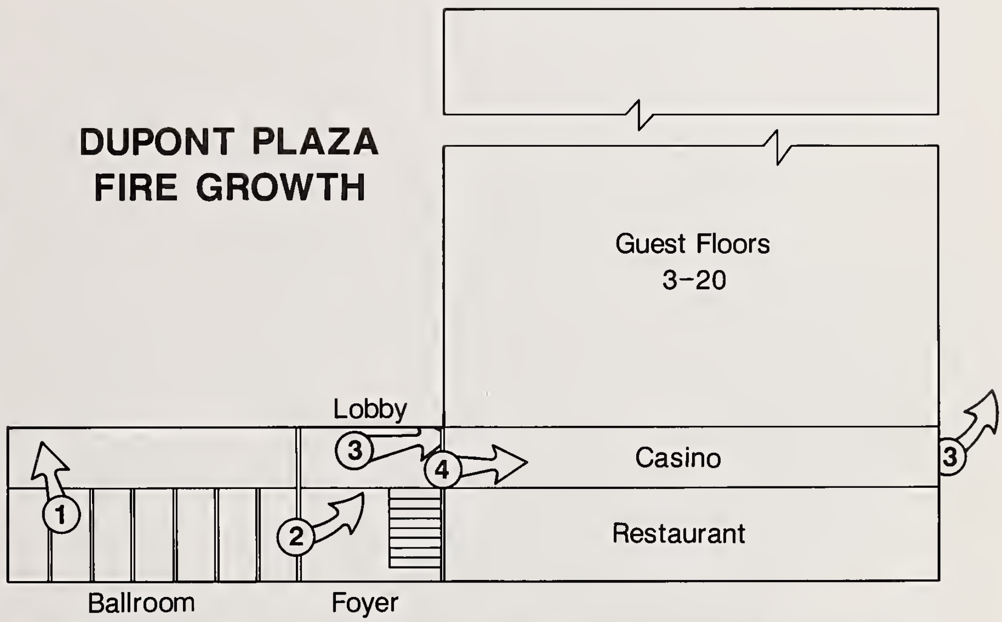
We need to determine what "would have" happened if various alternatives, for example, better materials or compartmentation, early warning, or suppression systems, had been used. What I am suggesting is that we need methods to simulate the performance of a building under assumed conditions of fire—methods like those routinely used, for example, by airline pilots to "practice" in-flight emergencies safely on ground-based computerized simulators. Such realistic simulations are possible because sufficient knowledge of aeronautical engineering exists to predict aircraft performance and thus produce realistic software. Until recently there simply wasn't sufficient knowledge about fire to do the same thing.

The type of tools NBS is now working with others in the fire protection community to produce can provide the bases for powerful new means to address these needs. For example, these tools can be used to produce simulators and related materials that will permit people to evaluate how well various combinations of fire protection technologies will work, to enable quantitative evaluation of fire safety trade-offs, and to stimulate and guide development of more effective and affordable technologies for fire protection.

Using Data in Fire Investigations

NBS staff have used such scientific and engineering tools to study the Dupont Plaza Hotel fire. Dr. James Quintiere, head of the NBS Fire Science and Engineering Division, and Harold Nelson, a senior research engineer, joined the onsite investigation on the fourth day following the fire. These men, along with investigators from the United States Fire Administration and a team from the National Fire Protection Association participated

*At the request of the governor of the Commonwealth of Puerto Rico, Snell served on the Commission on Fire Safety, which was set up to study Puerto Rico's fire safety practices and standards.



Simplified elevation of the Dupont Plaza Hotel viewed from the north.

in the investigation directed by the Bureau of Alcohol, Tobacco and Firearms.

Nelson and Quintiere had at their disposal—on pocket and portable, lap-sized microcomputers—recently developed fire models and engineering equations which they used to calculate the various stages of the fire development. This was a precedent-setting application of these models on the scene of an active fire investigation.

The investigation reported here focused on the application of scientific and engineering research to improving hotel fire safety. The continuing criminal investigation prevents discussion of the details of ignition or other factors that might affect the criminal investigation.

In the NBS analysis, the Dupont Plaza Hotel fire was assumed to originate on a large pile of cartons of new furniture in the south ballroom (see diagram, arrow 1). The south ballroom is under the balcony and behind a set of removable partitions which separated it from the much larger north ballroom. Smoke began to fill both the 10-foot-high south ballroom and flowed into the main 21-foot-high north ballroom as the fire progressed in the cartons. Ballroom doors leading to the foyer, which contained the main staircase to the lobby and outside, were open during this period.

As the smoke filled the ballrooms, it is estimated to have emerged into the foyer approximately 5 minutes after the fire started. This, we believe, was the first general indication of fire to the occupants of the lobby. About 5 minutes later, we estimate flashover** occurred in the south ballroom, involving large portions of the combustible floor and wall coverings. The window partitions to the foyer broke, and a large quantity of smoke and flames was released into the foyer (arrow 2). In roughly 40 seconds, a deep hot smoke front traversed the lobby area (arrow 3) forcing the occupants to flee. During these last few minutes, people in the casino became aware of the fire, but now those remaining had their only exits blocked by the dense, black smoke in the lobby.

Two minutes later, the exposed wood deck roof of the foyer became involved in fire, and the extended flames broke the glass partitions to the casino (arrow 4). This sent a deep front of fuel-rich smoke and flames across the casino. This front probably ignited most of the combustibles in the casino in the next minute. Occupants were hopelessly trapped.

This is now approximately 12 minutes from the initial development of the fire. That is all the time we estimate it took for this tragedy to occur.

The conditions leading to the rapid spread and growth of this fire had little if anything to do with the allegation that the fire was intentionally set. The outcome resulted from the design, materials, and fire protection devices and systems of the hotel as well as the training, attitudes, and perceptions of the hotel occupants and employees at the time of the fire or before.

Evaluating Alternative Systems

We applied the same equations and models used to predict the course of this fire to estimate the possible effect alternative fire protection devices or systems may

**Flashover is a phenomenon where fire suddenly spreads from an initial burning object to the whole room after hot gases build up near the ceiling of the room and descend downward.

have had. Specifically, we looked at smoke detectors for early warning; fire sprinkler protection in the ballrooms, foyer, and casino; and fire-resistant materials for the partitions and the wall and floor coverings in these spaces.

The response of a sprinkler depends on the particular style of sprinkler head and its location relative to the fire. Our analysis looked at a range of possibilities. A modern, quick response sprinkler located directly above the fire would have been expected to go off about 45 seconds after the cartons started to burn. At this time, the flame would have only been about 3 feet tall and there would have been very little increase in the smoke temperature. If, on the other hand, a traditional sprinkler had been about 10 feet away, probably the slowest response we should expect, it would have gone off in about 3 minutes. While this is a comparatively long time, the sprinkler would have been activated at just about the time the flames from the fire started to lick the 10-foot-high ceiling. The smoke layer would have filled down from the ceiling about 2 feet, and its temperature would have risen to about 265 °F. This would certainly be an uncomfortable place to be but not yet fatal. The hotel had a good water supply, and an operating sprinkler would have probably extinguished, or at least controlled, this fire.

Smoke detectors would have operated more quickly. If one had been located directly above the fire, it would have gone off about 15 seconds after the flame got established on the cartons. At this time that flame would probably have only been 5 to 6 inches tall. If a smoke detector had been located near the far end of the room, say as much as 40 feet from the point of fire initiation, it would have been another 45 or 50 seconds until the detector operated. Of course, detectors only send alarms. Their worth depends entirely on how people respond to them.

Many modern building codes would require that the wall between the south ballroom and the foyer have at least a 2-hour fire resistance. Had this been present, the fire would not have broken out into the foyer. There would, of course, have been serious damage inside the ballroom complex and a flow of hot smoke and gas into the kitchen service corridor, but probably little threat to people in the lobby or casino.

Had the partition between the north and south ballrooms been of a substantial construction, that is, a fire-rated partition, the time to flashover would have been greatly stretched out.

The number of "what if" predictions that could be made is almost as endless as the questions that can be asked. In some instances, we can now make reasonable engineering predictions, others would require extensive testing and experimentation. One example of the latter would be the contribution of the fabric wall-covering material used in both ballrooms. A series of tests on this material and full-scale tests of the stacked cartons of furniture that burned would be needed to resolve this issue.

Summary and Recommendations

There is no question about it: Technologies exist to make hotels and homes fire safe. The problem is that fire safety involves trade-offs—trade-offs among cost, function or comfort, and safety. Disasters result when the risks of fire were not perceived correctly, or these trade-offs weren't assessed properly, or both. Obviously, it is difficult to do these things, particularly in the absence of adequate measurement tools.

This tragedy, like many before it, demonstrates the fact that most people have inadequate knowledge of fire risks and hazards, thus aren't motivated to act appropriately.

Most people lack the understanding and the necessary information to make the properly evaluated trade-offs among safety, cost, and function that are required to reduce fire risks to acceptable levels.

Also, this tragedy confirms that available technologies either are too costly or are perceived as such by many hotel operators. (For example, the Dupont Plaza is not the only unsprinklered hotel. It has been estimated by the hotel industry that as many as 95 percent of hotels and motels are not protected by sprinklers.)

The public, state and local governments, and industry can benefit from further analysis this year of the Dupont Plaza Hotel fire. Much can be learned by examining answers to many "what if" questions and estimating the effect of proposed changes in codes and practices.

NBS scientists successfully applied their equations and models in the Dupont Plaza fire investigation. This experience suggests that this approach may become a powerful new component of future fire investigations. Specifically, future investigations might include the use of a multidisciplined on-site investigation team, including fire scientists and engineers; use of computer-based models and engineering tools for predicting fire and its consequences; and complementary small- and full-scale tests to verify computer-based fire "re-creations."

Atmospheric Contaminants Targets in NBS Version of 'Dating' Game

George Klouda twists a knob and releases the sample of Las Vegas air from a bottle.

The sample begins a journey through a maze of tubes, valves, and traps that looks like a tabletop jungle gym. As the air creeps through the apparatus, two carbon-based atmospheric contaminants in the sample—methane and carbon monoxide—are extracted.

Klouda and his research chemist colleagues at the National Bureau of Standards then convert the extracted components into a solid

...the method allows NBS researchers to determine whether contaminant sources are naturally occurring, manmade, or a combination of the two.

pellet about the size of a dime and evaluate them with a technique that is known mainly for its ability to establish the age of archaeological artifacts and geological samples. Called radiocarbon dating, the method allows NBS researchers to determine whether contaminant sources are naturally occurring, manmade, or a combination of the two.

Making these distinctions is important to government bodies like the U.S. Environmental Protection Agency and state environmental agencies, which identify industrial sources of pollution for regulatory action. On the other hand, if pollution sources are from nature, the dating method can prevent industrial firms from being penalized for pollution they did not create.

Another example, atmospheric methane, may be the product of leaking industrial gas. But more often than not, says Dr. Lloyd Currie, who heads the NBS atmospheric chemistry group, nature is the main source of methane. "We know that biological sources such as swamps, grazing cattle, even termites in the tropics are major methane sources, though motor vehicles or industry may contribute significantly," Currie says. "We also know that when nature is responsible, there is little hope of controlling the source."

An overbalance of atmospheric carbon can cause a number of environmental problems. In methane's

Chemists Dr. Lloyd Currie (left) and George Klouda prepare to analyze an atmospheric carbon sample in the Bureau's mini-counter.

case, high levels are of concern to environmental agencies because of "greenhouse" properties. That is, the gas absorbs solar radiation—much like a greenhouse absorbs heat on a sunny day—causing the atmospheric temperature to rise and contributing to a suspected warming trend in the world's climate. Methane also has been implicated as a possible contributor to changes in the ozone layer that protects the Earth from excessive ultraviolet light.

"Levels of methane have been increasing at an annual rate of about 1 percent over the last decade," Currie says. "This has caused concern in the environmental community, which hopes to determine just where the elevated levels are coming from."

The Dating Technique

The NBS research is aimed at definitively pinpointing sources of methane and other atmospheric contaminants by determining the ratio of an unstable radioactive carbon isotope, carbon-14 (C-14), to stable carbon-12 concentration. This permits scientists to separate "living" carbon sources (burning wood or vegetative emissions) from "dead" ones (fossil fuels such as gasoline).

C-14 is present in the atmosphere through the action of cosmic rays, though significant concentrations of the isotope can be attributed to manmade causes like nuclear weapons testing. It is distributed throughout living matter as the result of carbon dioxide taken in by plant respiration. While alive, plants or animals exchange C-14 with the environment at an even pace. However, when an organism dies, its C-14 level decreases gradually through radioactive decay. C-14 has a half-life of about 5,700 years. That is, at the end of that period of time, only half of the original C-14 concentration will remain.

This "yardstick" works beautifully for the archaeologist, who can calculate the age of an artifact by comparing its C-14 level with that of living matter. For NBS atmospheric chemists, the radiocarbon dating method is used in much the same way. Fossil fuels such as oil and coal, because they were last "alive" hundreds of millions of years ago, have no C-14. Their levels of the isotope have long since decayed, so researchers can establish their origins because of this absence. On the other hand, living carbon sources, like burning wood logs or tree emissions, have high C-14 levels, which allow them to be identified.

Tiny Samples Needed

Despite its similarity to archaeological radiocarbon research, the NBS technique differs in the way samples are analyzed. Archaeologists typically have had the luxury of handling large carbon samples taken from an artifact at hand—1 to 10 grams (.035 to .35 ounce) is necessary for traditional radiocarbon dating. Atmospheric scientists are not so lucky. Even under the most polluted conditions, an air sample only yields about 50 millionths of a gram of carbon per cubic meter of air, which means it could take weeks to collect enough material for classical analysis methods.

"We realized that a special apparatus was needed to permit reliable radiocarbon measurements of small samples," says Currie, "so we decided to build our own."

Early successes came in the middle 1970's when Currie and his colleagues fashioned an analytical instrument—known as a mini-counter—from part of a World War I-vintage cannon barrel the Navy had slated for scrapping. The 6-ton iron barrel, in which the researchers placed sensitive measuring devices, provided an excellent shield against the natural background radiation that would have overwhelmed attempts to measure the tiny carbon-14 concentrations. And unlike modern steel, the World War I barrel did not contain minute amounts of radioactivity from fallout or from radioactive tracers that would interfere with C-14 measurements. (Currie emphasizes the minute amounts of C-14 the researchers examine by explaining that human beings naturally contain about "1 million times as much radioactivity" as what NBS is trying to measure.)

While the small counter allowed the researchers to scale down sample size and gauge C-14 accurately, some specimens were still too small to be measured reliably by the NBS device. A more sensitive technique was needed.

...NBS researchers were able to trace elevated carbon particle concentrations to the abundance of residential woodstoves in the cities studied.

By 1978 a method developed at the University of California (Berkeley) a few years earlier, and improved by the University of Rochester (N.Y.), had attracted the attention of NBS researchers. Called accelerator mass spectrometry (AMS), the new method offered 1,000 times the sensitivity of traditional radiocarbon techniques and a tenfold improvement over the in-house NBS device. The technique, however, required samples in the form of solid elemental carbon for analysis. (The mini-counter method used samples in the form of carbon dioxide gas.)

Using laboratory techniques, NBS chemists converted samples to carbon powder and began successfully using AMS. A later device designed at NBS by Dr. Michael Verkouteren improved sample conversion. His invention takes either gaseous atmospheric samples (methane or carbon dioxide, for example) or particle samples (woodstove or automobile exhaust emissions) and converts them to a solid carbon pellet which then can be analyzed by AMS for C-14 concentration. The method results in samples that are smaller and contain less contamination than those produced with previous techniques.

NBS, which has no AMS facility of its own, used the Rochester instrument until the early 1980's. Bureau researchers now are primarily using an AMS device at the University of Arizona in Tucson. All sample preparation is done at NBS labs in Gaithersburg, Md.

Real World Results

One recent study using the AMS technique was a cooperative effort between NBS and the Clark County Health District in Las Vegas. Among other things, the two agencies wanted to determine the origin of elevated carbon monoxide levels detected in the area. Carbon monoxide, well known as a noxious compound, also prompts a chemical reaction that disturbs the "natural sync" of atmospheric methane. In effect, this increases methane levels and adds to the greenhouse effect and other methane-related environmental problems.

Our study results pointed to fossil fuel emissions—most likely from auto exhaust—as the culprit in this case, says Klouda, who coordinated the Las Vegas study. (Had a significant amount of C-14 been found in the samples, the source could have been a living one such as wood burning or tree emissions.)

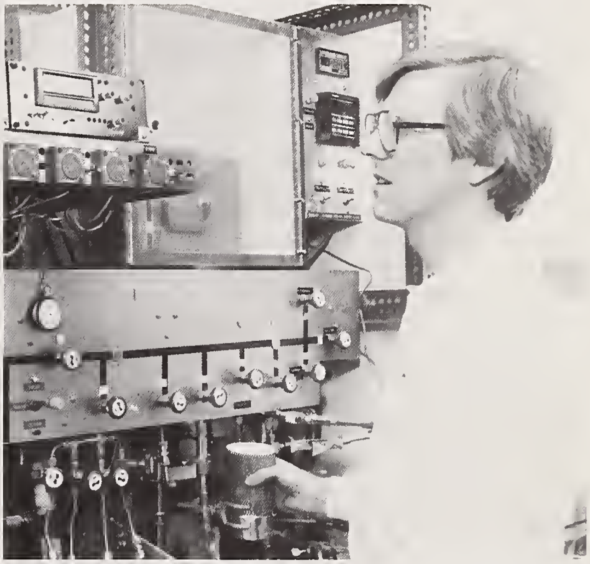
NBS also has contributed to the Environmental Protection Agency's Integrated Air Cancer Program. Part of this project aims to determine the atmospheric concentration of carbon particles from woodstoves. With support from EPA, NBS has conducted studies in several cities, including Albuquerque, N.M., and Raleigh, N.C. Using radiocarbon dating to track the "living" carbon of burning wood, NBS researchers were able to trace elevated carbon particle concentrations to the abundance of residential woodstoves in the cities studied. The EPA—which can place controls on woodstoves by requiring scrubbing devices such as catalytic converters—has accepted the Bureau research as definitive, Currie says, and now plans to use the NBS data to validate an analysis method it will use routinely for similar particle measurements.

A cooperative study with Norwegian scientists of particle concentrations in Elverum, Norway, (which also has many homeowner woodstoves) yielded conclusions similar to the EPA/NBS study about wood-created smoke.

What's Next?

Currie says future projects for his group include using the AMS technique to analyze other carbon-based species in the atmosphere. NBS scientists already have taken a step in this direction by examining C-14 concentrations in polycyclic aromatic hydrocarbons (PAH's), which are suspected cancer-causing compounds from sources such as automobile exhaust and combustion of wood and coal.

Also high on Currie's projects list is radiocarbon research at the ice caps in Greenland and Antarctica. Here, he says, is "an archive of the atmospheric processes of the past that would allow us to use radiocarbon dating to produce accurate data about the state of the environment over history."



Dr. Michael Verkouteren uses his custom-designed apparatus to convert gaseous samples into solid elemental carbon for analysis by accelerator mass spectrometry.

In such pristine surroundings, he adds, where atmospheric pollution has drifted to the arctic area and has been trapped by the continual accumulation and compaction of snow, a "time capsule" has formed. Scientists can examine this and determine, for example, the history of ancient fires, or when pollution caused by the Industrial Revolution first appeared (because factory emissions are still trapped there), or when automobile exhaust first entered the environment (fuel particles are still in the polar ice).

"In order to track future pollution trends, we must be able to look at the pollution of the past," Currie says. "And there are no better places than in the polar region. Here, we can apply what we've learned through NBS radiocarbon measurements in urban surroundings to a setting where there is no contamination. For a scientist, this is ideal." J.H.

NEW PUBLICATIONS

COOPERATIVE RESEARCH AT NBS

Cooperative Research Opportunities at NBS, *Natl. Bur. Stand. (U.S.), NBS Spec. Pub. 723, 52 pages (December 1986). Order by sending a self-addressed mailing label to the NBS Office of Research and Technology Applications, A402 Administration Building, NBS, Gaithersburg, MD 20899.*

To accomplish its objective of supplying the measurement foundation for industry, science, and technology, NBS conducts research in many areas, including advanced ceramics, automated manufacturing, optoelectronics, and biotechnology. Numerous opportunities exist for scientists and engineers from industrial, professional, trade, and other organizations to collaborate in research at NBS on projects of mutual interest. This guide explains a variety of successes NBS has had in conducting cooperative research with private companies, universities, and other government agencies. These programs include research consortia, individual Research Associate programs, and joint research centers. In addition, the publication describes specific NBS research projects that are particularly well suited for collaborative ventures and outlines ways cooperative programs can be established.

REPORT ON NBS LARGE-SCALE SEISMIC PROJECT

Cheok, G.S. and Stone, W.C., ***Behavior of 1/6-Scale Model Bridge Columns Subjected to Cyclic Inelastic Loading,*** *Natl. Bur. Stand. (U.S.), NBSIR 86-3494, 291 pages (November 1986). Order by stock no. PB 87-152245 from NTIS, $24.95 prepaid.*

As part of their studies on how full-scale bridge columns perform during earthquakes, researchers at NBS constructed and tested six one-sixth scale replicas of the columns. The results will be used to determine if the behavior of full-scale columns can be extrapolated from model behavior. The first in a series of reports on the project is available and gives a detailed description of the design, fabrication, testing, and evaluation of the model columns. Included among the findings for small-scale columns is that recent California Department of Transportation specifications were sufficient to prevent longitudinal reinforcing bars from pulling out of the footings for all the specimens. Testing of the first full-scale column was completed in July 1986. A second full-scale column is being fabricated at NBS and will be tested this year.

SUMMARIES OF 1986 NBS BUILDING RESEARCH

Wright, R.N., ***Building Technology Project Summaries 1986,*** *Natl. Bur. Stand. (U.S.), NBSIR 86-3490, 67 pages (November 1986). Order by stock no. PB 87-140216 from NTIS, $13.95 prepaid.*

NBS researchers conduct research leading to safer structures which are more economical to build and maintain. They develop technologies to predict, measure, and test the performance of building materials, components, systems, and practices. While NBS does not promulgate building standards or codes, its research is used widely by those in the building industry and government who do have standards and codes responsibilities. This report summarizes recent research projects such as conducting studies on using sound to determine flaws in concrete and studying the behavior of full-scale bridge columns during earthquakes. Other areas covered include computer-integrated construction and building physics and equipment.

ABILITY OF AEC INDUSTRY TO EXCHANGE CAD DATA

Palmer, M.E., ***The Current Ability of the Architecture, Engineering, and Construction Industry to Exchange CAD Data Sets Digitally,*** *Natl. Bur. Stand. (U.S.), NBSIR 86-3476, 31 pages (October 1986). Order by stock no. PB 87-134334/AS from NTIS, $11.95 prepaid.*

The use of computer-aided (CAD) systems in the architecture, engineering, and construction (AEC) industry is increasing steadily. But a recent study at NBS confirms that it is difficult and often impossible to transfer data and drawings from one CAD system to another. Researchers found the primary constraint is a lack of dependable and verifiable methods of exchanging data between different CAD systems. Intermediate formats and translators are available, but, say the NBS researchers, they are not adequate for comprehensive AEC CAD operations. To help resolve the problem, a committee was formed in 1984 to develop specifications for exchanging AEC information as part of the Initial Graphics Exchange Specification (IGES), a national standard since 1981. The IGES/AEC Committee currently is developing additional exchange specifications to be incorporated into the next version of IGES.

CATALOG OF STANDARD REFERENCE MATERIALS

Seward, R.W., editor, ***NBS Standard Reference Materials Catalog 1986-87,*** *Natl. Bur. Stand. (U.S.), NBS Spec. Pub. 260, 154 pages (June 1986). Order from the Office of Standard Reference Materials, B311 Chemistry Building, NBS, Gaithersburg, MD 20899, 301/975-OSRM (6776).*

For 80 years, NBS has been providing scientific, industrial, and commercial users with carefully characterized materials to assess measurement techniques and to calibrate instruments. This catalog lists more than 900 Standard Reference Materials (SRM's) available from the Bureau. These materials are certified by NBS for specific chemical and physical properties to help companies and other users to achieve quality assurance of materials and goods. The SRM catalog includes a description of each reference material, its certified characterization, and unit size. Ordering and shipping information also are included.

SOUND WAVES THAT DETECT FLAWS IN CONCRETE

Sansalone, M. and Carino, N.J., ***Impact-Echo: A Method for Flaw Detection in Concrete Using Transient Stress Waves,*** *Natl. Bur. Stand. (U.S.), NBSIR 86-3452, 234 pages (September 1986). Order by stock no. PB 87-104444/AS from NTIS, $24.95 prepaid.*

NBS researchers have developed a nondestructive method to detect flaws in concrete. Known as "impact-echo," the technique works on the same principle as the sonar pings used to locate and determine the depth of a submarine. An impact on the concrete generates sound waves which are reflected by flaws inside the concrete. A receiver mounted on the surface of the concrete picks up the reflections, or echoes. The location of a flaw is determined by measuring how long it takes to receive the reflected echo. So far, the NBS researchers have successfully used the technique to find artificial flaws embedded in a number of different concrete slabs. In addition, they have been able to detect pockets of unconsolidated concrete and the depth of cracks which are perpendicular to the surface. They also have been able to distinguish a hollow metal duct from one that is filled with grout. The NBS team plans to test the technique on other structural elements such as rectangular beams and round columns.

HVAC PERFORMANCE IN "SMART" BUILDINGS

Persily, A.K., ***Specifications for Thermal and Environmental Evaluations of Advanced-Technology Office Buildings,*** *Natl. Bur. Stand. (U.S.), NBSIR 86-3462, 95 pages (November 1986). Order by stock no. PB 87-134326/AS from NTIS, $13.95 prepaid.*

In this report for the General Services Administration, researchers at NBS describe specifications for evaluating the thermal and environmental performance of advanced-technology buildings. These buildings, sometimes called "smart" buildings, have sophisticated controls for heating, ventilation, and air-conditioning systems. The specifications will help avoid design, construction, and operation errors which may result in buildings which are unsuitable for occupants or which have excessive operating costs. They include ways to measure airtightness and infiltration rates, determine insulation effectiveness, and evaluate indoor pollutant levels. The report describes various diagnostic tests and the materials and equipment needed. It also contains work statements which describe how each test should be conducted, how data should be analyzed, and how the results should be presented. Although the specifications were developed for use on advanced-technology buildings, most of the methods can be used to evaluate other buildings as well.

SUMMARY OF NBS REACTOR ACTIVITIES

Shorten, F.J., editor, ***NBS Reactor: Summary of Activities July 1985 Through June 1986,*** *Natl. Bur. Stand. (U.S.), NBS Tech. Note 1231, 161 pages (November 1986). Order by stock no. 003-003-02787-1 from GPO, $8 prepaid.*

The National Bureau of Standards reactor is a national center for the application of neutron methods to problems of national interest. The reactor power, recently increased from 10 to 20 MW, combined with 25 experimental facilities ranging from intense neutron beams to extensive irradiation facilities, make the NBS reactor one of the most versatile high-performance research reactors in the country. This report summarizes NBS research and collaborative programs conducted at the NBS reactor from July 1985 to June 1986. The programs described range from the use of neutron beams to study the structure and dynamics of materials through nuclear physics and neutron standards to sample irradiations for activation analysis, isotope production, radiation effects studies, neutron radiography, and nondestructive evaluation.

OPTICAL FIBER MEASUREMENTS SYMPOSIUM PROCEEDINGS

Day, G.W. and Franzen, D.L., editors, ***Technical Digest—Symposium on Optical Fiber Measurements 1986,*** *Natl. Bur. Stand. (U.S.), NBS Spec. Pub. 720, 158 pages (September 1986). Order by stock no. 003-003-02772-3 from GPO, $8 prepaid.*

The 1986 Optical Fiber Measurements Symposium, sponsored by NBS, brought together over 300 representatives from 17 countries to present 34 papers. This digest summarizes the 29 contributed papers, which span the full range of measurements necessary to specify an optical fiber, with a heavy emphasis on dispersion and mode-field diameter measurements in single-mode fibers. Also included are abridged versions of the five invited papers which summarize the state of the art and look to related and future measurement problems in the characterization of sources, detectors, specialty fibers, and planar waveguide devices.

NEW CALIBRATION SERVICES USERS GUIDE

Uriano, G.A., Garner, E.L., Kirby, R.K., and Reed, W.P., editors, ***NBS Calibration Services Users Guide 1986-1988/Revised,*** *Natl. Bur. Stand. (U.S.), NBS Spec. Pub. 250, 183 pages (Revised January 1987). Order from the Office of Physical Measurement Services, B362 Physics Building, NBS, Gaithersburg, MD 20899, 301/975-2007.*

Calibration services, special test services, and measurement assurance programs (MAP's) available from NBS are listed in this "users guide." These physical measurement services are designed to help the makers and users of precision measurements achieve the highest possible levels of measurement quality and productivity. The hundreds of individual services described in this guide are the most accurate calibrations of their type available in the United States. These measurements directly link a customer's precision equipment or transfer standards to national measurement standards.

The calibrations and special tests include NBS services that check, adjust, and characterize instruments, devices, and sets of standards. The MAP's are quality control programs for calibrating a customer's entire measurement system. The following measurement calibration areas are listed in the new guide: dimensional; mechanical; thermodynamic; optical radiation, ionizing radiation; and electromagnetic. The guide explains fees, types of services, measurement criteria, reports of test results, references to NBS in advertisements, traceability of calibrations, and shipment of equipment.

ORDERING INFORMATION

To order publications from NTIS, send request with payment to: National Technical Information Service, Springfield, VA 22161. Publications can be ordered from GPO by mailing order with payment to: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. ■

CONFERENCE CALENDAR

4th International Congress on Oxygen Radicals, University of California at San Diego, La Jolla, CA

June 27-July 3, 1987

This congress will deal with free-radical processes and peroxidized products in chemistry, food technology, nutrition, biology, pharmacology, and medicine. The energetics, kinetics, and mechanisms of simple model systems will be applied to complex biochemical processes and clinical medicine. The meeting will also explore the mechanisms of agents that protect against free radicals and peroxy products *in vitro* and *in vivo*. These agents include antioxidants used in materials, food antioxidants, physiological antioxidants, and antioxienzymes (SOD, glutathione, peroxidase, and catalases). Sponsored by NBS. Contact: Michael G. Simic, C205 Radiation Physics Building, NBS, Gaithersburg, MD 20899, 301/975-5558.

MFPG 42: Technology Innovation—Key to International Competitiveness, NBS, Gaithersburg, MD

September 15-17, 1987

Principal economic indicators point to increased foreign competition in the decades ahead. Because productivity growth rates in most major competing nations are higher than in the United States, U.S. government and industry are focusing attention on the impact of technological change on productivity growth. The 42nd meeting of the Mechanical Failures Prevention Group (MFPG) will concentrate on technological innovation, especially for small companies, that results in improved products, processes, and services. They will also examine the need for establishing the communications and linkages required between high-technology companies and the interdisciplinary community of industry, government, and universities.

Sessions being organized will highlight materials, fabrication technology, equipment monitoring, protection of surfaces, mechanics, and machinery. Specific topics will include polymers, ceramics, robotics, instrumentation, and nondestructive inspection. Sponsored by NBS and the Office of Naval Research. Contact: T. Robert Shives, A113 Materials Building, NBS, Gaithersburg, MD 20899, 301/975-5711.

10th National Computer Security Conference, Baltimore Convention Center, Baltimore, MD

September 21-24, 1987

At this year's conference, individuals from government, private industry, and academia will come together in a setting that fosters the sharing of information and the development of valuable relationships. The theme is "Computer Security—From Principles to Practices." In order to present a varied program, the conference will be divided into two tracks of information: technical and general managerial. Attendees may switch between tracks according to their interests. Sponsored by the National Computer Security Center and NBS. Contacts: Linda Muzik, Attn: C421, National Computer Security Center, 9800 Savage Road, Ft. George G. Meade, MD 20755-6000, 301/859-4506 or Irene Isaac, B266 Technology Building, NBS, Gaithersburg, MD 20899, 301/975-3360.

11th International Symposium on Polynuclear Aromatic Hydrocarbons, NBS, Gaithersburg, MD

September 23-25, 1987

This meeting encourages open discussions between scientists representing government, academia, industry, and research facilities investigating the chemical properties and biological effects of polynuclear aromatic hydrocarbons (PAH's). It will include presentations on parent PAH's as well as heteroatomic species and PAH derivatives including amino-, nitro-, and halogen-substituted compounds. Sponsored by NBS, the National Institutes of Health, and the Battelle Memorial Institute. Contact: Dr. Willie E. May, A113 Chemistry Building, NBS, Gaithersburg, MD 20899, 301/975-3108.

Accuracy in Trace Analysis—Accomplishments, Goals, Challenges, NBS, Gaithersburg, MD

September 28-October 1, 1987

This symposium will focus on current trends in quantitative trace analytical chemistry and will provide perspectives on future challenges. The first day will be devoted to plenary sessions that will review the history of quantitative trace analysis, the present situation from academic and industrial viewpoints, and future directions. Key issues will be highlighted in individual talks. Topics will include the following: biomolecules in trace analysis, robotics, chemometrics, process analytical chemistry, expert systems, and reference materials for the future. The remainder of the symposium will consist of parallel sessions dealing with considerations of the measurement process; quantitation in environmental, clinical, and nutrient analyses; and advances in analytical techniques. Sessions directed to the measurement process will specifically consider industrial needs for quality assurance and efficient sample throughput. Sponsored by NBS. Contact: Harry S. Hertz, A309 Chemistry Building, NBS, Gaithersburg, MD 20899, 301/975-3145.

Tenth Symposium on Thermophysical Properties—Call For Papers, NBS, Gaithersburg, MD

June 20-23, 1988

This tenth symposium of the well-established series of conferences on thermophysical properties is concerned with theoretical, experimental, and applied aspects of thermophysical properties for gases, liquids, and solids. Featured topics are: properties of new materials; properties of gaseous and liquid mixtures; new developments in experimental techniques; and interpretation of experimental data in terms of new theoretical developments.

Prospective authors are requested to submit their abstracts (200-300 words) before December 1, 1987, to one of the cochairmen of the symposium: Ared Cezairliyan, Thermophysics Division, NBS, Gaithersburg, MD 20899, USA, 301/975-5931 or J.V. Sengers, Institute for Physical Science and Technology, The University of Maryland, College Park, MD 20742, USA, 301/454-4117. Sponsored by the American Society of Mechanical Engineers, NBS, and The University of Maryland. ■

The National Bureau of Standards was established by an act of Congress on March 3, 1901. The Bureau's overall goal is to strengthen and advance the nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the nation's physical measurement system; (2) scientific and technological services for industry and government; (3) a technical basis for equity in trade; and (4) technical services to promote public safety. The Bureau's technical work is performed by the National Measurement Laboratory, the National Engineering Laboratory, the Institute for Computer Sciences and Technology, and the Institute for Materials Science and Engineering.

THE NATIONAL MEASUREMENT LABORATORY

Provides the national system of physical and chemical measurement; coordinates the system with measurement systems of other nations and furnishes essential services leading to accurate and uniform physical and chemical measurement throughout the nation's scientific community, industry, and commerce; provides advisory and research services to other government agencies; conducts physical and chemical research; develops, produces, and distributes Standard Reference Materials; and provides calibration services. The laboratory consists of the following areas:
- Standard Reference Data
- Measurement Services
- Basic Standards
- Radiation Research
- Chemical Physics
- Analytical Chemistry

THE NATIONAL ENGINEERING LABORATORY

Provides technology and technical services to the public and private sectors to address national needs and to solve national problems; conducts research in engineering and applied science in support of these efforts; builds and maintains competence in the necessary disciplines required to carry out this research and technical service; develops engineering data and measurement capabilities; provides engineering measurement traceability services; develops test methods and proposes engineering standards and code changes; develops and proposes new engineering practices; and develops and improves mechanisms to transfer results of its research to the ultimate user. The laboratory consists of the following centers:
- Applied Mathematics
- Electronics and Electrical Engineering
- Manufacturing Engineering
- Building Technology
- Fire Research
- Chemical Engineering

THE INSTITUTE FOR COMPUTER SCIENCES AND TECHNOLOGY

Conducts research and provides scientific and technical services to aid federal agencies in the selection, acquisition, application, and use of computer technology to improve effectiveness and economy in government operations in accordance with Public Law 89-306 (40 U.S.C. 759), relevant Executive Orders, and other directives; carries out this mission by managing the Federal Information Processing Standards Program, developing federal ADP standards guidelines, and managing federal participation in ADP voluntary standardization activities; provides scientific and technological advisory services and assistance to federal agencies; and provides the technical foundation for computer-related policies of the federal government. The institute consists of the following centers:
- Programming Science and Technology
- Computer Systems Engineering

THE INSTITUTE FOR MATERIALS SCIENCE AND ENGINEERING

Conducts research and provides measurements, data, standards, reference materials, quantitative understanding, and other technical information fundamental to the processing, structure, properties, and performance of materials; addresses the scientific basis for new advanced materials technologies; plans research around cross-country scientific themes such as nondestructive evaluation and phase diagram development; oversees Bureau-wide technical programs in nuclear reactor radiation research and nondestructive evaluation; and broadly disseminates generic technical information resulting from its programs. The institute consists of the following divisions:
- Nondestructive Evaluation
- Inorganic Materials
- Fracture and Deformation
- Polymers
- Metallurgy
- Reactor Radiation

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