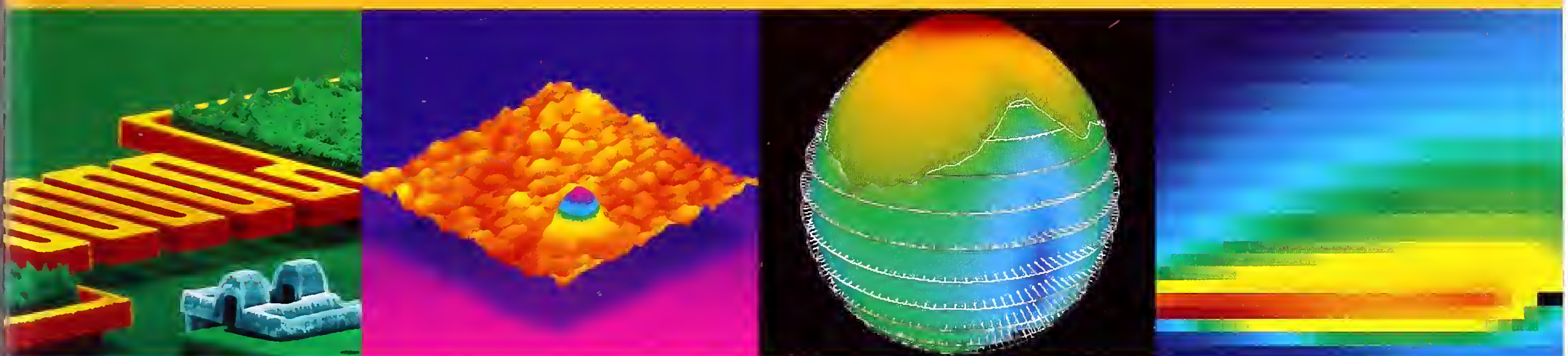
Guide to NIST

National Institute of Standards and Technology



U.S. DEPARTMENT OF COMMERCE
Technology Administration

On the cover:

Computerized graphics of scientific and engineering data are used frequently by NIST researchers to improve understanding of production processes, measurement methods, or scientific experiments. Shown on the cover from right to left are computer-generated graphics of:

- the temperature profile emanating from a fire source;
- measurement points taken by a coordinate measuring machine of a "perfect" stainless steel sphere showing systematic errors in the machine's performance;
- a contaminant particle less than 5 nanometers (billionths of a meter) across that has deposited on a light-sensitive film used in making solar energy panels;
- a polysilicon heater measuring 4 micrometers across used in a NIST-developed miniaturized pop-up switch;
- grid of gold on silicon made with neutral atom lithography;
- scanning electron micrograph of tin spheres;
- moiré pattern used in measuring strain within electronic interconnections; and
- a temperature profile of air flow in the wake of a speeding bullet.

FOREWORD

Greetings! Welcome to your personal printed tour of the National Institute of Standards and Technology (NIST).

NIST is the federal government's multipurpose technology partner for U.S. industry. An agency of the Commerce Department's Technology Administration, NIST promotes economic growth by working with industry to develop and apply technology, measurements, and standards. NIST provides the research, products, services, and cost-shared funding that U.S. industry needs to continually overcome barriers to better, faster, and less expensive products.

NIST carries out its mission through four major programs: the Advanced Technology Program (ATP), the Manufacturing Extension Partnership (MEP), a multidisciplinary laboratory research program, and the National Quality Program. These programs enhance the development, commercialization, adoption, and continual improvement of U.S. technology.

The ATP's cost-shared funding of promising but risky industrial research helps ensure that America's best technology ideas make it to the starting blocks of commercialization, where they can pay off with broad-based benefits for the economy. NIST's laboratory research at the frontiers of measurement science and our efforts to ensure that standards promote international trade provide key elements of the technical infrastructure critical to economic growth. The MEP helps level the competitive playing field for smaller manufacturers, giving them access to business and technology advice and resources previously available only to larger corporations. At the same time, the Quality Program provides inspiration and information to companies, large and small, on how to stay competitive through effective business and quality management.

Created in 1901 as the National Bureau of Standards, NIST devised standard tests of light bulb performance, helped ensure that grocery scales don't shortchange customers, and helped fire fighters ensure that their water hoses will fit the fire hydrants of neighboring jurisdictions—efforts that seem modest by today's standards. NIST's current challenges are far greater and more sophisticated—for example, find ways to measure reliably semiconductor "wires" a thousand times thinner than a human hair, assist the nation's small manufacturers to move up the technology and quality ladder and become more competitive, develop rapid DNA analysis tools, and reduce costs with transparent, interoperable information systems.

This report gathers in one place descriptions of NIST's many programs, products, services, and research projects, along with contact names, phone numbers, and email and World Wide Web addresses for further information. We know that finding information about federal government programs can sometimes be daunting. We hope we've taken the challenge out of your search.

Take a moment now to "tour" NIST programs and see how your organization might work with ours to keep U.S. technology thriving.

Arati Prabhakar

Arati Prabhakar, Director
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HOW TO USE THIS GUIDE

This guide is designed to make finding out about programs and contacts at the National Institute of Standards and Technology a little easier.

The pages that follow describe hundreds of NIST projects, grants, industry outreach programs, services, and facilities, followed by contact names, phone numbers, and mail, electronic mail, and, in some cases, World Wide Web addresses for further information. Unless otherwise noted, all addresses listed are at NIST, Gaithersburg, Md. 20899-0001.

This guide is divided into chapters covering each of NIST's major operating units. In addition, each chapter on laboratory programs includes subheadings for NIST organizational divisions or subject areas.

The Advanced Technology Program provides multiyear, cost-shared funding for high-risk, high-payoff development of civilian technologies by individual companies or industry-led joint ventures. ATP accelerates technologies that otherwise are unlikely to be developed in time to compete in rapidly changing markets without such a partnership of industry and government. See description on page 6.

The Manufacturing Extension Partnership operates a nationwide network of regionally based extension centers that help smaller manufacturers adopt modern technologies and business practices. MEP also aids the development of state-based technology extension efforts and linkages between federal, state, local, and other technology extension efforts. See description on page 28.

The Malcolm Baldrige National Quality Award has become both the U.S. standard of quality achievement in industry and a comprehensive guide to quality improvement. The National Quality Program supplies companies with guidelines and criteria important for establishing successful quality management programs. See description on page 38.

The NIST Laboratory Program develops and delivers measurement techniques, test methods, standards, and other types of infrastructural technologies and services.

Researchers in the NIST Laboratory Program actively seek out industrial and other collaborators to work on well-defined, cooperative research projects of mutual interest. In addition, NIST researchers collaborate informally with industrial and academic researchers to solve shorter-term technical problems. For an overview of the many different ways NIST may be able to work with your organization, see a description of the NIST Laboratory Program beginning on page 40.

A detailed subject index begins on page 156. Due to the interdisciplinary nature of NIST's work, many topic areas appear in more than one chapter. For example, research involving polymers is described in different chapters: polymer processing investigations within the Materials Science and Engineering Laboratory and polymer combustion studies within the Building and Fire Research Laboratory.

This guide attempts to include all major NIST program areas. However, no single report can be completely comprehensive. Institute programs change constantly as new research results and technologies become available. If you don't find a topic area that specifically matches your needs, contact the office for the research area closest to your field of interest. Phone numbers, fax numbers, electronic mail, and World Wide Web addresses are provided within each chapter.

If you review this guide and you're still not sure which office to call, the NIST General Inquiries Unit can probably help you. Contact: General Inquiries Unit, (301) 975-3058; email: inquiries@nist.gov; fax: (301) 926-1630.

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NIST AT A GLANCE

The National Institute of Standards and Technology was established by Congress "to assist industry in the development of technology ... needed to improve product quality, to modernize manufacturing processes, to ensure product reliability ... and to facilitate rapid commercialization ... of products based on new scientific discoveries."

An agency of the U.S. Department of Commerce's Technology Administration, NIST's primary mission is to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. It carries out this mission through a portfolio of four major programs:

- a rigorously competitive Advanced Technology Program providing cost-shared awards to industry for development of high-risk, enabling technologies with broad economic potential;

- a grassroots Manufacturing Extension Partnership with a network of local centers offering technical and business assistance to smaller manufacturers;

- a strong laboratory effort providing technical leadership for the nation's measurement and standards infrastructure; and

- a highly visible quality outreach program associated with the Malcolm Baldrige National Quality Award.

BUDGET
$810 million
(FY 1996 estimated operating resources from all sources)

STAFF
About 3,300 scientists, engineers, technicians, and support personnel, plus some 1,200 visiting researchers each year

SITES
Gaithersburg, Md. (headquarters—234-hectare campus) and
Boulder, Colo. (84-hectare campus)

MAIN RESEARCH AREAS IN NIST LABORATORIES
Electronics and electrical engineering
Manufacturing engineering
Chemical science and technology
Physics
Materials science and engineering
Building and fire research
Information technology

ADDITIONAL SOURCES OF INFORMATION
NIST issues more than 480 publications each year, such as reports on research results and standards, catalogs of products and services, and technical handbooks. NIST staff also author about 1,700 technical journal papers. To locate current and past Institute publications, call the General Inquiries Unit at (301) 975-3058.

The Institute also publishes serial publications. *The Journal of Research of the National Institute of Standards and Technology* reports NIST research and development results in physics, chemistry, engineering, mathematics, and information technology, with major emphasis on measurement methodology and basic technology underlying standardization. Issued bimonthly. Subscription price: domestic—$28 per year, foreign—$35 per year. Contact: (202) 783-3238.

Technology at a Glance is a four-page, lay language newsletter providing brief updates on NIST research, grants, and other program activities, with a contact name for each topic covered. Issued quarterly. Free subscription. Contact: Gail Porter, (301) 975-3392.

News and general information about NIST programs and services are available on the World Wide Web at http://www.nist.gov. The NIST homepage provides links to major NIST programs, facilities, and services. In addition, the site has a conference/workshop calendar, tour information, a staff directory, press releases, budget updates, congressional testimony, and answers to some frequently asked questions.

Click on "NIST in Your House," to take a tour of a house and find out where NIST research has had an unseen role. To find the NIST connection, you can click on items such as a smoke detector, watt-hour meter, clock, refrigerator, and medicine chest.

FREQUENTLY REQUESTED NUMBERS

General Inquiries
(301) 975-3058

Advanced Technology Program
(800) ATP-FUND

Manufacturing Extension Partnership
(301) 975-3593
(800) MEP-4MFG for center serving your area

Malcolm Baldrige National Quality Award
(301) 975-2036

Laboratory Programs:

Electronics and Electric Engineering
(301) 975-2220

Manufacturing Engineering
(301) 975-3400

Chemical Science and Technology
(301) 975-3145

Physics
(301) 975-4200

Materials Science and Engineering
(301) 975-5658

Building and Fire Research
(301) 975-5900

Information Technology
(301) 975-2900

Technology Services:

Standards Information Center
(301) 975-4040

Weights and Measures
(301) 975-4004

Laboratory Accreditation
(301) 975-4016

Industrial Partnerships
(301) 975-3084

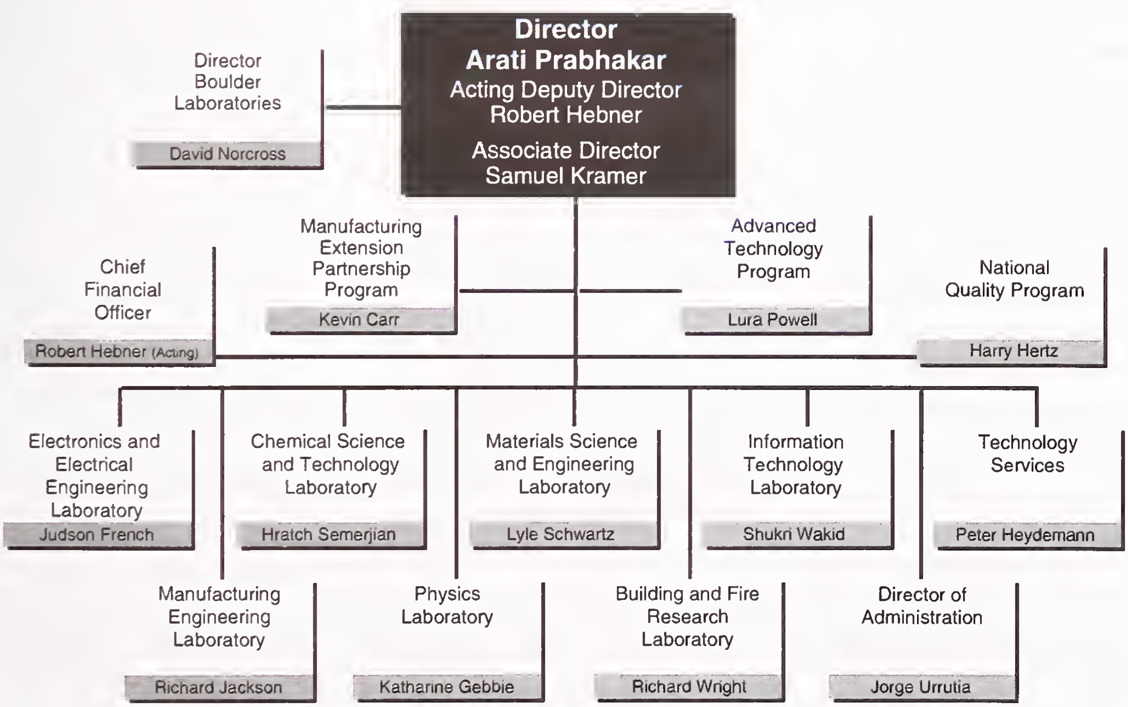
Standard Reference Data
(301) 975-2008

Standard Reference Materials
(301) 975-6776

Calibrations
(301) 975-2002

Technology Evaluation
(301) 975-5500

NIST Organization



ADVANCED TECHNOLOGY PROGRAM

Overview

Not-yet-possible technologies are the domain of the NIST Advanced Technology Program. The new synthetic materials technology that *might* revolutionize the auto industry—if the processing variables can be identified and controlled. The new polymer that can be used as a drug, binding and neutralizing disease-causing pathogens—if the design and manufacturing issues can be overcome. The new concept in distributed information systems that could both cut costs and potentially save lives in the nation's hospitals—if the proper software tools can be developed to make it cost effective on a large scale.

The ATP is a unique partnership between government and private industry to accelerate the development of high-risk technologies that promise significant commercial payoffs and widespread benefits for the economy. The ATP works by encouraging a change in how industry approaches R&D, by providing a mechanism for industry to extend its technological reach and push out the envelope of what can be attempted.

Major forces—globalization of markets and the pace of technology change—continue to drive private R&D to narrower, shorter-term investments to maximize returns to the company. Most private capital is reluctant to invest in anything less than a "sure thing" in terms of its own returns. In sharing the relatively high development risks of technologies that potentially enable a broad range of new commercial opportunities, possibly across several industries, the ATP fosters projects with a high payoff for the nation as a whole—in addition to strong corporate rates of return. The nature of ATP projects, risky but broadly applicable, stimulates joint research ventures that link small suppliers with users, or that link several firms together to solve a generic problem common to all.

The ATP has several critical features that set it apart from other government R&D programs:

- The goal of the ATP is economic growth and the good jobs and quality of life that come with economic growth—opening new opportunities for U.S. business and industry in the world's markets by fostering enabling technologies that will lead to new, innovative products, services, and industrial processes. For this reason, ATP projects focus on the technology needs of U.S. industry, not those of government. The ATP is industry driven, which keeps the program grounded in real-world needs. Research priorities for the ATP are set by industry: for-profit companies conceive, propose, co-fund, and execute ATP projects and programs based on their understanding of the marketplace and research opportunities.

- The ATP does not fund product development. It supports enabling technologies that are essential to the development of new products, processes, and services across diverse application areas. Private industry bears the costs of product development, production, marketing, sales, and distribution.

- ATP awards are made strictly on the basis of rigorous competitions designed to select the proposals that are best qualified in terms of the technological ideas, the potential economic benefits to the nation (not just the applicant), and the strength of the plan for eventual commercialization of the results. Expert reviewers (without conflicts of interest) drawn from the business community, government, and academe carefully examine and rate each proposal according to published selection criteria that focus on both business and technical potential.

- The ATP has strict cost-sharing rules. Joint ventures must pay at least half of the project costs. Single companies working on ATP projects must pay all indirect costs associated with the project. (This provision encourages small companies, particularly start-ups, that often have much lower overhead rates than large firms.)

- ATP support does not become a perpetual subsidy or entitlement—each project has goals, specific funding allocations, and completion dates established at the outset. Projects are monitored and can be terminated for cause before completion.

- The ATP benefits companies of all sizes. ATP funding stimulates companies of all sizes to take on greater technical challenges with larger, broader, and faster payoff potential for the nation—benefits that extend well beyond the innovators—than they could or would do alone. For smaller, start-up firms, early support from the ATP can spell the difference between success and failure. To date, nearly half (46 percent) of the ATP awards have gone to individual small businesses or to joint ventures led by a small business. Large firms can work with the ATP, especially in joint ventures, to develop critical, high-risk technologies that would be difficult for any one company to justify because, for example, the benefits spread across the industry as a whole. Universities and non-profit independent research organizations also play significant roles as participants in ATP projects. More than 100 different universities are involved in about 150 ATP projects as either joint-venture participants or subcontractors.

- Since its inception, the ATP has made economic evaluation of the outcomes of ATP projects a central element of its operations. The ATP has developed and implemented a thorough measurement program that pushes the state of the art in evaluating the long-term outcomes of R&D investment.

AN ATP PROJECT SAMPLER

The ATP portfolio is highly diversified. The 280 projects selected in the first 22 competitions span a broad array of key technologies, with particular concentrations in information technology, electronics, biotechnology, and advanced materials. These awards committed a total of $970 million in ATP funds and $1 billion in cost-sharing funds from industry (assuming all projects are pursued to conclusion). Nearly 800 companies, universities, independent non-profit research organizations, and government laboratories already have participated in ATP projects. Several hundred additional organizations have participated as subcontractors and strategic partners.

Some typical projects include:

- A new technology for microsoldering tiny leads on integrated circuits, developed by MicroFab Technologies, Inc. (Plano, Texas), that essentially is ink-jet printing with molten metal instead of ink. The new soldering technology promises to increase greatly productivity and flexibility in the production of circuit boards and significantly reduces hazardous wastes. The ATP award enabled the small 18-person company to attract additional funding for product development from a consortium of six major electronics manufacturers.

- A radically new approach to treating gastrointestinal diseases such as human rotavirus, which causes diarrhea in children, and *Cryptosporidium parvum*. No effective therapy currently exists for either disease, but GelTex Pharmaceuticals, Inc., a Massachusetts company, is exploring the use of specially tailored polymers that are not absorbed by the body but rather unfold in the gastrointestinal tract like tiny molecular nets to selectively trap pathogens or their toxins.

- A technique for using laser holography to "write" very high resolution optical elements such as filters in the interior of crystals. Under development by Accuwave, a small California company, the technology has potentially far-reaching applications in the rapidly growing fiber-optics communication industry. Specifically, the work is aimed at producing a wavelength division multiplexing system that would allow several independent communications channels to share the same optical fiber at the same time, thereby increasing the capacity of a single optical fiber many times over current practice. In 1994 the company introduced three new products, early spin-offs of the ATP-sponsored technology: an optical network monitor, a wavelength standard, and a "wavelength locker." In 1995, the company added a fourth spin-off, an electronic wavelength controller. The new devices, not much bigger than matchboxes, replace a benchtop of lab equipment costing tens of thousands of dollars.

- Groundbreaking computer modeling technology for a "virtual human." The work of an Iowa firm, Engineering Animation, Inc. (EAI), this 3-year project developed computer visualization technology with broad potential applications in medicine, engineering, and product development. As a result of that work, the company was able to establish alliances with Johns Hopkins University, the National Library of Medicine, Silicon Graphics, and Hewlett-Packard. The company has grown from fewer than 20 employees to 150 full- and part-time employees, and revenues have doubled every year since receiving the award. EAI attributes 14 percent of its business since 1992 to the core technology developed under the ATP.

- An innovative technique to create "prosthetic tissue" from animal by-products. Under development by Tissue Engineering, Inc., a small start-up company in Massachusetts, the tissue substitute would be processed and woven like a cloth to make biodegradable implants that would serve as matrices where the body's own cells could grow and eventually replace damaged tissues. The research is at the leading edge of the infant science of tissue engineering, integrating advanced technologies in cellular biology and textile manufacturing. This ATP project already has opened up a whole new range of reconstructive treatments for damaged periodontal, connective, and vascular tissues and created a line of products for the research and testing markets.

- A novel high-speed, high-capacity optical data storage system developed by Optex Communications, a small Maryland company. Using quantum-electronic rather than thermal effects, the Optex drive is aimed at achieving much higher recording and reading rates than conventional technologies allow. This improved performance will enable new markets in digital video and other information technologies. The Optex work also resulted in a new type of data encoding allowing higher data densities in its system.

Competitions

Until 1994, the ATP used general competitions open to proposals in all areas of technology as its sole investment mechanism. Since then, the ATP has added another element to its investment strategy—focused program competitions. Each type of competition has its unique advantages. General competitions ensure that all good ideas receive consideration, no matter what the technology area. Focused programs create a mechanism to provide critical-mass support for high-risk, enabling technologies in particular technology areas identified by U.S. industry as offering especially important opportunities for economic growth.

An ATP focused program identifies a specific set of research and business goals to be reached within a specific time—typically about 5 years. Often these require the parallel development of a suite of interlocking R&D projects. By managing groups of projects that complement and reinforce each other, the ATP reaps the benefits of synergy and, in the long run, can have a stronger impact on U.S. technology and the economy.

Focused programs are developed in response to specific suggestions received from industry and academia. In the form of white papers, the proposals outline a specific technology area and describe the potential for U.S. economic benefit, the technical ideas available to be exploited, the strength of industry commitment to the work, and the reasons why ATP funding is necessary to achieve well-defined research and business goals.

Areas that attract particularly strong interest—30 or more white papers from different sources proposing the same general effort are not unusual—then are developed further through discussions with industry, meetings, workshops, and other interactions.

Within a focused program, the ATP holds special competitions open only to project proposals that would advance the goals of the specific program. Specific projects are selected through the normal ATP competitive review process.

The ATP has received over 1,000 white papers suggesting specific focused program areas. Drawing from 304 of the white papers, ATP has established 11 focused programs to date.

Focused Program Descriptions

Information Infrastructure for Healthcare

The healthcare industry has a pivotal role in the economic health of the country, and information has a pivotal role in healthcare—conservative estimates figure 20 percent of today's healthcare costs are related to the processing of information. Using effective information technology systems in the healthcare industry can deliver substantial cost savings while also strengthening an important sector of our industry. On the other hand, continuation of today's segmented applications of information systems to healthcare will only move the industry further from the possibility for a seamless information infrastructure.

The ATP Information Infrastructure for Healthcare program will develop technologies at each of three consecutive levels:

- technologies to form the foundation of a private-sector-driven, nationwide information system, including tools for enterprise integration, domain identification, and business process modeling;
- technologies to make such a system efficient and user friendly, including computerized knowledge-based systems, digital libraries, and natural language processing; and
- applications that directly meet healthcare users' needs, such as clinical decision support systems and consumer health information and education systems.

Existing multimillion-dollar programs of research in healthcare information technology lack the coordination and integration necessary to share information nationwide. For example, individual hospitals are developing or installing their own information technology systems without knowing how to make sure that they will be connected seamlessly to the national healthcare enterprise. These institutions run the risk of investing huge resources in systems that will limit inherently the ability of others—including suppliers, insurance companies, and non-affiliated physicians—to make the best, most efficient use of the information contained in those systems. Furthermore, they miss out on the economies of scope that a more systematic approach to healthcare information systems would bring.

The Information Infrastructure for Healthcare program builds on major industry consortia that in the past 3 years have begun to address the very complex interoperability issues related to a national information infrastructure for healthcare. These consortia include the Computerized Patient Record Institute, Microelectronics and Computer Technology Corporation's Healthcare Open System Trials program, and the National Healthcare Industry Consortium. Although member companies do research on individual technologies, ATP funding is needed to catalyze development of an infrastructure that will connect these islands of automation.

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Component-Based Software

Paradoxically, the most visible portion of the software market—the shrink-wrapped accounting spreadsheet programs for home and office, word-processing programs, entertainment software, and other offerings in computer stores—represents only a relatively small fraction of the domestic installed base of software. The vast majority of business-critical software development activity is in major custom applications: complete systems for financial services, manufacturing, or chemical processing, for example.

This custom software industry bears a strong resemblance to many industries of the early 19th century—virtually all of the products are expensive, hand-crafted, error prone, one of a kind. Large industrial software systems tend to be monolithic. Individual pieces of the system cannot be reused easily (except possibly in the same company) because of the close cooperation required between the programmer and the systems integrator. Object-oriented technology and computer-aided software engineering tools have helped but have not provided the complete solutions to these problems. By most estimates, over half of all large application development projects in this industry end in failure—after all the time and money is spent, the product still cannot be used operationally.

The goal of the ATP Component-Based Software program is to develop the technologies needed to enable systematically reusable software components—relatively small, carefully engineered software elements suitable for a broad array of applications. These technologies would enable software companies to build specialized components that can be sold to systems integrators and custom builders, who would combine them with other, largely purchased, off-the-shelf components to create high-quality custom applications. Software tools would automatically match components to applications systems, ensuring compatibility and reliability. Numerous sources of cost and error in application development would be eliminated.

Major applications would no longer be large monolithic structures built from the ground up but rather assemblies of smaller components, competitively purchased from vendors who would have the specialized skills to concentrate on issues such as domain- and industry-specific knowledge, quality, and reliability for the components they provide.

The technical goals of the Component-Based Software program include:

- Enabling practical, automated composition of major software applications based on semantic analysis of independently produced components—thus enabling systematic reuse of the components.
- Developing automated tools and methods for component-based software to expand the portion of the process that can be automated and thus reduce the need for error-prone, hand-crafted solutions.
- Developing necessary technologies to overcome other barriers to the widespread use and reuse of software components. This includes:
    - New linguistic methods to allow for imprecise or incomplete specifications of functionality, performance, and other software characteristics.
    - Robustness—so that critical systems can continue to perform in the presence of errors.
    - Improved methods of confirming software dependability.

In the long run, an established software-components industry would provide a rapid, responsive channel for marketing software innovations, while constantly improving quality, reliability, and capability, in much the same fashion that the semiconductor component industry has constantly reduced cost and improved performance of computer chips since the invention of the integrated circuit, through rapid infusion of technical innovations.

The structure of the software industry and the demand for business-critical software adapted to the needs of changing industries provide strong reasons for ATP support of the Component-Based Software program:

- The Component-Based Software program addresses problems—including quality, development time, cost, interoperation, labor intensity, and the lack of a viable software-components industry—which are pervasive throughout all large-scale software developments, but it involves broad-based solutions and significant technical risks that are beyond the scope of any one company or project.
- Component-based software will put new capabilities in the hands of content providers or application experts, which will allow businesses to concentrate on areas of core expertise. Businesses will not have to expend resources supporting and maintaining non-business-critical system components.
- Software is a key element of the technology infrastructure, so ATP funds in this area are highly leveraged. New and better software-development capabilities will allow industries to supply new products and services utilizing software and to improve productivity through enhanced automation. Component-based software projects are addressing key industries such as manufacturing, finance and banking, and healthcare.

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Digital Video in Information Networks

As computers become multimedia workstations, as television moves to high-definition digital formats, and as telephony takes on elements of both, information technologies are merging in unprecedented ways. The industries that are creating information networks fully expect digital video to be an essential element of this convergence. And they anticipate huge annual markets for digital video—in the range of hundreds of billions of dollars—for phone, pay-per-view movies, home shopping, financial, educational, and other services that will include a video component. The overwhelming economic benefits from genuinely interoperable digital video technology stem from expanded and more attractive capabilities and services on the user end of the information framework. The categories of entertainment, manufacturing, education and training, and health services alone account for several trillion dollars of commerce. Industries that distribute information and make, sell, and integrate network equipment account for another few hundred billion dollars of economic activity.

Crucial technology decision points regarding convergence and digital video are arriving with disconcerting rapidity. One key issue is precisely how video-based information will be digitally packaged and distributed in an information network in which the producers of the video products, the distributors of the information, and its users all employ a diversity of processing, transmission, and receiving components. The ideal is that any video-based information product—whether it be motion pictures, television programs, educational material, or healthcare information—can travel via wire, optical fiber, satellite, or broadcast seamlessly into regular TVs, high-definition TVs, computer monitors, and other information appliances at homes, factories, hospitals, and schools.

To develop truly interoperable digital video capability across future information networks means creating R&D structures under which distinctly different industries with different histories, technology bases, and approaches to standards development can work together toward the goal of interoperability between and among network components. Individual companies already have begun facing challenges such as finding means of greatly compressing the enormous amount of data that video information requires while maintaining image quality and remaining cost effective. Under the ATP focused program, many companies will be able to coordinate their efforts so that the collective outcome will be far more valuable for everyone on all sides of the information network. The ATP focused program will fill a critical R&D gap, establishing a long-term program involving both industry and government to facilitate development of an interoperable infrastructure, address intellectual property rights, support R&D in interoperable systems, and establish pilot programs to demonstrate and apply advanced video technology.

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Technologies for the Integration of Manufacturing Applications

Companies in every manufacturing industry face the challenge of responding rapidly to changing markets and evolving business opportunities. Today, the speed with which new products are developed and delivered to market often is the chief determinant of competitive success. However, even highly automated plants and factories struggle to overcome difficulties in adapting or reconfiguring production operations to accommodate design changes and new product lines. Peculiarities in manufacturing software and incompatibilities among software applications, which necessitate customized systems-integration efforts, often are the primary sources of costly delays.

The overall technical goal of the ATP focused program on Technologies for the Integration of Manufacturing Applications (TIMA) is to develop and demonstrate the technologies needed to create affordable, "integrable" manufacturing systems—those that can be rapidly integrated and reconfigured and, in the long run, that can automatically adjust their performance in response to changing conditions and requirements. If successful, TIMA will enable greater speed and agility among U.S. companies in the discrete manufacturing sector. Technical work carried out under the program will facilitate industry-led efforts to create a real-time, "plug and play" manufacturing software environment.

Discrete manufacturing includes some of the largest industries in the United States, such as electronics and transportation, and represented over $1 trillion in sales and accounted for well over one-third of all manufacturing jobs in 1991. Since this focused program also will affect discrete operations within the process industries, the government investment can be leveraged into savings totaling in the billions. The TIMA technologies potentially will benefit companies across a range of industries.

A major roadblock for most firms is the costly, massive effort required to implement and integrate information systems that share real-time manufacturing data throughout organizations. Factory-floor information systems communicate neither directly nor regularly with front-office information systems dedicated to accounting, forecasting, and other resource planning activities, or with design and engineering systems. Middle-level information systems, known as Manufacturing Execution Systems (MES), bridge this critical information gap between upstream and downstream activities. Today's MES solutions, however, are burdened by complexities that make them difficult to implement and integrate and, often, even more difficult to modify and upgrade. While these tasks are important to the management and operation of all manufacturing businesses, only a small fraction can afford the cost of installing and maintaining an integrated MES solution, estimated to run between $400,000 and $1 million. The sizable costs incurred for maintenance and systems integration work required to upgrade or otherwise change the system place MES further out of the reach of smaller manufacturers.

The TIMA program aims for "integrable MES" that can be assembled from piece-like and reusable components to build comprehensive, system-wide surveillance and reporting. But unlike existing approaches, integrable MES will be more comprehensive, and it is expected to accommodate rapid customization, incremental installation, as-needed reconfiguration, and enhanced information flow throughout the enterprise. There are numerous technical barriers, some owing to the complex nature of real-time data, which must be overcome to achieve manufacturing execution system interoperability in a general and reusable manner.

The technologies that the TIMA program supports are primarily infrastructural: they constitute an underlying foundation required to enable and support important applications of information technology to manufacturing. Individual companies also do not have the capabilities needed to develop the full collection of underpinning technologies. The MES industry is too fragmented for any one vendor's integration approach to dominate the marketplace, or for any one vendor to invest substantial resources in the uncertain prospect of establishing its technology as an industry standard. Playing the role of catalyst, ATP can help MES vendors and manufacturers to overcome this impasse, to focus their collective expertise, and to concentrate some of their resources on surmounting the barriers to developing integrable MES architectures and applications.

The TIMA program expands and replaces an earlier ATP focused program on Computer-Integrated Manufacturing for Electronics, which was announced in April 1994. Based on the results of the first competition and extensive consultations with industry, ATP managers decided the original program was focused too narrowly to attract the desired generic, broadly enabling R&D projects.

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Tools for DNA Diagnostics

Research on deoxyribonucleic acid (DNA), accelerated by the Human Genome Project, is providing deep new insights into now poorly understood biological phenomena and diseases and into new treatments for genetically based ailments. The biotechnology industry expects that it will become both the impetus and basis of new multibillion dollar markets stemming from DNA-based diagnostic tests.

According to industry projections for 1997, the DNA-based portion of the in-vitro (outside of the body) diagnostics industry is expected to reach into the vicinity of $500 million of a total estimated market of well over $18 billion, up from a $58 million portion of an estimated $5 billion market in 1992. By 2005, DNA probes are expected to account for $6 billion, or 15 percent, of a $40 billion in-vitro diagnostics market. At the moment, the United States enjoys a lead position in this ever more global industry.

Reaping the full potential of DNA technology will require the development of new methods, instruments, and data-handling protocols. The ATP focused program on Tools for DNA Diagnostics seeks to speed up the process of DNA analyses and sequence interpretation by a factor of 10 and reduce costs from one-tenth to one-hundredth of the present price tag (which is in the range of $100 or more per test). Meeting these goals will help U.S. companies maintain their advantageous position in the coming years of the biotechnology revolution. The industries and technical areas that stand to benefit from the program include healthcare, forensics, biomedical research, environmental monitoring and bioremediation, toxicology, drug design, industrial bioprocessing, animal husbandry, agriculture, and quality control in the food industry.

The initial goal of the Tools for DNA Diagnostics program is to develop cost-effective methods for sequencing, interpreting, and storing DNA sequences for diagnostic applications ranging from healthcare to agriculture to environmental monitoring. Moreover, these methods need to be highly automated, miniaturized whenever possible, easy to use, and inexpensive as well as able to determine and analyze DNA sequences accurately and rapidly. A working system meeting these criteria might begin with the injection of a sample into a cassette, which then would be positioned automatically into an instrument that performs the sequencing and stores the results. These results then could be displayed immediately on a computer screen and transferred to a patient's records. By the end of the ATP focused program, industry should have the technical tools and know-how in hand with which they can design, engineer, and produce commercial products like this one.

The ATP program on DNA diagnostics can leverage existing government investments in DNA research to achieve the aim of low-cost DNA diagnostic technologies on a much larger scale. It can help U.S. industry to maintain its global leadership in the biotechnology industry. The Human Genome Project is a vital investment in the research that produces the maps and sequences. But it does not support technology development for diagnostics, which ultimately must be more user friendly and automated than state-of-the-art instruments for basic research in the laboratory setting.

At the moment, companies that are well positioned to develop DNA diagnostic tools are often hesitant to push forward without additional government support because any of a number of competing analytical methodologies could turn out to be the most suitable for DNA diagnostics. Betting on one technology, which is all that most companies could hope to do, is too much of a gamble. The ATP Tools for DNA Diagnostics program both reduces and dilutes that risk. The payoff could be the technology base for a new multibillion dollar industrial base in the United States that will keep the country on top in gene biotechnology and widen its scope of industrial applications.

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Catalysis and Biocatalysis Technologies

Catalysts transform vast reservoirs of chemical feedstocks into products like nylon and polyethylene polymers, themselves the industrial starting point for thousands of products ranging from milk jugs and mountain-climbing rope to toys and textiles. Catalysts, along with their biologically derived forms known as biocatalysts, sculpt chemical precursors into the precise molecular shapes that are the heart of many pharmaceuticals. Catalysts are becoming ever more central to the competitiveness of individual products, companies, industries, and countries. Those who develop new cost-effective catalysts and biocatalysts that improve the yields of products, cheapen or simplify processes, enable vendors to meet customers' needs more quickly and precisely, open up attractive products previously too costly for the marketplace, or reduce the amount of pollution produced during manufacturing processes will gain clear competitive advantages.

In economic terms, catalysts add an estimated $2.4 trillion of value worldwide to raw chemical ingredients as scores of industries transform them into petroleum products, synthetic rubber and plastics, food products, chemicals, and pharmaceuticals, or as they control vehicle and industry emissions. In the United States, over 20 percent of all industrial products, an annual value of $500 billion, involve catalysis. The worldwide market for catalysts themselves, which come in forms as disparate as biological enzymes (specialized proteins) to fine metal powders to complex inorganic compounds called zeolites, amounted to about $7.8 billion in 1993 and is expected to rise to nearly $11 billion by 1998.

The overall goal of the cost-shared ATP focused program in catalysis and biocatalysis technology is to accelerate industry's own long-term attempts to develop the analytical tools, synthetic abilities, and theoretical insight to identify, design, and implement new catalytic tools and processes of major economic importance. Program technical goals focus on the general areas of catalysis process chemistries—catalyst design and fabrication and catalytic process design.

Major tasks in catalysis process chemistry include:

- reducing to routine the use of structure/function knowledge for designing catalysts and associated process and products;
- developing innovative catalyst characterization and design technologies;
- developing novel approaches to speed design and increase reliability of catalyst manufacturing techniques;
- developing unique and innovative approaches to extend significantly catalyst yield, selectivity, life, or operational stability by more than 20 percent over current practice; and
- developing catalysts that greatly simplify process chemistry and/or improve environmental performance beyond current practice or regulatory trends.

Major tasks in catalytic process design include:

- developing novel reactor engineering designs coupling reaction and transport properties, reaction and product separation, or other innovative process couplings;
- developing advanced scale-up methods—reducing pilot steps, speeding process model validation, and improving reliability;
- improving prediction of end-use product properties through catalyst design and process models; and
- enhancing or maintaining product performance in catalytic processes while feedstock quality is reduced or feedstocks shift to renewable resources.

Leap-frog advances in catalysis of the sort targeted in this ATP focused program can come only from research of uncommon technical difficulty. At the bottom of every catalytic process are complex physical and chemical dramas playing out on tiny scales, often at blindingly fast speeds and under surveillance-unfriendly conditions common in industrial processes, factors that traditionally have made scientific study and design of catalysis technologies extremely challenging, costly, or technically impossible. Just as important, the program will forge novel liaisons for catalysis technology research that would not have formed without the collective participation of many companies throughout the program's planning and implementation.

Improving catalysts and catalysis processes promises several important payoffs downstream in manufacturing. New catalysts that are more precisely designed than ones in present use can maximize desired products while minimizing byproducts, or can produce the same products using less expensive feedstocks. They can even replace feedstocks based on non-renewable and depletable resources, such as petroleum, with renewable ones, such as grains or switch grass. New catalysis processes also could eliminate manufacturing steps and lower capital retrofit, energy, or operating costs, as well as increase capacity and product yield.

Another payoff, one that analysts predict will grow in relative importance in the coming years, will come from catalysis technologies that reduce pollution by obviating the need for organic solvents, eliminating troublesome byproducts that subsequently need to be recycled or disposed of, or converting pollution that is produced during manufacturing processes into valuable co-products or more benign forms. Pollution prevention and abatement catalysts like these will play increasingly large roles in reducing the costs of environmental compliance while making products more attractive to environmentally concerned clientele.

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Manufacturing Composite Structures

Composite materials—plastics, for example, reinforced with glass, polymer, or carbon fibers—have opened the possibility of a true materials revolution in industry. Advanced composites technology can produce materials that far outperform traditional materials such as steel while reducing weight, maintenance expenses, and operating costs of cars, bridges, offshore oil rigs, and other structures. But the development of advanced composites—which typically combine the lightness of a polymer with the stiffness and strength of glass reinforcing fibers—has been driven by the needs of the defense industry, stressing performance and traditionally ignoring cost.

The ATP focused program in Manufacturing Composite Structures was established to help U.S. companies develop the technical capability for producing vast amounts of affordable high-performance composites for large-scale *commercial* applications. The ability to produce commercial quantities of high-performance composites at competitive prices will open new annual markets in the range of tens of billions of dollars to U.S. companies, according to industry projections. Auto manufacturers alone estimate that composites orders for building lighter weight vehicles that consume less fuel could go as high as $20 billion.

Methods of manufacturing composites now are too labor intensive or too product specific to work smoothly in larger volume commercial settings such as auto manufacturing and bridge building. The ATP program is working to correct that with an ambitious program to:

- develop low-cost manufacturing processes;
- integrate design and simulation tools for predicting the properties and reliability of the composites during their service lifetimes; and
- develop advanced sensor technologies—some built directly into the composite structures where they will monitor the health of the composites throughout their manufacturing phases and lifetimes.

These and other advances also should lower the cost of designing with composites since fewer prototypes will have to be built and tested. The ATP focused program is the means to trigger expansion of advanced composites beyond military applications and small commercial niches, such as sports equipment, into much larger commercial markets. Most federal support (which accounts for more than half of all R&D in advanced polymer matrix composites) focuses on aerospace and military structures. That, together with the inherent risk of developing new materials in markets where traditional materials have been used for decades, has kept private investment in non-military applications to a trickle.

The ATP effort is enabling U.S. industry to develop advanced composites, whose technological advantages have been demonstrated in military and aerospace applications, into a sound and expansive business for known commercial markets where the cost of these materials has kept them out of reach. By the end of the program, participants should be able to demonstrate cost-effective manufacturing processes for making large composite structures for several classes of applications and be in a position to develop and adapt those processes for commercial-scale production.

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Materials Processing for Heavy Manufacturing

Members of the heavy manufacturing "food chain"—materials suppliers, materials processors, processing equipment manufacturers, component manufacturers, and original equipment manufacturers—estimate that they could achieve up to $25 billion in additional market share in the next decade if they could more economically translate new laboratory developments in materials processing to the robust, cost-effective systems need for the production floor. These are the industries that compete for $1 trillion worth of global infrastructure work, which supports a $100 billion annual worldwide market in heavy off-road equipment that is expected to double early in the next century. They compete to supply equipment for large power plants, a $45 billion worldwide market each year, which is growing at a rate of 2 percent per year. The same set of industries competes for the annual $60 billion domestic market in vehicular engines, power trains, and chassis of vehicles, which also is growing at a 2 percent annual rate.

The primary technical goal of the cost-shared ATP focused program in Materials Processing for Heavy Manufacturing is to develop and demonstrate innovative materials-processing technologies that will help U.S. companies in the heavy manufacturing sector make longer lasting, more reliable, and more efficient products, features that will give their products a competitive advantage in the marketplace.

Truck engines that need overhauls only after 1,600,000 km (1 million miles), drive trains that require only half as much maintenance and repair, and a 2 percent increase in power-generation efficiency are among the specific goals. One versatile tactic for achieving these and other ends is to develop surface treatments and coatings that make ceramic and metal components more resistant to wear, corrosion, fatigue, or temperature-mediated degradation.

Another key technical goal is to significantly reduce manufacturing costs, a factor that will enable U.S. manufacturers to offer passenger cars, light trucks, and heavy equipment at prices that will make them especially attractive in the rapidly growing and highly competitive markets of developing countries. Some of the major strategies for lower manufacturing costs are the elimination of processing steps, the prevention of waste and pollution, and the reduction of manufacturing cycle time. One specific tactic to increase efficiency is to implement "intelligent processing" methods in which on-line monitoring and real-time process control enable manufacturers to tune their process continuously to maximize efficiency and quality. A way to reduce manufacturing time is through more intensive process modeling and rapid prototyping techniques, which also can make it possible to concurrently engineer several process steps rather than having to wait for the completion of earlier steps before focusing on later ones. Among tactics to prevent, control, and minimize waste and pollution are the conversion of steel waste into cement and concrete feedstock and the recovery of iron from the dust and slag of steel making.

These projects typically fall under the high-risk category that companies cannot pursue amid more immediate challenges. In addition, this ATP focused program will forge new forms of vertical integration among companies, thereby creating versatile technology development and commercial infrastructures that will outlast the ATP program itself.

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Vapor Compression Refrigeration Technology

Manufacturing of air-conditioning and refrigeration equipment in the United States alone each year amounts to a $22 billion industry, which is about 40 percent of the world's production, and employs about 125,000 people. Conventional technology, however, is falling short on enough engineering, environmental, consumer, and technological fronts that refrigeration and air-conditioning engineers have entered an innovate-or-wither phase. According to industry projections, new demand for air-conditioning and refrigeration products by developing countries will fatten the global market by an estimated $150 billion over the next 10 years. With competition from Japanese makers, who now win 40 percent of the market, and from those in Europe, China, and Korea, the U.S. share of this emerging market will depend heavily on who innovates faster and better. The goal of the ATP focused program in advanced vapor compression refrigeration systems is to help U.S. manufacturers build the technical basis for developing lower cost and better performing products than all foreign competitors.

Besides bolstering industrial competitiveness for these manufacturers, the program promises additional broad-based benefits. Increasing the average energy efficiency of air-conditioning and refrigeration equipment could simultaneously save industry users billions of dollars in energy costs and significantly reduce the emission of carbon dioxide and other pollutants as a result of reduced fuel consumption at power plants. Moreover, the focused program includes air-cleaning technologies, which include chemical systems that absorb or catalytically destroy many of the indoor air pollutants thought to be responsible for the "sick building syndrome." The Environmental Protection Agency estimates that as many as 50 percent of commercial buildings have problems with their indoor air and that improving air quality could yield annual savings of several billion dollars in the form of improved worker productivity, decreased public health costs, and reduced maintenance costs.

The technical challenge centers on the vapor compression cycle, which is the principle of operation for the vast majority of cooling equipment now manufactured and in use both in individual residences and in industrial settings. During the cycle, liquid refrigerants—among them the soon-to-be-phased-out chlorofluorocarbons (CFCs), as well as their replacements—expand in a metal coil. This is an energy-absorbing process that extracts heat from the space to be cooled. A mechanical compressor then consolidates the expanded gas and pushes it into a condenser where the vapor liquefies, which is an energy-releasing procedure that prepares the refrigerant for another run of the cooling cycle while releasing the heat associated with the condensation process away from the cooling system. The overall technical goals are to increase system efficiency by 25 percent, to reduce the noise levels and size of refrigeration components by the same amount, and to design and manufacture a system in which no refrigerant leaks. By providing a solid basis for industry collaboration on high-risk, cutting-edge technologies, the ATP can catalyze development that no individual company can undertake. ATP support will assist the industry in its own efforts to get a jump on the emerging worldwide markets that are rapidly developing.

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Motor Vehicle Manufacturing Technology

Changeovers to new car, van, or truck models are engineering and manufacturing marathons, taking U.S. auto makers and their suppliers an average of 42 to 48 months. More agile equipment and processes that sharply reduce the time and cost of converting factories to new models could reduce significantly the span from initial design to consumer-ready vehicle and give the U.S. automobile industry an important competitive advantage.

The ATP focused program on Motor Vehicle Manufacturing Technology fosters innovations in manufacturing practices that could slash time to market to 24 months, markedly better than even the best times logged to date by foreign or domestic car makers. These advances will lead to more versatile equipment, better control and integration of processes, and greater operational flexibility at all levels, from suppliers of parts, dies, and machine tools to assembly plants. With the reusable, modular equipment and processes envisioned by the program, the cost of retooling car-manufacturing facilities—now ranging between $1.2 billion and $2.9 billion, depending on the extent of the changeover—could be reduced by as much as tenfold. The savings would reduce the size of break-even production volumes needed to recover investment costs, making it profitable for U.S. automobile companies to compete in small-volume markets at mass-production prices.

The automotive sector, which accounts for about 4 percent of the U.S. gross domestic product and employs more than 2 million people, will be the initial beneficiary of the anticipated technologies. Within the sector, parts and equipment suppliers, who are directly involved in ATP program efforts, will benefit most directly from the improved performance capabilities enabled by the technologies. Outside the sector, a variety of other manufacturing industries, from metal furniture to precision instruments, will be able to exploit targeted improvements in machining, grinding, and other widely used processes.

The new focused program will concentrate on four major technical areas that underpin significant improvements in capabilities and performance:

- Material forming processes: Develop processes that substantially improve the quality of stamped sheet metal parts; improve stamping precision to achieve submillimeter dimensional tolerances; reduce by 30 percent the time required to design, test, and produce sheet metal dies; develop manufacturing systems that enable a range of cost-effective applications of advanced materials in light vehicles.

- Material removal processes: Increase the capabilities and speed of machining and grinding processes; enable greater flexibility so that machining stations can be reconfigured to meet new-model requirements; accelerate design and fabrication of tooling—the most costly and time-consuming phase of changeovers.

- Assembly processes: Develop economical, modular systems for body and powertrain assembly that can be implemented (or reconfigured) within 4 to 6 months (compared with today's average of 24 to 36 months); improve technologies for controlling paint and coating processes.

- Systems integration: Advance technologies for intelligent, or predictive, monitoring and control of processes; accelerate progress in efforts to achieve plug-and-play compatibility among equipment, processes, and information management systems, an emphasis that complements other manufacturing R&D efforts.

Without the collaborative efforts that the ATP aims to marshal, U.S. auto makers and their suppliers would not mount and sustain the range of activities needed to achieve the major advances in technology, manufacturing practices, and industry performance that are the objectives of the new program.

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Digital Data Storage

The nation's digital storage industry—maker of the tapes, disks, and other gear that have become the archives and the retrieval tools of the information age—achieved its world-leading status by doubling storage capacity about every 3 years. Now foreign competitors match that rate of progress, and new storage-hungry applications are multiplying rapidly. Industry observers say regaining lost market shares and pulling away from the global pack will require an annual improvement rate of about 60 percent—more than twice as fast as today's already-supercharged pace.

The ATP focused program on digital data storage aims to build the springboard for that kind of ambitious leap in technological capability and marketplace performance. The program concentrates on six key technical objectives:

- Media: Push the ultimate limits of magnetic recording capacity by increasing storage densities to 10 billion to 100 billion bits per square inch for disks and to 1 trillion bytes per cubic inch for tapes; for electro-optical disks, develop new materials to increase storage density and improve performance.

- Heads: Develop technologies for high-performance magnetic recording heads that are vastly superior to today's state of the art, and significantly improve magneto-optical record and sense technologies.

- Tribology: Develop new lubricants and surface finishes, because, as the space between heads and media diminishes, separation cannot be assured, creating the potential for wear and increased error rates.

- Tracking: Develop reliable micropositioning devices for high-precision placement of sensing devices over data tracks to achieve high signal-to-noise ratios.

- Channel electronics: Improve signal-processing electronics to achieve very low error rates.

- Software: Significantly advance the state of the art in data storage and retrieval software over the range extending from error detection and correction within storage units and disk controllers to management of menageries of data storage systems.

Opportunities for improved data-storage technologies are multiplying in business and consumer markets. The visual communications market, which includes video-on-demand services and video server hardware, is growing at an annual rate of 40 percent. Companies adept at incorporating new technologies will have a strategic advantage in existing and emerging markets. For the domestic industry as a whole, that advantage would advance efforts to establish U.S. formats as international standards, which would be a boon to exports.

In helping U.S. industry to move to the head of the curve of technology development and application, the ATP program also will better position U.S. companies to compete in consumer markets now dominated by soon-to-be-outdated analog storage products made by foreign manufacturers. In turn, a technologically advanced, globally competitive data storage industry will enhance the competitive prospects of computer manufacturers as well as the telecommunications, entertainment, and other important user industries.

In establishing a comprehensive set of technical goals far beyond the capabilities of individual firms, the ATP focused program will help companies and research organizations to pool their talents, expertise, and resources. Through collaborations that minimize risks and costs, the industry can make large strides in innovation that lead to markedly superior technologies beyond the capabilities of competitors. Because of today's stiff competition in markets for digital data storage products, U.S. firms must concentrate almost exclusively on rapid, but incremental, improvements to existing products, which are quickly matched or outdone by other companies. Shared efforts, facilitated by the ATP, that concentrate on early-stage needs and obstacles can reduce overall R&D costs and accelerate the U.S. digital data storage industry's progress toward developing technologies critical to ensuring that it will be a top performer in a worldwide market projected to grow tenfold, to $1 trillion, during the next decade.

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Economic Returns

ATP projects are expected to make significant contributions to scientific and technical knowledge, produce new technologies that will be developed and introduced into the marketplace by the project awardees (using their own funds), and in the long run yield substantial benefits to the economy beyond those accruing directly to the award recipients.

This is a lengthy process. ATP projects typically run from 2 to 5 years, the commercialization phase could add several more years, and the full economic impact may not be realized for some years after commercial introduction. It also is costly—companies must spend additional time, effort, and money on their own to pursue product development and marketing. Because of the risks involved—commercial as well as technical—some ATP projects will fail. Others may proceed faster than anticipated, and intermediate results may lead to marketable products even before the ATP project ends. Regardless of whether initial commercialization takes place before an ATP project ends, or long after, the company must invest its own money to design specific products incorporating the technology and to pay any other costs associated with commercialization.

True economic impacts occur when ATP-fostered technologies enter the market—and not just as products. Long-term evaluation of the ATP must take into account downstream effects of the technologies: higher productivity and lower reject rates for manufacturers using new processes and equipment based on ATP technologies; better medical care at lower costs from hospitals and clinics that benefit from ATP biotechnology projects or the ATP focused programs on Tools for DNA Diagnostics and Information Infrastructure for Healthcare; and longer-lived, lower maintenance structures and equipment made possible by ATP focused programs in advanced composites.

Such long-range effects are real—even if they are difficult to measure accurately.

Using a variety of analysis tools, including third-party surveys and statistical analyses, the ATP has documented several important near-term results of the program, including:

- The majority of companies receiving ATP awards would not have been able to pursue the technology at all without the ATP, and the balance would have been able to proceed only at a significantly smaller scale. The bottom line: U.S. industry today has important new technical capabilities that would not exist without the ATP.

- R&D on the high-risk, high-payoff technologies fostered by the ATP has been significantly accelerated, according to award winners, a large majority estimating that the award has put them ahead by 2 years or more. In today's marketplace, where product cycles are shorter, a lead time of only a few months can mean the difference between success and failure in time-critical markets.

- U.S. firms have found new commercial opportunities—and some early growth—based on these new technical capabilities.

- A new element in the R&D culture of U.S. business is emerging—one that emphasizes more high-risk, high-payoff, enabling R&D and greater use of cooperative research ventures and industrial alliances, and that views government and industry as partners rather than opponents.

ATP Projects

Ongoing and completed ATP projects and their participants are listed below, sorted into related technical categories. The ATP manages projects through three technical offices: Information Technology and Electronics Office, Chemical and Life Sciences Office, and Materials and Manufacturing Office.

The focused programs for which each office is responsible are listed under each office's heading. Projects selected in focused program competitions are listed under the corresponding focused program. Projects closely related to the subject of a focused program but selected in our general competitions are included in the focused program listing. When the ATP selects a number of projects in one particular area, such a cluster of projects is managed for synergy as a "virtual focused program" even though there has not been a formal competition in that technical area.

General competition projects that do not fit within a focused program category are listed separately, grouped in appropriate technical categories. For information, contact the office under which the project is listed.

Information Technology and Electronics Office

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Focused Program in Information Infrastructure for Healthcare

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Infrastructure Development Technologies (Enterprise Integration)

- Development of a Seamless Clinical Management System for Behavioral Health Organizations—Instream Corp.

- An Expert Knowledge Server with a General Vocabulary Server Interface—Applied Medical Informatics, Inc.

- Voyager: Browsing and Automatically Extracting Healthcare Data from Scattered Databases—Belmont Research, Inc.

- An Evolvable, Distributed Information Infrastructure for Interoperation of the Healthcare Delivery System—Andersen Consulting, Center for Strategic Technology Research*; Enigma Logic, Inc.; Expersoft Corp.; MedicaLogic; and Medical Records Corp.

- Healthcare Lifetime Data Repository Infrastructure—3M Co., Health Information Systems

- "MEDencode": A Technology to Populate a Clinical Data Repository as a Byproduct of Producing the Clinical Note—Datamedic Clinical Systems

- Enterprise Tools for the Continuously Available Medical Care (CAMC) Home Healthcare System—Intermetrics, Inc.

- Enterprise Integration Tool Set (EITS) for Healthcare Professionals—Digital Systems Resources, Inc.; and Unisys Corp.*

- Patient-Oriented Management System (POMS): An Integration Infrastructure for Health Care—Benchmarking Partners

Infrastructure Development Technologies (Domain Analysis and Business Process Re-engineering)

- Healthcare Information Infrastructure Technology Proposal—BellSouth Network Solutions; Coleman Information Services; Connecticut Health Technology Group; Danbury Health Systems; General Electric Corporate R&D; Healthcare Research and Education; Liberty Health Systems; Macro International; Medical University of South Carolina, Center for Computing & Information Technology; Microelectronics & Computer Technology Corp.; New Jersey Institute of Technology; South Carolina Research Authority*; Statewide Health Information Network, Inc.; Unitron Medical Communications; and University of Georgia

* Joint venture lead partner

• Health Informatics Initiative—AT&T Bell Laboratories; Booz-Allen & Hamilton, Inc.; Corporation for Studies & Analysis; D. Appleton Co., Inc.; International Cancer Alliance; Koop Foundation, Inc.*; Logicon, Inc.; Strategic & Information Systems; Meta Software Corp.; Oracle Corp.; Systems Research & Applications Corp.; and Wizdom Systems, Inc.

• An Information Infrastructure to Redefine Caregiver Roles: A New Approach to Integration—Health Data Sciences Corp.*; and New York City Health and Hospitals Corp.

Infrastructure Development Technologies (Total Quality Management)

• Methodologies for Automating Clinical Practice Guidelines—Cerner Corp.

• Automated Care Plans and Practice Guidelines—American Healthware Systems

• Development of an Episode Grouper—3M Co., Health Information Systems*; and Actuarial Sciences Associates

User Interface and Efficiency-Enhancement Technologies (Information Access, Transmission, Storage, and Retrieval)

• Healthcare Information Technology Enabling Community Care—Advanced Radiology; BellSouth Telecommunications; Charleston Area Medical Center, Inc.; Connecticut Healthcare Research and Education; General Electric Corporate R&D; Shared Medical Systems Corp.; South Carolina Research Authority*; Technology 2020; Univ. of Florida at Gainesville, Dept. of Anesthesiology; and Univ. of Maryland at Baltimore, Diagnostic & Radiology

• Decision Support Technology for LDR Infrastructure—3M Co., Health Information Systems

• Development of National Medical Practice Knowledge Banks—Allegheny-Singer Research Institute*; AT&T Corp., Business Markets Division; NCR Human Interface Technology Center; and NCR Parallel Systems

• Health Object Library On-Line Project (HOLON)—Beth Israel Hospital; Concept 5 Technologies, Inc.; Forefront Group, Inc.; George Washington University, School of Engineering; IntelliTek, Inc.; Koop Foundation, Inc.*; Lumina Decision Systems; Meta Software Corp.; Norwalk Hospital, Center for Informatics; Oracle Corp.; Talisman Dynamics, Inc.; Time Warner Cable; Windom Health Enterprises; and Wizdom Systems

User Interface and Efficiency-Enhancement Technologies (Multimedia Information)

• Automating Disease Surveillance from Structured and Text Data—Sunquest Information Systems

• A Multimedia Medical Dialog (MMD) System for Home Healthcare—Dragon Systems, Inc.

• Intelligent Spoken Medical Records—Berdy Medical Systems

• Open, Voice-Enabled, Structured Medical Information—Kurzweil Applied Intelligence, Inc.

• Wellnet™: An Interactive Multimedia Consumer Health Management Tool—Caresoft, Inc.

• TELEOS™: An Authoring System for Virtual Reality Surgical Simulations—High Techsplanations, Inc.

• A Three-Dimensional Database for Visualization of Human Physiology—Engineering Animation, Inc.

Focused Program in Component-Based Software

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Creating New Software Development Paradigms

• Component Integration: An Architecture Driven Approach—Andersen Consulting, Center for Strategic Technology Research

• Reusable Performance-Critical Software Components Using Separation of Implementation Issues—Xerox Corp., Palo Alto Research Center

• Cost-Based Generation of Scalable, Reliable, Real-Time Software Components—Sagent Corp.

• Design Maintenance System—Semantic Designs

Enhancing the Capability of Application Experts

• Automatic Generation of Mathematical Modeling Components—SciComp, Inc.

• A Component Technology for Virtual Reality (VR) Based Applications—Aesthetic Solutions

• Automation of Dependable Software Generation with Reusable Components—Lucent Technologies, Inc.

• A Component-Based Software Approach to Analog and Mixed Signal Model Development—Analogy, Inc.

• Component-Based Software for Advanced Interactive Systems in Entertainment and Education—Extempo Systems, Inc.

Automating the Software Development Process

• Component-Based Re-engineering Technology—Reasoning Systems, Inc.

* Joint venture lead partner

- Scalable Business Application Development Components and Tools—Continuum Systems
- A Plausible Dependability Model for Component-Based Software—Reliable Software Technologies
- Graph Visualization Technology—Tom Sawyer Software
- Component-Based Software Tools for Real-Time Systems—Real-Time Innovations, Inc.
- Component-Based Software System for Parallel Processing Systems—Applied Parallel Technologies, Inc.

Focused Program in Digital Video in Information Networks

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Improve Information Capacity for Transmission and Distribution

- Mobile Information Infrastructure for Digital Video and Multimedia Applications—Lucent Technologies; and Sun Microsystems Computer Co.
- Perceptual-Based Video Encoding and Quality Measurement—Bell Atlantic; David Sarnoff Research Center*; Texas Instruments; and Sun Microsystems
- Adaptive Video Codec for Information Networks—Cubic Defense Systems

Interoperable System Components

- HDTV Broadcast Technology—Advanced Modular Solutions; Comark; David Sarnoff Research Center*; IBM; MCI; Philips Laboratory; Sun Microsystems; and Thomson Consumer Electronics, Inc.
- Interoperability Tools for Digital Video Systems—Bell Communications Research, Inc.

Digital Video Tools and Management Capabilities

- Advanced Distributed Video ATM Network for Creation, Editing, and Distribution—Tektronix, Inc.

Focused Program in Technologies for the Integration of Manufacturing Applications

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- A Product-Family-Based Framework for Computer Integrated Manufacturing—IBM Corp.
- Model-Driven Application and Integration Components for MES—Vitria Technology, Inc.
- An Agent-Based Framework for Integrated Intelligent Planning-Execution—IBM Manufacturing Unit*; Berclaim USA, Limited; Cimplex; Ingersoll-Rand Co.; J.D. Edwards; and QAD, Inc.
- Advanced Process Control Framework Initiative—Advanced Micro Devices; and Honeywell, Inc., Technology Center*
- Solutions for MES-Adaptable Replicable Technology (SMART)—AMP, Inc.; Applied Automation Technologies, Inc.; FASTech Integration, Inc.; IBM Corp. (NIIP Consortium Project Office)*; IBM Manufacturing Industry Solutions Unit; IBM Software Solutions Division; IBM Manufacturing Systems; Industrial Computer Corp.; International Technical Group, Inc.; MESA International; STEP Tools, Inc.; UES, Inc.; Univ. of Florida at Gainesville, Database Systems R&D Center; and Wonderware Corp.

Focused Program in Digital Data Storage

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Optical Recording Technology

- A High-Density and High-Speed Read-Only Optical Data Storage System—Calimetrics
- A Revolutionary, High Density, High Speed, Low Cost Optical Information Storage Technology—Optex Communications Corp.
- Digital Data Storage Technology via Ultrahigh-Performance Optical Tape Drive Using a Short-Wavelength Laser—LOTS Technology, Inc.
- Electron-Trapping Optical Memory for Digital Recording Applications—Optex Communications Corp.
- Short-Wavelength Sources for Optical Recording—Carnegie Mellon University, ECE Department; Eastman Kodak Co., Mass Memory Division, Research Labs; IBM Corp., Almaden Research Center; National Storage Industry Consortium*; Uniphase; and University of Arizona, Optical Science Center
- Technology Development for Optical-Tape-Based Rapid Access Affordable Mass Storage (TRAAMS)—Carnegie Mellon University; Energy Conversion Devices, Inc.; Motorola, Inc., Phoenix Corporate Research Laboratories; NASA Goddard Space Flight Center; Polaroid Corp.; Science Applications International Corp.; Terabank Systems, Inc.*; and University of Arizona, Optical Sciences Center
- Ultra High Capacity Optical Disk: Multi-Layer Short Wavelength Write-Once and Erasable Optical Disk Recording System—Carnegie Mellon University; Eastman Kodak Co.; National Storage Industry Consortium*; and SDL (Spectra Diode Laboratories, Inc.)

* Joint venture lead partner

Magnetic Recording Technology

- Enhanced Rigid Disk Drive Technology: High Resonance Suspension—Hutchinson Technology, Inc.
- High-Performance, Variable-Data-Rate, Multimedia Magnetic Tape Recorder—3M Co.*; Advanced Research Corp.; and Seagate Tape Technology, Inc.
- Ultra-High Density Magnetic Recording Heads—Applied Magnetics Corp.; Carnegie Mellon University, ECE Department, Data Storage Systems Center; Eastman Kodak Co.; George Washington University, Dept. of Electrical Engineering & Computer Science; Hewlett-Packard Co.; IBM Corp., Almaden Research Center; National Storage Industry Consortium*; Quantum Corp.; Read-Rite Corp.; Seagate Technology; Stanford University, Department of Materials Science and Engineering; Storage Technology Corp.; University of Alabama at Tuscaloosa, Center for Materials Information Technology; University of California at San Diego, Center for Magnetic Recording; University of Minnesota, Electrical Engineering and Computer Science; and Washington University, Department of Electrical Engineering

General Competition Projects Related to Information Technology

- New User-Interface for Computers Based on On-Line Recognition of Natural Handwriting—Communication Intelligence Corp.
- Advanced Spoken Language User Interfaces for Computer Applications—Kurzweil Applied Intelligence, Inc.
- Pen-Based User Interface for the Emerging Chinese Computer Market—Communication Intelligence Corp.
- High Fidelity Digital Image Compression—Iterated Systems, Inc.

General Competition Electronics and Photonics Projects

Displays and Graphic Image Manipulation

- Advanced Manufacturing Technology for Low-Cost Flat Panel Display—Electro-Plasma, Inc.; Kent Display Systems; Photonics Imaging, Inc.*; Planar America, Inc., Division of Planar Systems; and Westinghouse Norden Systems, Inc., Division of United Technologies
- FLC/VLSI High-Definition Image Generators—Displaytech, Inc.
- High Information Content Display Technology—Kopin Corp.*; and Philips Consumer Electronics North America
- High Resolution Multimedia Laser Projection Display—Laser Power Corp.*; and Proxima Corp.
- Large Area Digital HDTV Field Emitter Display Development—FED Corp.
- Mathematical Algorithms and Software for the Restoration and Reformatting of Moving Pictures—Mathematical Technologies, Inc.
- Optically Controlled Alignment Materials for Liquid-Crystal Displays—Alliant Techsystems, Research Center
- Patterning Technology for Color Flat-Panel Displays—Electro-Plasma, Inc.; Kent Display Systems; Photonics Imaging, Inc.; Planar America, Inc., Division of Planar Systems (American Display Consortium)*; and Plasmaco, Inc.
- Scalable High-Density Electronics Based on MultiFilm Modules—Kopin Corp.*; and Microelectronics & Computer Technology Corp.
- Technology Development for the Smart Display: A Versatile High-Performance Video Display Integrated with Electronics—BFGoodrich Avionics Systems; Cetek Technologies, Inc.; FED Corp.*; InfiMed, Inc.; and Kaiser Electronics
- Diamond Diode Field Emission Display Process Technology Development—SI Diamond Technology, Inc.*; and Supertex, Inc.

Semiconductor Devices, Materials, and Fabrication

- New Technology for High-Current, Parallel, Broad-Beam Implanters for Microelectronics Fabrication—Diamond Semiconductor Group, Inc.
- Dry Gas-Phase Cleaning Technology for Single-Wafer Surface Conditioning—FSI International, Inc.
- A Feedback-Controlled Metalorganic Chemical Vapor Deposition Reactor—Spire Corp.
- Development of Blue/Green Emitters Utilizing Homoepitaxial ZnSe-Based Heterostructures—Eagle-Picher Research Laboratory
- Fabrication and Testing of Precision Optics for Soft X-Ray Projection Lithography—AT&T Bell Laboratories
- Flip Chip Monolithic Microwave Integrated Circuit (MMIC) Manufacturing Technology—Hughes Aircraft Co., Microelectronic Circuits Division
- GaAs Super Microprocessor Technology Development—Vitesse Semiconductor Corp.
- Manufacturing Technology for High Performance Optoelectronic Devices Based on Liquid Phase Electro-Epitaxy—AstroPower, Inc.
- Solid-State Laser Technology for Point-Source X-Ray Lithography—Hampshire Instruments, Inc.*; and McDonnell Douglas Electronic Systems Co.
- Advancement of Monocrystalline Silicon Carbide Growth Processes—Cree Research
- Nonvolatile Magnetoresistive Semiconductor Technology—Nonvolatile Electronics, Inc.

* Joint venture lead partner

Optical/Electro-optical Components and Systems (including lasers)

- Tunable Deep UV and VUV Solid-State Laser Source—Light Age, Inc.
- Incoherent Combining of Radiation from a Two-Dimensional Array of Semiconductor Lasers—Cynosure, Inc.
- Advanced Technology for Microchannel Plates—Galileo Electro-Optics Corp.
- A Novel Microminiature Light Source Technology—Philips Laboratories
- Fiber Fabry-Perot Tunable Filters for All-Optical Networks—Micron Optics, Inc.
- Holographic Graded-Index Non-Lambertian Scattering Screens and Components with Light-Shaping Capability—Physical Optics Corp.
- Jitney: A Low-Cost, High-Performance Optical Bus—3M Co.; IBM Corp., T.J. Watson Research Center*; and Lexmark International, Inc.
- Monolithic Multiwavelength Laser Diode Array Spanning 430 to 1100nm—SDL (Spectra Diode Laboratories, Inc.)*; and Xerox Corp., Palo Alto Research Center
- Precision Optoelectronics Assembly—Adept Technology, Inc.; AT&T Bell Laboratories, Engineering Research Center; Boeing Co., Defense & Space Group; Ford Motor Co., Electronics Technical Center; Motorola, Inc., Phoenix Corporate Research Labs; New Jersey Institute of Technology, Center for Manufacturing Systems; and Precision Optoelectronics Assembly Consortium (c/o NCMS)*
- Wavelength Division Multiplexing for Optical Telecommunications Systems—Accuwave Corp.
- X-Ray and Neutron Focusing and Collimating Optics—X-Ray Optical Systems, Inc.

New Materials/Manufacturing for Electronics and Electrical Systems

- Diamond-Like Nanocomposite Technology—Advanced Refractory Technologies, Inc.
- Integrated Force Array—Microelectronics Center at North Carolina
- Novel Synthetic Fused Quartz for Semiconductor Manufacturing—General Electric Corporate R&D
- Printed Wiring Board Interconnect Systems—AT&T Bell Laboratories; AT&T Micro Electronics; AlliedSignal Laminate Systems; Hughes Aircraft Co.; IBM Corp.; National Center for Manufacturing Sciences, Inc.*; Sandia National Laboratories; Texas Instruments, Inc.; and United Technologies Corp., Hamilton Standard Division

Superconducting Systems and Devices

- High-Temperature Superconducting Racetrack Magnets for Electric Motor Applications—American Superconductor Corp.
- Technologies for HTS Components for Magnetic Resonance Applications—DuPont, Superconductivity Group; and Intermagnetics General Corp.*
- Advanced Thallium Superconductor Technology—DuPont
- Thick-Film Superconducting Materials for Radiofrequency Communication—Illinois Superconductor Corp.
- Hybrid Superconducting Digital System—Conductus, Inc.*; Hewlett-Packard Co.; National Institute of Standards and Technology; Stanford University, Department of Applied Physics; TRW Applied Technology Division, Space & Technology Group; and University of California at Berkeley, Dept. of Electrical Engineering & Computer Science

Other Electronics, Electrical, and Photonics Projects

- Advanced Cathode for Flat Fluorescent Light Sources—Thomas Electronics, Inc.
- Development of Rapid Thermal Processing to Produce Low Cost Solar Cells—Solarex, A Business Unit of Amoco/Enron Solar
- Low Dielectric Foams for Microelectronics Applications—IBM Corp., Almaden Research Center
- Low-Cost Amorphous Silicon Manufacturing Technology—EG&G Reticon; and General Electric Corporate R&D*
- Polymeric Switches for Optical Interconnects—IBM Corp., Almaden Research Center
- Ultra-Low k Dielectric Materials for High-Performance Interconnects—Texas Instruments, Inc.

Chemistry and Life Sciences Office

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Focused Program in Tools for DNA Diagnostics

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- Genosensor Technology Development—Beckman Instruments; Baylor College of Medicine; Genometrix, Inc.; Genosys Biotechnologies, Inc.; Houston Advanced Research Center; Laboratories for Genetic Services, Inc.; Massachusetts Institute of Technology; Microfab Technologies, Inc.; Triplex Pharmaceutical Corp.

* Joint venture lead partner

• Miniature Integrated Nucleic Acid Diagnostics (MIND™) Development—Affymetrix, Inc.*; and Molecular Dynamics, Inc.

• DNA Diagnostic Systems Based on Novel Chem-jet Techniques—Combion, Inc.

• SBH Format 3 Megabase Diagnostics Instrumentation—Hyseq, Inc.

• An Integrated Microelectronic DNA Diagnostic System—Nanogen, Inc.

• Arrayed Primer Extension (APEX): The Next Generation DNA Analysis System for Sequencing in DNA Diagnosis—Baylor College of Medicine; Duke University; Identigene, Inc.; and Pharmacia Biotech, Inc.*

• Integrated Microfabricated Devices for DNA Typing—Molecular Tool, Inc.

• MicroLab: A High-Throughput, Low-Cost Approach to DNA Diagnostics by Array Hybridization—David Sarnoff Research Center

• Development of Bar Code Diagnostics for DNA Analysis—Vysis, Inc.

• Development of Rapid DNA Medical Diagnostics—GeneTrace Systems, Inc.

• Diagnostic Laser Desorption Mass Spectrometry Detection of Multiplex Electrophore Tagged DNA—Bruker Analytical Systems, Inc.*; Genome Therapeutics; and Northeastern University

• Development and Commercial Application of Genosensor Based Comparative Genome Hybridization—Vysis, Inc.

• Molecular Cytogenetics Using the GeneScope: An Ultrafast, Multicolor System for Automated FISH Analysis—Bio-Rad Laboratories

• Integrated Microfabricated DNA Analysis Device for Diagnosis of Complex Genetic Disorders—CuraGen Corp.*; and Soane Technologies, Inc.

• Automated DNA Amplification and Fragment Size Analysis—E.I. du Pont de Nemours & Co., FQMS Group

• Real-Time Micro-PCR Analysis System—Cornell University Medical College; IC Sensors (EG&G); Louisiana State University; Perkin Elmer Corp.*; and University of Minnesota

• Compact Blue Laser for Diagnostics—Uniphase Corp.*; and Perkin-Elmer Corp.

• Development of a Generic Technology for the Targeted Detection and Cleavage of DNA and RNA—Third Wave Technologies, Inc.

• DNA Diagnostics Using Self-Detected Target-Cycling Reaction (SD-TCR)—NAVIX, Inc.; and Profile Diagnostics, Inc.

• Hyperthermophilic Microorgansims in Molecular Biology and Biotechnology—Amersham Life Sciences, Inc.

• Generation and Development of Novel Nucleic Acid Binding Proteins and Their Use as DNA Diagnostics—Sangamo BioSciences

• Self-Contained Cartridge Integrating Nucleic Acid Extraction, Specific Target Amplification, and "Dip Stick" Immediate Detection—Immunological Associates of Denver

Focused Program in Catalysis and Biocatalysis

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• A Process for Biocatalytic Desulfurization of Crude Oil—Energy BioSystems Corp.

• Biosynthesis of Monomers—General Electric Co.

• Continuous Biocatalytic Systems for the Production of Chemicals from Renewable Resources—Argonne National Lab.; Eastman Chemical Co.; Electrosynthesis Co., Inc.; Genencor International, Inc.*; and MicroGenomics, Inc.

• Development of Improved Catalysts Using Nanometer-Scale Technology—Catalytica, Inc.*; and Microfluidics International Corp.

• Three-Phase Circulatory Flow Reactor Technology for Vapor-Phase Organic Oxidations—Praxair, Inc.

• Thin-Film Solid Acid Catalyst for Refinery Alkylation—ABB Lummus Global

• Breakthrough Process for Direct Oxidation of Propylene to Propylene Oxide—Dow Chemical Co.

• Breakthrough Technology for Oxidation of Alkanes—Rohm and Haas Co., and Sun Co.*

• Elastomeric Polypropylene and Elastic Non-Wovens Venture—Amoco Corp.*; and Fiberweb North America, Inc.

• Polar-Tolerant Organometallic Catalytic Technology for Functionalized Linear Polyolefins—W.R. Grace & Co.

• Tailored Optical Polymers Through a Novel Catalyst System (TOPCAT)—3M Co.; and BF Goodrich Co.*

• Computational Methods for Catalyst Design—Phillips Petroleum Co.

General Competition Chemical and Biomedical Technology Projects

Separations Technology

• Facilitated Transport Process for Low-Cost Olefin-Parafin Separations—Amoco Corp.

• Novel Anion-Selective Separations Using Molecular Recognition Technology—IBC Advanced Technologies, Inc.

• Dual Purpose Ceramic Membranes—BP Chemicals*; Praxair, Inc.; and Seattle Speciality Ceramics, Inc.

• Advanced Sorbents for Reducing the Cost of Oxygen—Praxair, Inc.

• Non-Chromatographic Enantiomer Separation and Purification with High Separation Factors—IBC Advanced Technologies, Inc.

* Joint venture lead partner

- Development of New Technologies for Treating and Recycling Wastewater from Aquaculture Facilities—Aquatic Systems/Kent SeaFarms Corp.

- Energy-Efficient Oxygen Production Using Novel Ion Transport Membranes—Air Products and Chemicals, Inc.

- Development of a High-Pressure Oxygen Generator Using a Solid Electrolyte Oxygen Separation (SEOS) Technology—Ceramatec, Inc.

Tissue Engineering

- Fabrication of Clinical Prosthesis from Biomaterials—Tissue Engineering, Inc.

- Structurally New Biopolymers Derived from Alpha-L-Amino Acids—Integra LifeSciences Corp.

- Application of Gene Therapy to Treatment of Cardiovascular Diseases—Progenitor, Inc.

- Disease Treatment Using Living Implantable Microreactors—BioHybrid Technologies, Inc.*; and Synergy Research Corp.

- Treatment of Diabetes by Proliferated Human Islets in Photocrosslinkable Alginate Capsules—VivoRx, Inc.

- Universal Donor Organs for Transplantation—Alexion Pharmaceuticals, Inc.

- Computer-Integrated Revision Total Hip Replacement Surgery—Integrated Surgical Systems, Inc.

Drug Design and Chemical Modeling

- Development and Applications of Density Functional Software for Chemical and Biomolecular Modelings—Biosym Technologies, Inc.

- Molecular Recognition Technology for Precise Design of Protein-Specific Drugs—American Home Products; and CuraGen Corp.*

- Molecular Recognition Polymers as Anti-Infectives—GelTex Pharmaceuticals, Inc.

- Enhanced Molecular Dynamics Simulation Technology for Biotechnology Applications—Moldyn, Inc.

- Crystallization and Structural Determination of G-Coupled Protein Receptors—3-Dimensional Pharmaceuticals, Inc.

- RNA Binding Protein Technology for Identification of Novel Therapeutics—Symphony Pharmaceuticals, Inc.

- Marine Microorganisms and Saline Fermentation: A New Industrial Resource—Aphios Corp.

Other Chemistry, Biotechnology, Agricultural, and Medical Projects

- Standardization of 2-D Protein Analysis Using Manufacturable Gel Media—Large Scale Biology Corp.

- Development of Multi-Photon Detection Technique and Its Application to Environmental and Biomedical Diagnostics—BioTraces, Inc.

- Oleaginous Yeast Fermentation as a Production Method for Squalene and Other Isoprenoids—Mycogen Corp.

- Transgenic Cotton Fiber with Polyester Qualities via Biopolymer Genes—Agracetus, Inc.

- U.S. Self-Sufficiency in High Quality Pyrethrin Production—Agridyne Technologies, Inc.

- Low-Temperature Viral Inactivation—Aphios Corp.

- Human Stem Cell and Hematopoietic Expansion Systems—Aastrom Biosciences, Inc.

- Plasma and Phosphor Technology for Mercury-Free Fluorescent Applications—General Electric Corporate R&D

Materials and Manufacturing Office

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Focused Program in Manufacturing Composite Structures

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Technologies for Vehicles

- Automotive Composite Structures: Development of High-Volume Manufacturing Technology—Chrysler Corp., Organic Materials Engineering; Ford Motor Co., Scientific Research Labs; General Motors (Automotive Composites Consortium)*; and General Motors Corp., Polymers Department

- Cyclic Thermoplastic Liquid Composite Molding for Automotive Structures—Ford Motor Co., Scientific Research Labs*; and General Electric Corporate R&D

- Development of Manufacturing Methodologies for Vehicle Composite Frames—Budd Co., Design Center

- Engineering Design with Injection-Molded Thermoplastics—General Electric Corporate R&D; and General Motors Corp., Research and Environmental Staff

- Integrated Agile Manufacturing for Advanced Composite Electric Vehicles—Bonded Technology, Inc.; Boston Edison Co.; Composite Engineering; Massachusetts Division of Energy Resources; Northeast Alternative Vehicle Consortium*; Solectria Corp.; TASC, Inc.; Textron-Defense Systems; Tillotson Pearson, Inc.; and Tufts University, Fletcher School of Law and Diplomacy

*Joint venture lead partner

- Low-Cost Advanced Composite Process for Light Transit Vehicle Manufacturing—Advance USA

- Low-Cost Automotive Manufacturing With Injection Molding PET Composites—AlliedSignal, Inc.

- Low-Cost Elastomeric Composites with Application to Vehicle Tires—AlliedSignal, Inc.

- Manufacturing Methodologies for Automated Thermoset Transfer/Injection Molding (TIM)—Budd Co., Design Center

- Vapor-Grown Carbon-Fiber Composites for Automotive Applications—Applied Sciences, Inc.*; General Motors Corp., North American Operations R&D Center, Environmental; General Motors Delphi Chassis Systems, Advanced Composite Engineering; and Goodyear Tire & Rubber Co., Goodyear Technical Center

Technologies for Off-shore Oil Production

- Composite Drill Pipes—Amoco Production Corp., Tulsa Technology Center; Cullen Engineering Research Foundation*; Phillips Petroleum Co., Engineering Materials and Service; SpyroTech Corp.; and University of Houston—CEAC

- Composite Production Risers—Amoco Corp., Worldwide Engineering (Composite Production Risers JV); Amoco Performance Products, Inc.; Brown & Root USA, Inc.; Conoco, Inc., Technology Infrastructure; Cullen Engineering Research Foundation (Composite Production Risers JV)*; Exploration and Production Technology Co., a Division of Shell Co.; Hercules, Inc.; Hydril Co.; Lincoln Composites; Stress Engineering Services, Inc.; and University of Houston—CEAC

- Innovative Joining/Fitting Technology for Advanced Composite Piping Systems—Specialty Plastics, Inc.

- Light-Weight/High-Strength Composite Intelligent Flexible Pipe Development—Wellstream Corp.

- Manufacturing Composite Structures for the Offshore Oil Industry—ABB Vetco Gray, Inc.; Hercules, Inc.; Northrup Grumman Corp./Westinghouse Electric Corp.*; Reading & Bates Development Co.; Texaco, Inc./Deep Star Project; and Texas Engineering Experiment Station, Offshore Tech. Res. Ctr. (UT and TX A&M)

- Spoolable Composite Tubing—Amoco Corp., Resource Center; Cullen Engineering Research Foundation (Spoolable Composite Tubing JV)*; Elf Atochem North America, Inc.; Exploration and Production Technology Co., a Division of Shell Co.; Hydril Co.; Phillips Petroleum Co.; and University of Houston—CEAC

Technologies for Bridges and Other Large Structures

- High-Performance Composites for Large Commercial Structures—Brunswick Technologies, Inc.; Dow Chemical Co.; DuPont/Hardcore Composites, Inc., Advanced Materials Systems*; and Johns Hopkins University, Whiting School of Engineering

- Innovative Manufacturing Techniques to Produce Large Phenolic Composite Shapes—Morrison Molded Fiberglass Co.

- Low Cost Manufacturing and Design/Sensor Technologies for Seismic Upgrade of Bridge Columns—Composite Retrofit Corp.*; Hercules, Inc.; and Trans-Science Corp.

- Polymer Matrix Composite Power Transmission Devices—Hercules Aerospace Co.; New Venture Gear, Inc.*; Quantum Composites of Midland; and Quantum Consultants, Inc.

- Polymer Matrix Composites for Surface Transportation Applications—Hexcel Corp.

- Structural Composites Manufacturing Process—GenCorp, Inc., Corporate Technology Center

- Synchronous In-line CNC Machining of Pultruded Lineals—Ebert Composites Corp.

- Thermoplastic Composites for Structural Applications—Cambridge Industries, Inc.; and DuPont Fibers, Engineering Polymers*

Focused Program in Materials Processing for Heavy Manufacturing

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- Aqueous Injection Molding for Low-Cost Fabrication of Silicon Nitride Components—AlliedSignal, Inc., Ceramic Components

- Ceramic Coating Technology for the Internal Surfaces of Tubular/Cylindrical Components—Praxair Surface Technologies, Inc.

- Cost-Effective Blade Manufacturing for Combustion Turbine Applications—PCC Airfoils, Inc., Manufacturing Technology Center; and Westinghouse Electric Corp., Power Generation Business Unit*

- Cost-Effective, Near-Net-Shape, Superalloy Forgings for Power Generation Gas Turbines—Wyman-Gordon Co.

- Development of Casting Technology to Produce Large Superalloy Castings for Industrial Applications—Precision Castparts Corp.

- Engineered Surfaces for Rolling and Sliding Contacts—Caterpillar, Inc., Advanced Materials Technology*; General Motors Corp., Gear Center; and Timken Co.

- Fabrication of Advanced Structures Using Intelligent and Synergistic Materials Processing—A.O. Smith Corp.; Caterpillar, Inc., Fabricated Structures R&D*; Lincoln Electric Co.; and U.S. Steel

- Functionally Gradient Materials: Synthesis, Process and Performance—Caterpillar, Inc.

- Intelligent Processing of Materials for Thermal Barrier Coatings—General Electric Corporate R&D, Power Generation

* Joint venture lead partner

• Low-Cost, Near Net-Shape Aluminium Casting Processes for Automotive and Truck Components—AlliedSignal, Inc.*; Stahl Specialty Co.; and Top Die Casting Co., Inc.

• Rapid Solidification Powder Metallurgy for High-Nitrogen Stainless Steels—Crucible, Compaction Metals Division

Focused Program in Motor Vehicle Manufacturing Technology

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• Advanced Welding Technology for Structural Automotive Products—Dana Corp., Parish Light Vehicle Structures Division

• Agile Precision Line Boring—Lamb Technicon

• Agile Precision Sheet-Metal Stamping—A.J. Rose Manufacturing Co.; Allen Bradley Co., Inc.; American Iron and Steel Institute; Atlas Technologies; Autodesk, Inc.; Autodie International, Inc.; Chrysler Corp.; Classic Design, Inc.; Data Instruments, Inc.; Deneb Robotics, Inc.; Ford Motor Co.; General Motors Corp., Flint Metal Fabricating Plant; HMS Products Co.; Helm Instrument; Lamb Technicon; Lobdell-Emery Manufacturing Co.; Near Zero Stamping, Inc. (c/o Auto Body Consortium)*; Ohio State University; Perceptron, Inc.; Sekely Industries; Signature Technology; Tecnomatix Technologies, Inc.; Tower Automotive; and Verson

• Flexible Low-Cost Laser Machining for Motor Vehicle Manufacturing—SDL (Spectra Diode Laboratories, Inc.)*; Teledyne Brown Engineering; and Utilase Systems, Inc.

• Cubic Boron Nitride (cBN) Coatings for Cutting and Specialty Tools—Extrude Hone Corp.; and Kennametal, Inc., Corporate Technology Center*

• Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing—2mm-Auto Body Consortium*; CDI-Modern Engineering; Chrysler Corp.; Classic Design, Inc.; Detroit Center Tool, Inc.; General Motors Corp., Technical Center; ISI Robotics; Perceptron, Inc.; Pioneer Engineering & Manufacturing; Progressive Tool & Industries, Inc.; University of Michigan, Mechanical Engineering and Applied Mechanics; and Weber Technologies, LLC

• Die Casting Technician's Digital Assistant—AI Ware; Doehler-Jarvis; and Edison Industrial Systems Center*

• Flow-Control Machining—Extrude Hone Corp.*; Ford Motor Co., Scientific Research Labs; and General Motors Corp., Powertrain Division

• Intelligent Resistance Welding—Alcan Rolled Products Co.; Allen Bradley Co., Inc.; American Iron and Steel Institute; Ansys, Inc.; Battelle Memorial Institute; Chrysler Corp.; DuPont Central Research; Ford Motor Co., Manufacturing Development Center; General Motors Corp., NAO, Mid-Lux; Helm Instrument; InTech R&D U.S.A.; Intelligent Resistance Welding Consortium (c/o Auto Body Consortium)*; Johnson Controls, Inc., Automotive Systems Group; Lamb Technicon; Lobdell-Emery Manufacturing Co.; Medar, Inc.; Progressive (PICO); Robotron; Sensotech; and Tower Automotive

• Machine Tool Process Monitoring Diagnostic System—Montronix, Inc.

• Manufacturing Composite Flywheel Structures—Dow-United Technologies Composite Products, Inc.

• Non-Circular Turning Process for Camshaft Machining—Saginaw Machine Systems, Inc.

• Plasma-Based Processing of Lightweight Materials for Motor-Vehicle Components and Manufacturing Applications—A.O. Smith Corp.; ABB High Power Semiconductors; Diversified Technologies, Inc.; Empire Hard Chrome, Inc.; Environmental Research Institute of Michigan*; General Motors Corp., Electrical and Electronics Department; Harley-Davidson, Inc.; IONEX; Kwikset Corp.; Litton Electron Devices; NANO Instruments Inc.; PVI; and University of Wisconsin at Madison, Engineering Research

• Rapid Fabrication of Superabrasive Grinding Tools—Abrasive Technology Aerospace, Inc.

• Springback Predictability in Automotive Manufacturing—Alcoa Technical Center; Budd Co., Technical Center; Chrysler Corp.; Environmental Research Institute of Michigan*; Ford Motor Co., Scientific Research Labs; General Motors Corp., North American Operations Research Analytics; and U.S. Steel

• The Next-Generation Industrial Production Process for High-Density Powder Metal Products—General Motors Corp., Powertrain Division; IAP Research, Inc.*; and Zenith Sintered Products, Inc.

• Wet Paint Thickness Measurement System—Autospect, Inc.

• Fast, Volumetric X-Ray Scanner for Three-Dimensional Characterization of Critical Objects—EG&G Reticon; General Electric Aircraft Engines; General Electric Corporate R&D; General Motors Corp., Technical Center; and Scientific Measurement Systems, Inc.*

* Joint venture lead partner

Focused Program in Vapor Compression Refrigeration Technology

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- Ejector-Expansion Refrigeration Cycle (EERC)—Calmac Manufacturing
- Advanced Screw-Compressor-Based Air-Cooled Chiller Technology Development—Trane Corp.
- Compact Heat-Pump-Based Microchannel and Tangential Fan Technologies—Emerson Electric; Heatcraft, Inc.; and Lennox Industries, Inc.*
- Development of Closed Cycle Air Refrigeration Technology for Refrigeration Markets—Air Products and Chemicals, Inc.*; and Toromont Process Systems, Inc.
- High- and Variable-Speed Co-Rotating Scroll—Copeland Corp.
- Innovative, Small, High-Speed, Centrifugal Compressor and Integrated Heat-Exchanger/Fan Technologies—AlliedSignal, Inc.; Carrier Corp.; DuPont Fluoroproducts; General Electric Corporate R&D; Martin Marietta Corp., Control Systems; SatCon Technology Corp.; and United Technologies Corp., Research Center*
- Novel Leak Detection Technology Development—Adaptive Optics Associates, Inc.; DeMaria Electroptics Systems, Inc.; and United Technologies Corp., Hamilton Standard Division, Research Division*
- Photocatalytic Indoor Air Purification for Air Conditioning Systems—E. Heller & Co.
- York Coil Technology Project—York International Corp.

General Competition Projects Related to Materials and Manufacturing

Ceramics

- Ceramic Technology for Broad Based Manufacturing—AlliedSignal, Inc.
- Novel Cost-Effective Process to Fabricate Surface Feature Micro-Optics in Pure Silica—Geltech, Inc.
- Novel Near-Net-Shape Processing of Engineered Ceramics—Garrett Ceramic Components (Division of AlliedSignal Aerospace)
- Synthesis and Processing of Nanocrystalline Ceramics on a Commercial Scale—Nanophase Technologies Corp.

Coatings, Diamond Deposition, and Multilayer Materials

- Accelerated Commercialization of Diamond-Coated Round Tools and Wear Parts—Kennametal, Inc., Corporate Technology Center; and Norton Diamond Film*
- Film Technologies to Replace Paint on Aircraft—3M Co.*; and Lockheed Martin Corp.
- CVD Diamond-Coated Rotating Tools for Machining Advanced Composite Materials—Boeing Commercial Airplane Group; Electronic Designs, Inc.*; Ford Motor Co., Research Laboratory; General Motors Corp., Technical Center; Hughes Aircraft Co.; and Rogers Tool Works, Inc.
- Plasma Technology for Low-Cost Diamond Production—SGS Tool Co.; and Westinghouse Electric Co.*

Machine Tools

- Advanced Compensation Techniques for Enhancing Machine-Tool Accuracy—Saginaw Machine Systems, Inc.
- Development of an Adaptive Compensation Technique for Enhancing CMM Accuracy—Giddings & Lewis, Inc., Sheffield Measurement Division
- Octahedral Hexapod Machine Development Program—Ingersoll Milling Machine Co.
- Strategic Machine Tool Technologies: Spindles—Aesop; Ford Motor Co., Alpha Development Center; General Motors Corp., NAO Technical Center; Giddings & Lewis, Inc., Automation Technology; Manufacturing Laboratories, Inc.; National Center for Manufacturing Sciences, Inc.*; ORSCO, Inc.; Olofsson Machine Tools, Inc.; Setco Sales Co.; and Torrington Co.

Other Manufacturing and Materials Projects

- Development of Improved Functional Properties in Renewable-Resources-Based Biodegradable Plastics—Cargill, Inc.
- A Software Technology for Optimizing On-time Performance in the Transportation Industry—Union Switch & Signal, Inc.
- Autonomous Navigation in Quasi-Structured Environments—Transitions Research Corp.
- Collaborative Decision Support for Industrial Process Control—Amoco Corp., Worldwide Engineering & Construction; Applied Training Resources; BP Oil; Chevron; Exxon; Gensym Corp.; Honeywell, Inc., Technology Center*; Mobil; Shell Chemical Co.; and Texaco, Inc.
- Conducting Polymers: Three Dimensional Engineering for Advanced Applications—IBM Corp., T.J. Watson Research Center
- Development of Cost-Effective Routes to Compatibilize Polymers in a Commingled Waste Stream—Michigan Molecular Institute
- Electrochromic Materials—3M Co., Industrial and Consumer Sector Research Laboratory*; and SAGE Electrochromics

* Joint venture lead partner

- NCMS Rapid Response Manufacturing—Cimplex Corp.; Ford Motor Co., Manufacturing Development Center; General Motors Corp., Technical Center; ICAD, Inc.; MacNeal Schwendler Corp.; National Center for Manufacturing Sciences, Inc.*; Spatial Technology Inc.; Teknowledge Corp.; Texas Instruments, Inc.; and United Technologies Corp., Hamilton Standard Division, Research Division

- Neural Network Control and Sensors for Complex Materials—3M Co., Engineering Systems & Technology; Alliant Techsystems; Honeywell, Inc., Technology Center*; and Sheldahl

- Novel X-ray Source for CT Scanners—Teledyne Electronic Technologies, Vacuum Technology Business Unit

- PREAMP: Pre-Competitive Advanced Manufacturing of Electrical Products—Boeing Co., Defense & Space Group; Hughes Aircraft Co.; Martin Marietta Corp., Electronics Information & Missiles Group; Mentor Graphics Corp.; Rensselaer Polytechnic Institute; Rockwell International Corp., Collins Avionics & Communication Division; and South Carolina Research Authority*

- Robust, Fast 3-D Image Processing and Feature Extraction Tools for Industrial Automation Applications—Perceptron, Inc.

- Solder Jet Technology Development—Microfab Technology, Inc.

- Thermal Insulation Materials: Morphology Control and Processes for the Next Generation of Performance—Armstrong World Industries, Inc., Innovation Center

- Thick Ductile Metallic Glass for Electric Power Applications—AlliedSignal, Inc.

- Advanced Gear Measurement Technologies to Achieve Submicron-Level Accuracies—M&M Precision Systems Corp.

- Non-Contact Optical Metrology of Complex Surface Forms for Precision Industrial Manufacturing—Tropel Corp.

- Rapid Agile Metrology for Manufacturing—Brown & Sharpe Manufacturing Co.; Caterpillar, Inc., Technical Services Division; Central State University; Cleveland Advanced Manufacturing Program; CyberOptics Corp.; Eaton Corp., Manufacturing Technical Center; General Electric Aircraft Engines; General Electric Corporate R&D; Industrial Technical Institute; Intelligent Automation Systems; NASA Lewis Research Center; Ohio Aerospace Institute (Consortium for Non-Contact Gauging)*; and University of Cincinnati, Department of Electrical and Computer Engineering

Applications

The ATP accepts project proposals only in response to specific, published solicitations. Notices of ATP competitions are published in *Commerce Business Daily*. You also may request to be placed on a mailing list (or emailing list) to receive notification of ATP competitions and other events by calling the ATP automated hotline (1-800-ATP-FUND) or by sending email to atp@nist.gov.

The ATP *Proposal Preparation Kit* may be requested at any time. In addition to the necessary application forms, the kit includes a thorough discussion of ATP goals and procedures as well as useful guidance in the preparation of a proposal.

Contact:
Advanced Technology Program
A430 Administration Building
1-800-ATP-FUND (1-800-287-3863)
email: atp@nist.gov
fax: (301) 926-9524 or (301) 869-1150
http://www.atp.nist.gov

MANUFACTURING EXTENSION PARTNERSHIP

Overview

The NIST Manufacturing Extension Partnership is a nationwide network of locally managed centers offering technical assistance and the newest business practices to help the nation's 381,000 small and medium-sized manufacturers improve their competitiveness. All centers rely on experienced field agents who work directly with smaller manufacturers to address their most critical needs. Typical MEP services include helping small manufacturers access information on new equipment such as automation systems, find high-quality consultant advice for optimizing manufacturing systems, reduce costs by lowering waste, improve quality, expand markets for products, and find financing for modernization efforts. Today, all states and Puerto Rico have centers affiliated with MEP.

To ensure that federal participation and investment in manufacturing extension efforts add value and contribute new capabilities to the mix of services available to manufacturers, MEP:

- is industry driven and market defined;
- builds on the foundation of existing state and local industrial extension resources;
- focuses on needed services that the private sector cannot deliver economically to smaller manufacturers;
- focuses services on those companies that demonstrate a commitment to investing in their own growth and development;
- develops common tools, resources, and systems needed by each of the individual centers—enhancing centers' local efforts while achieving economies of scale;
- supports shared learning between and integration among individual manufacturing extension centers;
- promotes continuous improvement of services through common evaluation methodologies and a focus on bottom-line results;
- forges constructive working relationships with consultants to make private-sector expertise more accessible to smaller manufacturers; and
- brings national technology and information resources—from federal laboratory technology to national information databases—to support and enhance state and local efforts.

MEP Extension Services

MEP extension centers are designed to help link sources of improved manufacturing technology and the small and mid-sized companies that need it. Center staff work with individual companies or with groups of companies organized around common needs, industries, or technologies.

While each center tailors its services to meet the needs dictated by its location and manufacturing client base, some common services are offered by most extension centers. Broadly, these include helping manufacturers assess their current technology and business needs, define avenues for change, and implement improvements. Many centers also assist companies with quality management, workforce training, workplace organization, business systems, marketing, or financial issues.

With the goal of improving access for smaller manufacturers to public and private-sector resources, MEP and the individual centers have developed relationships with hundreds of organizations. Among these partners are non-profit technology or business assistance centers, non-profit economic development organizations, community colleges and technical schools, private consultants, universities and four-year colleges, and federal agencies.

Centers encourage client companies to establish programs for continuous improvement and to focus on long-term "bottom-line" impacts, rather than working just to solve an immediate problem. Centers rely on experienced field agents and private consultants who provide the companies with on-site advice and practical assistance. Since 1989, MEP centers have provided services to more than 44,000 companies.

NIST's Role

In 1988, Congress directed NIST to begin helping the nation's smaller manufacturers adopt and apply performance-improving technologies as needed to meet intensifying domestic and global competition in manufacturing. NIST was selected for this role because of its expertise in manufacturing engineering and its long-standing tradition of productive partnerships forged with public and private organizations at the national, state, and local levels.

To carry out this role, NIST/MEP conducts a variety of regional, national, and program development activities. Regionally, MEP works with the states or local organizations to establish manufacturing extension centers or expand existing services that assist smaller manufacturers. Future centers are cultivated through MEP's State Technology Extension Program (STEP). STEP helps states better understand the needs of their smaller manufacturing companies and offer services these companies need to modernize and to become more competitive. STEP-funded projects enable states to build their own infrastructure for business and technology outreach services by planning extension systems or technical and business assistance

MEP Success Stories

MEP's locally managed centers have worked with thousands of smaller manufacturers, providing the technical and business assistance the companies needed to turn their businesses around. The following examples show how companies have benefited by working with an MEP center.

• A producer of space solar arrays and power subassemblies used in satellites, TECSTAR INC., City of Industry, Calif., wanted to cut down on solar cell breakage and to reduce costs while increasing production throughput and yields to keep up with increased sales. TECSTAR requested the assistance of the California Manufacturing Technology Center (CMTC) to improve its process. With CMTC's help, TECSTAR was able to save $3 million annually, increase staffing by 56 employees, reduce reactor downtime by 15 percent, and improve cycle time by 10 percent. "CMTC's recommendations to reduce solar cell mechanical breakage and cycle time made us realize where the major dollar losses were occurring within our production processes," says Mark Shumaker, director of quality and production support. The $3 million savings equals the amount the CMTC received in FY 1995 from NIST.

• Chicago Metal Rolled Products (CMRP), Chicago, Ill., bends, rolls, and coils metal, producing structural elements for such major projects as the International Terminal at O'Hare Airport, the McCormick Place expansion, and the Navy Pier renovation. The Chicago Manufacturing Center helped Chicago Metal President George Wendt institute a company-wide learning program involving basic reading, language and math skills, and job training. Wendt believes his investment in workforce development is key to the company's growth. Over the past 2 years, CMRP has seen a 30 percent increase in sales and a 20 percent growth in employment.

• Midland Lithographing Co., a North Kansas City, Mo., printer of greeting cards, sports trading cards, and pre-printed litho labels, decided it needed more efficient and effective ways of operating as well as a new marketing plan to attract new business. That's when Midland went to the Mid-America Manufacturing Technology Center (MAMTC) for help. MAMTC's assessment of the company and subsequent actions by Midland led to sales increases and cost decreases totaling $1 million in the following year and a 30 percent reduction in press set-up time. "We're happy with the progress we've made so far. We're working with MAMTC to apply this same methodology to other plant functions, such as our pre-press operation," notes Janice Keefer, plant manager.

• With locations in Latrobe and Glassport, Pa., Pakco Industrial Ceramics asked the Southwestern Pennsylvania Industrial Resource Center (SPIRC) to help it develop an overall improvement program. A SPIRC consulting team first started working with Pakco in June 1992 and has worked on a variety of Pakco projects over the years. The partnership reduced set-up time by about 50 percent without major capital expenditures and decreased throughput time from 10 to 12 weeks to approximately 6 weeks in 1992-1993. Sales rose more than 40 percent in 1994, and higher demand levels are now being serviced with 10 percent less work-in-progress inventory than 2 years ago.

• Sherwood Plastics, Fostoria, Ohio, found its production area too small and the layout too inefficient to meet increased market demands for its roto-molded plastic products. The Lake Erie Manufacturing Extension Partnership worked with Sherwood to create a larger, more efficient, and better organized plant. Their collaboration more than doubled Sherwood's workforce and, with new order-handling machinery, Sherwood grew from a $3 million operation to a $6 million company in 2 years. "The Lake Erie MEP helped us meet the demands of our growing markets. Now we have a much roomier, more efficient operation," notes President Mark Jones.

• After 3 years of declining profits, a feeling of slowly losing their competitive edge was prevalent among management at Tiffany Fine Woods, White Hall, Wis., so they contacted the Northwest Wisconsin Manufacturing Outreach Center (NWMOC) for assistance. Working with NWMOC, Tiffany had an initial cost savings of $250,000 and expects sales to grow 5 percent in 1995-1996 and 10 percent per year for the next 2 years. "Without this program we would have been forced to decrease our work force by 20 percent. As things now appear, we anticipate increasing our work force by 10 percent over the next 3 years," adds Vice President Robert Ofsdahl.

programs, supporting the initial implementation of such programs, or developing links between existing programs and those in other regions.

STEP grants provide matching funds (the grantee provides at least 50 percent of the cost of the proposed project) to qualified proposals from state governments and public/private, non-profit organizations acting with the approval of state governments. Since 1990, STEP has supported 32 states in building and improving manufacturing extension programs.

MEP also helps foster a more unified network by working with centers to identify and coordinate the services, technology, and information needed at a national scale. MEP is developing a uniform system to help centers evaluate and continuously improve the success of services they deliver.

To increase the breadth and depth of capabilities at each center and of the entire network, MEP makes a variety of services available to the centers. For example, MEP is funding projects that will develop training and tools to help MEP center field engineers provide improved services to smaller manufacturers. Easy-to-use, readily available courses are being designed in sales skills, assessment skills, and solving business problems. These courses will help field agents diagnose a smaller manufacturer's problems and then work with the company to find the right solutions that fit its financial resources. Special tools will better prepare agents to help smaller firms in areas such as environmental assessment, benchmarking, and marketing.

Access to credit and financing is vital for small manufacturing firms to survive and prosper. A study by the National Research Council found that a scarcity of capital and difficulty acquiring sufficient investment funds are barriers to increased manufacturing competitiveness for America's smaller manufacturers. MEP is funding four pilot projects to help smaller manufacturers better understand, identify, and access sources of financing and credit options that will enhance their ability to compete. The pilots are being conducted at four MEP affiliates: the Chicago Manufacturing Center, the Michigan Manufacturing Technology Center/Industrial Technology Institute, the Mid-America Manufacturing Technology Center, and the New York City Industrial Technology Assistance Corp.

The purpose of these pilot projects is to develop a method by which service providers at the MEP centers can forge strong relationships with financial intermediaries and institutions such as investment banking firms, merchant bank operations, leasing firms, venture capital firms, and private investors that are looking for qualified firms with which they can do business. Ultimately, the goal is to satisfy the financing demands of extension center clientele by developing innovative services that expand their range of financing alternatives, including private placements of debt and equity, industrial revenue and bonds, employee stock ownership plans, mergers and acquisitions, and equipment leasing.

Developing working linkages with other organizations in support of the entire extension network also is a high MEP priority. Among MEP's strategic partners are the National Governors Association, the National Alliance for Business, the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Labor (DOL). With the EPA, for example, MEP has launched several programs aimed at helping smaller manufacturers solve environmental concerns in the most cost-effective manner before they become problems requiring regulatory or compliance action.

MEP currently is providing cost-shared funding for 17 projects to help smaller manufacturers reduce or eliminate pollution sources in their operations. The projects are in the following three areas:

- Integration of environmental services into Manufacturing Extension Centers. Eleven projects, for which an MEP center is the lead partner, support the integration of environmentally focused technical assistance, especially pollution-prevention assistance, into the broader services provided by MEP centers.
- Development of environmentally related technical assistance tools and techniques. Five projects encourage the development and implementation of tools or techniques that will aid manufacturing extension centers in providing environmentally related services to smaller manufacturers.
- Pilot for a national industry-specific pollution prevention and environmental compliance information center. This project enables pilot implementation of a national center to provide specific industries with easy access to current, reliable, and comprehensive information on innovative technologies, pollution prevention opportunities, and regulatory compliance.

Other activities provide information, best practices, and professional development to help centers address the workforce development needs of smaller manufacturers. Some examples of current projects are:

- Labor Participation in Modernization Project—works to involve organized labor more effectively in the process of planning and implementing modernization efforts in unionized manufacturing plants. The project funds labor specialists and educational and modernization projects in four manufacturing extension centers and is conducted in conjunction with the Work and Technology Institute and Eastern Michigan University.

- Skills for Industrial Modernization—develops regional skills coalitions in Cleveland. The project's goal is to model the effectiveness of networks of small manufacturers in jointly addressing training and development needs.

- Competitive Firms, Skilled Workers—promotes the integration of workforce, technology, and economic development activities at the state level through working conferences and research. The work is conducted in cooperation with the National Governors' Association.

- Implementing High-Performance Work Organizations—supports two consortia of supplier firms in the implementation of training necessary for the adoption of high-performance work practices. Conducted by the Council of Adult and Experiential Learning, the National Association of Manufacturers/Manufacturing Institute, and the Massachusetts Industrial Service Program, the project's funding partners include the PEW Charitable Trusts and DOL.

Looking toward the future, MEP conducts research to better understand the barriers small firms face in modernizing and is finding new services, products, and delivery systems to help them overcome these hurdles. In addition, MEP is exploring new partnerships with organizations that have a stake in manufacturing modernization and new technology to help smaller manufacturers take advantage of electronic information and communications.

For example, MEP is funding a project to provide MEP centers with tools and techniques that will make it easier to find, synthesize, and present electronic information needed by center staff. In particular, centers will be able to access a variety of on-line and internal information sources using a single information interface.

How Are Centers Funded?

Funding to support this network of non-profit manufacturing extension centers initially is shared by the federal, state, and local partners. Federal funding is provided either directly by NIST or through the Technology Reinvestment Project, led by the Defense Advanced Research Projects Agency. In all cases, federal support is matched by state or local funding, fees for services, and industry contributions. The regional sponsor must contribute 50 percent or more of the center's capital and annual operating and maintenance costs. At least 50 percent of the sponsor's initial contribution must be in cash. As the center's program becomes more established, federal funding decreases.

How Are Centers Created?

NIST selects which programs to fund through a rigorous, merit-based competition that begins with a request for proposals posted in the *Federal Register*. NIST cannot accept proposals unless they are in response to a specific solicitation. In general, proposals are evaluated and selected based on knowledge of the numbers, types, and needs of target firms in the proposed region; technology and business resources; technology delivery mechanisms; and an effective management and financial plan.

Where Are MEP Centers Located?

ALABAMA

Alabama Technology Network
1500 Resource Dr.
Birmingham, Ala. 35242
(205) 250-4727
Serving firms throughout Alabama via 10 regional centers. In development.

ALASKA

Alaska Manufacturing Extension Partnership
c/o Industry Network Corp.
1155 University Blvd. S.E.
Albuquerque, N.M. 87106
(505) 843-4250
Serving firms throughout Alaska. Affiliated with the Alaska Science and Technology Foundation, the Alaska Human Resource Investment Council, and the University of Alaska Small Business Center. In development.

ARIZONA

Industry Network Corp.
1155 University Blvd. S.E.
Albuquerque, N.M. 87106
(505) 843- 4250
Serving firms throughout Arizona through service centers in Phoenix, Tucson, Yuma, Kingman, and Prescott.

ARKANSAS

Arkansas Technology Exchange Centers
100 Main St., Suite 450
Little Rock, Ark. 72201
(501) 324-9006
Serving firms throughout Arkansas through seven field offices. Affiliated with the Arkansas Science and Technology Authority. In development.

CALIFORNIA

California Manufacturing Technology Center
13430 Hawthorne Blvd.
Hawthorne, Calif. 90250
(310) 355-3060
Serving the five-county Los Angeles basin through two regional offices and three manufacturing outreach centers. Established in 1992 and affiliated with the El Camino Community College District, the California Trade and Commerce Agency, the California Community Colleges, and the California Employment Training Panel.

Corporation for Manufacturing Excellence
46750 Fremont Blvd., Suite 200
Fremont, Calif. 94537
(510) 249-1480
Serving firms initially in the nine-county San Francisco Bay region. Established in 1995.

San Diego Manufacturing Extension Center
World Trade Center
1250 Sixth Ave., 5th Floor
San Diego, Calif. 92101-4301
(619) 685-1425
Serving firms in San Diego county. Affiliated with the Center for Applied Competitive Technologies-San Diego and UCSD CONNECT. In development.

COLORADO

Mid-America Manufacturing Technology Center
10561 Barkley, Suite 602
Overland Park, Kan. 66212
(913) 649-4333 or (800) 653-4333
Serving firms throughout Colorado through six offices. Affiliated with Colorado State University.

CONNECTICUT

Connecticut State Technology Extension Program
185 Main St., Suite 408
New Britain, Conn. 06051
(860) 832-4600
Serving firms throughout Connecticut through four offices. Established in 1994 and affiliated with the Connecticut Technology Associates, the Edison Welding Institute, and the Central Connecticut State University.

DELAWARE

Delaware Manufacturing Alliance
Delaware Technology Park
One Innovation Way, Suite 301
Newark, Del. 19711
(302) 452-2520
Serving firms throughout Delaware. Established in 1994 and affiliated with the Delaware Development Office.

FLORIDA

Florida Manufacturing Extension Partnership
Sun Trust Center
200 S. Orange Ave., Suite 1200
Orlando, Fla. 32801
(407) 425-5313
Serving firms throughout the state through four regional centers. Established in 1995 and affiliated with Enterprise Florida Innovation Partnership, Inc.

GEORGIA

Georgia Manufacturing Extension Alliance
Georgia Institute of Technology
223 O'Keefe Building
Atlanta, Ga. 30332-0640
(404) 894-8989
Headquartered in Atlanta, with 18 regional offices serving firms throughout Georgia. Established in 1994 and affiliated with Georgia Tech's Economic Development Institute, the Georgia Department of Technical and Adult Education, the University of Georgia Small Business Development Centers, and Georgia Power Co.

HAWAII

Hawaii Manufacturing Extension Partnership
c/o Industry Network Corp.
1155 University Blvd. S.E.
Albuquerque, N.M. 87106
(505) 843-4250
Serving firms throughout Hawaii. Affiliated with the Hawaii Department of Business, Economic Development and Tourism, the Hawaii Board of Agriculture, the Hawaii Department of Labor and Industrial Relations, and the Hawaii Small Business Development Center. In development.

IDAHO

Idaho Manufacturing Alliance
1021 Manitou Ave.
Boise, Idaho 83706
(208) 385-3767
Serving firms throughout Idaho through three regional offices. In development.

ILLINOIS

Chicago Manufacturing Center
Homan Square
3333 West Arthington
Chicago, Ill. 60624
(312) 265-2020
Serving metropolitan Chicago. Established in 1994 and affiliated with the Economic Development Commission of the City of Chicago.

Illinois Manufacturing Extension Center
1501 W. Bradley Ave.
Peoria, Ill. 61625
(309) 677-2264
Serving firms throughout Illinois outside the Chicago metropolitan region. Affiliated with Bradley University. In development.

INDIANA

Indiana Business Modernization and Technology Corp.
One North Capitol Ave., Suite 925
Indianapolis, Ind. 46204-2242
(317) 635-3058
Serving firms throughout Indiana through 13 regional offices.

IOWA

Iowa Manufacturing Technology Center
Des Moines Area Community College
ATC Bldg. 3E
2006 South Ankeny Blvd.
Ankeny, Iowa 50021
(515) 965-7040
Serving firms throughout Iowa via 24 field agents. Established in 1994 and affiliated with Iowa State University and the Des Moines Area Community College.

KANSAS

Mid-America Manufacturing Technology Center
10561 Barkley, Suite 602
Overland Park, Kan. 66212
(913) 649-4333 or (800) 653-4333
Serving firms throughout Kansas through eight offices. Established in 1991 and affiliated with the Kansas Technology Enterprise Corp.

KENTUCKY

Kentucky Technology Service
P.O. Box 1125
Lexington, Ky. 40589
(606) 252-7801
Serving firms throughout Kentucky. Established in 1994 and affiliated with the Kentucky Economic Development Cabinet.

LOUISIANA

Louisiana Manufacturers Technical Extension Center
P.O. Box 44172
Lafayette, La. 70504-4172
(318) 482-6767
Serving firms throughout Louisiana. Affiliated with the Louisiana Productivity Center at the University of Southwestern Louisiana. In development.

MAINE

Maine Manufacturing Extension Partnership
87 Winthrop St.
Augusta, Maine 04330
(207) 621-6350
Serving firms throughout Maine through three regional offices. Established in 1995 and affiliated with the Maine Science and Technology Foundation.

MARYLAND

Maryland Manufacturing Modernization Network
University of Maryland Engineering Research Center
Potomac Building 092, Room 2104
College Park, Md. 20742-3415
(301) 405-3883
Serving firms throughout Maryland. Established in 1994 and affiliated with the University of Maryland.

MASSACHUSETTS

Massachusetts Manufacturing Partnership
Bay State Skills Corp.
101 Summer St., 4th Floor
Boston, Mass. 02110
(617) 292-5100, ext. 271
Serving firms throughout Massachusetts through five regional offices. Established in 1994 with the Massachusetts Executive Office of Economic Affairs and the Bay State Skills Corp.

MICHIGAN

Michigan Manufacturing Technology Center
P.O. Box 1485
2901 Hubbard Rd.
Ann Arbor, Mich. 48106
(800) 292-4484
Serving firms throughout Michigan, through seven regional offices. Established in 1991 and operated by the Industrial Technology Institute.

MINNESOTA

Minnesota Manufacturing Technology Center
111 Third Ave. South, Suite 400
Minneapolis, Minn. 55401
(612) 338-7722
Serving firms throughout Minnesota through six regional offices. Established in 1992 and operated by Minnesota Technology, Inc.

MISSISSIPPI

Mississippi Technology Extension Partnership
Building 1103, Room 140
Stennis Space Center, Miss. 39529
(601) 688-3144
Serving firms throughout Mississippi. Affiliated with the Mississippi Enterprise for Technology. In development.

Mississippi Polymer Institute and Pilot Manufacturing Extension Center
P.O. Box 10003
Hattiesburg, Miss. 39406-5157
(601) 266-4607
Serving polymer and polymer-related firms throughout Mississippi. Affiliated with the University of Southern Mississippi. In development.

MISSOURI

Mid-America Manufacturing Technology Center
10561 Barkley, Suite 602
Overland Park, Kan. 66212
(913) 649-4333 or (800) 653-4333
Through two offices, serving 21 counties in western Missouri as well as the seven-county St. Louis metropolitan area.

MAMTC Missouri Rolla Regional Office
800 W. 14th St., Suite 111
Rolla, Mo. 65401
(573) 364-8570
Serving rural Missouri through four regional offices. Affiliated with the Missouri Enterprise Business Assistance Center.

MONTANA

Montana Manufacturing Extension Center
315 Roberts Hall
Montana State University
Bozeman, Mont. 59717
(406) 994-3812
Serving firms statewide. Established in 1995 and affiliated with Montana State University.

NEBRASKA

Nebraska Industrial Competitiveness Service
8800 O St.
Lincoln, Neb. 68520
(402) 437-2535
Serving firms statewide via 10 field agents. Established in 1994 and affiliated with the Nebraska Department of Economic Development.

NEVADA

Nevada Manufacturing Extension Partnership
c/o Industry Network Corp.
1155 University Blvd. S.E.
Albuquerque, N.M. 87106
(505) 843-4250
Serving firms throughout Nevada. Affiliated with the University and Community College System of Nevada and the Nevada Manufacturers Association. In development.

NEW HAMPSHIRE

New Hampshire Regional Manufacturing Technology Center
505 Amherst St.
Nashua, N.H. 03061-2052
(603) 598-8800
Serving firms throughout New Hampshire. Established in 1995 and affiliated with the New Hampshire Regional Community Technical College System.

NEW JERSEY

New Jersey Manufacturing Extension Partnership
Center for Manufacturing Systems, NJIT
218 Central Ave., Suite 350 ITC
Newark, N.J. 07102-1982
(201) 642-4869
Serving firms statewide through two regional offices. Affiliated with the New Jersey Commission on Science and Technology. In development.

NEW MEXICO

Industry Network Corp.
1155 University Blvd. S.E.
Albuquerque, N.M. 87106
(505) 843-4250
Serving firms statewide through eight field engineers. Established in 1994.

NEW YORK

New York Manufacturing Extension Partnership
New York Science and Technology Foundation
99 Washington Ave., Suite 1730
Albany, N.Y. 12210
(518) 474-4349
Serving firms statewide through 10 regional manufacturing outreach centers listed below. Affiliated with the New York Science and Technology Foundation.

- Alliance for Manufacturing and Technology
  61 Court St., 6th Floor
  Binghamton, N.Y. 13901
  (607) 774-0022
  Serving a nine-county area within New York's southern tier through two offices.

- Center for Economic Growth
  One Key Corp. Plaza, Suite 600
  Albany, N.Y. 12207
  (518) 465-8975
  Serving the 11-county Capital District in the Albany area.

- Central New York TDO
  1201 E. Fayette St.
  Syracuse, N.Y. 13201
  (315) 425-5144
  Serving the five counties in Central New York in the Syracuse area.

- CI-TEC
  Box 8561
  Peyton Hall
  Potsdam, N.Y. 13699-8561
  (315) 268-3778
  Serving six counties in the North Country area through three offices.

- High Technology of Rochester
  Five United Way
  Rochester, N.Y. 14604
  (716) 327-7930
  Serving the nine-county Finger Lakes region in and around Rochester.

- Hudson Valley Technology Development Center
  300 Westage Business Center, Suite 130
  Fishkill, N.Y. 12524
  (914) 896-6934
  Serving the seven-county mid-Hudson region.

- Industrial Technology Assistance Corp.
  253 Broadway, Room 302
  New York, N.Y. 10007
  (212) 240-6920
  Serving the five boroughs of New York City.

- Long Island Forum for Technology
  P.O. Box 170
  Farmingdale, N.Y. 11735
  (516) 755-3321
  Serving Nassau and Suffolk counties.

- Mohawk Valley Applied Technology Commission
  207 Genessee St., Room 1604
  Utica, N.Y. 13501
  (315) 793-8050
  Serving Oneida, Herkimer, Hamilton, Fulton, Montgomery, and Schohari counties.

- Western New York Technology Development Center
  1576 Sweet Home Rd.
  Amherst, N.Y. 14228
  (716) 636-3626
  Serving New York's five western-most counties through three field offices.

National Center for Printing, Publishing and Imaging (CIMSPrint)
Rochester Institute of Technology
111 Lomb Memorial Dr.
Rochester, N.Y. 14623
(716) 475-5101
Center will partner with and act as a printing industry resource for all MEP affiliates. Affiliated with the Rochester Institute of Technology. In development.

NORTH CAROLINA

North Carolina Manufacturing Extension Partnership
IES Technical Services
Box 7902
North Carolina State University
Raleigh, N.C. 27695-7902
(919) 515-5408
Serving firms statewide through six outreach offices. Two additional offices in development. Established in 1995 and affiliated with North Carolina State University Industrial Extension Service.

NORTH DAKOTA

North Dakota Manufacturing Technology Partnership
1833 East Bismarck Expressway
Bismarck, N.D. 58504
(701) 328-5300
Serving firms statewide through four field offices. Established in 1995 and affiliated with Technology Transfer, Inc.

OHIO

Great Lakes Manufacturing Technology Center
Prospect Park Building
4600 Prospect Ave.
Cleveland, Ohio 44103-4314
(216) 432-5322
Serving northeast Ohio through seven field offices. Established in 1989 and affiliated with the Cleveland Advanced Manufacturing Program.

Lake Erie Manufacturing Extension Partnership
1700 N. Westwood St.
Toledo, Ohio 43607
(419) 534-3705
Serving 26 counties of northwest Ohio through four satellite offices. Established in 1995 and affiliated with the Edison Industrial Systems Center.

Miami Valley Manufacturing Extension Center
3171 Research Blvd.
Kettering, Ohio 45420
(513) 258-6187
Serving 23 counties of southwest Ohio. Established in 1994 in partnership with the Institute for Advanced Manufacturing Sciences. Affiliated with the Edison Materials Technology Center.

Plastics Technology Deployment Center
GLMTC Manufacturing Outreach Program
Prospect Park Building
4600 Prospect Ave.
Cleveland, Ohio 44103
(216) 432-5340
Serving 10 counties in northeast Ohio surrounding Cleveland and 14 counties in northwest Pennsylvania surrounding Erie. Established in 1994 and affiliated with the Great Lakes MTC and Penn State-Erie.

OKLAHOMA

Oklahoma Alliance for Manufacturing Excellence
525 South Main St., Suite 500
Tulsa, Okla. 74103
(918) 592-0722
Serving firms throughout Oklahoma via a network of over 25 broker/agents and sector specialists. Established in 1994 and affiliated with the Oklahoma Center for the Advancement of Science and Technology.

OREGON

Oregon Manufacturing Extension Partnership
29353 Town Center, Loop East
Wilsonville, Ore. 97070
(503) 657-6958
Serving manufacturing firms throughout Oregon. Affiliated with the Oregon Advanced Technology Consortium. In development.

PENNSYLVANIA

North/East Pennsylvania Manufacturing Extension Partnership
125 Goodman Dr.
Bethlehem, Pa. 18015
(610) 758-5599
Through two offices, serving the region north of Doylestown, east of Reading, and west of the Delaware River. Established in 1994 and affiliated with the Manufacturers Resource Center.

Southeastern Pennsylvania Manufacturing Extension Partnership
A coalition of organizations providing assistance to manufacturers throughout the region:

- Delaware Valley Industrial Resource Center
  12265 Townsend Rd., Suite 500
  Philadelphia, Pa. 19154-1286
  (215) 464-8550
  Serving the five counties surrounding Philadelphia and greater southeastern Pennsylvania in coordination with the following two offices. Established in 1995.

- Industrial Modernization Center, Inc.
  Farm Complex
  R.R. #5, Box 220-62A
  Montoursville, Pa. 17754
  (717) 368-8361
  Serving 12 counties in central Pennsylvania. In development.
- Manufacturing Technology Industrial Resource Center
  227 W. Market St.
  P.O. Box 5046
  York, Pa. 17405
  (717) 843-5054
  Serving nine counties in southcentral Pennsylvania. In development.

Southwestern Pennsylvania Industrial Resource Center/Northwest Pennsylvania Industrial Resource Center
4516 Henry St.
Pittsburgh, Pa. 15213
(412) 469-3530
Serving firms in western Pennsylvania. Established in 1994. Expansion into northwest Pennsylvania in coordination with the Northwest Pennsylvania Industrial Resource Center. In development.

Plastics Technology Deployment Center
c/o Penn State-Erie
Behrend College Station Rd.
Erie, Pa. 16563-0101
(814) 898-6132
Serving 14 counties in northwest Pennsylvania surrounding Erie. Established in 1994 and affiliated with the Great Lakes Manufacturing Technology Center and Penn State-Erie.

PUERTO RICO

Puerto Rico Manufacturing Extension, Inc.
Economic Development Administration
Mercantil Plaza Building, Suite 819
2 Ponce de Leon Ave.
Hato Rey, Puerto Rico 00918
(787) 756-0505
Serving firms throughout Puerto Rico. Affiliated with Puerto Rico's Economic Development Administration.

RHODE ISLAND

Rhode Island Manufacturing Extension Services
205 Lippitt Hall
University of Rhode Island
Kingston, R.I. 02881
(401) 874-2381
Serving firms throughout the state. Established in 1995 and affiliated with the University of Rhode Island.

SOUTH CAROLINA

Southeast Manufacturing Technology Center
1136 Washington St., Suite 300
Columbia, S.C. 29201
(803) 252-6976
Through 13 regional outreach centers, serving firms in South Carolina and the western/foothills region of North Carolina. Established in 1989 and operated jointly by the University of South Carolina and Enterprise Development, Inc.

SOUTH DAKOTA

South Dakota Manufacturing Extension Partnership Center
South Dakota State University
Harding Hall
P.O. Box 2220
Brookings, S.D. 57007-0199
(605) 688-4184
Serving manufacturing firms throughout South Dakota. Affiliated with South Dakota State University. In development.

TENNESSEE

Tennessee Manufacturing Extension Partnership
Department of Economic and Community Development
7th Floor, Rachel Jackson Building
320 6th Ave. North
Nashville, Tenn. 37243-0405
(615) 741-2626
Serving firms throughout Tennessee through five regional offices. Established in 1994 and affiliated with the State of Tennessee Economic and Community Development Department and the University of Tennessee.

TEXAS

Texas Manufacturing Assistance Center
1700 Congress Ave., Suite 200
Austin, Texas 78701
(512) 936-0235
Serving firms throughout Texas through five regional offices. Established in 1995 and affiliated with the Texas Department of Commerce.

UTAH

Utah Manufacturing Extension Partnership
Western Coalition for Advanced Manufacturing Processes
1025 Riverbreeze Dr., Suite 300
Orem, Utah 84058
(801) 378-9000
Serving firms via a network of manufacturing and business resource centers located throughout the state. Established in 1995.

VERMONT

Vermont Manufacturing Extension Center
Box 500
Randolph Center, Vt. 05061
(802) 728-1312
Serving firms throughout the state through three regional offices. Established in 1996 and affiliated with Vermont Technical College.

VIRGINIA

A.L. Philpott Manufacturing Center
P.O. Box 5311
645 Patriot Ave.
Martinsville, Va. 24115
(540) 666-8890
Serving 23 counties of southern Virginia through four regional offices. Established in 1994.

WASHINGTON

Washington Manufacturing Extension Partnership
2001 6th Ave., Suite 2700
Seattle, Wash. 98121
(206) 464-6009
Serving firms throughout Washington. In development.

WEST VIRGINIA

West Virginia Partnership for Industrial Modernization
634 8th St.
Huntington, W.Va. 25701
(304) 525-1916
Serving firms throughout West Virginia through five regional offices. Established in 1995 and affiliated with the West Virginia Development Office, the Marshall University Research Corp./Robert C. Byrd Institute, and the West Virginia University Extension Service.

WISCONSIN

Northwest Wisconsin Manufacturing Outreach Center
University of Wisconsin
Stout Technology Transfer Institute
103 First Ave. West
Menomonie, Wis. 54751
(715) 232-2397
In coordination with Wisconsin Manufacturing Extension Partnership, serving 32 counties in northwest Wisconsin through five satellite offices. Established in 1994 and affiliated with the University of Wisconsin-Stout.

Wisconsin Manufacturing Extension Partnership
Wisconsin Center for Manufacturing and Productivity
432 N. Lake St., Room B121-B
Madison, Wis. 53706-1498
(608) 262-2224
Serving manufacturers throughout the state through four regional offices, including the Northwest Wisconsin Manufacturing Outreach Center.

WYOMING

MAMTC Wyoming Regional Office
10561 Barkley, Suite 602
Overland Park, Kan. 66212
(913) 649-4333 or (800) 653-4333
Serving firms throughout Wyoming. Affiliated with the Mid-America MTC.

Additional Information

For further information contact:

Manufacturing Extension Partnership
(301) 975-5020
email: MEPinfo@mep.nist.gov
fax: (301) 963-6556
http://www.mep.nist.gov
C121 Building 301
or phone 1-800-MEP-4MFG
for the center serving your area

NATIONAL QUALITY PROGRAM

First presented in 1988, the Malcolm Baldrige National Quality Award has become the nation's premier award for business performance excellence and quality achievement. The Baldrige Award program was established by Congress in 1987 not only to recognize individual U.S. companies for their achievement but also to promote quality awareness and to provide information on successful performance and competitiveness strategies. The award is *not* for specific products or services. Two awards may be given annually to companies in each of three categories: manufacturing, service, and small business. In conjunction with the private sector, NIST developed and manages the award program.

Award Criteria

The award program focuses on quality as an integral part of today's business management practices. The award criteria, which are used by thousands of organizations as a general performance and business excellence model, are designed to help companies deliver ever-improving value to customers and improve overall company performance and capabilities. More than a million copies have been distributed since 1988. The criteria's seven categories focus on requirements that all businesses—especially those facing tough competitive challenges—should understand. The criteria are:

- Leadership. Have senior leaders clearly defined the company's values, goals, and ways to achieve the goals? Is the company a model "corporate citizen"?

- Information and analysis. Does the company effectively use data and information to support customer-driven performance excellence and marketplace success?

- Strategic planning. How does the company develop strategies and business plans to strengthen its performance and competitive position?

- Human resource development and management. How does the company develop the full potential of its work force? How are its human resource capabilities and work systems aligned with its strategic and business plans?

- Process management. How does the company design, manage, and improve key processes such as customer-focused design and product and service delivery?

- Business results. How does the company address performance and improvement in key business areas—product and service quality, productivity and operational effectiveness, supply quality, and financial performance indicators linked to these areas?

- Customer focus and satisfaction. How does the company determine requirements, expectations, and preferences of customers? What are its customer satisfaction results?

Using the criteria as an assessment tool provides firms with a clear view of where they stand and of how far they must go to achieve world-class levels of performance.

Rigorous Evaluation

Applications for the award undergo a rigorous evaluation by an independent review board composed of more than 250 business and quality experts from many industries (along with a smaller contingent from universities and governments at all levels). These experts volunteer many hours reviewing applications for the award, conducting site visits at firms that receive high scores after an initial screening, and providing each applicant with an extensive feedback report citing strengths and areas to improve.

Interactions

The National Quality Program has proven to be a remarkably successful government and industry team effort, starting in 1987 with industry's assistance in raising more than $10 million to help launch the program. Since that time, NIST has worked closely with a wide variety of groups to extend the benefits of quality management and stimulate activities nationwide. These organizations run the gamut from trade, professional, and business groups such as the National Association of Manufacturers and the U.S. Chamber of Commerce, to state and local government organizations such as the National Governors' Association, to broad-based interest groups like the National Education Association.

The cooperative nature of this joint government/private-sector team is perhaps best captured by the award's board of examiners. In addition to many hours spent during the award evaluation process, board members have given thousands of presentations on quality management and the award program.

The award-winning companies, too, have taken seriously the charge to be quality advocates. One of the main purposes of the award is to pass on information about the winners' quality programs that other companies can tailor for their own needs. Representatives from the winning companies have willingly shared their companies' quality strategies and methods with thousands of other firms. Their efforts to educate and inform other companies and organizations on the benefits of using the Baldrige framework and criteria have far exceeded expectations.

Award as Quality Model

Private-sector reviews and surveys are showing that the award is having a profound effect on shaping how people and organizations operate and work. For example, a report on the Baldrige Award program by the Council on Competitiveness states, "More than any other program, the Baldrige Quality Award is responsible for making quality a national priority and disseminating best practices across the United States."

The program has helped to stimulate an amazing movement to improve quality among U.S. organizations, including companies; academic institutions; and federal, state, and local government agencies. Nationwide, interest in the Baldrige model is growing steadily. In 1991, fewer than 10 state and local quality awards existed. Now, more than 40 states have or are establishing award programs. Most are modeled after the Baldrige Award.

For many companies, these award programs are "proving grounds," helping them to better understand quality management before they consider an application for the national Baldrige Award. In 1991, state programs received 110 applications; in 1995 that number climbed to over 575, about a 25 percent increase over 1994's 428 applications.

Internationally, more than 25 quality awards have been established, most within the past several years. Many of them are based on the Baldrige Award. Japan, home of the Deming Prize, recently launched an award that more closely resembles the U.S. Baldrige Award.

Interest also is increasing in organizations other than for-profit businesses. Working with experts from health care and education organizations, NIST tailored the Baldrige Award criteria and framework for these sectors and conducted a pilot application program in 1995.

Quality Award Winners

Winners of the Malcolm Baldrige National Quality Award:

1995—Armstrong World Industries' Building Products Operation, Lancaster, Pa. (manufacturing); and Corning Telecommunications Products Division, Corning, N.Y. (manufacturing)

1994—AT&T Consumer Communications Services, Basking Ridge, N.J. (service); GTE Directories Corp., Dallas/Ft. Worth, Texas (service); and Wainwright Industries Inc., St. Peters, Mo. (small business)

1993—Eastman Chemical Co., Kingsport, Tenn. (manufacturing); and Ames Rubber Corp., Hamburg, N.J. (small business)

1992—AT&T Network Systems Group/Transmission Systems Business Unit, Morristown, N.J. (manufacturing); Texas Instruments Inc. Defense Systems & Electronics Group, Dallas, Texas (manufacturing); AT&T Universal Card Services, Jacksonville, Fla. (service); The Ritz-Carlton Hotel Co., Atlanta, Ga. (service); and Granite Rock Co., Watsonville, Calif. (small business)

1991—Solectron Corp., Milpitas, Calif. (manufacturing); Zytec Corp., Eden Prairie, Minn. (manufacturing); and Marlow Industries, Dallas, Texas (small business)

1990—Cadillac Motor Car Division, Detroit, Mich. (manufacturing), IBM Rochester, Rochester, Minn. (manufacturing); Federal Express Corp., Memphis, Tenn. (service); and Wallace Co. Inc., Houston, Texas (small business)

1989—Milliken & Company, Spartanburg, S.C. (manufacturing); and Xerox Corp. Business Products and Systems, Rochester, N.Y. (manufacturing)

1988—Motorola Inc., Schaumburg, Ill. (manufacturing); Commercial Nuclear Fuel Division of Westinghouse Electric Corp., Pittsburgh, Pa. (manufacturing); and Globe Metallurgical Inc., Beverly, Ohio (small business)

Forty-six health care and 19 education organizations submitted applications. NIST distributed over 20,000 copies of the criteria for the pilot programs. NIST is continuing to work with the health care and education communities to establish a base of long-term, private-sector funding to support an award program.

Contact:
National Quality Program
(301) 975-2036
email: oqp@micf.nist.gov
fax: (301) 948-3716
A526 Administration Building
http://www.nist.gov/director/quality_program

LABORATORY PROGRAMS

Higher quality products, more reliable and more flexible processes, fewer rejected parts, speedier product development, more efficient market transactions, higher levels of interoperability among machines, factories, and companies. These are some of the practical advantages that U.S. companies realize from the NIST laboratories' research, services, and standards-related activities. The ultimate U.S. reference point for measurements with counterpart organizations throughout the world, the laboratories provide companies, entire industries, and the whole science and technology community with the equivalent of a common language needed in nearly every stage of technical activity. In furthering the technical aims and capabilities of U.S. industry, the NIST laboratory program serves as an impartial source of expertise, developing highly leveraged measurement capabilities and other infrastructural technologies.

Several hundred laboratory projects are under way at NIST during a single year. Some relate to the evolving needs of mature industries such as steel, machine tools, automobiles, and chemical processing. Others concentrate on the technical challenges confronting emerging industries such as those sprouting from advances in nanotechnology or the ones facing established high-technology sectors undergoing rapid technology change such as microwave communications. NIST has stepped up efforts to address the infrastructural needs of the biotechnology and information technology industries as well as others pursuing commercial prospects in young, rapidly developing areas of technology.

Collaborative Research

NIST actively seeks industrial, academic, and non-profit research partners to work collaboratively on projects of mutual benefit. A wide variety of mechanisms are available for carrying out these research collaborations. Special efforts are made to tailor collaborations to specific needs.

Most research collaborations start with one-to-one interactions between industry or other researchers and NIST scientists and engineers. To locate NIST researchers in specific fields of interest, see the project listings on pages 51 to 155. For further information about the process for implementing specific types of research agreements, contact the Industrial Partnerships Program, (301) 975-3084.

The most common types of arrangements include:

Cooperative Research and Development Agreements (CRADAs)

Typically cover joint research efforts in which both NIST and the cooperating company provide staff, equipment, facilities, and/or funds, in any number of possible combinations, for a project of mutual interest. NIST is currently working with more than 300 research partners on 365 CRADAs in nearly 230 different areas of research. Ninety-five percent of NIST's CRADA partners are U.S. businesses, with about equal numbers from large and small companies.

When companies conduct joint research with the Institute under a CRADA, NIST can protect confidential or proprietary information exchanged during the project, keep research results confidential, and provide exclusive rights for intellectual property developed during the course of the project. Each CRADA is negotiated separately between NIST and prospective partners. Most CRADAs take 6 to 8 weeks to implement.

Copies of a model NIST CRADA agreement are available from the NIST Industrial Partnership Program, (301) 975-5073.

Guest Researcher Agreements

Typically used when an industrial or other researcher wishes to join an ongoing NIST research effort. The researcher gains access to NIST research staff and facilities and, in return, results from the collaboration are made publicly available. Such agreements cannot protect proprietary information and do not allow cooperating companies to receive exclusive intellectual property rights. Once a NIST research group agrees to host a guest researcher, implementation of such agreements takes only about 1 week. Each year NIST hosts about 1,200 guest scientists and engineers at its Gaithersburg, Md., and Boulder, Colo., laboratories. Contact: domestic guest researchers, (301) 975-3084; international guest researchers, (301) 975-4119.

Research and Development Contracts

Used when external organizations contract with NIST researchers to receive specific technical services or results uniquely available at the Institute. The cooperating organization funds the NIST effort on a cost-reimbursable basis. Individual contracts may provide protection of proprietary information under certain circumstances.

Research results are made publicly available, and any intellectual property rights revert to NIST. Preparation of contracts for such agreements typically takes about 4 weeks.

Informal Collaborations

Informal one-to-one collaborations between Institute and other researchers. Such collaborations often involve exchange of research results and/or samples between NIST and other researchers, rather than transfers of personnel or research funds.

Examples of NIST Lab Projects

The examples of recent accomplishments described below are a small sampling of laboratory activities. They illustrate the ways in which NIST is carrying out its mission to provide infrastructural support to U.S. industry.

• NIST measurements are vital to the functioning of the entire economy, helping to ensure fairness and efficiency in the sale of more than $2 trillion worth of goods and services. Accurate and uniform measurements of weight, size, volume, and other quantities maximize efficiency and promote customer confidence in the sale of goods ranging from lunch meat at the deli counter to natural gas flowing through transnational pipelines to ultrapure gases purchased by semiconductor manufacturers.

• NIST tools and services are the ultimate references for the hundreds of millions of measurements made daily by U.S. companies, small and large. More than 350 different NIST-developed measurement tools and services are embedded into the quality control systems of the automotive industry—from small suppliers of metal parts to large refiners of gas and oil. Virtually all U.S. semiconductor manufacturers depend on NIST-developed test methods to evaluate their raw materials, processes, and products. The entire U.S. steel industry relies on more than 125 NIST Standard Reference Materials in assessing the quality of raw materials and finished products.

• Women getting mammography exams at licensed U.S. facilities will have greater assurance of receiving proper X-ray exposures thanks to a new NIST radiation standard and instrument calibration facility. The new facility will allow the operators and inspectors of more than 10,000 U.S. mammography centers to trace the accuracy of their X-ray exposure measurements to the primary X-ray standards at NIST. The calibration facility was established to help the U.S. Food and Drug Administration implement the Mammography Quality Standards Act of 1992.

• A NIST computer model that compensates for a common source of error in coordinate measuring machines (CMMs) promises to increase greatly manufacturers' ability to check accurately the shape and dimensions of products. The new "SuperFit" software corrects "probe-lobbing" errors, a chronic and relatively large source of measurement uncertainty in 98 percent of the 30,000 CMMs in U.S. factories and laboratories.

• NIST researchers have produced quantitative images of dopant densities in semiconductor circuits with 20 to 30 nanometer (billionths of a meter) resolution. The achievement brings the industry closer to meeting a key requirement of the National Technology Roadmap for Semiconductors for producing next-generation microcircuits by the year 2000. Dopants are chemical elements such as boron or phosphorus that are introduced into silicon and other semiconducting materials to selectively change their electrical characteristics.

• NIST scientists completed work on a fingerprint classification system for the Federal Bureau of Investigation (FBI) that helps to automate the last step in fingerprint analysis done completely by hand. For the last 30 years, NIST researchers have worked with the FBI to speed up the process by which fingerprint evidence is matched against the FBI's files—currently some 30 million sets of fingerprints.

• A new NIST quality assurance standard will help forensic and medical laboratories ensure that DNA profiles made with the polymerase chain reaction, or PCR, method are accurate. PCR is a relatively new method of DNA analysis that produces results in hours rather than the weeks required for earlier methods and requires only tiny amounts of DNA, such as the few cells carried in saliva left on a cigarette butt or a postage stamp.

• Working in collaboration with engineers at Howmet Corp., Whitehall, Mich., NIST researchers have developed an X-ray sensor that could take some of the guess work out of turbine blade technology. Manufacturers of jet turbine blades often can't tell if a blade has been "cooked" right until they remove the mold and take a look. The NIST system should allow manufacturers to optimize their processes so that they consistently grow single-crystal blades in the shortest amount of time.

• In collaboration with voluntary standards organizations, NIST has developed a standard, called BACnet, to allow interoperability of heating, ventilating, and air conditioning control systems in buildings. NIST worked with a consortium of 17 companies to test their prototype products implementing the standard. Use of the standard should lead to competitive, open procurement; integration of separate systems; and increased energy efficiency.

Research Consortia

On research topics of broad interest to a number of different research partners, NIST may sponsor research consortia. Research consortia usually are structured through NIST CRADAs and involve groups of companies and other organizations that exchange data, ideas, researchers, and/or materials among themselves and with NIST to meet agreed-upon research goals. Most consortia require payment of membership fees in exchange for advance knowledge of research results produced by the consortia effort. Currently active NIST-centered consortia include the following:

Flowmeter Installation Effects
Supports research in fluid flow measurements to help industry understand, evaluate, and assess flowmeter performance under non-ideal installation conditions. Contact: George Mattingly, (301) 975-5939.

North American Integrated Services Digital Network Users' Forum
Promotes the implementation and use of ISDN standards and the development of interoperable systems for the simultaneous transmission of voice, data, and images over high-speed digital networks. Contact: Leslie Collica, (301) 975-4856.

Microwave Monolithic Integrated Circuits
Develops metrology for design and manufacture of microwave monolithic integrated circuits, especially measurement methods and standards to reduce testing costs. Contact: Roger Marks, (303) 497-3037.

Ceramic Machining Consortium
Develops cost-effective production processes for grinding components made from advanced, structural ceramics, such as silicon nitride and silicon carbide. Contact: Said Jahanmir, (301) 975-3671.

Casting of Aerospace Alloys
Supports efforts to improve understanding and, ultimately, control of the net-shape casting process so that the alloys in finished parts attain the desired structural and performance properties required by the aerospace industry. Contact: Robert Schaefer, (301) 975-5727.

BACnet Interoperability Testing
Works to overcome communication barriers among building control systems from different manufacturers, making it possible to design truly "smart" buildings where all systems work together and are controlled from a central location. Contact: Steven Bushby, (301) 975-5873.

Coatings Service Life Prediction
Develops test methods to quickly and reliably predict the service life of painted products exposed to the elements in order to help the paint industry get better products to market more quickly. Contact: Jonathan Martin, (301) 975-6717.

EPDM Seams
Develops test protocols and criteria for evaluating the performance of pre-formed tape for bonding seams of EPDM roof membranes (a system commonly used to make low-sloped roofs watertight) to assist roofing contractors, consultants, and manufacturers in the selection and design of satisfactorily performing tape adhesive systems. Contact: Walter Rossiter, (301) 975-6719.

Air Speed Proficiency Testing
Improves measurement of very low air flows of importance to semiconductor fabricators, pharmaceutical manufacturers, and others whose products are very sensitive to airborne contaminants or whose facilities require clear air environments such as nuclear power plants. Contact: Vern Bean, (301) 975-4830.

Scanning Capacitance and Electromagnetic Sensors
Researches new ways to measure accurately the relative location or overlay of features in successive semiconductor chip layers, including examining and comparing the merits of two new methods—scanning capacitance probes and electromagnetic sensors. Contact: Michael Cresswell, (301) 975-2072.

Computer-Aided Manufacturing Engineering
Develops standards and interfaces for a manufacturing engineering tool kit designed to allow software tools made by different vendors with different engineering functions to work together. Contact: Swee Leong, (301) 975-5426.

Enhanced Machine Controller
Develops interface standards needed to produce an open architecture controller for manufacturing equipment that would allow machine builders, users, and systems integrators to customize more effectively equipment, reduce training and maintenance costs, and make retrofitting of existing equipment with new capabilities more practical. Contact: Fred Proctor, (301) 975-3425.

Orthopedic Accelerated Wear Resistance
Helps shorten development and approval time for new orthopedic implants by identifying test methods with the greatest promise for accelerated screening of materials for wear resistance. Contact: John Tesk, (301) 975-6799.

Environmentally Friendly New Flame Retardants
Works to replace current fire retardants with environmentally friendly additives that reduce heat release rates of polymers used in carpets, upholstery, and other products without increasing smoke or carbon monoxide production. Contact: Jeff Gilman, (301) 975-6573.

Technical Assistance

NIST provides without charge informal technical advice to U.S. companies and others seeking assistance in specific areas. Often NIST experts can help a company solve a technical problem through one or several phone conversations or a brief visit to the Institute's Gaithersburg, Md., or Boulder, Colo., laboratories. (Institute researchers are not permitted to consult on their own behalf or to receive personal payments for technical advice in areas within NIST's mission.) See project descriptions on pages 51 to 155 to locate a NIST expert in a specific research field or call the General Inquiries Unit for assistance, (301) 975-3058.

Technology Services and Products

NIST provides many different technology services and products to help U.S. industry improve the quality, reduce the cost, and increase the competitiveness of its products. Summaries of the NIST programs providing these services and products appear on pages 44 to 50. Examples include Standard Reference Materials, Standard Reference Data, calibration and laboratory accreditation services, and evaluations of energy-related inventions.

Use of NIST Facilities

The Institute operates more than 40 different research facilities that are accessible to outside researchers for collaborative or independent research. Some are one-of-a-kind facilities not available elsewhere in the United States.

Access to NIST facilities generally occurs through one of four mechanisms: under the provisions of a NIST CRADA or consortium agreement; through a guest researcher agreement; through contract R&D in which Institute staff members conduct specific experiments or tests at NIST and are reimbursed for their time and supplies; and, for a limited number of facilities, through scheduled appointments for qualified researchers wishing to conduct proprietary research.

Scheduling and priorities for NIST facilities use are determined by the relevant director for each NIST disciplinary laboratory, in some cases assisted by designated user group committees.

An index of NIST facilities appears on page 156. For detailed information on capabilities and availability of individual facilities, call the contact person listed for that facility. For general information on typical facility use agreements, contact the Industrial Partnerships Program, (301) 975-3084.

Technology Licenses

NIST seeks patents for its product and process inventions with commercial potential. Individuals or companies may obtain a license to use, make, or sell NIST patented inventions, on either an exclusive or non-exclusive basis. Normally licenses are granted only in cases where the licensee agrees that resulting products will be manufactured substantially in the United States.

The goal of NIST's licensing process is to encourage commercial use of NIST-developed technologies. For a current listing of the more than 100 NIST inventions available for licensing, contact the NIST Industrial Partnerships Program, (301) 975-4188.

Research Grants

Grants supporting research at industry, academic, and other institutions are available on a competitive basis through several different Institute offices. For general information on NIST grants programs, contact Sharon Green, (301) 975-6328.

Small Business Innovation Research Program
Funds proposals by small businesses for research and development efforts that fall within areas recommended yearly by the U.S. Department of Commerce. See description on page 45.

Precision Measurement Grants
Supports researchers in U.S. colleges and universities for experimental and theoretical studies of fundamental physical phenomena. Contact: (301) 975-4220.

Fire Research Grants
Sponsors research by academic institutions, non-federal government agencies, and independent and industrial laboratories that supports NIST's fire research laboratory programs. Contact: (301) 975-6854.

Standard Reference Data Grants
Supports research at academic, industrial, and other non-federal institutions to critically evaluate data in chemistry, physics, and materials properties. Contact: (301) 975-2200.

Materials Science and Engineering Grants
Supports work in polymers, ceramics, metallurgy, and neutron scattering and spectroscopy research at academic, industrial, and other non-federal institutions. Contact: (301) 975-5731.

TECHNOLOGY SERVICES

NIST provides a wide variety of services and programs to help U.S. industry improve its international competitiveness, commercialize new technology, and achieve total quality in all facets of business operations.

Companies spanning nearly all industrial sectors depend on the precision and reliability of NIST measurement services and products to keep their production processes running smoothly, efficiently, and safely. NIST reference materials, data, and calibrations help industry maintain quality control in the production of everything from aerospace alloys to voltmeters to breakfast cereals.

Responding to increased emphasis on quality standards in international markets, NIST provides information and assistance to about 20,000 organizations and individuals every year concerning national and international voluntary and regulatory product standards and certification systems.

In addition, NIST offers a user-friendly environment for businesses interested in cooperative research and development efforts, NIST-developed technologies available for license, guest researcher opportunities, technical information, or technical assessments.

The most current information is available from our home page on the World Wide Web (http://ts.nist.gov/ts/). There you can find the latest information on normative standards, laboratory accreditation, technology transfer, catalogs of calibration services, Standard Reference Databases, and Standard Reference Materials.

Contact:

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Room 306 NIST North
http://ts.nist.gov/ts

SERVICES AND PROGRAMS

SERVICES AND PROGRAMS

METRIC PROGRAM

The Metric Program helps implement the national policy to establish the metric system as the preferred system of weights and measures for U.S. trade and commerce. It provides leadership and assistance on metric usage and conversion to federal agencies, state and local governments, businesses, trade associations, standards organizations, and the educational community.

Implementing the 1988 amendments to the Metric Conversion Act of 1975, the Metric Program coordinates the metric transition activities of all federal agencies. Executive Order 12770, "Metric Usage in Federal Government Programs," issued in 1991, reaffirms the legislation by instructing federal agencies to implement formal plans for using the metric system and to report metric progress annually. The order authorizes the Secretary of Commerce to direct and coordinate the federal agency metric transition and to assess progress in annual reports to the President. The Metric Program carries out the direction and coordination responsibilities of the Secretary.

Because of the metric system's importance as an international standard, its use in product design, manufacturing, marketing, and labeling is essential for U.S. industry's success in the global marketplace. The use of the metric system in federal agency programs relating to trade, industry, and commerce is intended to support industry's voluntary adoption of the metric system.

Current Metric Program initiatives focus on education and public awareness to gain broad-based support for national metrication from industry and the general public.

Under the banner "Toward a Metric America," a series of regional metric town meetings and workshops seeks to build state and regional partnerships to accelerate adoption of the metric system in trade and commerce; encourage use of the metric system in all facets of education, including honing of worker skills; and develop programs of public awareness.

Contact:
Gerard C. Iannelli
(301) 975-3690
email: metric_prg@nist.gov
fax: (301) 948-1416
Room 306 NIST North

SMALL BUSINESS INNOVATION RESEARCH PROGRAM

The Small Business Innovation Research (SBIR) Program provides funding on a competitive basis to small high-tech businesses that can carry out research on topics of interest identified by each of NIST's laboratories. Annually in October, NIST issues a list of research and development topics for which proposals are solicited. There are two phases of awards. In Phase I, awardees can receive up to $50,000 for a 6-month study to establish the technical feasibility of a proposed project. Successful Phase I participants may compete in Phase II for up to $200,000 not to exceed 2 years to support further development of the work. Funds available for SBIR contract awards are tied directly to the NIST appropriation for Industrial Technology Services.

Contact:
Norman H. Taylor
(301) 975-4517
email: norman.taylor@nist.gov
fax: (301) 548-0624
Room 306 NIST North

OFFICE OF STANDARDS SERVICES

The Office of Standards Services (OSS) is the focal point for the Commerce Department's standards and conformity assessment activities. The office formulates and implements standards-related policies and procedures to enhance domestic commerce and international trade. The office provides representation to domestic and international organizations and federal agencies concerned with standardization, product testing, certification, laboratory accreditation, and other forms of conformity assessment. It chairs the Interagency Committee on Standards Policy to implement the Office of Management and Budget Circular No. 119, "Federal Participation in the Development and Use of Voluntary Standards," which is aimed at harmonizing standards and related programs of federal agencies.

Contact:
Belinda L. Collins
(301) 975-4000
email: belinda.collins@nist.gov
fax: (301) 963-2871
Room 287 NIST North

LABORATORY ACCREDITATION PROGRAM

The National Voluntary Laboratory Accreditation Program (NVLAP) provides third-party accreditation of testing and calibration laboratories. Accreditation programs are established in response to mandates or administrative action by the federal government or requests from private-sector organizations. Accredited laboratories are listed in a published directory and on the Technology Services site on the World Wide Web. NVLAP is in full conformance with the standards of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), including ISO Guides 25 and 58. Accreditation provides confidence that a laboratory can provide the technical services claimed and has the quality system to maintain high levels of proficiency.

NVLAP accredits laboratories in the following fields of testing: acoustics, asbestos fiber, carpet, commercial products, computer applications, construction products, electromagnetic compatibility and telecommunications, energy efficient products, ionizing radiation dosimetry, and thermal insulation. NVLAP also accredits laboratories in these calibration areas: dimensional, electromagnetic-dc/low frequency, electromagnetic-rf/microwave, ionizing radiation, mechanical, optical radiation, thermodynamics, and time and frequency.

Contact:
James L. Cigler
(301) 975-4016
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fax: (301) 926-2884
Room 282 NIST North

TECHNICAL STANDARDS ACTIVITIES PROGRAM

The Technical Standards Activities Program (TSAP) provides technical support for public and private-sector standardization and standards-related activities. TSAP manages U.S. representation and participation in the International Organization of Legal Metrology (OIML). OIML is a treaty organization of the international measurement community that promotes global trade through harmonization of performance requirements (regulations) for measuring instruments used to ensure equity in commerce, assure public and worker health and safety, and monitor environment protection.

TSAP also manages technical support for domestic and international standardization activities and coordination for U.S. standards advisers posted abroad. The program serves as the Commerce Department's technical contact point to investigate non-tariff trade barriers for non-agricultural products under the Agreement on Technical Barriers to Trade of the World Trade Organization. It administers the DOC Voluntary Standards Program, providing a mechanism for private-sector sponsors to develop standards in the public interest with significant domestic and international trade impact. Current standards pertain to construction and industrial plywood, wood-based structural-use panels, and softwood lumber. The program provides the executive secretariat for the Interagency Committee on Standards Policy and coordinates NIST participation in the annual U.S. observance of World Standards Day.

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GLOBAL STANDARDS POLICY PROGRAM

The Global Standards Policy Program (GSPP) provides technical information and support to federal agencies and industry to assist them in resolving trade issues related to standards and conformity assessment. GSPP monitors developments in standards and conformity assessment activities in the Western Hemisphere, the European Union, Russia and the Newly Independent States (NIS), Central Europe, the Middle East, and the Asia-Pacific region. It supports programs of the Commerce Department's International Trade Administration, such as the Special American Business Intern Training for Russian and NIS technical experts, and conducts standards-related economic and policy analyses.

GSPP works with standards and conformity assessment bodies in other countries to ensure the adoption of common procedures based on international guidelines. It also chairs or participates in the activities of interagency groups to establish U.S. government positions on standards-related aspects of major international agreements, such as the North American Free Trade Agreement.

The program provides assurance of the competence of U.S. conformity assessment bodies that are deemed to be qualified under the procedures of the National Voluntary Conformity Assessment System Evaluation Program, an essential element of mutual recognition agreements between the United States and foreign governments.

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STANDARDS INFORMATION PROGRAM

The Standards Information Program (SIP) operates the National Center for Standards and Certification Information (NCSCI), a central repository for standards-related information in the United States. NCSCI provides access to standards, technical regulations, and related documents published by U.S. and foreign governments as well as by domestic, foreign, and international private-sector standards organizations. SIP responds to domestic and foreign requests for information on U.S. standards, technical regulations, and conformity assessment procedures and to requests for information about foreign standards and technical regulations through its access to the network of information centers (ISONET) of the International Organization for Standardization.

SIP serves as the U.S. inquiry point under the Agreement on Technical Barriers to Trade of the World Trade Organization (WTO) to inform the WTO Secretariat in Geneva of proposed U.S. government regulations that might affect trade, receiving corresponding proposed foreign regulations and disseminating them to U.S. industry and cognizant government agencies. SIP operates the U.S. NAFTA inquiry point, which provides information about standards and technical regulations of the NAFTA countries. SIP also operates two telephone hot-lines that offer weekly updates on draft European standards [(301) 921-4164] and proposed foreign regulations for those concerned about regulations and standards that might create technical barriers to trade [(301) 975-4041]. The EC hotline reports on draft standards of the European Committee for Standardization, the European Committee for Electrotechnical Standardization, and the European Telecommunications Standards Institute.

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STANDARDS TRAINING AND SUPPORT PROGRAM

The Standards Training and Support Program (STSP) administers a network of standards experts in foreign countries who work with U.S. businesses, other U.S. government agencies, and foreign organizations to identify and remove technical barriers to trade. The program also conducts a series of training workshops to familiarize foreign standards officials with U.S. standards and conformity assessment procedures. STSP recruits and assigns standards experts to posts at key U.S. embassies and missions to provide U.S. industry, government agencies, and standards developers with timely and accurate information about foreign standards and conformity assessment procedures and to provide U.S. embassy personnel with technical advice for resolving trade issues related to technical barriers to trade.

STSP conducts workshops to furnish timely information on U.S. practices in standards and conformity assessment for foreign standards officials, to encourage their adoption of harmonized programs, and to build good working relationships for resolving future technical problems.

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OFFICE OF TECHNOLOGY PARTNERSHIPS

The primary objective of the Office of Technology Partnerships (OTP) is to build and sustain technology partnering activities between the NIST laboratories and its mission-related organizations. OTP does so by managing various technology transfer programs; managing NIST's intellectual property; carrying out assigned technology transfer functions under the Stevenson-Wydler Technology Innovation Act of 1980 and the Federal Technology Transfer Act of 1986; performing industrial and intergovernmental liaison; and strengthening NIST-wide awareness of technology transfer options and their implications. The office assists NIST leadership in reviewing related policies and practices and in helping to propagate improvements in research and development relationships throughout NIST.

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RESEARCH AND TECHNOLOGY APPLICATIONS PROGRAM

The Research and Technology Applications Program is located at NIST laboratories in Boulder and provides information on NIST activities and services to industry, academia, and state and local governments in the western region.

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INDUSTRIAL PARTNERSHIPS PROGRAM

The Industrial Partnerships Program provides assistance on:

- working with NIST research and development (R&D) programs;
- joint R&D relationships;
- cooperative R&D agreements (CRADAs);
- domestic (U.S.) guest researchers;
- industry fellow agreements;
- NIST R&D relationship policies;
- use of NIST facilities;
- intellectual property issues;
- patents;
- licenses;
- non-disclosure arrangements; and
- commercializing NIST technologies

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OFFICE OF MEASUREMENT SERVICES

The four components of the Office of Measurement Services (OMS)—data, materials, calibrations, and weights and measures—provide U.S. technologists with access to the U.S. national standards of measurement. Uniform and accurate measurements order the marketplace and reduce risk and cost to buyers and sellers. Connection to a solid measurement foundation is essential to industry in attaining quality and performance goals, demonstrating standards conformity, and removing non-tariff trade barriers. The business of America is business, and the competitive forces within business drive the need for increased use and accuracy of measurement. NIST measurement services meet these needs at the point of measurement usage by delivering services directly to about 10,000 companies. A current thrust of the program is to expand service delivery via accredited, NIST-traceable intermediate service providers.

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STANDARD REFERENCE DATA PROGRAM

For critical technical decisions, engineers and scientists in industrial and academic research rely on the NIST Standard Reference Data Program (SRDP). For 30 years, SRDP has provided well-documented numeric data to scientists and engineers for use in technical problem solving, research, and development. These recommended values are based on data that have been extracted from the world's literature, assessed for reliability, and then evaluated for the preferred values. These data activities are conducted by scientists at NIST and other institutions.

The NIST Standard Reference Database series has grown to over 50 electronic databases in chemistry, physics, materials, building and fire research, software recognition, and electronics. Versatile interactive databases provide easy access to NIST high-quality data. A World Wide Web catalog of data products distributed by the NIST Standard Reference Data Program is available at http://www.nist.gov/srd. To receive a printed copy of the catalog, contact Joan Sauerwein at (301) 975-2216.

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STANDARD REFERENCE MATERIALS PROGRAM

The Standard Reference Materials Program (SRMP) has pioneered and continues to be the leader in the development of certified reference materials for quality assurance of measurements. Through the Standard Reference Materials Program, NIST provides more than 1,300 different Standard Reference Materials (SRM®) that are certified for their specific chemical or physical properties. SRMs are used for three main purposes: to help develop accurate methods of analysis (reference methods); to calibrate measurement systems; and to assure the long-term adequacy and integrity of measurement quality assurance programs. NIST SRMs also legally constitute part of the National Measurement System infrastructure of the United States and, as such, are essential transfer mechanisms for national (and international) measurement traceability. The SRM Program provides a series of publications, known as the SP260 series, that is available to assist users in the application of SRMs. Some of these publications give practical guidance for using the SRMs while others give additional information about the certification process of particular SRMs. Of special note is SP260-100 *Standard Reference Materials Handbook: Handbook for SRM Users*, by John K. Taylor, which was written to discuss general concepts of precision and accuracy as applied to SRMs and their impact on quality assurance and the measurement process.

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CALIBRATION PROGRAM

The calibration services of NIST link the makers and users of precision instruments to the basic and derived units of the International System (SI) of measurements. As one of the cornerstones for assuring the consistency of measurements in the United States and internationally, this measurement transfer system is a critical factor in controlling manufacturing, assembly processes, and marketing as well as assuring the quality of manufactured goods. Users of these services send transfer standards to NIST where they are calibrated according to a measurement process that is stable, predictable, and statistically controlled. Currently, NIST provides more than 500 different calibrations, special tests, and measurement assurance programs in seven major measurement areas.

The Calibration Program distributes selected publications of general interest, including the *Calibration Services Users Guide* (SP 250), describing the calibration services

NIST provides; the *Calibration Fee Schedule* (SP 250 appendix); *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* (TN 1297); *Guide for the Use of the International System of Units* (SP 811); and *Experimentation and Measurement* (SP 672). To request these publications, fax your name and address to the number below.

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WEIGHTS AND MEASURES PROGRAM

The Weights and Measures Program promotes uniformity among the states in weights and measures standards, laws, and practices to facilitate trade and protect U.S. businesses and citizens, whose sales or purchases by weight or measure total over $2 trillion annually. The program is known outside of NIST as the Office of Weights and Measures (OWM), a name that dates back to 1837 when the program was established. OWM sponsors the National Conference on Weights and Measures (NCWM), an organization of state weights and measures officials and representatives of industry, consumers, and federal agencies. NCWM develops uniform laws, regulations, and methods of practice that are published by NIST. When these standards are adopted by regulatory agencies, they become mandatory. OWM administers the State Standards Program, which accredits state weights and measures laboratories; the National Type Evaluation Program, which evaluates models of commercial weighing and measuring equipment to determine compliance with NIST Handbook 44; and the NCWM National Training Program.

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OFFICE OF TECHNOLOGY INNOVATION

The Office of Technology Innovation (OTI) encourages, stimulates, and facilitates private-sector innovation. Special attention is directed to small businesses and the individual inventor or technical entrepreneur. It provides evaluation services designed to comment on product feasibility for the benefit of the developers and to establish technical credibility for the benefit of potential investors. OTI develops educational and other mechanisms to improve inventor/entrepreneur capabilities and supports their dissemination and implementation by state and local public-sector agencies. The office outreach activities are designed not only to promote use of evaluation services but also to build networks aimed at integrating state and local agency efforts to assist or support small businesses in technology commercialization efforts.

OTI also provides evaluation services to other federal agencies and to state small business assistance and economic development organizations. Services include peer and oversight reviews through OTI's staff engineers and its consultant network.

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In addition, OTI provides an unbiased independent evaluation service to other federal agencies and state organizations. Services include peer reviews through OTI's staff engineers and its consultant network, in a confidential manner. The review service is conducted in accordance with the customized review criteria provided by the clients to meet their specific needs.

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TECHNOLOGY EVALUATION SERVICES PROGRAM

Under the Energy-Related Inventions Program, the Technology Evaluation Services Program (TESP) evaluates inventions, technologies, and new product ideas submitted by small businesses/individual inventors as a prerequisite to possible financial and other support by the Department of Energy (DOE). Technology is evaluated for technical feasibility, energy savings, and commercial potential. The evaluations provide feedback from recognized experts drawn from a network of over 450 consultants. This "added value" enhances the attractiveness of promising technology as business opportunities for private-sector investors. TESP recommends promising technology to DOE, which provides financial support and other commercialization services.

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COMMERCIALIZATION ASSISTANCE PROGRAM

The Commercialization Assistance Program encourages technology innovation by developing networks in selected technology-oriented communities and marketing the Technology Evaluation Services Program (TESP) support services to small businesses and individual inventors. TESP's services, which include technology evaluation and commercialization training, are marketed either directly to small businesses/ individual inventors or through grass roots service providers such as state small business development centers, economic development agencies, universities, and trade associations/professional societies. Networks supporting technology commercialization also have been developed by marketing and supplying TESP services to other federal agencies such as DOE, Environmental Protection Agency, and the Patent and Trade Office (PTO) as well as other NIST activities such as Manufacturing Extension Partnership and Small Business Innovation Research. OTI builds these networks or infrastructures through an outreach program that includes presentations at national and regional conferences and periodic nationwide mailings to inventors through the PTO.

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OFFICE OF INFORMATION SERVICES

The Office of Information Services (OIS) maintains a comprehensive, international collection of information in scientific disciplines such as metrology, mathematics, physical sciences, computer science, and materials science. OIS staff serve the technical information needs of NIST scientists and engineers and communicate the results of NIST research to scientific and engineering communities worldwide.

OIS programs include selecting, acquiring, organizing, and disseminating primarily scientific and technical information in print and electronic forms. The NIST Library, with its specialized collection of approximately 200,000 volumes, including subscriptions to approximately 1,500 journals, microform collections, and electronic databases available on CD-ROMs or through on-line services, serves the entire NIST scientific and research community.

OIS also can be reached on the Internet through the NIST Virtual Library (http://ts.nist.gov/nvl), a resource that brings a selection of information resources available at the OIS Library, as well as pointers to other related information resources available through the Internet, including the World Wide Web.

To obtain further information about the NIST Library and the specialized reference services, on-line search services, and available databases, contact NIST Library reference staff at (301) 975-3052 or email: reflib@nist.gov

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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY

The Electronics and Electrical Engineering Laboratory (EEEL) provides the fundamental basis for all electrical measurements in the United States. In close consultation with industry, research and calibration programs are tailored to meet the most critical measurement needs for the manufacture and operation of electrical and electronic systems, including semiconductor, magnetic, radio-frequency, microwave, optical, optoelectronic and superconducting equipment; flat-panel displays; electronic instrumentation; and electrical power apparatus and systems.

Other programs are concerned with basic research to develop quantum standards that enable more accurate maintenance of the fundamental electrical units. Laboratory researchers also conduct studies on the new measurements needed for the successful development of promising future technologies such as high-temperature superconductors, quantum mechanical devices, and hybrid computer chips that utilize both electronic and lightwave signals. These measurement techniques, as well as Standard Reference Materials, such as those developed for optical fiber diameter, silicon resistivity, and superconducting critical current, play a significant role in helping to improve the efficiency and quality of manufacturing.

In addition, the laboratory manages metrology development work across NIST in response to the needs of mainstream silicon semiconductor device manufacturing. It also applies science and technology to solve key problems of the criminal justice communities.

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COOPERATIVE RESEARCH OPPORTUNITIES

Electricity

Semiconductor Electronics

Electromagnetic Fields

Electromagnetic Technology

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COOPERATIVE RESEARCH OPPORTUNITIES

OFFICE OF MICROELECTRONICS PROGRAMS

The Office of Microelectronics Programs (OMP) serves as an information focal point for semiconductor-related research at NIST. OMP is responsible for matrix management and contemporary relevance of the National Semiconductor Metrology Program (NSMP). OMP also manages NIST's strong working relationships with the Semiconductor Industry Association (SIA), the Semiconductor Research Corp. (SRC), and SEMATECH.

The NSMP was established by Congress (within the Department of Commerce) in 1994 in direct response to industry needs. The FY 1996 program portfolio consists of 23 multiyear projects with activities spanning nearly all of the NIST laboratory organizations. Strong emphasis is on metrological issues for mainstream silicon CMOS technology identified in the National Technology Roadmap for Semiconductors (SIA, 1994). OMP actively seeks industry collaborations in support of the portfolio and sets priorities based on direct industry contact and through participation in the planning activities of the SIA, SRC, and SEMATECH. Results from NSMP activities are largely public information and are freely available to domestic manufacturers.

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OFFICE OF LAW ENFORCEMENT STANDARDS

The mission of the Office of Law Enforcement Standards (OLES) is to apply science and technology to the needs of the criminal justice community, including law enforcement, corrections, forensic science, and fire service. To accomplish this mission, OLES develops methods for testing equipment performance and for examining evidentiary materials; develops standards for equipment and operating procedures; develops Standard Reference Materials; and performs other scientific and engineering research as requested by external sponsors.

The areas of research investigated by this office include clothing, communication systems, emergency equipment, investigative aids, protective equipment, security systems, vehicles, speed measuring equipment, weapons, analytical techniques, and Standard Reference Materials used by the public safety community. Exact projects are based upon the most recent recommendations of the Law Enforcement and Corrections Technology Advisory Council and vary depending upon the priorities of the criminal justice community.

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ELECTRICITY

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RESISTANCE STANDARDS AND MATERIALS

Component precision resistors of both film and wire construction have found widespread use as references and dividers in precision instrumentation such as digital multimeters and calibrators. The quality of these resistors and their level of immunity to the effects of environmental parameters, such as temperature and mechanical shock, have enabled the 3-month performance of these instruments to begin to approach that of the standards most commonly used to calibrate them. This fact and the desirability of calibrating such instruments where they will be used have heightened the need for a next generation of resistance standards—standards whose performance in adverse conditions would eclipse that of existing standards in a laboratory environment.

NIST scientists are beginning a program to develop new standards with sub-ppm performance, both short- and long-term, under field conditions. To do so, the electrical/physical properties of a number of alloys are being investigated, and new resistor designs are being formulated and tested. Future efforts will investigate metallurgical techniques such as rapid quenching, ion implantation in semiconductors and glasses for resistors $>10^7$, and Evanohm or Nichrome film deposition on Si substrates. The desired output will be fixed-value standards in the range from 1 Ω to 10^{12} Ω with sub-ppm per year drift rates, temperature coefficients less than 0.1 ppm/°C, and low power and voltage coefficients. A metallurgical facility with the capability of monitoring the electrical properties of materials during annealing and a silicon processing facility are available, along with access to precision resistance measurement systems and the national resistance standards.

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QUANTUM HALL EFFECT

The quantum Hall effect now provides the basis for the national unit of resistance. The realization of the resistance standard presents many interesting problems; researchers at NIST are investigating the physical principles underlying the effect, understanding sample-specific artifacts, exploring the ac quantum Hall effect, and improving the measurement systems. Research is being conducted on the range of parameters over which the quantum Hall effect provides the most accurate and reproducible standard of resistance.

Using GaAs heterostructures grown at NIST, researchers are using a dedicated class-10 clean room facility to investigate different methods of making contacts to the devices that will have very low resistances (in the milli-ohm range) even at temperatures below 4.2 K and in high magnetic fields.

NIST researchers also are working to improve and simplify the measurement systems used to calibrate resistors; a new ^{3}He refrigerator and 16-T magnet facility have been developed for use with a new cryogenic current comparator. This improved the accuracy of NIST calibrations severalfold.

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APPLYING HIGH-T_C SUPERCONDUCTORS TO PRECISION ELECTRICAL MEASUREMENTS

NIST and other national standards laboratories for years have used cryogenic current comparators (CCCs) to make ratio measurements of voltage, current, and resistance with uncertainties of 0.01 ppm or less. This approach has not found widespread commercial use because the cryogenic current comparator must be operated at liquid-helium temperatures, which presents a variety of operational difficulties. Moreover, existing comparators are working prototypes rather than completed instrumentation systems and are difficult to use.

Recent advances in superconductivity technology have made the application of high-temperature superconductors practical. In at least one case, an integrated circuit SQUID magnetometer, similar to devices used in CCCs to detect low levels of magnetic flux, has been built that operates at liquid-nitrogen temperatures. Thus, the possibility for developing a commercial instrument based on a CCC now has been opened. Such an instrument might be run with a refrigerator at liquid-nitrogen temperatures.

This development and the possibility of commercialization make it feasible to automate the basic CCC design, which then will be more attractive for general calibration use. NIST scientists are engaged in designing, building, and testing CCCs to support measurements of the new national resistance standards based on the quantized Hall effect. This involves establishing a few select ratios that range from 1:1 to 100:1. Future efforts will include the development of CCCs with selectable ratios over a somewhat larger range.

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JOSEPHSON-EFFECT VOLTAGE STANDARDS

High-accuracy voltage-standard systems have proliferated among many industrial, government, and international standards laboratories with the advent of the Josephson-array device. Within this laboratory, there are three array voltage-standard systems in operation, including a fully automated 10-V array system. Guest researchers can gain hands-on experience with array system operation and verification, as well as cooperate on studies into both precision voltage metrology and Josephson-array physics.

The metrology goals are to improve measurement precision to better than one part in 10^8 in applications of direct system-to-system intercomparisons and lab-to-lab volt transfers, achieve greater reliability in automation algorithms, and further the development of solid-state reference standards and precision digital voltmeters.

The physics research addresses the effects of electromagnetic noise on the stability and accuracy of the Josephson quantized-voltage steps, studies the boundaries of chaotic behavior in junction-junction interactions, and explores other possible array device applications, such as the generation of ac signals through frequency modulation of the millimeter-wave drive frequency.

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ADVANCED AC-DC VOLTAGE AND CURRENT MEASUREMENTS

Thermal voltage and current converters offer the most accurate and broadband method for measuring ac voltage and current for applications in communications, power generation, aerospace, and defense. Thermal transfer standards are calibrated by NIST in terms of reference converters, which themselves have been characterized by reference to the NIST primary standards—special multijunction thermal converters whose performance is known. These primary and working standards in common use throughout the metrology community employ thermal converters fabricated from wire elements. Researchers at NIST are studying new methods for the manufacture of film thermal converter structures made by the use of photolithography on silicon substrates. The application of this new technology may result in improved performance and reduction in the cost of thermal converters.

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SYNTHESIS OF PRECISE SIGNALS

NIST is conducting both theoretical and experimental research on the synthesis of precision ac waveforms for use in ac voltage standards operating nominally below 100 MHz and producing both sinusoidal and arbitrary waveforms. The theoretical work includes Walsh functions and Fourier analysis, time-domain analysis, and precision RMS-to-dc conversion techniques. Experimental work involves high-speed, high-accuracy digital-to-analog conversion; precision, high-speed switching; assembly and interpretive-level programming for hardware control; and wideband, fast-settling amplifiers.

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TESTING ELECTRONIC SYSTEMS

NIST scientists are developing new testing approaches for electronic systems to minimize the attendant testing costs while assuring product quality. Program emphasis is on development and application of generic error modeling methods for describing the systems to be tested. Once an accurate model is available, it can predict the performance of a device based on the fewest possible tests. Theoretical work centers on dimensionality selection for empirical models to minimize prediction errors and on the assignment of uncertainties and confidence limits when making predictions based on empirical models. Results of this work are being used by the semiconductor industry to reduce the costs of testing mixed-signal integrated circuits and by electronic instrument manufacturers to cut the high costs of calibration test points.

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FAST PULSE AND WAVEFORM ACQUISITION STANDARDS

NIST has an active program to provide a basis for characterizing both the time domain and frequency domain performance of sampling and digitizing systems, including analog/digital converters, sampling oscilloscopes, and waveform recorders. Theoretical and experimental research establishes test methods, reference waveforms, and state-of-the-art sampling technology to support these systems. Research areas include opto-electronic and electro-optical techniques for sampling and pulse generation in the 1- to 5-picosecond regime; advanced signal processing methods, including deconvolution, phase-plane compensation and spectral estimation; and ultrahigh accuracy techniques to support modern sigma-delta sampling technology.

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METROLOGY FOR ELECTRICAL POWER SYSTEMS

Electrical measurements are critical to the operation of electrical power systems in many ways: they are fundamentally important to control power flow, the maintenance of reliability and quality, and the revenue metering of electrical power. NIST research is conducted to support the high reliability of electric power delivery, public safety, and fairness in the sale of electric power to customers.

Nearly all equipment installed in the electric power system is subjected to acceptance tests at high voltage to ensure it can withstand accidental high voltage surges as well as ones occurring during normal system operation. NIST researchers are working both to improve the precision of conventional methods traditionally used in high voltage testing as well as to develop optical and electro-optical techniques that complement and offer significant advantages over conventional measurement approaches. Power quality is also of great concern for utilities, who provide the electric power, and for consumers, who have equipment such as computers that is sensitive to electric power surges, sags, and other transient phenomena. NIST is working with the electric power industry to identify the sources and presence of electric power degradation and to mitigate its effects on sensitive equipment. Magneto-optical measurement devices of electrical current are being developed for metering of electrical power. Research at NIST includes the verification of the accuracy of these devices that are being introduced into the power system. Other research areas include measurement of electric and magnetic fields and precision measurements of electric power and energy.

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B344 Metrology Building

DIELECTRICS RESEARCH

NIST scientists are developing measurement methods to characterize dielectrics used as electrical insulators in electric power systems. Emphasis is on the investigation of phenomena that affect reliability and safety associated with operation of electrical systems. Specific projects include investigation of the production of toxic byproducts in electrical discharges, research on the environmental impact of the use of gaseous dielectrics, and the development of diagnostics for predicting failure (or breakdown) of insulating materials. Theoretical work addresses Boltzmann equilibrium statistics, chemical kinetic computer codes, and computer-aided data acquisition and analysis. Experimental work focuses on high-voltage ac and dc tests, gas chromatography and mass spectrometric techniques for chemical characterization, and partial discharge measurements in cables and in gas- and liquid-insulated systems.

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PLASMA PROCESSING/ PLASMA CHEMISTRY

NIST scientists are investigating the chemical and physical processes occurring in low-temperature discharges by applying a wide range of diagnostics to well-characterized discharges that are similar to those used in the manufacturing of microelectronic devices. The goal of this research is to improve the measurement techniques required to ensure the reproducibility and control of semiconductor etching discharges. The discharges under study include radio-frequency (rf) discharges (generated in Gaseous Electronic Conference rf reference cells, a standard cell used by research labs worldwide) and low current dc Townsend discharges. Diagnostics applied to these discharges include mass spectrometric detection of neutral and ionic species generated in the discharges, analysis of discharge electrical parameters, detection of plasma optical emission, and laser-induced fluorescence. Additional areas of research include the accumulation and critical analysis of standard reference data (such as cross sections and rate coefficients) for use by the semiconductor industry, the measurement of electron attachment cross sections for etching gases, and the investigation of the role of surface charging in low-temperature discharges.

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VIDEO PROCESSING

Video quality is presently evaluated using subjective means; however, the exploding digital video revolution requires significantly more sophisticated and accurate measurements. The static test patterns and linear measurement tools for analog video systems do not characterize adaptive, non-linear digital compression systems. NIST is developing a collection of measurement tools for the testing and evaluation of digital video signals subjected to compression processing. Similarly, measurement techniques are being developed for the evaluation of the visual performance of video displays.

One of the tools used for real-time video processing is the Princeton Engine, a video supercomputer. Consisting of 1,024 parallel processors with wideband video input and output channels, each processor operates on one picture element per video scan line, and all processors execute the same instruction. Programming is accomplished using a subset of the C language having special constructions for parallel operation. Video recorders, multiscan monitors, high-definition monitors, and additional video support equipment are available. NIST researchers are interested in using the Video Technology Laboratory for a wide variety of collaborative research projects. Such collaborations would focus on precompetitive research with broad applications in advancing the state of the art in digital video systems.

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METROLOGY FOR FLAT-PANEL DISPLAYS

Researchers at NIST are developing the measurement technology for the characterization of advanced image display systems. A set of meaningful performance specifications is needed that can be used to assess display quality and that can be applied across the wide spectrum of display technologies that either are available or will shortly become available. Display quality issues are not simply a matter of light measurement, power efficiency, display environment, or signal quality. Rather, many of these factors act in concert to affect display quality, with an important addition—the complexities of human visual perception. Research topics include the development of radiometric and colorimetric measurements of emissive and non-emissive displays, the automation of such measurements, investigation of the visual perception of the eye, and modeling of display characteristics using the Princeton Engine video supercomputer (see item above).

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AUTOMATED ELECTRONICS MANUFACTURING PROGRAM

The Automated Electronics Manufacturing Program (AEMP) at NIST is working with industry to build the infrastructure for an electronic marketplace and to demonstrate and apply this technology to the electronics industry. AEMP researchers are actively working in the area of electronic commerce of component information (ECCI). The objective of ECCI is to show the viability of today's technology coupled with emerging standards to broker electronic component information across the national information infrastructure. Another enabling technology for electronic commerce is a complete and consistent suite of standards for the exchange of electronic product data descriptions. AEMP is involved in efforts to "harmonize" existing, overlapping standards (such as EDIF, AP210, and IGES) to help industry test for compliance with those standards, and to work with industry to develop standards in critical areas where none exist. Another emerging area in which AEMP researchers are involved is the manufacturing execution systems domain for electronics manufacturers. One current project involves technical support and testing of SEMATECH's object oriented computer integrated manufacturing framework project. This framework is intended to streamline integration of new equipment and software on the semiconductor manufacturing floor, thereby helping to minimize the time to market for new products. This technology is crucial to helping the United States maintain a leadership role in the global semiconductor manufacturing industry.

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SEMICONDUCTOR ELECTRONICS

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METROLOGY FOR NANOELECTRONICS

The goal of this project is to provide technological leadership to semiconductor and equipment manufacturers by developing and evaluating the methods, tools, and artifacts needed to improve the state of the art in compound semiconductor growth and nanometrology (measurements on a scale of 10 to 100 nm). A state-of-the-art molecular-beam epitaxy facility is devoted to in-situ metrology using a variety of X-ray and optical in-situ methods. Among these are an in-situ X-ray fluorescence probe, multiple wavelength ellipsometry, X-ray reflectivity, and various radiometric methods to measure wafer temperature during deposition. A focused ion beam facility is used to fabricate nanostructures for both research and metrology of nanoscale devices. In-situ measurements of growth and structural parameters are being examined in addition to fabrication properties required for the reliable manufacture of nanostructure devices. Research materials and methods to improve measurement standards also are being developed.

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A305 Technology Building

OPTICAL CHARACTERIZATION METROLOGY

Optical spectroscopic studies in the visible and near-visible regions of the electromagnetic spectrum are invaluable for determining both materials- and device-related properties. The ability to couple to electronic states of interest in device applications and their non-destructive nature make optical spectroscopic analyses attractive research and analytical tools. Studies currently under way at NIST focus on understanding the electronic and structural behavior of semiconductor materials, such as Si, GaAs, and GaN; microstructures, including quantum wells and superlattices; and photonic and electronic devices. Excellent spectroscopic facilities are available to perform high-resolution photoluminescence, photoluminescence-excitation, Raman and resonance Raman scattering, reflection, absorption, spectroscopic ellipsometry, and modulation spectroscopic measurements, such as electroreflectance and photoreflectance. The equipment used includes spectroscopic ellipsometers, high-resolution spectrometers, excitation lasers, spectrometers, cryostats, and associated optical and electronic instruments.

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ELECTRICAL CHARACTERIZATION METROLOGY

This project conducts research on semiconductor materials, processes, and devices to provide the necessary basis for understanding measurement-related requirements in semiconductor technology. Electrical methods are used to study such quantities as the resistivity, densities, and mobilities of the charge carriers and the deep-level properties in semiconductor materials. The Hall effect and magnetoresistance can be measured as a function of temperature and magnetic field in a high-field superconducting magnet system. Software has been developed to resolve the density and mobility of each component from these measurements in a multicarrier system. A computer-automated system for deep-level transient spectroscopy permits high-accuracy measurements of deep-level cross sections and energies. A new technique, scanning capacitance microscopy, has been developed for determining dopant distributions in processed wafers. This method is based on atomic-force microscopy (AFM), with the probe metallized and connected to a very sensitive capacitance meter. This represents an advance in capacitance-voltage profiling by replacing the traditional metal probe pad with a metallized AFM probe. Measurements can be made down to 20 nm resolution. Advanced computer codes for two- and three-dimensional simulations have been developed to obtain the dopant distribution from the capacitance values measured as a function of probe position and bias voltage.

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THIN-FILM PROCESS METROLOGY

Fabrication of thin films of various types is a fundamental building block in the semiconductor device industry. Increasingly stringent requirements on the structure and composition of those films are reflected in increasingly stringent requirements on the metrology tools and procedures used for process development and process monitoring. NIST researchers are developing improved procedures, reference data, and calibration artifacts to support in-situ process monitoring needs as well as in-line and at-line measurements. Current activities focus on thin-film dielectrics and ion-implant technology. Research on dielectrics, principally SiO_2 but also including nitrides and layered structures, includes improving ellipsometric characterization of materials needed for gate dielectrics for the year 2000 and beyond, developing an understanding of the effect of interface roughness on accurately determining the film properties needed by industry, developing new and more flexible mechanisms for supporting traceability to NIST in the area of measurement of thin-gate dielectrics, and developing a database of high-accuracy optical constants for silicon and important dielectric layers at temperatures typical of silicon processing steps. Research in ion-implant technology focuses on the development of reference artifacts for ion-implant absolute dose tied to common at-line measurements such as sheet resistance.

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SILICON-ON-INSULATOR METROLOGY

Silicon-on-insulator (SOI) wafers have advantages over bulk silicon in process simplicity and for applications involving low power, high temperature, integrated power, high speed, and radiation hardness. The National Technology Roadmap for Semiconductors notes that development of low-cost SOI substrate wafers could advance integrated circuit performance a full generation. SOI has been identified as the material of choice for the Defense Advanced Research Projects Agency's Low Power Electronics Program, which is developing the infrastructure for the fabrication of integrated circuits for the portable, battery-operated, communications/computer electronics of the future. This project supports development of improved SOI material by creating and applying advanced metrology techniques to the evaluation of the material. NIST has developed the capability of annealing SOI wafers at the high (1350 °C) temperatures required for fabricating the material and has the capability to fabricate simple test structures on SOI. Analytical capabilities include advanced chemical-etching techniques combined with optical and electron microscopy and precision electronic measurements.

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METROLOGY FOR DEVICES AND PACKAGES

The efficient and reliable application of semiconductor devices and packages requires accepted methods for characterizing and modeling these structures. This requires technically sound methods for measuring the electrical and thermal properties of devices and packages as well as procedures for validating models and simulations. Studies currently under way at NIST are focusing on model validation procedures for power semiconductor devices and microelectronic package thermal characterization and model validation procedures. To accomplish these tasks, NIST has state-of-the-art modeling and simulation capability for electrical and thermal behavior of semiconductor device structures, electronic circuits and systems, and computational fluid dynamics simulations for electronic cooling. Laboratory capabilities include infrared microthermography, low to very high current and voltage metrology systems, and time-domain reflectometry for package characterization.

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METROLOGY FOR PROCESS AND TOOL CONTROL

Integrated-circuit (IC) test structures, test-structure-based reference materials, and test methods developed by NIST are used widely by the semiconductor industry and other government agencies. These devices can be used to characterize IC manufacturing processes, to evaluate the effectiveness of semiconductor processing equipment, to obtain crucial parameters for process or circuit simulators, to perform product acceptance tests, and to determine the reliability of the products manufactured. NIST work involves test-structure design, modeling, data acquisition, and data analysis. Institute engineers are investigating pattern recognition techniques for the rapid diagnosis of IC manufacturing processes. They also are developing new structures for nanometer-level metrology and for establishing methods to determine the reliability of thin films used in state-of-the-art microcircuits.

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INTERCONNECT RELIABILITY METROLOGY

Electrical interconnect reliability of integrated circuits continues to be a topic of intense interest as evidenced by an increasing number of publications on the subject each year. This interest is the result of the planned aggressive scaling of integrated circuits and the need for ever greater reliability as expressed in the National Technology Roadmap for Semiconductors. A key underpinning of efforts in this area is the development of the measurement tools and standards to facilitate the goals of the industry. NIST researchers work with domestic semiconductor manufacturers and others to develop new and improved test structures, test methods, and diagnostic procedures for enhanced characterization and reliability of thin-film metal interconnects used in integrated circuits.

Advances in microelectronic circuit density, complexity, and reliability as well as greater demands for ever-shorter times to develop and market new products are forcing the U.S. semiconductor industry to use a new approach to reliability. The traditional approach of using screen and accelerated stress tests is becoming increasingly impractical to assure the reliability of microelectronic products because too many parts and too much time are required. NIST is working with the semiconductor industry to implement the new "building-in reliability approach," which emphasizes understanding and controlling the causes for reduced reliability.

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DIELECTRIC RELIABILITY METROLOGY

The U.S. semiconductor industry is aggressively scaling gate-oxide film thickness in microelectronic devices to achieve higher chip performance and packing density. Reduced time to market and new oxide processes require fast and effective reliability characterization techniques. NIST, in collaboration with the semiconductor industry, is developing physically correct models and tests to predict reliability of thin oxides under dc and ac operating conditions. Research is being performed to advance the understanding of time-dependent dielectric breakdown in thin SiO_2 films by verifying the electric field dependence of the mechanism. High temperature is used to accelerate dielectric failure so data can be obtained at lower electric fields in reasonable test times. Current projects focus on the evaluation of accelerated stress tests for predicting the long-term reliability of ultra-thin dielectrics. The project also facilitates the development of national standards for characterizing dielectric integrity to help ensure consistent measurements among a company's multiple manufacturing plants and between vendors and customers.

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MICROELECTRO-MECHANICAL SYSTEMS (MEMS)

MEMS is a rapidly growing segment of the U.S. semiconductor industry with a multi-billion-dollar market expected to expand tenfold over the next decade. This emerging technology uses mechanical structures, made with integrated circuit microfabrication techniques, to perform sensing and actuation functions. Commercial applications for this technology include pressure sensors, inertial sensors, fluid regulation and control, optical switching, mass data storage, and chemical- and biological-sensing and control. Areas of interest include standardization, environmental monitoring, and control in biomedical, military, and space applications. Systems aspects address the development of new circuits and processing techniques for monolithic integration of MEMS-based systems with new circuits for control, communication, self-test, and self-calibration functions. Standards aspects address the need for test structures and test methods for measuring and understanding the electromechanical properties and reliability aspects of these micromechanical-based systems. Custom processing techniques and incorporation of these techniques to post-processing of commercial foundry-fabricated ICs are being developed and utilized for device fabrication. Computer-aided design methods and standard libraries of device designs are being developed for rapid commercialization and technology transfer. Areas of specialization include microheating elements to produce temperature-programmable surfaces for applications in thermal flat-panel displays and integrated gas analyzers and development of CMOS-based broad-band power detectors for precision power measurement.

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ELECTROMAGNETIC FIELDS

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GUIDED-WAVE MICROWAVE STANDARDS AND MEASUREMENTS

The commercial and defense electronic industries rely on microwaves for a variety of applications. Microwaves are used in many applications, such as communications, radar, navigation, and environmental monitoring. Microwaves are desirable because of their high frequency and short wavelength. The high frequencies allow for very wide bandwidths, and the short wavelengths are important for reducing the size of components and devices. The accurate characterization of microwave devices and components is critical to the design, development, testing, and performance of modern microwave systems. The primary task of device characterization at microwave frequencies consists of measuring the transmission or reflection response of a device to a known or controlled stimulus.

The principal quantities that characterize electromagnetic waves propagating in transmission lines or similar guided wave structures are impedance, attenuation, scattering parameters, power, and noise. Rapidly developing microwave technology requires the support of advanced measurement techniques and standards for these quantities. The microwave industry and the U.S. Department of Defense rely on NIST for calibrations of transfer standards to provide accurate, traceable measurements required for product development, performance evaluation, quality assurance, and commercial interchangeability. To support international traceability requirements, NIST compares its measurements of these quantities with those made by other national metrology institutes by participating in international comparisons coordinated by the Bureau International des Poids et Mesures.

During the past decade, NIST researchers have developed six-port vector network analyzers (VNAs) for measuring scattering parameters, impedance, and attenuation. The six-ports provide an independent measurement technique for verifying the accuracy of commercial VNAs. Calibration services for scattering parameters, impedance, and attenuation are offered in popular coaxial and waveguide sizes from 10 MHz to 100 GHz. NIST also supports the microwave community by developing new measurement techniques and evaluating the accuracy of current techniques. Commercial VNAs have become an indispensable tool for modern microwave measurements. NIST is currently working on methods for assessing and for verifying the accuracy of vector network analyzers. As part of this effort, NIST administers a measurement comparison program with the IEEE Automatic RF Techniques Group that allows VNA users to compare their measurements with the measurements of others.

Microcalorimeters have been developed at NIST for the most accurate microwave power measurements. NIST researchers have developed both coaxial and waveguide microwave calorimeters to characterize thermistor mounts. Thermistor mounts serve as reference standards for calibrating power meters and other power measuring equipment. Present efforts are directed toward developing coaxial power standards that will operate up to 50 GHz. Calibration services for coaxial and waveguide thermistor mounts are available from 10 MHz to 100 GHz.

NIST does research on primary noise standards and radiometer systems to support noise temperature and noise figure measurements. One port noise temperature is determined by reference to a standard noise generator via a radiometer. Calibration services for measuring the thermal noise of coaxial and waveguide noise sources are available at limited frequencies from 30 MHz to 100 GHz. Researchers are developing an automated noise figure radiometer that will operate over the frequency range from 1 to 18 GHz. This system will measure the noise figure of active devices.

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HIGH-SPEED MICROELECTRONICS

While the explosion of wireless applications is fueling the demand for microwave and radio-frequency microelectronics, advances in the silicon industry continue to drive the size of digital circuits down and their clock rates up. These trends in the wireless and digital industries have led to increasingly stringent requirements for the electromagnetic characterization of monolithic microwave integrated circuits (MMICs), dense multilayer interconnects, and other high-speed microelectronic structures. In response to these requirements, NIST researchers are developing measurement methods to characterize key, high-frequency components and high-performance electronic packages and interconnections.

NIST supports the industry through research and development of on-wafer metrology, particularly for the measurement of scattering, impedance, and noise parameters. Fabrication of co-planar and microstrip calibration standards is an important element in the task. The project is supported by the NIST Industrial MMIC Consortium, which provides close collaboration with industry in developing accurate and traceable on-wafer measurements.

The project aims for practical calibration and measurement methods that are suitable for commercial laboratories. Methods are implemented in instrument control and data processing software that interface with a range of laboratory instruments, including microwave network analyzers, radio-frequency network analyzers, and digital sampling oscilloscopes. This range of options brings the advanced NIST technology into the hands of microwave, wireless, and digital engineers.

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JOSEPHSON ARRAY DEVELOPMENT

Manufacturers of precision electronic components and instrumentation need intrinsic electrical standards at a level of accuracy above that achievable by traditional electrical metrology and artifact standards. The characterization and calibration of modern digital voltmeters, reference standards, and analog-to-digital and digital-to-analog converters require the development of new and improved intrinsic standards for the measurement of ac and dc voltage. Target customers are electronic instrument makers, Department of Defense contractors, and national and military standards laboratories.

The project pioneered the development of practical Josephson voltage standards and, by encouraging the commercialization of these standards, has allowed U.S. industry to dominate the world market for Josephson voltage systems and components. Continuing work is designed to make these systems faster, easier to use, and more reliable. The project is developing a new generation of programmable voltage standards that can move rapidly to any specified output voltage. Ultimately, the new standards should be fast enough to synthesize ac waveforms.

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NANOSCALE CRYOELECTRONICS

Ultrasmall electronic devices operated at cryogenic temperatures offer unique capabilities that impact both fundamental metrology and industrial instrumentation. This project is developing a device for accurately counting electrons that will provide a fundamental standard for capacitance and allow an essentially new determination of the fine-structure constant. Operated in ultrasmall (100 nm) tunnel junctions at ultralow temperature (0.05 K), the device pumps electrons onto a capacitor one by one at a rate determined by an external clock. This device will become metrologically important when it is improved to the point where electrons are counted with an error rate less than about 1 part in 10^9.

Another cryogenic device under development meets the need for an X-ray detector with the improved energy resolution required for precise X-ray microanalysis. Such an X-ray detector, with an energy resolution of a few electron volts, can be made using the rapid change in resistance of a superconductor near its transition temperature to sense the X-ray-induced temperature rise of electrons in a normal metal film held at about 0.1 K. Such ultrasensitive thermometers offer enormous potential to materials analysis in the semiconductor and other industries and promise remarkable advances for optical detectors, high-energy physics, and analysis of biological molecules.

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HIGH-PERFORMANCE SENSORS, INFRARED DETECTORS, AND MIXERS

This project addresses the needs of users and manufacturers of long-wavelength infrared (IR) detectors. Precise radiometric calibration of such systems requires an improved absolute cryogenic radiometer for blackbody and band-limited IR radiation with higher accuracy and sensitivity than is presently available. The physical foundation of the project is the low noise and high sensitivity of superconducting transition-edge thermometers. Use of a transition-edge detector also is expected to improve the sensitivity of the ac/dc thermal conversion measurements by a factor of between 10 and 100 over room temperature detectors. In addition, manufacturers and users of room-temperature infrared imagers are seeking increased functionality from their systems. With support from the Department of Energy and a large commercial defense contractor, the project explores novel means of obtaining increased functionality, such as antenna-coupling of IR detectors for polarization discrimination.

This project also explores the capabilities of very high frequency diodes of various types, particularly superconducting and room-temperature metallic tunnel junctions. The frequency agility provided by such high-speed diodes will be important to applications such as the wavelength-division multiplexed telecommunications system in which very precise measurement and control of IR frequency is required. A further application for these devices is infrared rectification for solar energy generation, which, because it offers the possibility of raising the efficiency beyond conventional solar cells, is of great interest to the Department of Defense for size-constrained, power-starved environments such as satellites.

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SUPERCONDUCTOR STANDARDS AND TECHNOLOGY

Manufacturers of superconducting wire need practical and accurate methods for characterizing critical current, ac loss, and other performance parameters. The unbiased feedback of conductor performance and measurement considerations to U.S. manufacturers is important to maintain their competitive position in support of magnetic resonance imaging, electric power, laboratory magnets, and other applications.

For Nb_3Sn wires, the properties and handling of the sample mandrel can significantly affect the measured critical current. For high-temperature superconductors, sample damage, sample variability, and mounting variability can significantly affect the measured critical current. This project provides standards, measurement techniques, quality assurance, reference data, and clarification of issues for both high- and low-temperature superconducting wire technology. In conjunction with international standards organizations, it develops standards for critical current and other parameter measurements, conducts research, and leads interlaboratory comparisons. It represents, updates, and seeks input from U.S. industry throughout the process of standards creation in order to protect U.S. interest in international trade.

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SUPERCONDUCTOR INTERFACES AND ELECTRICAL TRANSPORT

The high-temperature-superconductor (HTS) industry needs high-quality contacts and interfaces for both thin-film and bulk conductors. Industry has looked to NIST for engineering help and an understanding of how to control the surfaces of these new materials. The new HTS materials also have significant magnetic field anisotropy, which has opened a new set of measurement and modeling problems for conductor performance. Many of the companies that have expressed a need for the expertise and the equipment available at NIST are small start-up companies without extensive infrastructure.

The thin-film fabrication equipment offers both sputter and laser-ablation deposition of HTS materials, reflection high-energy electron diffraction analysis, in situ characterization of process gas and background contaminants, ion-milling, and etching, all in the same vacuum chamber. Equipment to perform in situ scanning tunneling microscopy surface analysis of HTS films allows surface conductivity maps to be made immediately after film fabrication.

In magnet technology, both HTS and low-temperature-superconductor magnets are being developed with larger volumes and higher fields. Both lead to higher magnetic loading of the superconductor, which necessitates measurements of the effect of stress on electrical performance. The project instrumentation in the electromechanical area is the only apparatus in the United States for electrical transport measurements of superconductors at high magnetic fields.

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HIGH-TEMPERATURE SUPERCONDUCTING ELECTRONICS

High-temperature superconductivity (HTS) has opened the possibility for operating superconducting electronic instrumentation at temperatures accessible with present-day cryocoolers. Low-temperature superconductors are used to produce unique standards, such as the Josephson volt, and measurement apparatus, such as superconducting quantum interference devices (SQUIDs). Equivalent HTS devices would expand the applicability of these devices far beyond standards and research laboratories.

This project has developed fabrication, testing capabilities, and theoretical competence for HTS devices in the areas of microwave and terahertz metrology and technology. The project works with the HTS communication industry to measure and improve the power-handling capabilities of HTS devices as well as improve microwave measurement and characterization techniques for HTS films and devices. It works with industry and with other NIST divisions to develop and test HTS bolometers for calibrated radiometers, and it evaluates and improves HTS Josephson junctions for use in voltage standards, terahertz detectors, and other devices to meet the measurement and application needs of industry.

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MICROSTRUCTURAL ANALYSIS FOR ELECTROMAGNETIC TECHNOLOGY

Microstructural properties are primary limitations for applications of high-temperature superconductivity, magnetic recording, and non-linear optics. Understanding and controlling the relationships between microstructure and properties are key to improving and implementing these technologies. Flux pinning, phase uniformity and stability, surface roughness, process reproducibility, and degradation due to processing are a few of the issues restricting applications of high-temperature superconductors. Magnetic recording materials must be improved to achieve higher recording densities and faster data storage and retrieval. Non-linear optical materials are emerging with broad applications for the communications and medical industries. The further development and understanding of the microstructures of all these materials are important for supporting national goals of improved communications and competitiveness.

This project performs detailed evaluations of the microstructures of a variety of electromagnetic materials by using scanning probe microscopies, electron microscopies, and X-ray analysis. By correlating these data with measured properties, an understanding is developed of how the microstructures depend on processing and how they, in turn, influence properties. This knowledge is used to determine the materials and processing conditions necessary to obtain desired properties for specific applications, such as step-edge junctions, microwave devices, magnetic recording media, read-write heads, and compact blue-green lasers.

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MAGNETIC RECORDING METROLOGY

The magnetic recording industry is rapidly advancing the state of the art in high-density information storage and read devices. To maintain their competitive advantage in rigid-disk manufacture, U.S. firms must constantly look to new properties of magnetic materials. The accurate characterization of new materials is often beyond the capability of small companies most eager to exploit them. Thus, NIST develops metrology to assist the magnetic recording industry and develops techniques to characterize the performance of ultrahigh-density magnetic recording systems and of submicrometer magnetoresistive sensors.

This project has developed a scanning micromagnetic recording system to characterize ultrahigh-density recording. The system combines the ability to read and write conventional bit tracks under a variety of controlled conditions with the ability to image the magnetic structure and allows the characterization of advanced sensors without the need for full head fabrication. Development is coordinated with the needs of commercial disk drive, head, and media manufacturers as well as with the National Storage Industry Consortium heads program. The project develops micromagnetic models of magnetoresistive sensors and media and develops characterization techniques for the new generation of submicrometer magnetoresistive sensors to be used in ultrahigh-density magnetic recording.

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MAGNETIC INSTRUMENTS AND MATERIALS CHARACTERIZATION

Researchers, developers, producers, and users of magnetic and superconductor materials need tools for the accurate determination of magnetic properties and the analytical interpretation of data. This project develops the instruments, devices, techniques, and theoretical models needed to characterize the magnetic properties of films, particles, and bulk and amorphous material as functions of magnetic field strength, field history, temperature, and time. Industries supported include low-temperature and high-temperature superconductor wire manufacturers; manufacturers and users of magnetic particles, thin-film recording media, and thin-film recording and read-back heads; producers of microwave materials; companies researching uses of magnetoresistive sensors; and researchers in medicine.

NIST develops, promotes, and transfers to industry magnetic metrology for applications in magneto-optics, magnetic recording, practical superconductors, medicine, power conversion, and high-frequency electromagnetics. This project also provides measurement services, often in the form of collaborations, to laboratories that do not have magnetic measurement capability and maintains unique measurement instrumentation. Examples are ultra-sensitive magnetic instruments based on superconducting quantum interference devices and a magneto-optic microscope with a resolution better than the wavelength of light.

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NANOPROBE IMAGING FOR MAGNETIC TECHNOLOGY

Magnetic recording technology in the mid 1990s is a $50 billion worldwide industry consisting mainly of tape-drive and disk-drive manufacturers. The technology has advanced to where nanometer-scale morphological, magnetic, and electrical properties play important roles in drive performance. Images showing microroughness, device dimensions, magnetic field patterns, and local electronic processes provide important information about the fundamental operation and ultimate limitations of drive components. In addition, images of components shipped for assembly can be used to determine quality before manufacture of the complete drive. Scanned-probe microscopies, such as scanned-tunneling, atomic-force, and magnetic-force microscopies, and scanning potentiometry are uniquely qualified for many of these applications because of the nanometer-scale dimensions of the various types of probes.

By working closely with industry, this project helps to determine which kinds of SPM technology developed by the scientific community may have commercial impact. By optimizing techniques for measurement, the project establishes standard levels of instrument performance. This project maintains an active research program to develop new imaging and image measurement techniques tailored to specific problems designated by the magnetic recording industry.

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OPTOELECTRONICS

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LASER RADIOMETRY

This project develops measurement methods and standards for characterizing laser sources and detectors used primarily with continuous-wave radiation. It also develops and maintains measurement services for laser power and energy, optical fiber power, and related parameters.

Accurate characterization of optoelectronic sources and detectors is crucial to the effective development and use of industrial technologies such as lightwave telecommunications, laser-based medical instrumentation, materials processing, photolithography, data storage, and laser safety equipment. The laser radiometry project focuses on selected critical parameters intrinsic to optoelectronic sources and detectors, especially the calibration of optical fiber power meters and laser power/energy meters at commonly used wavelengths and power levels. In addition, special test measurements are available for linearity, spectral responsivity, and spatial uniformity of optical power meters and detectors. In support of source characterization, measurement methods are developed to evaluate and reduce laser intensity noise and to characterize beam intensity profiles and propagation of laser beams. Project members participate in national and international standards committees developing standards for laser safety, laser radiation measurements (such as beam profile and pointing stability), and optical-power-related measurements. They extend and improve source and detector characterizations, including development of low-noise, spectrally flat, highly uniform pyroelectric detectors and tunable-wavelength optical-fiber power measurement systems.

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HIGH-SPEED MEASUREMENTS

This project provides advanced metrology, standards, and measurement services relating to temporal properties of optical sources and detectors used with optoelectronic systems.

High-bandwidth measurements are needed to support high-performance systems that take advantage of the potential bandwidth of optical fiber. Systems presently being installed operate at 5 to 10 gigabits per second (Gbit/s) using pure optical time division multiplexing (OTDM); research is being conducted on the next generation of OTDM systems at 20 to 40 Gbit/s. Methods are needed to characterize the frequency and impulse response of high-speed sources and detectors to at least the third harmonic of the system modulation rate. Burst mode operation in asynchronous transfer mode networks requires characterization at very low frequencies. Increasingly tight tolerances in both digital and analog systems require frequency response measurements with low uncertainty. Source and detector noise measurements are required to predict low bit error ratios in computer interconnects, high carrier-to-noise ratios in analog systems, and to support Erbium-doped fiber amplifier noise-figure measurements using electrical noise methods. The high-resolution photolithography and corneal sculpting markets require pulsed Excimer laser measurements. Intensive use of laser target designators by the armed forces requires traceable, low-level pulse power and energy calibration standards at 1.06 μm and 1.55 μm.

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FIBER-OPTIC METROLOGY

Optical fibers have largely replaced coaxial cable in long-distance telecommunications systems and rapidly are being installed in local-area applications. NIST staff interact with industry groups to develop measurement methods and reference standards for the characterization of these components. The joining of optical fibers requires the fiber to have accurately controlled dimensions. NIST-developed Standard Reference Materials for cladding diameter allow manufacturers to calibrate instrumentation used in manufacturing and quality control; geometrical standards for fiber coatings and connector ferrules are being developed as well. Dispersion, the variation of propagation velocity with wavelength or polarization, sets the limit for the rate at which information can be transmitted; measurement methods and standards for both chromatic dispersion and polarization-mode dispersion are currently under development. The development of optical amplifiers has brought revolutionary changes to the design of communications; these new components require special methods of characterization now in development. Non-linear properties of fiber, such as four-wave mixing and soliton effects, have been studied and applied to instrumentation. Novel implementations of reflectometry in fiber are also studied.

This project develops advanced measurement methods and Standard Reference Materials for optical fibers and interacts with standards groups to provide a metrology base for the lightwave communication industry.

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INTEGRATED OPTIC METROLOGY

Optical waveguides in planar geometries, often called integrated optics, are increasingly used in communications and other optoelectronic systems. This project develops advanced measurement methods for integrated optical waveguides and interacts with standards groups to provide a metrology base for the lightwave communications industry. As the optical communications industry moves toward local area networks and toward fiber to the home, there is increasing need for inexpensive passive components, such as splitters. Additionally, such components are needed because long-distance telephony is retrofitting to wavelength-division multiplexing. Several companies are manufacturing 1 × N splitters or are about to market them. There are, however, no standard measurement procedures similar to those for fiber-index profile and mode-field diameter. Nor are there artifact standards similar to those for fiber geometry. It also is not obvious how to perform analogous measurements when the mode field pattern of an integrated optical waveguide is not circularly symmetric or when the fiber measurement is performed using a cutback technique or a mandrel wrap. Thus, several critical measurements are under examination.

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OPTICAL FIBER SENSORS

The NIST optical fiber sensors project supports the sensor industry broadly by providing measurements and standards for the characterization of optical materials and components used in sensors. Researchers also develop and evaluate new fiber optic sensors for other government agencies and industry. Most of the work has been devoted to high-sensitivity, high-bandwidth electric current and magnetic field sensing, although recent work has involved other measurands. A broad range of research and development is performed, including transducer, component, systems, and materials work. When possible, newly developed sensor technology is transferred to interested U.S. companies. A successful example involves annealed fiber coil technology that creates stable current sensors out of common optical fiber and is now commercially available.

In collaboration with U.S. companies NIST also is developing a Standard Reference Material for optical retardance. The device, based on Fresnel rhombs, will have nominally 90 degree retardance at 1.3 μm with 0.1 degree stability over wide ranges of wavelength, angle, and temperature. In addition to the Standard Reference Material, special measurement services for retardance using the accurate methods developed at NIST will be offered.

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FIBER AND DISCRETE COMPONENTS

Advanced optical communications systems use many different types of components to control and modify propagating signals. NIST develops measurement technology to characterize these components and understand their limits.

This project is currently conducting research on polarization-dependent loss and gain metrology, characterization of photo-induced Bragg fiber gratings, and wavelength standards for optical fiber communications. Polarization-dependent loss and gain in components affect a system's performance, especially when many components are in the system. NIST is developing a polarization-dependent loss calibration standard for commercial test instruments and is characterizing polarization-dependent gain of fiber amplifiers. Photo-induced Bragg gratings in optical fiber are likely to be incorporated in fiber lasers, dispersion compensators, and filters. The project evaluates the growth characteristics and long-term stability of these fiber gratings. The project is also developing Standard Reference Material absorption cells for wavelength calibration in the 1.5 µm region. These cells can be used to calibrate the instruments that characterize the spectrum of sources and wavelength dependence of components. This calibration capability will become increasingly important as wavelength-division multiplexing optical communication systems are implemented.

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DIELECTRIC MATERIALS AND DEVICES

NIST is developing measurement methods and acquiring critical data to improve the manufacturing of dielectric optical devices and materials. This work supports eventual and current commercial applications requiring passive optical components, electro-optic and non-linear devices, and compact solid-state lasers. Research activities include developing rapid non-destructive evaluation methods for bulk and thin-film ferroelectric materials such as lithium niobate, lithium tantalate, potassium titanyl phosphate, and non-linear polymers. Domain-engineered geometries of these materials also are under investigation. Commercial application of this work supports device and product development for optical data storage, biomedical lasers, vehicle navigation, and optical communications. NIST also is improving methods for the manufacture of compact rare-earth-doped solid-state waveguide lasers and amplifiers. This effort is currently emphasizing Nd-, Er-, and Yb-doped silicate and phosphate glasses. Critical measurements include evaluation of the dopant concentration profiles that define waveguides and spectroscopic properties such as lifetimes and cross sections. Rigorous numerical modeling is leading to optimized designs of mode-locked lasers, Q-switched lasers, and optical amplifiers. Various pulsed, continuous-wave, branched, and narrow-line lasers have been developed, including distributed Bragg-reflector lasers. Commercial applications include sensors and optical telecommunications.

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SEMICONDUCTOR MATERIALS AND DEVICES

The commercial success of semiconductor optoelectronic devices in an ever widening array of applications (telecommunications, computer interconnects, data storage, display, printing, and sensor systems) requires low-cost manufacturing. NIST scientists develop measurement tools suitable for critical stages in the manufacture of compound semiconductor light-emitting diodes, diode lasers, detectors, and modulators. To improve wafer yield, NIST is studying optical methods for in-process monitoring and control of semiconductor layer deposition. The operation of optoelectronic devices depends critically on the thickness and compositional uniformity of epitaxial layers. NIST researchers use computer simulations and the correlation of data from several techniques—X-ray diffraction, transmission electron microscopy, reflectance spectroscopy, and photoluminescence spectroscopy—to improve the measurement accuracy. Test structures and novel measurement techniques have been developed to precisely measure optical constants, defect diffusion, and quantum microcavity effects. Researchers fabricate semiconductor quantum-well devices for use in optical metrology and sensing. In support of next-generation optical interconnect, display, and data storage products, NIST scientists are measuring the properties of arrayed surface-emitting lasers.

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RESEARCH FACILITIES

SEMICONDUCTOR PROCESSING LABORATORY

As integrated circuit (IC) sizes increase to more than 1 cm^2 and feature sizes within the circuits decrease to less than 1 μm, critical demands are placed on the measurement capability required to control and monitor IC fabrication successfully. To meet the demand, NIST researchers are developing state-of-the-art measurement procedures for microelectronics manufacturing.

The Semiconductor Processing Laboratory provides a quality physical environment for a variety of research projects in semiconductor microelectronics as well as in other areas of physics, chemistry, and materials research. The laboratory facilities are used for projects addressing many areas of semiconductor materials and processes, including process control and metrology, materials characterization, and the use of integrated circuit materials and processes for novel applications.

The laboratory complex occupies about 372 square meters, approximately half of which is composed of clean rooms. Within the clean rooms, work areas are maintained at class 10. The facility is designed so the work areas can be modified easily to accommodate the frequent equipment and other changes required by research.

CAPABILITIES

The laboratory has a complete capability for IC fabrication. Principal processing and analytical equipment is listed below. The capabilities are expanded and improved continuously to meet technological challenges.

- Diffusion, Oxidation, and Annealing. Six furnace tubes for up to 75 mm diameter wafers and nine tubes for up to 100 mm diameter wafers.

- Photolithography. Research mask aligner (proximity and contact) for wafers up to 100 mm in diameter and irregularly shaped samples and 10 × direct-step-on wafer system for 75 mm diameter wafers. Photoresist spin coating and developing and related chemical processing, including oxygen plasma stripping. E-beam writing and SEM examination of small features on 75 mm wafers.

- Film Deposition. Low-pressure chemical vapor deposition systems for depositing silicon nitride, polysilicon, and low-temperature silicon dioxide. Rf and dc vacuum sputtering of metals and dielectrics. Electron beam and hot filament vacuum evaporation of metals.

- Etching. Wet and dry etching processes. Reactive ion beam etcher capable of ion milling and chemical etching with gases such as freon, sulfur hexafluoride, oxygen, and chlorine. Plasma barrel etching of nitride films and wet chemical etching of silicon for micromachining.

- Ion Implantation. Multipurpose 200 keV ion implanter.

- Analytical Measurements. Thin-film reflectometry and other thickness measurements, optical microscopy, and grooving and staining.

- In-Situ Metrology. In-situ, real-time, multiple wavelength ellipsometry to measure optical constants of silicon and other CVD materials such as silicon dioxide, polysilicon, silicon nitride, etc.

APPLICATIONS

Small quantities of specialized semiconductor test specimens, experimental samples, prototype devices, and processed materials can be produced. The processes and processing equipment can be monitored during operation to study the process chemistry and physics. The effects of variations in operating conditions and process gases and chemical purities can be investigated. Research is performed under well-controlled conditions.

A research-oriented facility, the laboratory is not designed to produce large-scale ICs or similar complex structures. Rather, the laboratory emphasizes breadth and flexibility to support a wide variety of projects.

Currently, research projects address many aspects of microelectronic processing steps and materials as well as silicon micromachining. Examples include: metal-oxide-semiconductor measurements; metal-semiconductor-specific contact resistivity; uniformity of resistivity, ion-implanted dopant density, surface potential, and interface state density; characterization of deposited insulating films on silicon carbide; ionization and activation of ion-implanted species in semiconductors as a function of annealing temperature; electrical techniques for dopant profiling and leakage current measurements; and processing effects on silicon-on-insulator materials. A simple CMOS process has been established.

AVAILABILITY

Laboratory staff welcome collaborative research projects consistent with the research goals of the NIST semiconductor program. Work is performed in cooperation with the technical staff of the laboratory.

The most productive arrangements begin with development of a research plan with specific goals. The commitment of knowledgeable researchers to work closely with NIST staff and the provision of equipment and other needed resources are required. Because hazardous materials are present, laboratory staff must supervise all research activities.

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MOLECULAR-BEAM EPITAXY FACILITY

Molecular-beam epitaxy (MBE) of III-V semiconductors is used to fabricate heterostructures with highly controlled electrical, optical, and structural properties. The facility's primary role is to study and measure material parameters of advanced compound semiconductors, especially in ways that promote new and improved measurement techniques. The MBE facility is equipped with a dual-chamber MBE system. One chamber is devoted to the fabrication of heterostructures for research and metrology. This effort includes high-mobility modulation-doped field-effect transistors, quantum Hall devices, SEED devices, superlattices, lasers, and optical modulators. The adjoining chamber is a state-of-the art MBE for developing and performing in-situ metrology of advanced semiconductors. What distinguishes this effort from others is the availability of numerous in-situ probes that can simultaneously measure the same materials parameters over a wide range of temperatures. This will lead to a better understanding of the limitations of an individual probe and will provide industrial manufacturers with important correlations they can use for improved growth control.

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WAFER PROBING LABORATORY

The NIST Wafer Probing Laboratory provides the capability for automated dc probing of test devices on up to 200 mm wafers. The system consists of a state-of-the-art commercial parameter analysis test system upgraded with a nanovolt digital multimeter controlled by a workstation. A computer-controlled 200 mm wafer prober allows for fast wafer mapping of devices. A switching matrix allows for the use of up to 36 independent connections; these may go either directly to a probe card for wafer probing or, through use of adapter boards, directly to packaged parts. Currently, the Wafer Probing Laboratory is primarily used in the development and evaluation of VLSI test structures for metrology applications; the system also is capable of measuring the dc characteristics of devices such as transistors. Additional equipment in the Wafer Probing Laboratory includes a 125 mm manual wafer probe station and inspection microscopes. This facility is available in support of collaborative research with NIST.

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MODE-STIRRED CHAMBERS

NIST researchers have designed and constructed mode-stirred (reverberating) chambers to measure radiated electromagnetic emission, immunity of electronic equipment, and shielding effectiveness of materials and cable/connector assemblies. A mode-stirred chamber is an electrically large (in terms of wavelength), high-quality cavity whose boundary conditions are varied by means of a rotating conductive tuner.

CAPABILITIES

The mode-stirred chamber simulates near-field conditions for tests at frequencies from 200 MHz to 40 GHz. Equipment as large as 1.5 m × 2.0 m × 3.0 m can be tested in high-level test fields up to 1000 V/m.

APPLICATIONS

In addition to performing radiated-emission or immunity measurements of electronic equipment, the mode-stirred chambers can measure the shielding effectiveness of gasketing, composites, and other materials used for radio-frequency shielding applications. The chambers also can be used to measure the shielding effectiveness of wiring harnesses, printed circuit boards, and connector assemblies. To perform faster immunity measurements, NIST researchers are studying frequency stirring as an alternative to mechanical stirring. Preliminary data indicate that good field uniformity can be obtained by using bandwidths on the order of 10 MHz.

AVAILABILITY

Two chambers are available. NIST staff are available for collaborative programs or to advise and interpret measurement results.

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GROUND SCREEN ANTENNA RANGE

The ground screen antenna is an open area test site.

CAPABILITIES

The ground screen consists of 6.35 mm mesh galvanized hardware cloth stretched over a level concrete slab. The screen is 30.5 m wide by 61 m long and permits far-field measurements in the high-frequency portion of the spectrum. The mesh dimension provides for an efficient ground plane well into the ultrahigh frequency part of the electromagnetic spectrum.

APPLICATIONS

The range can be used for the following applications:

- antenna calibrations,
- antenna patterns at any polarization,
- electromagnetic immunity measurements,
- electromagnetic radiated emission measurements,
- calibration of field intensity meters, and
- wave propagation studies.

AVAILABILITY

This facility is used heavily in performing calibrations for industry and other governmental agencies. It is available for independent or collaborative work.

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TRANSVERSE ELECTROMAGNETIC CELL

NIST researchers have designed and constructed several transverse electromagnetic (TEM) cells that are available for use. A TEM cell is an enclosure for performing radiated electromagnetic emission and susceptibility measurements of electronic equipment. Its design is based on the concept of an expanded transmission line operated in a TEM mode.

CAPABILITIES

The cell provides a shielded environment for testing without introducing multiple reflections experienced with the conventional shielded enclosure. It simulates very closely a planar far field in free space and has constant amplitude and linear phase characteristics.

APPLICATIONS

In addition to radiated electromagnetic interference testing, other applications of the TEM cells include the calibration of antennas and the study of biological effects of radio-frequency radiation.

AVAILABILITY

Several TEM cells with five different sizes and five upper frequency limits in the 100 MHz to 1 GHz frequency range are available. In collaborative programs, NIST staff are available to advise and interpret measurement results. Independent testing also can be arranged.

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ELECTROMAGNETIC ANECHOIC CHAMBER

The electromagnetic (EM) anechoic chamber at NIST is a facility for generating standard, well-characterized electromagnetic fields. Such fields are fundamental to the research, development, and evaluation of antennas, field probes, and EM material properties.

CAPABILITIES

EM fields up to 100 V/m can be established in the chamber over the broad frequency range from 200 MHz to 40 GHz and up to 200V/m for certain bands above 1 GHz. A majority of the individual components composing the measurement system are under computer control, thus enhancing statistical control of the measurements. The chamber measures 8.5 m × 6.7 m × 4.9 m.

APPLICATIONS

The EM chamber is used in areas such as:

- research, development, and evaluation of new EM-field-generation and measurement methods;
- calibration of field measurement instruments;
- immunity testing of electronic equipment;
- shielding effectiveness and material parameter studies; and
- special tests for industry, government agencies, and universities.

AVAILABILITY

This facility is used heavily in performing calibrations for industry and other governmental agencies. It is available for independent or collaborative work with NIST.

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CONCENTRIC LOOP ANTENNA SYSTEMS (CLAS)

NIST researchers have developed an antenna system consisting of three concentric, orthogonal metal loops, each having two diametrically opposed gaps. Analog signals from the gaps are relayed to processing electronics by fiber optic links in order to prevent distortion of the measured fields by electrical conductors. The signals are combined to give both the electric and magnetic components of an incident field.

CAPABILITIES

The present system consists of 1 m diameter loops, which are usable from 3 kHz to 100 MHz. The frequency range can be shifted upward by using smaller diameter loops. The minimum detectable power radiated from a device near the center of the loops ranges from 0.1 fW at 10 MHz to 1 pW at 100 MHz, with a 1 Hz noise bandwidth. The system has a dynamic range of 100 dB.

APPLICATIONS

Loop antenna systems can be used for:

- measurements of total E and H emissions from electronic devices such as video display terminals (VDT) that are placed near the center of the three loops;
- determination of the Poynting vector from incident plane waves;
- near-field measurements of power radiated from strong sources used in EMI/EMP testing;
- measurement of field levels near large conducting structures where plane wave approximations are not valid.

AVAILABILITY

The present 1 m diameter system is being used as a research tool to develop standard measurement techniques for emissions from VDTs. It is available for collaborative work in this or other areas of potential usefulness. Loops with other diameters or special requirements could be fabricated by special arrangement.

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STANDARD TRANSIENT/ IMPULSIVE FIELD FACILITY

This facility is designed to generate and transmit standard transient fields. The system consists of a 30-square-meter ground plane and a 3 m conical transmitter. The input signal is transmitted as a well-defined spherically expanding wave that can be used to evaluate the impulse response of electromagnetic probes and sensors.

CAPABILITIES

The transmit capabilities are primarily limited by the output spectrum and amplitude of the input signal source. In-house sources allow measurements of frequency components between 50 MHz and 10 GHz, and field levels of up to 100 V/m. The transmitted wave is known to an accuracy of ± 1 dB.

APPLICATIONS

The primary use for this facility is the calibration of broadband probes and sensors. Other applications are measuring the shielding effectiveness of structures and walls and measuring the immunity of electronic devices and equipment to transient electromagnetic fields.

AVAILABILITY

This facility is available for calibration of broadband devices. Other applications are possible on a limited basis. Tests requiring higher frequencies or field levels are possible with special arrangements.

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MOBILE TRANSIENT RECEPTION/TRANSMISSION SYSTEM

Several broadband antennas are available for transmission and reception of transient signals. By combining these antennas, broadband transient generators, high-speed transient digitizers, and sophisticated signal processing, a variety of measurements are possible.

CAPABILITIES

The capabilities are closely related to the desired application. With existing antennas it is possible to transmit transient signals with spectral components from 25 MHz up to 14 GHz and field amplitudes of greater than 200 V/m. Receiving antennas have similar frequency restrictions and sensitivities determined by the receiving equipment. Sensitivities of better than 500 V/m are typical.

APPLICATIONS

This system has been applied in a wide variety of diverse applications, and many more are possible. Some of the specific applications are measurement of the shielding effectiveness of materials, automobiles, and aircraft; non-invasive evaluation of electrical properties of materials; reflectivity of dissipative macrostructures, specifically, RF absorber, ferrite tiles, etc., and evaluation of reverberation and anechoic chamber performance; and measurement of fields radiated from electrostatic discharges.

AVAILABILITY

This system is readily available for interesting applications. Higher frequencies, amplitudes, and greater sensitivities are possible but require fabrication of special antennas.

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INTEGRATED-CIRCUIT FABRICATION LABORATORY

NIST maintains a complete fabrication laboratory for superconducting integrated circuits. Devices employing both low- and high-temperature superconductors are supported. Demonstrated capabilities include the fabrication of 20,000-junction Josephson 10-volt array standards, using niobium trilayer technology. The laboratory is housed in an M2.5/3.5 (Class 100/1000) clean room. Individual facilities include a digital pattern generator, submicrometer resolution waferstepper, precision contact aligner, laboratory-scale electron-beam lithography system, pulsed laser deposition system, metal and insulator thin-film deposition and etching systems, and requisite accompanying processing tools. Silicon wafer processing facilities for microelectromechanical system fabrication include oxidation, diffusion, silicon nitride growth, polysilicon growth, and low-temperature doped oxide growth. These facilities are available on a limited basis in support of collaborative research with NIST.

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ULTRALOW-TEMPERATURE ELECTRONICS FACILITY

A H^3/H^4 dilution refrigerator provides an approximately 20 millikelvin low-temperature environment for ultrasensitive measurement systems. Two projects using this system are integrated circuits incorporating ultrasmall metal tunnel junctions for counting single electrons and a record-setting X-ray detector having superior energy resolution and speed compared with any other detector. The facility is remarkable for its shielding from external radiation, including that from thermal sources at temperatures higher than its own.

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MAGNETIC THIN-FILM FABRICATION AND IMAGING FACILITY

NIST maintains a magnetics fabrication and characterization facility. The fabrication facility provides vacuum deposition of layered magnetic thin films, including materials that exhibit giant magnetoresistive behavior. Instrumentation includes several varieties of scanned probe microscopies such as the magnetic force microscope, magnetic resonance force microscope, and scanning near-field magneto-optic microscope. Other instrumentation includes an ac susceptometer, a Kerr optical analysis platform, a SQUID magnetometer, and a vibrating sample magnetometer.

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MANUFACTURING ENGINEERING LABORATORY

NIST engineers and scientists are developing many of the tools for automated intelligent-processing systems that will soon be the core of all world-class manufacturing operations. These components include intelligent machines; advanced sensors for real-time in-process measurements; software for precision control of machine tools; and information technology for integrating all elements of a product's life cycle, from planning and design through marketing and customer support.

The Manufacturing Engineering Laboratory (MEL) provides technical support for industry groups that develop standards for measurements, measurement techniques, hardware, software, and data interfaces. It operates the National Advanced Manufacturing Testbed, a unique national resource for studying advanced infrastructure technologies required to support future manufacturing operations at both the systems and equipment levels. Laboratory researchers also work at the forefront of the emerging field of nanofabrication, developing measurement tools for atomic-scale production technologies of the future.

Laboratory staff members work closely with their industry counterparts, from the planning of research projects to the dissemination of results.

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COOPERATIVE RESEARCH OPPORTUNITIES

COOPERATIVE RESEARCH OPPORTUNITIES

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COORDINATE METROLOGY SYSTEMS

Coordinate measuring machines (CMMs) are very accurate robots capable of measuring the physical dimensions of manufactured parts. They are rapidly replacing the more traditional method of using "hard gages" because they are more flexible, accurate, and faster. Ball bars and step gages are among the physical calibration standards used to trace CMM measurements to the international standard of length. Interim test artifacts are a new form of physical standard used to test CMM performance and to detect defective operation. In collaboration with the Department of Defense and industrial partners, such as Caterpillar and Boeing, NIST is developing both more effective types of CMM calibration standards, such as a prototype "ball step gage" system, and the means to evaluate and critique prototype interim test artifacts. NIST's deployment of interim test artifacts has been so successful that a major CMM manufacturer now manufactures the system as part of its commercial line. In addition, procedures for conducting interim testing of CMMs have been included in the new revision of the ANSI B89.4 CMM Performance Evaluation

Standard. In the future, a NIST Standard Reference Material interim test artifact and prototype ball-step gage will be offered.

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COMPLEX FORM METROLOGY LABORATORY

The mission of the Complex Form Metrology Laboratory is to develop and extend the world-class dimensional measurement capabilities of the Precision Engineering Division to include forms with complex shapes (e.g., gears, threads, turbine blades), necessary to satisfy industry's advanced measurement needs. Building on NIST's expertise in the measurement of American Petroleum Institute thread gages, MEL currently is re-establishing NIST as the pinnacle of dimensional traceability for complex form three-dimensional artifacts for gear manufacturers. Traceability is essential if U.S. industry is to maintain quality and interchangeability of its parts and assemblies, especially as dimensional tolerances continue to decrease. In turn, reliable methods for assuring dimensional precision and accuracy underlie the ability of U.S. manufacturers to compete in world markets. To this end, the division has installed, error mapped, and "super tweaked" a new high-accuracy coordinate measuring machine in a state-of-the-art temperature (± 0.1 °C) and humidity (± 2 percent) controlled environment. Working with an industrial advisory group—the American Society of Mechanical Engineers' Committee on Gear Metrology—the division already has begun to satisfy the traceability needs of the gear industry. A special measurement capability for gear involute artifacts is now available; the capability for lead and index artifacts soon will follow. The laboratory, in its research and measurements, places particular emphasis on the establishment of uncertainty for the measurement of complex forms.

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SURFACE FINISH AND MICROFORM MEASUREMENT

Surface microstructure affects the operation of components in the automobile, aerospace, semiconductor, metals, and optics industries. NIST is developing measurement techniques and standards to benefit all of these manufacturing industries.

NIST played a key role in coordinating the development of a new national standard for surface texture measurement as part of the American Society of Mechanical Engineers Committee B46. For the metals industry, NIST has developed a new approach to measuring the geometry of Rockwell C hardness indenters that has quickly become the most accurate in the world. NIST plans to use the instrument to control indenter geometry, thereby controlling the accuracy of the hardness measurement itself. This will unify Rockwell C hardness scales worldwide. For the optics and semiconductor industries, NIST has developed a calibrated atomic force microscope, which is calibrated against the wavelength of light in all three coordinate axes. A principal goal of this project is to calibrate three-dimensional artifacts that will be used to calibrate scanned probe microscopes. NIST also is using this instrument to measure prototype step height standards that collaborators at the University of Maryland fabricated from single silicon atoms. The Precision Engineering Division is responsible for certifying Standard Reference Materials for roughness as well as for calibrating the magnification of scanning electron microscopes.

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ADVANCED OPTICAL SYSTEMS

Advanced optical systems increasingly are designed around high-accuracy, aspheric optical elements. Measuring the figure error of generalized aspheres to the required accuracy is a complex and unsolved problem. NIST has embarked on a program to characterize the systematic errors of commercial, phase-measuring interferometers used for surface figure metrology and to develop techniques for using these instruments for aspheric metrology. The goal of the program is to close the gap between the resolution and the accuracy of phase-measuring interferometers. NIST researchers are working with personnel at the WYKO and Zygo corporations, manufacturers of interferometry systems.

NIST researchers already have demonstrated a significant sensitivity to fringe density of the measured figure error for several commercial phase-measuring interferometer systems. They are working to build a dedicated test facility for future systematic investigations. The results of this work will make it possible to manufacture lightweight, high-performance optical systems for space-based applications and multilayer mirror systems for projection X-ray lithography.

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ATOMIC-SCALE MEASURING MACHINE

To help meet the measurement needs of industries preparing to manufacture future generations of nanoelectronic devices and circuits, NIST has designed and built a system—called the Molecular Measuring Machine (M-Cubed)—to measure to nanometer accuracy the positions of features located anywhere within a 50 mm by 50 mm area. Achieving this capability for M-Cubed required the development and integration of many forefront technologies: atomic-resolution scanning probes, combined active and passive vibration-isolation systems, ultrahigh-accuracy interferometry for displacement measurements, and precision nanomotion generation. Currently, M-Cubed is performing one of its principal design functions by measuring to nanometer-level accuracy over millimeter-scale dimensions. In one successful application, it measured the spacings of an array of chromium lines over a distance of 1 mm, yielding an average spacing of 212.83 nanometers. The estimated standard uncertainty for this measurement was of 0.02 nm, which is about one-tenth the distance of typical interatomic spacings. M-Cubed also will serve as an exploratory tool for building mechanical and electrical structures in the nanometer-size range. Among the organizations collaborating on the construction of M-Cubed are several major universities and national laboratories as well as Watson Research Center, AT&T Bell Laboratories, and Zygo Corp.

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MEASURING PATTERNED LAYERS ON INTEGRATED CIRCUITS

NIST researchers are developing techniques for measuring the critical dimensions of patterned layers on integrated circuits. Work involves theoretical projects on the formation of images in optical and scanning electron microscopes as well as experimental and design projects on the construction of new metrology instruments for the calibration of standards. The project was initiated about 20 years ago at the request of the semiconductor industry.

Ever smaller dimensions on integrated circuits have created a demand for new and improved measurement techniques and related standards. As feature sizes approach, and then become smaller than, the wavelength of light used in conventional optical metrology instruments, measurements and standards become especially important. The dimensions of present interest range from about 0.5 μm to 30 μm and will extend to smaller dimensions in the future. A series of three linewidth/pitch Standard Reference Materials for photomasks is now in production. Ongoing research will develop new and improved standards for use in instruments utilizing optical or scanning electron microscopy.

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CLOSED LOOP MANUFACTURING PROGRAM

This program aims to achieve higher quality in existing manufacturing processes. A four-layer, closed-loop, control architecture has been proposed. Three layers are being implemented: real-time, process-intermittent, and post-process control loops. The real-time and process-intermittent control loops implement algorithms to predict and/or measure in-process variations and process-related systematic errors and then to compensate for them via process modification. Closed loop manufacturing is being demonstrated on existing machine tools, achieving superior levels of part accuracy. In this case, the post-process control loop is used to verify the cutting process and to tune the other two control loops by detecting residual systematic errors measured on the finished parts, correlating these errors to the uncompensated machine- and process-related errors, and modifying the control parameters of the other loops accordingly.

Feature-based, error-analysis techniques are being developed to identify the residual systematic errors of the system. NIST researchers are working with industry and academia to use the dimensional measurement interface specification, an ANSI standard, in analyses of part features. They are developing tools for feature segmentation of part geometries to improve analyses of the manufacturing process. They also are developing a quality database using feature types and the errors measured on these features as key fields.

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MACHINE-TOOL PERFORMANCE EVALUATION AND ACCURACY ENHANCEMENT

The concept of deterministic manufacturing is based on the premise that most errors in manufacturing are repeatable, thus predictable. Errors that are predictable can be measured and corrected, thereby improving quality through better control of existing manufacturing equipment. Machine tools are computer controlled and operate with several to many degrees of freedom. They exhibit inherent quasistatic and thermally induced geometric errors. Complete characterization of these errors is being investigated to evaluate and enhance performance under changing thermal conditions. This process is complicated and time consuming.

NIST researchers are working with industry and academia to optimize this process to make it feasible for even small manufacturers. NIST, industry, and academia worked together to develop the industry standard for evaluating the performance of machining centers (ASME B5.54). Compensation for machine-tool errors is an area of continuing interest. Researchers are developing generic electronic hardware to implement error-compensation capabilities without intruding into existing machine-tool controllers. They also are working to speed up on-machine part inspection by introducing fast probing and powerful data analysis capability at the machine-tool level.

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PRECISION PISTON TURNING

The Precision Piston Turning Project is a cooperative research effort involving NIST, General Motors Corp., Ford Motor Co., and Giddings and Lewis, with funding through the National Center for Manufacturing Sciences. The primary objective is the transfer of NIST's expertise in machine tool enhancement and technology to U.S. industry.

This project comprises several activities. The first task was performed in 1992, when a research team from NIST traveled to Giddings and Lewis' Fraser, Mich., plant to analyze the design of a prototype of the company's model 3000. Using infrared technology and contact temperature-sensing devices, an investigation of the thermal behavior of the machine tool was performed. Based on analysis of the data collected during this investigation, several design changes were recommended. These changes were implemented on the machine tool, which was sent to NIST for a more rigorous thermal analysis.

NIST then performed a full geometric-thermal characterization of the machine, using laser interferometry and other advanced sensors. Characterization was performed by monitoring error motions as the machine tool cycled through a variety of thermal states. The thermal states were quantified by the use of remote temperature-sensing devices attached at various locations on the components and structure of the machine. The end result of this characterization is a geometric-thermal error map of the piston-turning machine. This error map then can serve as the database for real-time error compensation. As a result of this effort, the variability of the pistons was reduced by 80 percent.

Current work is concentrated on determining the robustness and general applicability of the machine tool models, enabling broader use of the models. This would allow machine tool builders and users to avoid the costly and time-consuming task of modeling every machine tool.

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ENHANCED MACHINE CONTROLLER

In 1980, nearly half of the machine tools in the world were manufactured in the United States. Today, U.S. market share is 10 percent. Because machine-tool technology is critical for both civilian and military uses, it is important to recapture some of this market. The Enhanced Machine Controller (EMC) project goals include reducing the life-cycle cost of machine tool controllers by developing modular interface specifications that support interoperability of key controller components and validating these specifications on a broad class of machines in production applications. Controllers underlie the capabilities of machine tools and, consequently, the machining processes. Currently, competition is based on controller hardware. The Enhanced Machine Controller project concentrates on controller software, an area where the United States still has a commanding lead. An operational enhanced machine controller has been developed, based on a candidate set of interface specifications. It is composed of basic controller components: trajectory generator, servo control, part program interpreter, operator interface, and programmable logic controller. The validity of the enhanced machine controller interfaces will be demonstrated by installing controllers, based on off-the-shelf components, on machines in production environments. NIST is working closely with a consortium of machine tool builders and users and controller-component manufacturers. The benefits of this project will include reduced life cycle costs, reduced integration costs, and improved performance for machine controllers.

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NEXT GENERATION INSPECTION SYSTEM

In-process and post-process inspection with coordinate measuring machines often slows the manufacturing process. The inspection of parts with complex geometry, for which closely spaced inspection points are needed, is especially time consuming. The goal of the Next Generation Inspection System (NGIS) is a hundredfold increase in inspection speed, without sacrificing measurement accuracy.

A NIST testbed consists of a CMM equipped with advanced sensors and the NIST Real Time Control System enhanced machine controller. Advanced sensors include analog touch probes, a video camera, an analog capacitance probe, and a laser triangulation probe. The real-time, open architecture controller will provide interfaces to the STandard for Exchange of Product (STEP) model data and to the Dimensional Measuring Interface Standard (DMIS), enabling inspection that is driven by model data. It also will permit real-time processing of sensor data for feedback control of the inspection probe. A precommercial Next Generation Inspection System will be tested and evaluated in a production environment. All Next Generation Inspection System technology developed at NIST will be transferred to the marketplace through vendors that manufacture and support software and hardware systems using this technology.

NIST is collaborating with the National Center for Manufacturing Sciences consortium on this project. Industrial members of the consortium include the General Motors Corp., Ford Motor Co., Hughes Information Technology, United Technologies/Pratt & Whitney, Brown & Sharpe, Sensor Adaptive Machines, Inc., Automated Precision Inc., Extrude Hone, Wizdom Systems, and ICAMP. Hardware and software technologies are being exchanged among members of the consortium.

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ADVANCED MACHINE TOOL STRUCTURES

Tighter tolerances and improved quality are required if U.S. manufacturers are to remain competitive. More sophisticated part geometries dictate increased use of multiaxis machining capability. Parallel-actuated machine tools have the potential to meet these needs. NIST is working with several machine tool builders and users who consider developments in this field to be an important factor in achieving future productivity gains. Industry and government researchers are cooperating in exploring the limits of new machine configurations in terms of positioning accuracy and resolution, calibration, and advanced control.

To meet these needs, NIST has procured an experimental prototype octahedral-hexapod, Stewart platform machine tool. NIST research will focus on evaluating the performance of this new class of machine tools and developing methods for providing higher resolution and more accurate position-sensing and control capability. An open architecture controller technology (based on the NIST Enhanced Machine Controller Architecture) will allow integration of third-party software and experimental control algorithms (e.g., for force-based machining). The hexapod machine tool has been installed in the NIST National Advanced Manufacturing Testbed, a facility focused on distributed and virtual manufacturing. Remote access to the hexapod through this testbed will allow machine tool builders, users, and researchers to gain first-hand experience with this new technology.

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INTELLIGENT SYSTEMS ARCHITECTURE FOR MANUFACTURING

Intelligent Systems Architecture for Manufacturing (ISAM) is a reference model architecture for intelligent manufacturing systems. It is intended to provide a theoretical framework for the development of standards and performance measures for intelligent manufacturing systems. It also is intended to provide engineering guidelines for a wide variety of manufacturing applications. The ISAM model addresses the manufacturing enterprise at a number of levels of abstraction.

- At the highest level of abstraction, ISAM provides a conceptual framework for viewing the entire manufacturing enterprise as an intelligent system consisting of machines, processes, tools, facilities, computers, software, and human beings operating over time on materials to produce products.
- At a lower level of abstraction, ISAM provides a reference model architecture for supporting the development of standards and performance measures, as well as for designing manufacturing systems and software.
- At a still lower level of abstraction, ISAM is intended to provide engineering guidelines for implementing specific instances of manufacturing systems such as machining and inspection systems.

ISAM consists of a hierarchically layered set of intelligent processing nodes organized as a nested series of control loops. In each node, tasks are decomposed, plans are generated, world models are maintained, feedback from sensors is processed, and control loops are closed. In each layer, nodes have a characteristic span of control, with a characteristic planning horizon and corresponding level of detail in space and time.

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INTEGRATION TESTBED FOR MOBILITY

Intelligent vehicle systems require open system architecture standards. Intelligent vehicles contain a multiplicity of subsystems that recognize objects such as obstacles and landmarks, map the environment for navigation, detect and react to unexpected objects, locate objects for manipulation and handling tasks, compare object scenes for security and surveillance, plan paths, and operate safely and robustly in unstructured environments. Open systems architecture standards are needed to promote efficient integration of these subsystems and simplify development.

The goal of this project is to provide a testbed for evaluating and validating open-systems architecture standards for intelligent vehicle systems. Two testbed environments are being developed. One, an indoor environment, consists of a battery-powered mobile platform and advanced sensors, including a rangefinder, cameras under computer pan/tilt control, and inertial sensors (e.g., gyroscopes and accelerometers). Vision processing is accomplished using real-time, image-processing computers. The indoor environment addresses physical security and surveillance in industrial facilities such as warehouses and office buildings.

The second testbed, an outdoor environment, consists of a high mobility multipurpose wheeled vehicle (HMMWV) a four-wheel-drive Army vehicle equipped with control actuators (on the steering, brake, and throttle, for example); advanced sensors; and an open-architecture, real-time control system. This vehicle is capable of both highway driving and off-road driving over rough terrain. Advanced sensors on the vehicle include cameras, a laser range-imaging camera, an inertial navigation system, and a Global Positioning System satellite-based navigation system. The vehicle can be operated remotely by a human operator via teleoperation or autonomously via machine vision systems. The control system for both indoor and outdoor mobility environments is the NIST Real-time Control System, an open system reference architecture. Emerging markets for intelligent vehicle systems include autonomous material handling, operations in hazardous environments, security surveillance, advanced motor vehicle control, and aids for the handicapped.

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ROBOCRANE®

The NIST RoboCrane, a versatile robot crane that can precisely position and orient its work platform in all six degrees of freedom, so that large loads and equipment can be held rigidly in place—even at an angle—is the core of the Intelligent Systems Integration Testbed for Large-Scale Manufacturing and Construction. The prime motivation for the testbed is to foster a coordinated and efficient technical response to industry's recognized need for open-architecture standards. These standards will facilitate development and use of sensor-interactive, intelligent-machine systems in large-scale tasks, such as construction, road building, bridge repair, and aircraft assembly. Because interface standards now are lacking, subsystems are difficult to integrate and new capabilities are not added easily. As a result, system functionality is limited, development is prolonged, and maintenance costs are high. By enabling plug-and-play compatability, standard interfaces would foster development of more efficient systems, and they would create new market opportunities for software and hardware manufacturers. Greater compatibility also would simplify and reduce the cost of customization and system upgrading. With the aim of testing and validating open systems architectures and their underlying components, researchers at the testbed are exploring precision applications, such as machining and finishing operations, and they are evaluating combinations of sensors and control strategies that result in safe and reliable operation in unstructured, perturbation-prone environments. Through collaborations with manufacturers, universities, and other organizations, prototype standards and technologies will be transferred into practical applications such as manufacture of aircraft, ships, construction equipment, and railroad rolling stock; construction and maintenance of buildings, highways, and bridges; environmental clean-up of radioactive or toxic waste sites; and undersea mining, construction, repair, and salvage operations.

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TOLERANCING AND METROLOGY RESEARCH

Concentrating on coordinate measuring system (CMSs), NIST researchers are developing the technical underpinnings of a unified framework for tolerance standards, essential to a range of design and manufacturing activities. Ongoing projects are applying fundamental metrology principles, numerical analysis theory, and statistical methods to develop concepts and approaches for evaluating the performance of CMS data-analysis software. Other work is developing formal mathematical definitions of dimensions and tolerances (including appropriate semantics for statistical tolerances, datums, and size) for application in product specifications. Dimensional measurement methods for CMSs are another focus, which ultimately should lead to more effective sampling strategies and data-analysis algorithms. Research is coordinated with ongoing standardization efforts in the United States and internationally. Participation in standards committees guides selection of specific research topics and ensures that the results are disseminated to industry.

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ENGINEERING DESIGN RESEARCH

Design plays a significant role in the iterative and collaborative engineering process. Decisions made during the engineering design stage have a considerable impact on the product's life-cycle costs. Hence, the global competitiveness of U.S. companies and industries depends significantly on the capabilities and intellectual resources embodied and leveraged in design technologies. Through research and technology development, the engineering design group supports and advances the evolution of future design-related standards that respond to industry to identified needs. Technical staff participate in various standards efforts. Technology transfer is facilitated through an engineering design testbed.

The primary goal is to help U.S. industry realize the full potential of current and future engineering-design tools and techniques. NIST researchers are investigating the issues involved in integrating a variety of commercial and university "design" tools. Topics addressed by current projects include virtual reality interfaces, product and process modeling, constraint representation, optimization, and engineering ontologies.

A key issue in achieving an integrated product development environment involves the development of appropriate communication and representation mechanisms. Standards are critical to these communication and representation mechanisms. Actively participating in the International Organization for Standardization's STEP (Standard for the Exchange of Product Model Data) initiative, NIST staff are addressing how to incorporate features, constraints, rationale, and other design information within the STEP framework.

To promote technology transfer, a testbed for engineering design has been established. This testbed provides a platform for testing and validating design methodologies, developing standards for product and process models, storing and accessing design case studies, aiding in supplier-chain integration, and helping in various aspects of technology transfer. NIST researchers are working with several universities and industries, particularly through the Defense Advanced Research Projects Agency.

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COMPUTER-AIDED MANUFACTURING ENGINEERING

Just as computer-aided design and engineering tools have revolutionized product design during the past decade, computer-based tools for production system engineering can revolutionize manufacturing. A new type of computer-aided engineering environment is envisioned, one that will improve the productivity of manufacturing and other industrial engineers. This environment would be used by engineers to plan the manufacture of new products and to design and implement future manufacturing systems and subsystems.

The overall goal of computer-aided manufacturing engineering is to lower manufacturing costs, reduce delivery times, and improve product quality through the coordinated development and use of advanced tools. This project is aimed at advancing the development of software environments and tools for the design and engineering of manufacturing systems. With industrial partners, universities, and Defense Department manufacturing facilities, NIST researchers are creating an integrated framework, operating environment, common databases, and interface standards for diverse manufacturing engineering software applications. This environment will support and integrate a variety of emerging tools and techniques for designing, modeling, simulating, and evaluating the performance of manufacturing processes, equipment, and enterprises.

One current project is building an integrated Manufacturing Engineering Tool Kit for developing and validating manufacturing data for machined parts production. Another is creating a Production System Engineering Tool Kit for designing and modeling production lines. Interface specifications are being developed to allow commercial off-the-shelf software to interoperate. Examples of the types of software products contained within the tool kits include computer-aided design, process planning, NC program verification, product data management, manufacturing simulation, and plant layout.

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NATIONAL INDUSTRIAL INFORMATION INFRASTRUCTURE PROTOCOLS

This activity is developing technology to enable industrial virtual enterprises and to accelerate adoption of STEP (Standard for the Exchange of Product Model Data) in the operation of these enterprises. Work is being accomplished under a Cooperative Research and Development Agreement with the National Industrial Information Infrastructure Protocols (NIIIP) Consortium, comprising various manufacturers, technology providers, universities, and federal agencies. The overall NIIIP program is funded through a Technology Reinvestment Project award. A virtual enterprise is a temporary confederation of firms that come together to share costs and skills to exploit fast-changing opportunities. The NIIIP Consortium will deliver iterations of a reference architecture, software toolkits that are the building blocks of an instantiated reference architecture, research prototypes, and pilot demonstrations. In accomplishing these deliverables, NIIIP will adopt and converge existing standards and technology from STEP, the Object Management Group (OMG), the Internet Society, and the Workflow Management Coalition.

NIST efforts enable improved engineering practices. Advanced communication capabilities for distributed computing resources are being applied to allow for transparent access to distributed resources, including shared data representations. Additionally, workflow management technology will be exploited to expedite the engineering process. NIST research has focused on the integration of STEP technology and standards with object-oriented technology and standards emerging from OMG. The project is premised on the adoption of STEP Data Access Interface (SDAI) as an international standard. This project will validate the proposal for an SDAI/IDL (Interface Definition Language) binding. Another NIST role is to help the NIIIP ensure that the protocols developed by the consortium become usable industry standards. To this end, NIST has been a major contributor in the development of a standards roadmap for NIIIP. NIIIP plans to develop, demonstrate, and transfer this technology into widespread industrial use.

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PRODUCT DATA EXCHANGE STANDARDS FOR MANUFACTURING

The goal of this activity is to accelerate the development and deployment of product data standards to enable the sharing and reuse of design, engineering, and manufacturing information. The strategy is to work with industry to translate its requirements into standards, principally ISO 10303 (Product Data Representation and Exchange), to validate these standards, and then to pilot these standards in an industrial setting. World-wide interest in ISO 10303, also known as STEP, is motivated by industry's desire to achieve critical operational and strategic capabilities. STEP:

- enables a number of improved product development strategies such as concurrent engineering, enterprise integration, and electronic commerce;
- facilitates companies working together as a virtual enterprise on product development; and
- makes possible the use of better approaches to increase efficiency and reduce time to market in developing new or improved products.

Initial implementations of this international standard are by vendors of computer-aided design (CAD) systems. Each CAD system's unique proprietary format inhibits the direct exchange of information among various manufacturing processes.

NIST is assisting industry by facilitating standards development and addressing feedback from validation and implementation activities. The initial STEP standard is capable of conveying existing CAD model representations. Additional capabilities are being developed to address other manufacturing applications. NIST is accelerating this work by providing an environment that supports and advances efforts to improve the efficiency and quality of these specifications. An integrated suite of software tools is being established that will interact with the STEP registry at NIST, which contains STEP specifications, related documents, and representative data. This suite will provide "intelligent" access to any part of these references and to generated aspects of the documents that do not require application domain knowledge.

To achieve widespread adoption of these standards, industry must understand the benefits and understand how to manage the risks associated with adopting this new technology. NIST currently is working with the automotive industry on the AutoSTEP pilot project, in which STEP is being used to exchange design and part data between suppliers and original equipment manufacturers. NIST is providing its expertise on requirements analysis, testing methods and STEP technology, and a neutral site for Internet communications between pilot members. The goal is to document the benefits of using STEP within the context of supply chain business scenarios.

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STEP CONFORMANCE AND INTEROPERABILITY TESTING

The STEP Conformance Testing project is sponsored jointly by the NIST Systems for Integrated Manufacturing Applications (SIMA) Program and Navy Mantech. The technical goal is to provide an objective means of evaluating a software system for its ability to meet the requirements of STEP, an international standard (officially ISO 10303) developed to let companies effectively exchange design and engineering information with their customers and suppliers as well as internally. The initial customers of the project results are vendors of computer-aided design systems and product data management systems. Experience with complex standards has shown that claims of compliance with a standard are not reliable. Further, if early implementations of a standard meet the requirements, adoption is much quicker. The primary focus of this effort is the development of software tools and methods for assessing whether new software applications comply with the standard. The tools need to be extensible to accommodate the expanding set of applications supported by STEP. This project leverages earlier work done on EXPRESS, the formal description language used to specify STEP, and STEP Class Library toolkits.

Various approaches are being used to overcome concerns of U.S. vendors. One approach is to leverage early implementation experience to validate the test system and test suites. NIST and the Industrial Technology Institute have formed alliances with U.S. pilot projects initiated by PDES Inc. and the Automotive Industry Action Group, industrial organizations driving the development and application of STEP. A beta testing program has been initiated to further ensure the utility of this testing capability. A complementary approach provides an infrastructure for an efficient conformance testing program. This opens a world market to U.S.- developed STEP products. In concert with these activities, NIST is aggressively participating in the international standards effort related to testing and client requirements. At least one European testing laboratory is in the process of licensing the NIST testing system.

Another approach, and perhaps the most important, is to give vendors access to these tools during their product development. This allows them to become familiar with the tools, gain confidence that their product can successfully pass testing, and use the tools to improve the quality of their products. They gain from the expanded market that user confidence in a tested product brings. The same tools also can be employed by end-users to assess the ability of these products to interoperate in an industrial context, further expanding the market for standards-based products. In addition, NIST is participating in a U.S.-based vendor round table and STEPNet interoperability trials.

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RAPID RESPONSE MANUFACTURING INTRAMURAL PROJECT

The NIST Rapid Response Manufacturing (RRM) Project is sponsored as an intramural project through the NIST Advanced Technology Program. Intramural project personnel collaborate with member companies of the RRM consortium, leveraging NIST skills and technologies to ensure the advancement of RRM capabilities. The industrial consortium is composed of both manufacturing facilities and software vendors and is organized through the National Center for Manufacturing Sciences. It aims to enhance and adopt key technologies, including variant design, rapid prototyping, design visualization, and generative NC, to enable use of advanced, highly integrated systems for manufacturing. Activities of the NIST RRM Intramural Project are selected based upon specific technology and research needs of the consortium member companies.

The primary focus areas of the RRM Intramural Project include research and development, standardization, and technology transfer. For example, NIST personnel have conducted in-depth assessments of the current state of the practice and state of the art in key technologies. NIST also has initiated a major development effort to establish information models that specify a common and standardized electronic representation for manufacturing resource data. This representation proposes a structure for the classification and characteristics of machine tools, cutting tools, tool holders, cutting inserts, and other resources. Project results provide a catalyst for a standardized manufacturing resource data structure. Standards activities have been initiated through both ISO and ANSI. Technology transfer activities are an important part of NIST's mission and also play a significant role in this project. Several project activities contribute to technology transfer, including cooperative research and development, industry workshops, participation on RRM consortium committees, liaison between RRM member companies and other NIST research, project publications and presentations, and participation on standards committees.

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SYSTEMS INTEGRATION FOR MANUFACTURING APPLICATIONS PROGRAM

Under the federal government's High Performance Computing and Communications effort, NIST has embarked on a major initiative to enhance integration of advanced manufacturing applications through utilization of information infrastructure technologies. This multiyear initiative, called Systems Integration for Manufacturing Applications (SIMA), involves all seven NIST laboratories with strong participation by U.S. industry, universities, and federal agencies. Launched in 1994, SIMA has three major elements: manufacturing systems, standards development, and testbeds/technology transfer.

The manufacturing systems element focuses on development of interface specifications for advanced manufacturing systems. Manufacturing applications being targeted by SIMA projects include design, planning, scheduling, process modeling, shop control, simulation, inspection, assembly, and machining. The integration and interface technologies being applied include networking, database technologies, frameworks, and protocols for data exchange. SIMA projects span the industrial manufacturing domains of mechanical products, electronics, and construction.

The standards development element focuses on applying NIST expertise to assist industry in implementing voluntary consensus standards relevant to computer-integrated manufacturing. Successful implementation of manufacturing standards requires validation, pilots, and formal testing to ensure the standards meet the intended requirements. To this end, SIMA projects work on deployment of standards testing methods utilizing HPCC technologies and participate in pilot implementations of HPCC technologies by industry.

The testbeds and technology-transfer element focuses on establishment of testbeds, which both serve the infrastructure needs of SIMA projects and can be used as demonstration sites for collaborative tests between SIMA projects and industrial partners. One such facility, the Advanced Manufacturing Systems and Networking Testbed (AMSANT), has been established, and another is under construction. Technology-transfer efforts also include development of infrastructure technologies specialized to disseminate manufacturing information using HPCC techniques.

Numerous successful collaborative relationships with industry are under way. Among these is the effort to design and develop a comprehensive electronic handbook for characterization of engineering problems and relevant software applications with SEMATECH (Austin, Texas). Making these NIST statistical solutions available remotely facilitates accurate analysis and solution of engineering problems in the most expeditious manner, i.e., at the user's workstation. Another SIMA project has facilitated the establishment of the PlantSTEP consortium (Kansas City, Kan.), which is working to speed the development of data exchange protocols needed for the design of process plants. Working with NIST, the consortium ensures that the developing standard satisfies the intended data exchange requirements for process-plant design. In another SIMA project, the development of testing methodologies for pilot implementations of a new product design data exchange protocol in the automotive industry is helping to verify the usability of that standard for exchanges between U.S. car companies and their suppliers.

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RESEARCH FACILITIES

NATIONAL ADVANCED MANUFACTURING TESTBED

The National Advanced Manufacturing Testbed (NAMT) is a new research program addressing needs for technologies and standards for distributed and virtual manufacturing. The program was developed with guidance from over 30 industrial leaders and launched in late 1995. The program's goals are to provide the infrastructure to enable companies to rapidly design and manufacture products and to speed U.S. industry's evolution toward distributed and virtual manufacturing.

NAMT researchers are developing the scientific basis and technical underpinnings necessary to achieve manufacturing environments that are shared, accessible, integrated, and information based. Research focuses on measurements, communication protocols, interfaces, and other standards and infrastructural technologies.

The first-year portfolio of NAMT research projects includes:

- framework for manufacturing integration,
- remote access and simulation of hexapod machines,
- machine-tool performance models, and
- distributed nanomanufacturing.

The common objectives for these NAMT projects are:

- to support distributed and virtual manufacturing,
- to promote interoperability of manufacturing systems through standards and measurements,
- to conduct manufacturing research in a distributed environment that leverages industrial and other partner expertise, and
- to provide a virtual manufacturing environment through simulations and other information technology tools.

These initial projects draw on the wide range of technical expertise available across MEL's five divisions. This expertise, along with key testbed facilities, are leveraged by the participation of collaborating organizations from industry, government, and academia.

A key element of the NAMT is the research facility developed in 1995 as part of the laboratory's Systems Integration for Manufacturing Application program. This facility, the Advanced Manufacturing Systems and Networking Testbed (AMSANT), supports the computing, communications, and information technology needs of the NAMT and SIMA programs. The objective of both programs is to provide a distributed, multinode facility at NIST that will enable collaborative development of technologies and standards to support distributed and virtual manufacturing enterprises through an advanced computing and communications infrastructure.

The AMSANT houses many high-performance computer workstations and servers, ATM networking capabilities, and large-screen computer display systems. Since its completion, the facility has been host to daily research activities, several large demonstrations, and several software training classes. In early FY 1996, plans were made to open a second facility to support the growing needs of both the SIMA program and the NAMT program.

Offering high-speed data-transfer, voice, and video capabilities, this second facility also will serve as a working laboratory for NIST researchers and their industrial collaborators, and it will be used to demonstrate proof-of-concept implementations of research and development results.

Remotely located, the NAMT researchers, working in their home environments, cooperate on an array of advanced manufacturing research projects. Their efforts benefit from a shared foundation of supporting technologies for textual, audio, and visual communications as well as common sets of computing tools, such as databases, electronic software repositories, and modeling and simulation programs.

Current and future work will concentrate on overcoming complexities that prevent "plug and play" interoperability across dispersed and disparate manufacturing systems.

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CHEMICAL SCIENCE AND TECHNOLOGY LABORATORY

The Chemical Science and Technology Laboratory (CSTL) performs cutting-edge research in measurement science; develops and maintains measurement methods, standards, and reference data; and develop models for chemical, biochemical, and physical properties and processes. CSTL provides these capabilities to enhance U.S. industry's productivity and competitiveness; assure equity in trade; and improve public health, safety, and environmental quality.

The technologies and services provided by CSTL help the U.S. chemical manufacturing, energy, health care, biotechnology, food processing, and materials processing industries to meet the broad range of international measurement requirements and compete in global markets.

One of CSTL's goals is to anticipate the measurement needs of new technologies, so that a measurement infrastructure is available by the time a new technology is implemented. Needs are expanding for accurate, quantitative measurements at ever-decreasing detection limits, in harsher environments, and for a wider range of chemical species.

In addition, the development of novel and improved processing techniques and new approaches to pollution prevention and control are critical to the economic success of U.S. industry. Through a strong commitment to basic research, and by leading the advancement of measurement science in critical areas, CSTL is poised to meet emerging national needs.

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COOPERATIVE RESEARCH OPPORTUNITIES

COOPERATIVE RESEARCH OPPORTUNITIES

BIOTECHNOLOGY

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DNA CHEMISTRY

Working in several areas of DNA chemistry, NIST scientists are actively manipulating DNA to produce proteins, developing methods for measuring DNA damage at the molecular level, and developing methods for characterizing DNA, including human identity profiling.

NIST scientists are developing experimental methods to measure DNA damage in mammalian cells exposed to free radicals, generated by ionizing radiation, elevated oxygen pressure, redox-cycling drugs, or carcinogenic compounds. Free radicals produced in-vivo are thought to be mutagenic and carcinogenic. Measurement of DNA damage at the molecular level in mammalian cells is a prerequisite to understanding the chemical mechanisms of damage by free radicals. Techniques used for measuring DNA damage include gas chromatography, mass spectrometry, high-performance liquid chromatography, and nuclear magnetic resonance spectroscopy.

NIST scientists are working on new methods for DNA profiling, ranging from developing well-characterized DNA standards for restriction fragment length polymorphisms to performing research for rapid determination of DNA profiles by polymerase chain reaction amplification and automated detection of fragments. In addition, NIST researchers are interested in cooperative development of short-tandem repeat technology, mitochondrial DNA sequencing, and attendant standards. Techniques for DNA detection include sensitive staining of electrophoretic gels, use of chemiluminescence, and enhanced applications of capillary electrophoresis.

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NUCLEAR MAGNETIC RESONANCE

Programs are under way in which NIST scientists are using nuclear magnetic resonance (NMR) spectroscopy to study simple peptides and proteins, aminoglycoside and macrocyclic antibiotics, carbohydrates, glycoproteins, and DNA. The studies are facilitated by research materials isotopically labeled with carbon-13 or nitrogen-15, which are prepared by synthetic or biosynthetic methods.

NIST researchers are making extensive use of two-dimensional NMR methods, including homonuclear and heteronuclear chemical shift correlation and J-resolved techniques, nuclear Overhauser measurements in the rotating frame, and indirect detection. Measurements of chemical shifts and coupling constants provide information on the structures, stereochemistry, and conformations of biomolecules. Determination of nuclear Overhauser effects and relaxation times allows the imposition of distance constraints for three-dimensional structure analysis and characterization of molecular dynamics, respectively.

In the near future, researchers plan to use three- and four-dimensional NMR techniques to investigate higher molecular weight biomolecules. Detailed knowledge of the three-dimensional structures and conformations of the biomolecules is important to an increased understanding of biochemical reaction mechanisms, enzyme specificity, drug-protein/DNA binding, and molecular-recognition processes.

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BIOPROCESS ENGINEERING MEASUREMENTS

NIST scientists are developing theories, measurement methods, models, and databases needed for the development and optimization of commercial bioprocesses.

They are developing technologies related to the use of biological enzymes in the production of fine chemicals. One research program is aimed at the unique potential of the hydroxylase class of enzymes. This research is focused on solving technical roadblocks through the use of state-of-the-art measurements and advanced modeling methods to characterize biocatalysts and molecular processes. Proof-of-principle experiments, involving electrode-driven redox chemistry incorporating the cytochrome P450 enzyme system, are being studied as the basis of controlling biosynthetic reactions. Success in this area involves finding generic routes for meeting the energy requirements of these enzymes and on developing synthetic methods of carrying out cell functions such as electron transfer between proteins.

Another emphasis is on the characterization of new chromatographic processes for separating biomolecules from fermentation broths. A NIST-developed electrochromatography method has been evaluated for the separation of DNA and viral particles from proteins.

In the area of biothermodynamics, NIST researchers have developed accurate and precise microcalorimeters to measure the heat released in enzyme-catalyzed biochemical reactions of interest to biotechnology. When coupled with equilibrium measurements, these measurements enable the reliable modeling of the thermodynamics of these processes. These data are used to predict reliably the efficiency of biochemical processes outside the normal measurement ranges for temperature, pH, and ionic strength.

Light-scattering studies are being made on biomacromolecular solutions to characterize their transport and thermodynamic properties. Models and experimental methods, needed to obtain the necessary data, are being developed to characterize aqueous two-phase separation techniques. NIST scientists are using small-angle neutron scattering to characterize chromatographic media in concentrated polymer solutions.

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BIOMOLECULAR MATERIALS

A current trend in materials development is to employ biological molecules and/or principles that are inspired by biology. Such materials are sometimes referred to as "biomimetic," indicating they have characteristics such as self-assembly, molecular recognition, specific chemical responses, and complex molecular architecture which lead to unique structural and/or functional characteristics. Chemically controlled biomimetic surfaces are essential components of biosensors, bioelectronics, biocatalytic systems, and many diagnostic devices. Biomolecular materials thus influence diverse applications such as health care, environmental pollution monitoring, agriculture, and chemical manufacturing. An underlying need for these applications of biotechnology is the characterization and control of biomolecules at interfaces.

Fundamental studies are being conducted to better understand the structure and function of natural and biomimetic materials that self assemble. Lipid membranes are one such class of self-assembling materials. They organize and control the structure of proteins that naturally reside within them, many of which have commercially important functions. Project staff members also study models of cell membranes as tools for achieving better quantification of therapeutic agents, which are likely to act at the level of the cell membrane via cell surface receptors or which have to pass through the cell membrane to be effective.

Interactions between biological molecules and between biological molecules and surfaces occur during sensor operation, diagnostic tests, cellular recognition events and mobility, and in the formation of modified surfaces as organized biomolecular materials. In some of these applications, it is desirable to enhance strong molecular specific interactions while minimizing weaker nonspecific interactions. In other cases, many simultaneous weak interactions are needed to effect the appropriate dynamic response. NIST develops both the experimental tools such as chemically controlled surfaces and techniques for monitoring reactions at surfaces, and the theoretical tools to improve understanding of dynamic biomolecular processes and permit predictions and optimization of reactions of biomolecules. Methods for kinetic analysis, current noise analysis, and stochastic models of processes at surfaces are under development in the biomolecular materials group.

Macromolecules including bacteriorhodopsin, DNA, and enzymes are examined in various configurations as potential components of electrochemical, electronic, and optical devices. This effort is closely coupled with the more fundamental studies within the group, with the intention of bringing the knowledge gained from basic science studies closer to potential applications such as environmental sensing or optical storage. Engineering prototype devices allows consideration of real world issues such as fabrication, and adaptation of instrumentation and methodology to field conditions.

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CENTER FOR ADVANCED RESEARCH IN BIOTECHNOLOGY

At the Center for Advanced Research in Biotechnology (CARB) in Rockville, Md., jointly established by NIST, the University of Maryland, and Montgomery County, Md., researchers study protein structure and function relationships. They are focusing on the measurement of protein structure by X-ray crystallography and nuclear magnetic resonance spectroscopy (NMR) as well as the manipulation of structure by molecular biological techniques, including site-directed mutagenesis. Scientists use protein modeling, molecular dynamics, and computational chemistry to understand protein structure and to predict the effects of specific structural modifications on the properties of proteins and enzymes. A variety of physical chemistry methods are used to measure and analyze structural changes, activities, and thermodynamic behavior of proteins under investigation. CARB maintains state-of-the-art facilities for protein crystallography, NMR spectroscopy, molecular biology, and physical biochemistry. Its computer facilities include a variety of computational and high-resolution graphics workstations as well as access to the NIST Cyber 205 supercomputer.

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PROCESS MEASUREMENTS

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FLOW MEASUREMENT RESEARCH AND STANDARDS

The accelerating costs of scarce fluid resources and valuable fluid products—particularly petrochemical fluids—are causing increased concerns about the performance of flow meters. Additionally, the role of flow meters in controlling and optimizing critical industrial processes is pushing performance limits and extending the required fluid and flow conditions. To attain these goals, improved flow traceability to NIST standards is essential.

Improved flow measurement traceability needs to be established and maintained so that realistic, quantified data are generated on a continuing basis to assure practical fluid measurements at satisfactory performance. To achieve the desired flow measurement traceability, NIST is conducting several flow measurement proficiency testing programs for a range of fluid and flow conditions. NIST also is designing new transfer standards to link the performance of calibration facilities having special conditions and capabilities to appropriate national reference standards.

Because of the importance of critical flow measurements, transfer standards need to be designed and used so that high levels of confidence can be placed in the measurements from critical flow meters. New transfer standards are evaluated rigorously against NIST fluid flow calibration standards. As part of these evaluations, the appropriate range of calibrations will be done on the developed standards so performance can be assured at specified levels. Current fluid metering research programs use computational fluid dynamics (CFD) with validation using laser Doppler velocimetry (LDV) techniques to focus on flows that are critical to U.S. industry. Currently, the two areas of metering research are the assessment of acoustic technology for making improved flow measurements and the description of flow meter installation effects. CFD and LDV are applied in both of these areas.

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CHEMICAL REACTIONS AND EMISSIONS IN SPRAY FLAMES

Control of combustion efficiency and exhaust emissions from combustion systems used for power generation and treatment of process liquid wastes is generally based on a priori knowledge of the input stream global physical and chemical properties, desired stoichiometric conditions, and monitoring of a few major chemical species in the exhaust. In general, there is a dearth of data on conditions within the reactor and, in particular, on the quality of the atomized liquid spray. It is precisely this region that requires a better knowledge base to enable optimization of the chemical and thermal processes and minimization of particulate and gaseous emissions. NIST researchers are developing the technology to measure and explore the feasibility of correlating the interrelationship between operating conditions, spray flame characteristics, and formation of pollutant emissions in combustion systems, with particular emphasis on the atomization process. The benefits to be gained from this research are improved combustor performance and reduced emission levels.

Experiments are being carried out in a spray combustion facility, with a movable vane swirl burner enclosed in a refractory chamber. The facility has evolved to handle different process liquid fuels and wastes, atomizer designs, and combustor configurations. A variety of intrusive probes, non-intrusive diagnostics, and flow visualization techniques are being employed to obtain comprehensive data on spray combustion characteristics. Current research involves measurement of the input fuel stream (fuel composition), spray flame (droplet size, velocity, number density, and temperature), and combustor exhaust (particulate size and volume fraction, and toxic gas concentrations). The measurements made are used to provide data for process optimization and control, real-time in-situ sensor development, and input and validation of numerical simulations.

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ENGINEERING MEASUREMENTS FOR HYDROTHERMAL PROCESSES

Supercritical water oxidation (SCWO) is a promising new technology for safe and efficient destruction of hazardous materials. It is a totally contained process that takes place in supercritical water, that is, at pressures greater than 22 MPa and temperatures above 374 °C. Under these conditions, many reactions proceed unusually rapidly, producing benign end-products carried in the output water stream. Implementation of SCWO systems is beginning, but development of robust designs is hampered by an inadequate understanding of critical processes such as reaction chemistry, corrosion, heat transfer, and salt deposition and phase separation as well as a lack of fundamental thermodynamic and transport data. Furthermore, because of the harsh environment, investigations have been limited by a lack of robust, in-situ measurements. Thus, the approach is to understand and model these processes through development and application of in-situ measurement techniques and acquisition of vital process data.

The experimental work centers around reactors for studies of waste destruction and corrosion, as well as unique optical cells that provide access for in-situ measurements of temperature, pressure, density, chemical species and concentrations, and phase discrimination. Current investigations target ammonia and acetic acid destruction as functions of temperature, residence time, and oxidant; corrosion detection and control with in-situ Raman spectroscopy; Na_2SO_4 precipitation and deposition; and near-critical, high-gradient heat-transfer for process design. The modeling work is integrated with the experiments and centers around thermodynamic predictions of phase boundaries and other properties for supercritical systems where data are extremely lacking. The experimental measurements and thermodynamic models will support process simulation and design efforts that are currently under way.

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VAPOR-PHASE SYNTHESIS OF NANOPARTICLES

Nanostructured materials have demonstrated novel magnetic, optical, and mechanical properties. However, practical application of these materials requires the development of economical synthesis and processing methods. NIST researchers have focused their efforts in two areas. The first is development of gas phase synthesis methods for bulk production of nanoparticles (e.g., superconductors, magnetic nanocomposites, metals). This work includes the use of gas-phase combustion and thermal flow reactors, with heavy emphasis on the use of in-situ optical diagnostics, such as planar laser-induced fluorescence and light scattering, for characterization. Current activities are focusing on the growth of composite particles with enhanced magnetic and structural properties and the use of novel chemistries to prevent agglomeration. Secondly, researchers are studying the application of molecular dynamics and quantum chemistry methods to describe particle nucleation and growth. Available facilities include excimer, Nd:YAG and tunable dye laser systems, cw-ion lasers, and graphics workstations. Expected results from this work are a better understanding of the mechanisms of particle nucleation and growth and strategies to obtain desired end-products.

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CHEMISTRY OF MATERIALS PROCESSING

This work focuses on both quantitative and qualitative measurements of the principal reacting species and the kinetics of the chemistry relevant to thermal chemical vapor deposition (CVD) and plasma processing. NIST researchers conduct experiments using either a high-temperature flow reactor or a low-pressure plasma coupled to a modulated molecular-beam mass-spectrometer sampling system. The current focus has been on the thermal and oxidation chemistry of precursors used in the deposition SiO_2 films and the chemistry of fluorocarbons relevant to low-pressure plasma etching processes. Experiments are supported with a strong modeling effort involving extensive use of modern computational chemistry methods as well as detailed reactor models.

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DIAGNOSTICS IN THERMAL AND PLASMA REACTORS

This project is aimed at providing measurements suitable for development and testing of models that may be used as design tools for development of next-generation process equipment used in the manufacture of microelectronic components. Research focuses on characterization of both thermal and plasma reactors. Measurements are being made in the Gaseous Electronics Conference plasma reference cell using planar laser-induced fluorescence to obtain two-dimensional gas phase species concentration maps and in-situ spectroscopic ellipsometry for surface characterization.

Electric probe and rf voltage and current waveform measurements provide electrical characterization of plasma parameters and reactor conditions. These electrical measurements are used with other ion energy measurements to characterize and model plasma sheath dynamics that strongly affect ion behavior in these reactors.

Thermal CVD chemistry is under investigation using a new optically accessible rotating disk reactor. A major focus of this work is the detection of the early stages of particle formation, which is supported by a substantial modeling effort. Available facilities include excimer, Nd:YAG, and tunable dye laser systems, cw-ion lasers, mass spectrometers, and graphics workstations. The results of this work are expected to aid in the development of molecular-based models of industrial process reactors and on-line diagnostics for process control, as well as broaden fundamental understanding of these processes.

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APPLIED COMPUTATIONAL CHEMISTRY

Improvements in process design and control, which can be realized from increasingly sophisticated process models, are not occurring because of the lack of high-quality data. New computational chemistry methods offer the potential to revolutionize the manner in which fundamental thermochemical, physical, and kinetic data are obtained. Research focuses on the development and application of robust methods for data estimation. NIST scientists are investigating the application of empirical correction schemes to ab-initio molecular orbital calculations as a means to obtain high-accuracy data at low computational cost. Such methods have been used to predict the thermochemistry of more than 110 hydrofluorocarbons and oxidized hydrofluorocarbons. These results when compared to available literature data showed excellent agreement.

Thermochemistry data on the Si-O-H and Si-P-H system also have been generated for application to the chemistry of microelectronics processing. A user-friendly reaction rate theory program has been developed that will enable the estimation of rate constants. This program, which currently is being tested, is applicable to any arbitrary reaction manifold and should find wide application by those interested in large-scale chemistry simulations. Molecular dynamic simulations are being used to simulate the structure, properties, and kinetics of cluster-cluster growth kinetics relevant to nanoparticle formation. These results are finding application in the development of aerosol models and in improving understanding of nanoparticle growth. Calculations are conducted using the NIST supercomputer facility and are processed using high-performance graphic workstations.

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REACTING FLOW SIMULATION

Research focuses on the chemical process industry's need to understand reacting systems. The primary focus is toward systems that involve complex chemistry in such environments as plasma and thermal processing of microelectronics, combustion, and two-phase flows. Researchers are simulating high-temperature reacting flows to understand the complex coupling between the fluid flow, heat release, multiple phases, and chemical reactions. Most recently, the primary focus has been on simulation of contaminant particle nucleation and growth in materials processing reactors in support of ongoing experimental efforts.

Scientists are developing large, detailed chemical kinetic mechanisms relevant to combustion and plasma etching as well as materials processing chemistries. In addition, researchers are pursuing automated methods for mechanism generation, analysis, and reduction, which rely heavily on interactive graphics. These approaches increasingly rely on the use of advanced methods for thermochemical and kinetic data estimation. Calculations are conducted using the NIST supercomputer facility and are processed using high-performance graphic workstations.

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SOLID-STATE CHEMICAL SENSOR ARRAYS

NIST scientists are conducting research on solid-state sensor array technology for real-time sensing of multiple species in multi-component gas mixtures. These sensors are based on NIST-designed and -patented micro hotplate arrays. These multilayer structures consist of a heater, a thermometer/heat distribution plate, and sensing film electrical contacts. Typical single element sizes range from 100 to 250 μm. The sensing film is typically a semiconducting oxide, such as SnO_2 or TiO_2, whose electrical conductance is changed by species adsorbed on the film surface. Surface dispersed, catalytic metal additives alter response sensitivity and selectivity of the metal oxide sensing films of individual array elements. Additionally, micro hotplates have low power requirements (tens of milliwatts), large operating temperature range (>800 °C), and heating time constants of 1 to 2 milliseconds. This capability supports a novel sensing approach, temperature programmed sensing, which has excellent potential to discriminate and quantify individual species in multicomponent gas mixtures. These sensor structures provide sensitivity, selectivity, capability for real-time monitoring, low cost, and mechanical robustness. Device fabrication takes advantage of commercially available CMOS processing, providing a path to a readily manufactured sensing technology.

Scientists are now working to detect and quantify oxygenated species found in automotive exhaust—CO, CO_2, and a range of organic species. Research investigations include study of the mechanisms governing surface adsorption and desorption processes, development of surface micromachining techniques and methods for sensing film deposition, and use of temperature-programmed sensing techniques that take advantage of NIST's unique, micro hotplate sensor structures. Development of signal processing algorithms capable of species detection and quantification also is of great interest.

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SELF-ASSEMBLED MONOLAYERS FOR BIOSENSING

Future generations of biosensors for applications such as DNA diagnostics and drug discovery will be required to perform multi-analyte measurements rapidly, accurately, and at lower cost. These technologies are expected to take the form of surface-confined arrays of highly selective sensing elements. Although considerable effort is currently focused on synthesizing peptide and DNA arrays on surfaces, these design efforts are based on highly empirical methods. Relatively little effort is directed toward understanding the molecular-scale structure and mechanisms that control surface interactions in these systems. To investigate these issues, NIST is using alkanethiol self-assembled monolayers (SAMs) formed spontaneously on gold substrates. These SAMs are robust, ordered structures with highly tunable surface characteristics useful to form fully functional protein and nucleic acid monolayers on gold surfaces. This model system supports development and application of characterization methods sensitive to physical and chemical surface properties of both single and multiple layer structures.

Researchers are determining both structural characteristics and demonstrating the occurrence of molecular recognition events such as hybridization reactions of single stranded DNA pairs. Scientists are currently using proteins and DNA with the thiol self-assembly process for studies of reproducible preparation and custom tuning of surface properties using a "mixed monolayer" approach. They also are evaluating monolayers as model platforms to study solid-phase biological processes and for the production of planar structures for use in a broad array of surface analytical techniques. In addition, researchers are investigating facile patterning of biological species with micrometer-scale control of dimensions using a photolithographic process developed at NIST.

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HIGH-TEMPERATURE THERMOCOUPLE RESEARCH

Industrial high-temperature processes and scientific research at high temperatures require stable thermometers that cover wider temperature ranges with better accuracy than previously required. Problems with thermocouples at high temperatures result primarily from unstable compositions (impurities, defects, and chemical reactions), causing their electromotive force, and thus their temperature indication, to drift with use and rapidly become highly uncertain. A second problem in process measurements is the unreliable measurement of surface temperatures resulting from the use of traditional contact and non-contact (radiation) thermometers. Accurate, high-speed measurements of temperatures of surfaces are especially critical in semiconductor wafer preparation by rapid thermal processing because accurate control of temperature during short high-temperature exposures is critical to product quality and device performance.

NIST is developing new wire and thin-film thermocouples as reference thermometers for secondary calibration laboratories and as high-accuracy, high-stability, high-temperature thermometers for industrial use, including use in surface-temperature measurements. Scientists are investigating noble metal thermocouples of exceptionally high purity and generally resistant to oxidation in high-temperature environments. They also are investigating thin-film thermocouples for accurate surface temperature measurements. These devices become a part of the surface and thereby obviate the uncertainties associated with conventional contact thermometers (uncertainty of the correlation between measured temperature and surface temperature) and with radiation thermometers (uncertainty with respect to the time-dependent, effective emissivity of the surface).

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PRESSURE, VACUUM, AND LOW-FLOW STANDARDS

Many industries depend on accurate pressure, vacuum, and low-flow measurements for research and development and for process and quality control. NIST develops and maintains pressure and vacuum standards from 200 MPa to 10^{-7} Pa; flow standards are operated from 10^{-3} mol/s to 10^{-14} mol/s. Facilities include five ultrahigh vacuum systems, two low-range flowmeters, a mid-range flowmeter, high-accuracy mercury manometers, oil and gas piston gauges, apparatuses for measuring gas densities using optical techniques, and the necessary pressure and vacuum control systems. These facilities are used to provide calibration support for industrial, academic, and government entities and for research in the areas where these capabilities can be used to improve the fundamental understanding of physical phenomena.

These measurement capabilities enable researchers to develop improved measurement techniques and equipment and to investigate the performance of vacuum and pressure equipment, specifically piston gauges, mechanical pressure gauges, momentum transfer gauges, ionization gauges, thermal mass flowmeters, standard leaks, and residual gas analyzers. In addition, NIST uses this measurement capability to investigate properties of materials and physical phenomena of fundamental interest. Among current projects are the development of an optical adsorption based standard for measuring low gas densities, development of a high-precision laminar flowmeter, modeling of primary pressure standards to reduce their uncertainties, characterization of thermal mass flowmeters, and characterization and modeling of residual gas analyzers. NIST researchers also are developing molecular drag gauges that operate in high vacuum conditions and precise isotopic reference standards for pure gases.

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QUANTITATIVE OPTICAL MEASUREMENTS OF PARTIAL PRESSURES AND MOISTURE

Low-level gaseous contaminants cause deleterious effects in chemical and materials processing such as semiconductor manufacturing systems. Many commercially available instruments are either not species specific, are not sufficiently sensitive, or utilize detection techniques that perturb the chemical composition and, therefore, compromise the measurement of contaminant composition. This research seeks to develop quantitative optical measurement techniques that have high species selectivity and sensitivity. This effort strives to produce a new generation of species-specific, partial pressure measurement standards with a particular emphasis on low density measurement of H_2O, CO_2, CO, O_2, H_2, and CH_4. Optical measurement techniques of primary interest include photon-induced ionization spectroscopies for partial pressures less than 10^{-2} Pa and absorption spectroscopy in the range of 1 kPa to 10^{-6} Pa. Initial efforts are emphasizing the use of cavity-ring-down-spectroscopy, an absorption technique for the measurement of H_2O, which should enable quantitative determinations in the range ~1 kPa to ~10^{6} Pa and resonant enhanced multiphoton ionization techniques with CO in the range of 10^{-4} Pa to 10^{-8} Pa. In addition to providing non-intrusive measurement techniques for measuring partial pressure of contaminant gases, this research may lead to a new generation of humidity measurement techniques and primary standards for concentrations as low as 1 part per billion.

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SURFACE AND MICROANALYSIS SCIENCE

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MICROBEAM ANALYSIS

The macroscopic properties and behavior of a wide variety of physical, biological, and technological phenomena are controlled by chemical events that occur on the micro-scale. Microbeam analysis techniques based on beams of electrons, ions, and photons can achieve lateral and depth resolution ranging from the micrometer to the nanometer scale, which is equivalent to a sample mass of picograms down to zepto-grams. NIST performs research in many aspects of the measurement science of microbeam analysis. This project develops standards, data, and standard methods to meet the critical need for chemical measurements that can provide quantitative information on small variations in composition. The role of trace constituents distributed in microstructures (often at levels of parts per million to parts per billion) in controlling, for example, device properties is studied through techniques that can achieve trace nanoanalysis, which combines trace fractional sensitivity with nanometer-scale resolution. Measurement of the atoms (elements) present in a microstructure is complemented by techniques that determine the molecular (chemical) forms present, as well as the arrangement of atoms and molecules into crystallographic forms.

The need to visualize lateral compositional distributions quantitatively has been the subject of an extensive effort to develop compositional mapping, in which the result is in the form of an image where the gray or color level is directly related to numerical concentration. Initially developed for picture elements (pixels) in two lateral dimensions, current efforts seek to extend compositional mapping to three-dimensional volume elements (voxels), a capability needed to meet the challenges posed by advanced technologies such as giga-scale electronics and microelectromechanical systems (MEMS).

Instrument resources available in the NIST microanalysis research and analytical microscopy groups include scanning electron microscopes (conventional, electron probe X-ray microanalysis, environmental, and field emission), high voltage transmission analytical electron microscopes (conventional and field emission, with X-ray and electron energy loss analytical spectrometries), an electron-optical/X-ray optical bench, and secondary ion mass spectrometers (ion microprobe, ion microscope, and laser microprobe with magnetic sector or time-of-flight mass spectrometers). Also available are conventional and Fourier-transform Raman optical microprobes; Fourier-transform infrared microscopy; X-ray diffraction, including capillary optic X-ray microfocusing facilities from conventional X-ray tube and high brightness rotating anode X-ray sources; and extensive facilities for computer-aided microscopy and analysis, sample synthesis, and sample preparation.

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ATMOSPHERIC AND CHEMOMETRIC RESEARCH

Concern is mounting worldwide over environmental contamination and wastes, atmospheric pollution, and potential effects on health and climate. It is imperative to determine with a high degree of accuracy the individual sources of pollutant species. State-of-the art research, pioneered at NIST, makes possible unique source identification by application of the most advanced micro-chemical and isotopic analytical techniques, including accelerator mass spectrometry and high-precision gas isotope ratio mass spectrometry. The data obtained provide city, state, and national governments with a unique opportunity to develop and test control strategies to reduce emissions of the identified pollutant sources.

Complementing advanced isotopic-chemical characterization of atmospheric gases and particles is basic research in chemometrics, which represents the synthesis of chemical knowledge and measurement with modern statistical and computational methods. Work in this area is directed toward improving the quality of chemical measurements generally through advanced design, measurement and data analysis quality assurance, and graphical multivariate data exploration.

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SURFACE DYNAMICAL PROCESSES

Understanding the processes that occur at surfaces and interfaces, such as the interactions of adsorbates with substrates, is critical for describing and controlling reactions at these locations. This understanding can lead to new procedures that are fundamental in tailoring surfaces to produce nanoscale structures, decrease wear and corrosion, or to develop new electronic devices, catalysts, or layered materials with improved properties. To address these important technological areas, NIST scientists are studying the fundamental atomic and molecular processes of the interactions of laser and synchrotron radiations and electrons with a broad spectrum of surfaces and the interactions of adsorbed molecules with these surfaces to obtain information on electronic structure, rotational and vibrational energy manifold populations, reactivity, and the mechanisms of energy transfer. These techniques also are applied in experiments with substrates of metals, semiconductors, oxides, and high-temperature superconductors as well as with selected deposited films and adsorbates.

The investigations of these processes have progressed from large spatial scales using femtosecond laser spectroscopy and other surface interrogative techniques to spatial scales on the order of tens of nanometers with the current development of infrared, near-field optical spectroscopic techniques. These experimental techniques are complemented by the development of theories that pull together diverse ideas to provide comprehensive, focused explanations of the processes, which, in turn, lead to new experimental designs and research.

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PHYSICAL AND CHEMICAL PROPERTIES

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FUNDAMENTAL PROPERTIES OF TRACE COMPONENTS OF NATURAL GAS

Natural gas is a complex mixture that can consist of between 300 and 400 organic and inorganic components, many of which are present at relatively low (trace) concentrations. Most of these materials are naturally occurring, while some are intentionally added during processing. The properties of many of these trace constituents are important since they can strongly affect the overall behavior of the natural gas. NIST researchers recently have completed measurements on the vapor pressure and the enthalpy of adsorption (on pipeline surfaces) of a family of chlorinated trace constituents. The vapor pressure studies were done on three pieces of equipment that were specifically constructed for measurements on involatile compounds. The enthalpic measurements were carried out on a modified gas chromatographic apparatus.

Current work is concerned with standardizing the extended analysis of natural gas through the use of measured chromatographic retention indices. The researchers have constructed dedicated chromatographic instrumentation specifically to provide the accuracy required for these measurements. This will facilitate component identification for custody transfer and calorific value calculations. They also are measuring the diffusion of odorants (strongly smelling sulfur compounds added to aid in detection) in natural gas. These measurements are performed on a Taylor-Aris apparatus that was constructed for high-pressure fluids. This work will provide a fundamental understanding of odorant fading, a problem that often occurs during winter months.

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FUNDAMENTAL AND APPLIED PROPERTIES OF ADSORBENTS

The industrial consumption of adsorbents for separation processes is in the range of a megaton per year. These adsorbents include silicas, aluminas, carbons, and zeolites, and their uses range from commodity chemical separations to small-scale environmental applications. An understanding of the properties of these materials is vital to efficient separation process design and operation. A NIST research program is focused on the measurement and modeling of fundamental parameters such as the enthalpy of adsorption and adsorption isotherms (which are measures of the attraction of a chemical on an adsorbent) and the skeletal density (a measure of the ultimate capacity) of adsorbents. NIST has designed and constructed apparatus for these measurements and has applied them to clay and carbon adsorbents. The techniques also allow the study of the effects of surface modifications of adsorbents that are produced by compounds such as surfactants. These measurements are combined with surface observations obtained from neutron scattering and dynamic light scattering to elucidate the surface structure. This will permit design of novel special-purpose adsorbents, since the researchers will have a clear idea of what components or areas of an adsorbent structure are important for the separation process.

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THERMOPHYSICAL PROPERTIES OF SUPERCRITICAL FLUID MIXTURES

All facets of chemical process technology require an accurate knowledge (or reliable predictive capability) of various thermophysical and chemical properties of pure chemicals and their mixtures. This is especially true of separations because of the great diversity of chemicals involved, with widely varying molecular sizes, shapes, and polarity. In addition to this inherent complexity, industry is now exploring the application of alternative solvents for separation processes because many traditional solvents have environmental and health risks associated with their use. This project explores the modeling of processes using alternative solvents through multivariate statistical analysis incorporating a number of empirical and semi-empirical chemical and thermophysical variables as input.

Work is in progress to extend significantly the Kamlet-Taft solvatochromic chemical parameters to the alternative solvents in the subcritical and supercritical phases. Both chemical and thermophysical variables are incorporated into a multivariate statistical model to better predict solution processes of industrially relevant compounds in the alternative solvents. This requires the experimental determination of acidity, basicity, polarity, polarizability, and density of potential solvents. These measurements are performed spectroscopically. In addition to providing a predictive approach to solvent behavior, this work provides insight into understanding the solution process itself. In addition to the spectroscopic-based techniques mentioned earlier, a magnetic levitation solubility instrument is being developed to measure phase equilibria of mixtures not amenable to spectroscopic measurement.

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FUNDAMENTAL PROPERTIES FOR MEMBRANE SEPARATIONS

Membranes are used increasingly in separation processes, novel synthesis processes, and as components of process sensors. To add to the science and engineering base of membrane technology, NIST is working on methods of measuring and correlating chemical and morphological structure with gas and vapor transport-property relationships in both phase-separated polymers and homopolymers. Ionomers, interpenetrating polymer networks, and polymer blends are examples of the former. The linchpin of this effort is obtaining consistent and accurate measurements of solubility and permeability for a variety of gases and gas mixtures in novel polymers that can be chemically or morphologically altered in a systematic way. These data then can be used as starting points for developing molecular-level prediction of transport properties.

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THERMOPHYSICAL PROPERTIES OF GASES AND STANDARDS FROM ACOUSTIC TECHNIQUES

Thermophysical properties of gases are required to design heat transfer machinery and chemical processes. NIST obtains very accurate values for these properties (equation of state, heat capacity, thermal conductivity, viscosity, and speed of sound) by exploiting high-Q acoustic resonators developed and modeled at NIST.

NIST routinely measures the speed of sound in gases with uncertainties of less than ±0.01 percent. NIST data were used to determine the thermodynamic properties of more than 20 environmentally benign, candidate replacement refrigerants and of helium-xenon mixtures used in thermoacoustic refrigerators. To extend these measurements to corrosive gases, and to gases at very high temperatures, NIST developed acoustic wave guides to conduct sound from remote transducers into and out of resonators through corrosion-resistant metal diaphragms. NIST also developed novel acoustic resonators for measuring the viscosity and thermal conductivity of gases with an imprecision of 0.1 percent.

NIST is using acoustic measurements of the highest possible accuracy to measure the imperfections in the internationally accepted temperature scale (ITS-90) in the range 200 K to 700 K. For this work, the speed of sound in argon is measured with an imprecision of 0.0001 percent in a spherical resonator. The thermal expansion of the resonator is measured using microwaves. To maintain the purity of the argon at 700 K, clean argon continuously flows through the resonator with a pressure that is controlled to 1 part in 10^6.

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THERMOPHYSICAL PROPERTIES OF GASES USED IN SEMICONDUCTOR PROCESSING

Mass flow controllers (MFCs) deliver process gases for plasma etching, chemical vapor deposition, and other processes used throughout the semiconductor industry. The operation of the most widely used kind of MFC depends upon heat transfer through the process gas; thus, the sensitivity of these MFCs depends upon the thermophysical properties of the process gas, and each gas requires a different MFC calibration. However, many process gases are toxic, corrosive, and/or pyrophoric, making it impractical to calibrate directly all MFCs for all 50 or so process gases.

An alternative to direct calibration is based upon flowing benign "surrogate" gases (such as N_2, CF_4, SF_6, C_2F_6) through the MFCs and scaling the MFCs' response to account for the differences between the thermophysical properties of the surrogate gas and those of the process gas. The relevant gas properties are density, heat capacity, thermal conductivity, and viscosity. These should be known throughout the temperature and pressure ranges in which MFCs operate. NIST is exploiting its expertise in acoustic technologies to measure the thermophysical properties of the four process gases (Cl_2, HBr, BCl_3, WF_6) and the three surrogate gases (CF_4, SF_6, C_2F_6) that were identified by the semiconductor industry as having the highest priority.

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CHEMICAL THERMODYNAMICS

The Chemical Thermodynamics Data Center carries out expert evaluations of thermodynamic data on organic and inorganic compounds. In addition to the JANAF Tables, current interests include comprehensive evaluations of thermodynamic data related to atmospheric chemistry, such as the destruction of the stratospheric ozone layer, and of data for organic compounds important to the chemical and related industries. The latter work has the long-range goal of producing reliable estimation schemes for predicting the properties of species for which measurements are not available or would be difficult or impossible to perform. In planning and executing its programs, NIST maintains close contact with industrial organizations such as the Design Institute for Physical Properties Data.

NIST researchers use precision oxygen-bomb and fluorine-bomb calorimeters to determine data on enthalpies of combustion, from which enthalpies of formation can be derived. The addition of a new low-temperature heat capacity calorimetry facility now gives the NIST thermodynamics laboratories the capacity to carry out the full range of measurements necessary to determine chemical equilibrium constants for systems of interest. The focus is on the determination of thermodynamic properties of materials important to modern technologies such as chemical process modeling and simulation and semiconductor processing, as well as on the certification of calorimetric Standard Reference Materials.

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CHEMICAL KINETICS

The chemical kinetics program at NIST provides reliable measurement methods, chemical kinetics data, and theoretical models. Applications of this research include combustion, plasma processing, new chemical and energy-related technologies, environmental chemistry, effects of ionizing radiation on materials, and analytical applications of kinetics. Among the experimental projects under way are high-pressure mass spectrometric studies of the kinetics and thermochemistry of ion/molecule reactions and clustering processes and pulse radiolysis of aqueous solutions. Researchers also are studying free-radical kinetics using heated single-pulse shock tubes and flash-photolysis kinetic-absorption and resonance-fluorescence techniques.

At present, there is significant emphasis on developing and using cavity-ring-down laser absorption spectroscopy to study chemical kinetics in the gas phase and at surfaces. In addition, this group uses resonance-enhanced multiphoton ionization spectroscopy to provide very sensitive and selective schemes for the optical detection of free radicals and to acquire new, previously unobtainable data about their electronic structures. An important focus of the kinetics program is the production of databases of evaluated chemical data, including kinetic data and spectral data for analytical chemistry, as well as the design of databases and relevant software.

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NIST/EPA/NIH MASS SPECTRAL DATABASE

One of the most widely used techniques for identifying organic compounds is gas chromatography/mass spectrometry. In this technique, complex mixtures of chemicals are separated using gas chromatography, and then each compound is "finger printed" using the mass spectrometer. The resulting spectra are then analyzed and compared to a library of known spectra. To be successful, the library of known spectra must have only high-quality, complete spectra, and the algorithms used to compare the library and unknown spectra must be robust and well tested.

NIST programs develop and test algorithms for matching and predicting, evaluate spectra from other contributors, and fill in missing data with an ongoing experimental effort. The goal is to develop a mass spectral database containing every compound in commerce. The result of these efforts is an increasing acceptance of the NIST database and algorithms as the standard. In addition to the experimental, evaluation, and algorithmic development work, NIST promotes the use of high-quality tools within the mass spectrometry instrument community.

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PROPERTIES OF ALTERNATIVE REFRIGERANTS

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have been used widely for the past 50 years as refrigerants, as foam-blowing agents, and in many other applications. Recent evidence has shown, however, that CFCs and, to a lesser extent, HCFCs, are breaking down the stratospheric ozone layer that protects the Earth from harmful levels of ultraviolet radiation. These fluids also contribute to greenhouse warming. Alternative chemicals must be found to replace the existing fluids as quickly as possible. To replace the CFCs and HCFCs, accurate knowledge of the thermophysical properties of the substitutes is required.

NIST provides these data to industry. Research includes extensive experimental measurements on pure fluids and mixtures, including saturation and single-phase densities, vapor pressure, heat capacity, thermal conductivity, viscosity, sound speed, and surface tension. The program includes a substantial effort in modeling fluid properties and in developing equations of state. NIST also leads efforts to arrive at international standards for refrigerant properties.

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PROPERTIES OF FLUIDS AND FLUID MIXTURES

The thermophysical properties of fluids and fluid mixtures are essential for process design and control in the chemical, natural gas, aerospace, environmental, and energy-related industries. The research program in fluid properties involves experimental and theoretical research and computer simulation studies on the thermodynamic and transport properties of pure fluids and fluid mixtures. A primary goal of this program is to develop highly accurate predictive models for the thermophysical properties of fluids and fluid mixtures. This is accomplished through an integrated program of measurement, theory, and correlation. Apparatus are available for state-of-the-art measurements of the thermodynamic and transport properties of pure fluids and mixtures, including pressure-volume-temperature relations, speed of sound, heat capacity, dielectric constant, viscosity, phase equilibria, and thermal conductivity over wide ranges of temperature and pressure. Included in this work are measurements in the critical and extended critical region. In concert with the experimental work, NIST researchers conduct theoretical studies to develop wide-range predictive models and computer codes.

A wide variety of research, both experimental and theoretical, is directed toward the understanding of complex fluid behavior, the microscopic structure of fluids, and the liquid-solid phase boundary. Included are studies of non-Newtonian fluids, colloidal suspensions, shear-induced chemical reactions, supercooled fluids and melting phenomena, and macromolecules. A unique shearing cell is available for neutron scattering studies at the NIST reactor.

Molecular-level computer simulation has proved an essential technique for utilizing statistical mechanics-based models of condensed matter. Molecular dynamics studies, involving both equilibrium and non-equilibrium systems, have been conducted. Computer simulation studies are important in interpreting and understanding the results of experimental studies in fluids and in developing predictive models of fluid properties. Other theoretical studies include dynamic and static critical region models (emphasizing mixtures), extended corresponding states, equations of state, kinetic theory of gases and dense fluids, theory of the glassy state, properties of mixtures of dissimilar compounds, phase transitions, and structure-based modeling.

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PROPERTIES OF GELS, MICELLES, AND CLAYS

NIST researchers are using small-angle neutron diffraction, static visible laser-light scattering, dynamic time-correlation spectroscopy, and computer simulation to study the structure and properties of systems containing particles with sizes in the range of 10 to 1000 nm. In addition to the fundamental information being obtained about complex fluids, these suspensions are interesting in their own right. For example, sol/gel technology is being used increasingly in the production of ultrahigh-purity optical glasses. Using neutron diffraction and computer simulation, NIST scientists are improving understanding of the formation dynamics and structure of the precursor gel (a state of matter intermediate to liquid and solid). Dynamic light scattering studies, coupled with experiments using neutron scattering, also are being used to better understand the interaction between surfactant micelles and clay platelets. This will improve understanding of how organic pollutants interact with clay. Current activities include the study of colloidal silica solutions, gelation of silica at high volume fraction, cationic surfactant micelles, and adsorption of large organic molecules on suspended and dispersed clay platelets.

Much of this research is directed toward understanding complex fluids. The characteristic time scales governing the dynamics of colloidal solutions are many orders of magnitude slower than in molecular fluids. Colloidal solutions thus provide NIST scientists with experimentally accessible models for the study of complex fluid behavior. Non-Newtonian fluid behavior is being studied using the NIST Couette-flow shearing cell at the small-angle neutron scattering beam lines of the NIST Cold Neutron Research Facility.

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DILUTE-SOLUTION THERMODYNAMICS

Much chemical technology, particularly in the environmental area, involves solutions where the concentration of the substance of interest is near zero. The thermodynamics of these dilute solutions presents special challenges and opportunities. One area of interest is the solubility of substances in liquid solvents. Water is the most important solvent, but dilute-solution thermodynamics (usually in the form of Henry's law) is used in many different applications.

Recently, new theoretical understanding of the high-temperature behavior of Henry's constant has been exploited to produce an improved model for correlating Henry's constants over a wide temperature range and for extrapolation of existing data to higher temperatures. This project works toward using structural and other data to predict Henry's constants of organic compounds in water at conditions characteristic of air stripping and steam stripping operations. Dilute-solution thermodynamics also can be used to analyze the solubility of solids in vapors and supercritical fluids, which is important for a variety of processes, including extraction using CO_2 and deposition of minerals in steam power plants. Modeling efforts focus on using the density of the solvent as the key variable. Molecular computer simulation is used to test the validity of modeling approaches.

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FINITE-ELEMENT MODELING OF COMPLEX PHYSICAL AND CHEMICAL PROCESSES

This group's objective is to elucidate the physicochemical details of industrial methodologies to provide a basis for improved processes, to provide quantitative information for selection among processing alternatives, and to uncover limiting factors in current approaches such as uncertainties in available property data, or geometrically caused flow instabilities. The group is using the finite-element technique to simulate and analyze fluid flow with associated heat transfer, mass transfer, and chemistry. Two areas of current modeling research are organometallic vapor-phase epitaxy and fluid/solid-particle systems.

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ADVANCED LOW-TEMPERATURE REFRIGERATION

Many new and developing technologies rely on the use of cryogenic temperatures. Some of these technologies include the cooling of infrared sensors for night vision, atmospheric studies, and process monitoring; semiconducting and superconducting electronics for increased speed and reduced noise; cryopumps for the production of clean vacuums in semiconductor processing; magnetic-resonance imaging superconducting magnets; some medical catheters; and the liquefaction of natural gas for a clean-burning transportation fuel. Specialized refrigerators known as cryocoolers are required to reach cryogenic temperatures. Significant research and development of cryocoolers has occurred in the last 15 years to meet the reliability, cost, and efficiency requirements of many different applications.

NIST has been a world leader in this advanced refrigeration field and has led the development of a new type of cryocooler, known as the orifice pulse tube refrigerator (OPTR), that is being considered for all of the applications discussed above. In its normal configuration, it has only one moving part at room temperature and can reach temperatures below 40 K in a single stage. Using thermoacoustic drivers in place of mechanical compressors, NIST and Los Alamos National Laboratory scientists developed an OPTR that became the first cryogenic refrigerator with no moving parts. A patent, a Strategic Defense Initiative Office innovative technology award, and an R&D 100 award have been received for this device, called a TADOPTR. NIST has been collaborating with dozens of companies and other government laboratories to transfer this and other new cryocooler technologies into specific application areas. NIST computer models on regenerator performance are used extensively in the field to aid in the optimization of regenerative cryocoolers.

NIST researchers have done substantial research on many types of cryocoolers to improve their technologies so they may be useful for various applications. In the area of Joule-Thomson refrigerators, NIST scientists have performed adsorption isotherm measurements for many different gases on various carbons. This extensive database is used by government and private laboratories in the design of adsorption compressors for cryocoolers.

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ANALYTICAL MASS SPECTROMETRY FOR INORGANICS AND ELEMENTAL ISOTOPIC METROLOGY

NIST researchers are improving and applying high-accuracy and precision isotope ratio measurements for isotope dilution mass spectrometry (IDMS), as well as identifying and tracking species with unique isotopic signatures. Available instruments—inductively coupled plasma (ICP-MS), thermal ionization, and laser resonance ionization mass spectrometers—have diverse capabilities. Research programs are possible in elemental, isotopic, and speciation measurement. Stable and radioisotopes can be applied to study environmental and health problems, materials, and processes. Research can be directed to innovative development of instrumentation and methods, the characterization and interpretation of unique samples, or the determination of natural, absolute isotopic abundances. Researchers are studying chemical separation schemes to eliminate ionization and isobaric interferences and to increase the speed and reliability of sample introduction. They are also investigating various schemes for quantitative analysis using ICP-MS for non-IDMS applications.

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FUNDAMENTAL STUDIES OF ATOMIC SPECTROSCOPY

The continued development and improvement of analytical atomic spectrometry requires understanding of fundamental processes that occur in flames and plasmas. Researchers are investigating sampling, excitation, emission, and absorption phenomena in all types of flames, glow discharges, and other plasma sources useful in chemical analysis. Advanced approaches used in these studies include laser probes and mass spectrometry for enhanced ionization and resonance ionization studies, as well as ultrahigh resolution spectroscopic investigations using one of the few ultraviolet Fourier transform spectrometer systems in the world. Research opportunities include spectral characterization such as hyperfine structure and isotopic shifts, application of advanced computational methodologies, and energy transfer mechanism studies.

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APPLICATION OF AUTOMATION AND CHEMOMETRICS TO IMPROVE THE ACCURACY OF SPECTROCHEMICAL ANALYSIS

Instrumental methods of analysis require the control of a complex list of parameters to ensure accuracy. Furthermore, such methods of chemical analysis produce large quantities of multidimensional data that challenge the analyst's ability to interpret the results. Using both advanced approaches in automation to control experimental parameters and mathematical tools to optimize, sort, and summarize complex data sets, NIST researchers are designing studies to improve the accuracy of all forms of atomic spectrometry. Research is directed toward developing optimized and automated sample treatments and separation chemistries using microwave-digestion and flow-injection technologies. Automated approaches for instrument control, drift, and interference corrections also are employed. Multidimensional data generated by both rapid scanning and array detector spectrometers are analyzed using personal computers and NIST central computing facilities.

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ANALYTICAL MASS SPECTROMETRY FOR ORGANICS AND BIOMOLECULES

Researchers are developing advanced techniques in mass spectrometry and applying them to the detection, identification, and accurate quantitation of trace levels of organic compounds. Available instrumentation includes a triple quadrupole mass spectrometer with electrospray, thermospray, cesium ion bombardment, positive- and negative-ion chemical ionization, and electron ionization; an ion trap mass spectrometer capable of MS^n experiments and a variety of inlets; and a magnetic mass spectrometer with capabilities for high resolution, fast atom bombardment, and linked scanning.

The group encourages research that is related to electrospray and other techniques suitable for coupling liquid chromatography or capillary electrophoresis to mass spectrometry, particularly if the work may lead to developing techniques for the quantitation of polar and non-volatile analytes, in complex matrices. Of particular interest are biomolecules that are markers for health status.

Research in understanding and applying ion trap technology to quantitative GC/MS/MS is also encouraged as is research into understanding and applying collision-induced and surface-induced dissociation to analytical problems.

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CHROMATOGRAPHY AND ELECTROMIGRATION TECHNIQUES

Solute retention in chromatography and electromigration systems is the result of a complex assortment of molecular interactions between the solute, the stationary phase, and the mobile phase. The diversity of these interactions can be utilized to optimize separations by varying separation parameters such as stationary phase and/or mobile phase composition and column temperature. An understanding of these fundamental retention and selectivity mechanisms facilitates the optimization of separations in gas chromatography (GC), liquid chromatography (LC), supercritical fluid chromatography and extraction (SFC and SFE), and capillary electrophoresis (CE).

Recent research interests have focused on the synthesis and characterization of bonded stationary phases in LC and GC (e.g., monomeric/polymeric C_{18} phases and charge transfer phases in LC and liquid crystalline phases in GC), which offer unique capabilities for the separation of isomeric compounds or compound classes. Researchers are investigating solute-stationary phase interactions using chromatographic and spectroscopic techniques and chiral interactions in LC, GC, SFC, and CE. In addition, NIST scientists are studying molecular modeling of solutes and stationary phases to investigate retention mechanisms and to correlate molecular descriptors with retention and are investigating solute-matrix interactions in SFE.

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NOVEL ANALYTICAL SEPARATION SCIENCE METHODOLOGY

Researchers are developing new, innovative approaches to separate and detect trace-level organic species in complex natural matrices. One priority is the design, synthesis, and characterization of bonded stationary phases for liquid chromatography, gas chromatography, and supercritical fluid chromatography. They also are developing novel separation media/modes for electromigration separation techniques, e.g., capillary electrophoresis (CE), capillary gel electrophoresis, micellar electrokinetic capillary chromatography, and capillary electrochromatography. In another effort, they are developing on-line multidimensional separation techniques based on orthogonal methodologies (LC-GC, LC-CE, LC-LC, GC-GC, etc.)and fast separation technology in GC, LC, SFC, and CE. They also seek application of existing separation modes in novel combinations (e.g., chiral separations in SFC and CE), design of new separation systems based on micellar and liposomal phases, antibody/antigen associations, and size-selective networks. Research is under way on sensitive and/or selective detection systems for microcolumn separations, e.g., mass spectrometry, laser-excited fluorescence, thermal-lens absorbance, chemical reaction, and chemiluminescence approaches. They also are developing supercritical fluid extraction systems for probing the interactions of analytes and matrices and for on-line coupled extraction and chromatography systems and chromatographic and electrophoretic approaches for the measurement of physico-chemical properties such as octanol/water partition coefficients, aqueous solubilities, and vapor pressures. Another effort involves designing microfluidic systems for capillary flow injection analysis, electrophoresis, and electrochromatography. Research will emphasize applications to environmental, clinical, nutritional, and forensic disciplines.

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SEPARATION SCIENCE TECHNIQUES FOR TRACE ORGANIC ANALYSIS

Researchers are developing and applying separation techniques such as gas chromatography, liquid chromatography, supercritical fluid chromatography, and capillary electrophoresis for trace-level determination of organic and organometallic compounds. Researchers are developing extraction systems for selective removal of analytes from natural matrices, e.g., supercritical fluid extraction (SFE) and microwave-assisted extraction. They also are developing chromatographic and electrophoretic approaches for sample preparation/clean-up and analyte preconcentration prior to analysis by LC, GC, SFC, or CE. Another project seeks to develop off-line and on-line multidimensional separation procedures (e.g., LC-GC, LC-LC, SFE-GC, and LC-CE) to measure individual species in complex mixtures. NIST researchers are developing and using simultaneous multiple and/or selective chromatographic and electrophoretic detection systems (e.g., mass spectrometric, electron capture, atomic emission, flame photometric, infrared, UV-visible diode array, fluorescence, electrochemical, and chemical reaction detectors) to enhance measurement selectivity and/or sensitivity. Recent activities have emphasized applications in environmental, clinical, and forensic areas, including the determination of environmental contaminants such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, pesticides, and organometallic species in natural matrices such as sediment tissue, and air particulate material; nutrients such as vitamins and carotenoids in food and serum; drugs of abuse in urine and hair; and biomolecules such as proteins, peptides, and DNA fragments. Research opportunities exist within the division for the application of these separation techniques to trace inorganic analysis problems.

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HIGH-ACCURACY COULOMETRY

The coulometry program entails a broad spectrum of research interests and activities, including improving the precision and accuracy of coulometric methods, determining chemical stoichiometry, redetermining physical constants (atomic weights, Faraday constant), and developing new methods and instrumentation including micro-coulometry. The application of absolute coulometric methods to the standardization of primary chemical standards and to the calibration of other analytical techniques is also a prime concern. Instrumentation is available for constant-current and controlled potential coulometric measurements.

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INORGANIC ELECTROANALYTICAL CHEMISTRY

Research interests encompass all areas of inorganic electroanalytical chemistry, with specific interests in aqueous and non-aqueous electrolytic conductimetry (theory and metrology) including measurements of acid dissociation constants, fundamental studies of pH including modeling of the junction potential, ion selective electrodes, high-precision coulometric research, and the development of electrochemical detection systems. The development of novel electrochemical instrumentation and the application of electroanalytical techniques to matters of national importance are given special attention. Instrumentation is available for precise conductivity, pH, emf, coulometric, potentiometric, and voltammetric measurements.

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TRACE-GAS ANALYSIS

Researchers are using Fourier transform infrared spectroscopy (FTIR), tunable diode laser adsorption spectroscopy, gas chromatography, electrochemical analysis, and other specialized analysis techniques to develop primary standard gas mixtures and to measure trace gases in air, the environment, stack emissions, and process streams. One goal is to analyze complex mixtures of gases emitted from process streams in real-time using spectroscopic techniques. Another is to develop an quantitative database of FTIR spectra of volatile organic compounds for use in remote monitoring. Researchers also are seeking to measure extremely low-level contaminant gases in ultrapure materials, to develop standards, and to analyze trace gases that are important in ambient atmospheric measurements. Additionally, researchers are pursuing analysis of environmentally important trace gases in air and from point sources and the development of very low concentration volatile organic standards.

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OPTICAL TECHNIQUES FOR TRACE-GAS ANALYSIS

This project involves development of optical techniques for trace gas analysis with applications in areas such as environmental and industrial process monitoring. Recent improvements in laser devices and data acquisition systems offer opportunities to extend highly sensitive spectroscopic techniques to detect and quantify the components of various gas mixtures. In particular, sensitive analytical detection techniques for molecules consisting of five or more atoms are desirable. Current approaches include Fourier transform infrared spectroscopy, tunable diode laser absorption spectroscopy, and polarization spectroscopy using a solid-state laser system.

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STANDARDS AND PROCESS ANALYTICAL APPLICATIONS FOR SPECTROSCOPY

Spectrophotometers are important tools for quality assurance, process control, and regulatory compliance measurements. To ensure that these devices are performing properly, NIST manufactures and certifies Standard Reference Material optical filters. Currently, NIST provides materials and filters to measure wavelength accuracy, assess photometric accuracy, and determine the amount of stray light in ultraviolet and visible spectrophotometers. NIST is conducting research to extend our offerings to the near-infrared region where Fourier transform near-infrared spectroscopy (FT-NIR) and Fourier transform Raman (FT-Raman) spectroscopy have become viable, routine techniques, especially for process monitoring. NIST is investigating the use of FT-NIR in combination with FT-Raman to identify and quantify mixtures in sealed containers. An example is the quantitation of mixed oxygenates in sealed ampoules of reformulated gasoline. A future goal is the design and evaluation of a combined NIR/Raman instrument for real-time identification and quantitation of mixtures in a process stream.

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LABORATORY AUTOMATION TECHNOLOGY AND STANDARDS

The thrust of this program is to develop, evaluate, and demonstrate new concepts that eventually can lead to the successful, routine application of laboratory automation. The full potential of automated chemical analysis systems has not been achieved because the process of interconnecting analytical and clinical chemistry laboratory devices remains resource-intensive and difficult. A general lack of interfacing standards, a dearth of instruments designed from a systems-use perspective, and an over-reliance on the anthropomorphic model further exacerbate the situation. To facilitate the automation of the analytical laboratory, standard methods for instrument-to-controller communication, device control, data and material transfer, and error and exception handling are needed to provide instruments with realistic "plug-'n-play" interfaces. New instrument designs need to allow remote control, provide automated access to sample and material ports, and exhibit system-centric behavior.

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AUTOMATED SAMPLE PREPARATION AND SENSING

Scientists often must prepare samples before analysis by extraction, digestion, or other isolation and purification techniques. NIST researchers are developing new chemistries, miniaturization approaches like microfluidics, and automation for techniques such as supercritical fluid extraction, solid-phase extraction, and flow injection. These automated sample preparation methods are being coupled with new and existing microseparation/detection schemes such as capillary electrophoresis, immunoassay-based techniques, and biosensors for real-time monitoring of chemical and biochemical reactions in flow- and batch-processes. NIST's sensors focus is on the development of inexpensive, yet sensitive devices. Research involves the use of planar and fiber optic sensors with immobilized antibodies for attenuation, fluorescent, chemiluminescent, opto-electrochemical, and interferometric assays. In addition, NIST is investigating the combination of micro-flow injection analysis and capillary electrophoresis with optical waveguide detection for laboratory-on-a-chip applications.

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ANALYTICAL INFOMETRICS

To ensure that chemical information necessary for decision making can be provided in an efficient and timely manner, NIST is investigating all aspects of the measurement process, including experimental design; data validation, storage, and retrieval; chemometrics, multivariate statistics, and applied mathematics; data rectification and meta-analysis; quality control, assurance, and improvement; and instrument control and communications. Examples include multivariate infrared and Raman spectroscopy for characterization of organic mixtures using multivariate statistical models. These models incorporate both Raman and near-infrared data to enhance the stability and transferability of these calibration sets, graphical methods for analysis and presentation of interlaboratory comparison studies, development of standards for laboratory automation, and improved methods for evaluating and utilizing analytical measurement uncertainties.

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CHEMICAL ANALYSIS WITH NEUTRON BEAMS

The use of prompt radiations from nuclear reactions is well established as a tool for elemental analysis and compositional mapping. Two techniques are used at NIST: neutron-capture prompt-gamma-ray activation analysis (PGAA) and neutron depth profiling (NDP). Each employs both thermal- and cold-neutron beams from the NIST Research Reactor. PGAA is used to determine a suite of elements that are inaccessible by conventional neutron activation analysis, such as hydrogen, boron, carbon, and nitrogen, as well as those with large capture cross sections, such as cadmium, gadolinium, and mercury. NDP measures the depth distribution of nuclides that emit charged particles on slow-neutron capture. Researchers are developing methods with improved specificity, accuracy, sensitivity, and spatial resolution through detailed studies of the interaction of neutrons and their products with samples and detectors.

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NEUTRON ACTIVATION ANALYSIS

Neutron activation analysis (NAA) provides the sensitivity, selectivity, and capability for multielemental determinations that are often required in studies involving the role of trace elements in biological, environmental, and materials analysis studies. Due to their unique capabilities, the various NAA techniques frequently play an important role in the certification of elemental concentrations in NIST Standard Reference Materials. The accuracy and precision of the various forms of NAA are ultimately limited by the precision of counting statistics that in favorable cases may be a few tenths of a percent. However, to achieve this level of accuracy, all other sources of error must be reduced to comparable levels. Experimental and computational studies address such matters as new and improved chemical separation procedures, neutron and gamma-ray interactions with analytical samples and detectors, high-accuracy neutron flux monitoring, high and varying count-rate gamma-ray spectrometry, peak integration routines, and gamma-ray and fast-neutron interferences. A variety of nuclear spectrometry equipment, laboratory facilities, personal and minicomputer facilities, and the irradiation facilities of the NIST Research Reactor are available for this work.

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FOCUSING OF COLD NEUTRONS FOR ANALYTICAL MEASUREMENTS

The availability of long wavelength neutrons and recent advances in neutron optics provide an opportunity to design analytical probes for use in materials research. The purpose is to measure the concentration of the elements in a fine (sub-millimeter) two-dimensional array across the surface of a material. The detection limit of neutron absorption experiments will be improved by using optical elements to focus long wavelength neutrons onto small sample areas. Different methods can be used to focus cold neutrons; the emphasis is on those based on the principle of total external reflection of neutrons at small grazing angles. These include polycapillary glass fibers, metal capillaries, nickel-coated conic sections of revolution, nickel-coated curved microguides, and curved channel plates. However, in all cases focusing is achieved at the expense of increased angular divergence. Therefore, it is more useful for measurement techniques that are dependent only on the neutron capture reaction rate and not on collimation. Such a system would have an impact on the detection limits for absorption techniques such as prompt gamma activation analysis and neutron depth profiling.

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B125 Reactor Building

RESEARCH FACILITIES

FLUID FLOW MEASUREMENT AND RESEARCH FACILITIES

The NIST flow measurement facilities are used to establish, maintain, and disseminate flowrate measurements, standards, and data for the wide range of conditions needed by U.S. industry and government agencies. Industry requests include flowmeter calibrations, special tests, round-robin testing programs to establish realistic traceability chains in the form of flow measurement assurance programs, data-generation programs for industrial groups and trade associations, and use of testbeds for carrying out industrial research programs focused on flow measurement topics.

The metering research facilities combine primary calibration techniques with the capability to conduct detailed surveys of fluid flows that affect flowmeter performance. These capabilities include computational fluid dynamics as well as laser Doppler velocimetry techniques used mainly in water flow facilities. CFD techniques include commercially available codes as well as specialized codes tailored to specific conditions.

CAPABILITIES

Fluid flow facilities enable a range of fluid and flow conditions in a wide range of pipe sizes:

- Water: maximum flowrate of 40,000 liters/min up to 0.5 m diameter with temperature near ambient and pressure up to 10 atmospheres.

- Hydrocarbon liquids having densities of 0.6 - 0.8 gms/cc and kinematic viscosities of 1-30 centistokes: maximum flowrate of 1600 liters/min in tubes and pipes up to 50 mm in diameter with temperature near ambient and pressure up to 10 atmospheres.

- Air: maximum flowrate of 85 cubic meters per minute in pipes up to 100 mm in diameter with temperature near ambient and pressure up to 35 atmospheres.

- Gas flows having variable composition and temperature: the component gases of auto exhaust with flows totaling 2.8 cubic meters per minute in 50 mm pipes and temperatures to 400 °C.

APPLICATION

These facilities are used to establish and maintain the national standards for fluid flowrate measurement systems to achieve orderliness in the marketplace, to produce satisfactory measurements for optimizing productivity in continuous industrial processes, and to monitor environmental quality. These facilities also are used to generate critical databases needed to initiate or update the national standards on generic fluid-metering topics. These standards are used for accurate custody transfer of fluid resources or products in the domestic and international marketplace or for studying critical industrial processes. Potential users are industries involved in the custody transfer of fluid resources and products, the chemical and petrochemical industries, the power and energy-generation industries, the auto industries, and government agencies such as NASA, DoD, and EPA.

AVAILABILITY

The facilities are available upon request to U.S. industry, other government agencies, and academia for collaborative research projects, including proprietary research, and calibrations of flowmeters or other pipeline elements.

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LIQUID-NITROGEN FLOW MEASUREMENTS

The liquid-nitrogen flow measurement facility serves as the national calibration facility for cryogenic flow measurement devices. The facility incorporates a dynamic gravimetric method to measure liquid nitrogen. Well instrumented for monitoring temperature, pressure, and time, the facility also is capable of determining volumetric flow rates. The facility is located completely indoors and is not subject to environmental changes.

CAPABILITIES

The facility has a flowrate range of approximately 1 to 10 kg/s. The pressure can vary from 0.4 to 0.76 MPa at temperatures between 80 and 90 K. In this closed-loop flow facility, NIST researchers can establish and maintain stable flow conditions for extended test periods. For volumetric flow measurements, the density is determined by making pressure and temperature measurements and calculating density from an equation of state.

APPLICATIONS

The nitrogen flow facility is used primarily as a calibration facility for cryogenic flowmeters; however, it also can be used for developmental testing and evaluation. NIST staff are able to vary the system parameters and evaluate flowmeter sensitivity to variables other than flowrate. Because they can accurately measure fluid properties as well as flowrate, the facility also can be used to evaluate pressure and temperature sensors associated with the flowmeters.

AVAILABILITY

Collaborative or independent programs for this test facility can be arranged. The facility must be operated by NIST staff.

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PHYSICS LABORATORY

The NIST Physics Laboratory supports U.S. industry by providing measurement services and research for electronic, optical, and radiation technology. It pursues directed research in the physical sciences; develops new physical standards, measurement methods, and data; conducts an aggressive dissemination program; and collaborates with industry to commercialize inventions and discoveries. The laboratory's programs range from tests of fundamental postulates of physics to the more immediate needs of industry and commerce.

Much of the laboratory's research is devoted to overcoming the barriers to the next technological revolution, in which individual atoms and molecules will serve as the fundamental building blocks of electronic and optical devices. To develop the necessary measurement capabilities for these new products, laboratory scientists use highly specialized equipment to study and manipulate individual atoms and molecules.

The laboratory's work in support of industry covers a broad scope of activities. For example, the laboratory is working to improve optical measurement techniques used in remote sensing, advanced color graphics systems, and optically pumped atomic clocks. Research also is focused toward advancements in the measurement and dosimetry of ionizing radiation used in medicine and industry and supports the development of emerging technologies such as X-ray lithography, digital X-ray imaging, and electron beam processing.

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COOPERATIVE RESEARCH OPPORTUNITIES

RESEARCH FACILITIES

SERVICES

COOPERATIVE RESEARCH OPPORTUNITIES

OFFICE OF ELECTRONIC COMMERCE IN SCIENTIFIC AND ENGINEERING DATA

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ELECTRONIC COMMERCE IN SCIENTIFIC AND ENGINEERING DATA

The Office of Electronic Commerce in Scientific and Engineering Data works to promote compatibility and integration in the dissemination of non-product-specific information required by U.S. industry. It seeks to make scientific, engineering, technical, codes/standards, and related regulatory information available to U.S. industry in a usable, accessible, unified manner. The office's goal is to help make it possible for industry to create an electronic marketplace that will allow participants to efficiently locate, access, protect, contribute, and pay for scientific, engineering, and regulatory information. This information will be provided in open formats and computer-sensible form along with specification of the quality and security of the provided information. Work on this effort began with an industry/government team organized in conjunction with the National Initiative for Product Data Exchange. The team identified and defined 19 specific functions needed to make such an information capability a reality. A World Wide Web (WWW) page is being created to identify the required functions and to provide information about progress in each of them. In addition, plans are to make WWW databases available to developers as testbeds to demonstrate their methods of achieving these functions. This WWW page will serve both to inform the data producing and using communities about progress toward an effective dissemination system as well as to encourage the computer technology community to build the capabilities necessary for technical data into its systems. In addition, the databases disseminated by the Physics Laboratory on its WWW page will serve as models of effective dissemination of scientific and engineering data.

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DISSEMINATION OF DATABASES OVER COMPUTER NETWORKS

The Office of Electronic Commerce in Scientific and Engineering Data is responsible for the Physics Laboratory's World Wide Web (WWW) page. It produces Physics Laboratory material for publication over the WWW, encourages and supports the production of material by others, and assures the high quality of information disseminated by the Physics Laboratory over the electronic networks. In addition, the office develops methods to display information generated within the laboratory in an effective manner over the WWW. This office also works with the Physics Laboratory divisions and Standard Reference Data staff in developing physical reference databases for dissemination over the WWW. It designs effective interfaces between the information and the user to facilitate use of the data. Several databases are available already and may be accessed from the Physics Lab WWW page under Physical Reference Data (http://physics.nist.gov/PhysRefData/contents.html), and a number of other databases are being developed for use over the WWW.

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FUNDAMENTAL CONSTANTS DATA CENTER

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EVALUATION OF FUNDAMENTAL CONSTANTS, MEASUREMENT UNCERTAINTIES, AND SI

The fundamental physical constants, such as the Rydberg, Planck, fine-structure, and Avogadro constants, are the links in the chain that bind all of science and technology together. Further, they can serve as the basis for improved practical representations of the International System of Units (SI) and thus for more accurate measurements of importance to both science and technology.

The primary goal of the Fundamental Constants Data Center (FCDC) is to issue periodically a set of recommended values of the fundamental physical constants and basic conversion factors of physics and chemistry. This is accomplished by critically reviewing all data relevant to the constants that is available at a given epoch and analyzing it by a variety of methods, including least-squares. The resulting set of recommended values is distributed widely via archival journals, handbooks and reference books, textbooks, professional society magazines, and electronically on the Physics Laboratory's WWW home page.

Because of the FCDC's expertise in analyzing fundamental constants data, it is deeply involved in the worldwide effort to standardize the method of expressing uncertainty in measurement. To this end, it revises and publishes from time to time NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*.

Another principal task of the FCDC is to serve as the NIST-authorized organization for the interpretation of SI in the United States. As part of this task, the FCDC revises and publishes periodically NIST Special Publication 811, *Guide for the Use of the International System of Units (SI)*.

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ELECTRON AND OPTICAL PHYSICS

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PHOTODIODE DETECTORS FOR RADIOMETRY

Highly stable photodiode detectors with uniform spatial sensitivity are developed, calibrated, and distributed as transfer standard detectors for radiometry in the wavelength region of 5 nm to 254 nm. Detectors presently available at NIST include Al_2O_3 photocathode windowless photodiodes for the region 5 nm to 122 nm; CsTe photocathode windowed (evacuated) photodiodes for the region 116 nm to 254 nm; and silicon photodiodes, developed in collaboration with industry, for the region 5 nm to 254 nm. Some other types of detectors can be calibrated by special arrangement. Broadband photometers also have been developed in collaboration with outside users and calibrated in this spectral region, e.g., combinations of silicon photodiodes with thin-film filters for plasma diagnostics and vacuum ultraviolet solar radiometry.

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EUV OPTICS CHARACTERIZATION

The emerging field of high-reflectance, normal-incidence soft X-ray or extreme ultraviolet (EUV) optics has a wide range of applications. The ability to produce high-quality images at wavelengths below 40 nm has allowed construction of EUV solar telescopes with unprecedented resolution, EUV microscopes able to study living biological samples with sub-micron resolution, and EUV photolithographic systems that are proposed as tools for the next generation of integrated circuits.

NIST has initiated an EUV multilayer characterization facility at the Synchrotron Ultraviolet Radiation Facility (SURF) II storage ring, which is available to all researchers on a cooperative basis. The current facility is capable of measuring the reflectance or transmittance of EUV optics such as mirrors, filters, and gratings as a function of wavelength, angle of incidence, and position on the optic. NIST is constructing a new facility that will extend measurement capabilities to larger and more curved optics. A thin-film deposition chamber has been added to the reflectometry facility that allows measurements of films as they are being deposited. From these measurements the optical constants of important multilayer materials can be determined free from influence of surface contaminants.

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TUNNELING MICROSCOPY

Scanning tunneling microscopy (STM) is a highly sensitive probe of surfaces, which utilizes the quantum mechanical principle of tunneling to probe surface topography on a nanometer scale. The STM also is inherently sensitive to surface electronic properties that can be exploited to detect the surface electron density of states and, in certain cases, for selective imaging of different elemental species. An ultrahigh vacuum STM with extensive facilities for tip and sample preparation and characterization has been used by NIST scientists to investigate four main areas relating to nanometer-scale science: epitaxial growth, correlation of microstructure and magnetism, electron spin dependent contrast measurements in STM, and electronic properties of nanostructures. Experimental efforts employ custom-designed instrumentation with which NIST scientists strive to push the frontiers of visualization of the nanometer-scale world. Currently, a tunneling microscope is being designed to operate in UHV at liquid helium temperatures with the possibility of applying a magnetic field up to 10 Tesla to the sample.

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MAGNETIC MICROSTRUCTURE

Low dimensional magnetic systems (such as thin films, multilayers, and surfaces) as well as reduced dimensional systems (such as granular materials and microscopic lithographic devices) exhibit many scientifically interesting and technologically useful properties. NIST scientists use three complementary magnetic imaging techniques—scanning electron microscopy with polarization analysis (SEMPA), magneto-optic Kerr microscopy, and magnetic force microscopy (MFM)—to determine the role physical and magnetic microstructure plays in determining macroscopic magnetic properties. SEMPA, which images the magnetization by measuring the spin polarization of secondary electrons emitted in a scanning electron microscope, features high (20 nm) resolution, long working distance, large depth of field, and a direct measurement of the vector components of magnetization independent of topography. SEMPA is a relatively surface sensitive technique, making it especially well suited for in situ studies of thin film and surface magnetism as recently demonstrated by investigations of the oscillatory exchange coupling of magnetic layers.

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NANOFABRICATION WITH ATOM OPTICS

NIST scientists are studying the physics of laser focusing of atom beams to find ways to develop a fabrication tool that could lead to more compact microcircuits, higher density magnetic recording media, better sensors, and novel materials. Laser beams form lenses that focus neutral atoms into tiny regions as they deposit, building nanostructures on a surface. The chromium atoms used in this process emerge from an effusive, high-temperature oven, are collimated by laser cooling, and pass through a laser standing wave, which acts as an array of "lenses," focusing the atoms into an array of lines. The nanofabrication of a two-dimensional array of chromium dots also can be achieved by using two orthogonal standing waves. The very regular arrays of chromium lines and dots with spacing tied to optical wavelength promise to provide useful standards. Atom optical methods potentially can be extended to a much broader range of materials. Metastable rare gas atoms can be manipulated with lasers and contain internal energy that has been used to expose a resist. A pattern of light can be used to de-excite the metastables; in this way light can be used as a mask for matter, instead of matter being used as a mask for light as in optical lithography.

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CONDENSED MATTER THEORY

A variety of theoretical techniques are used to study a wide range of problems related to the interactions of electrons in solids, including electronic structure calculations, transport in magnetic multilayers (giant magneto resistance), exchange coupling in magnetic multilayers, surface growth, spin-dependent reflection from interfaces, magnetic hysteresis in ultrathin films, light emission produced by scanning tunneling microscopy of a magnetic surface, electron energy loss in magnetic and non-magnetic solids, high-temperature superconductivity, and various microscopic tunneling phenomena. The theory effort helps interpret and guide experiments and provides the theoretical understanding crucial to the development and application of new measurement techniques.

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DATA FOR ELECTRONIC STRUCTURE CALCULATIONS

Great advances in the calculation of materials properties from first principles have been made by the use of density functional theory. It now is possible to compute ground-state electronic structure, geometries, cohesive energies, and various response functions for solids containing ~ 100 atoms/unit cell, with an accuracy needed for practical materials design. NIST researchers generate benchmark reference data for such calculations, which can be used by developers of new approximations or computational algorithms to test their results against data of known high numerical accuracy. The researchers have disseminated results for atomic total energies and orbital eigenvalues for all elements, as computed in several common variants of the local density approximation, and are preparing a set of standard calculations for condensed matter systems. Cooperation is invited from developers of materials modeling software who wish to benchmark their codes against these data or who are willing to participate in round-robin comparisons to generate new benchmarks for complex systems.

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ATOMIC PHYSICS

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VACUUM ULTRAVIOLET RADIOMETRY

As part of its research to understand and measure various forms of radiation, NIST is conducting vacuum ultraviolet studies involving radiation damage, polymerization of organic molecules, and solar simulation. NIST scientists have worked with researchers from industry to develop and test vacuum ultraviolet instrumentation, new spectrometer designs, and detector systems, especially for space flight. They also have collaborated on special sources, narrow-band filters, and lasers. NIST scientists are interested in doing cooperative research in several other areas, including studying hollow cathode lamps, laser plasmas, and spark-discharge light sources as secondary standards. State-of-the-art radiometric facilities and advanced optical equipment are available at NIST for these studies.

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CHARACTERIZATION OF LOW-TEMPERATURE PLASMAS

The properties of low-temperature plasmas play a key role in the processing of materials such as semiconductors. Proper characterization of these plasmas is essential to develop accurate plasma diagnostics and useful plasma models for specific applications. At NIST, plasma discharges are characterized utilizing optical emission spectroscopy, laser-induced fluorescence, laser scattering, and optogalvanic methods. Modeling of the plasma also is an integral part of this characterization. Discharge sources include low-pressure rf plasmas, stabilized arcs, glow discharges, heat pipes with laser resonance ionization, and inductively coupled plasmas.

An extensive array of laboratory equipment is available to accomplish this characterization, including several Nd:YAG pumped, high-resolution (<0.1 cm-1) dye lasers; Ar ion-pumped dye and ring dye lasers; a Fizeau wavemeter; a high-throughput (f/4), high-resolution (<.001 nm) spectrometer with an automated intensified diode array detector; an 80-MHz quadrature He-Ne laser interferometer; uv spectrometers; grazing incidence spectrometers; laboratory computers; and miscellaneous optics. The principal quantities measured are particle density distributions—both spatially and temporally—for electrons, atoms, ions, and molecules. Also included are electric-field distributions, electron and ion temperatures, and non-equilibrium phenomena.

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ION TRAP FACILITY FOR RESEARCH ON HIGHLY IONIZED ATOMS

NIST's new electron beam ion trap (EBIT) source provides many opportunities for definitive measurements aimed at a basic understanding of plasma processes and atomic structure. In addition, possibilities for using the new source for nanofabrication and ion lithography are currently being investigated.

Ions can be generated over a wide range of species and charge states (ultimately up to fully stripped uranium). Ions are trapped radially and probed with a mono-energetic electron beam. Electrostatic end caps confine the ions axially. A large magnetic field is applied by a superconducting magnet to pinch the electron beam to high density and provide additional radial trapping. The carefully controlled conditions in EBIT allow scientists to unravel complex collision processes and measure spectra with very high accuracy. Highly charged ions can be produced and observed in fluorescence with adequate brightness. The ion temperature can be lowered by evaporative cooling techniques. A variety of instruments are available to characterize and probe the trapped ions, including X-ray and visible/uv spectrometers and a laser system. An extraction system for directing beams of highly charged ions onto surfaces is fully operational.

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LASER COOLING AND TRAPPING

Thermal motion of atoms often adversely affects measurements. Using the radiation pressure from near-resonant laser beams, NIST scientists can cool a gas of atoms to within a few microdegrees of absolute zero. These cold atoms can be trapped by laser beams or other electromagnetic fields.

Facilities for cooling and trapping atoms include cw dye, solid-state, and semiconductor lasers. Atoms are trapped in laser traps, magneto-optical traps, and microwave traps. Sodium, rubidium, cesium, and xenon atoms are cooled, trapped, and used in such diverse applications as atomic-fountain frequency standards and studies of laser-modified chemical reactions. Control of atomic motion by lasers also is being applied to problems such as atom interferometry and laser-directed deposition of atoms on surfaces.

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HIGH-PRECISION LASER SPECTROSCOPY

Highly stabilized tunable lasers permit the investigation of atoms and molecules with a level of detail and precision that cannot be obtained with conventional spectroscopic techniques. NIST work in this area ranges from observations of laser ionization of diatomic molecules in dense vapors to highly precise wavelength measurements that test the most advanced atomic theories for simple atoms. The high resolution provided by laser scanning permits studies of spectral line profiles, including pressure broadening, isotope shifts, and hyperfine structure. Sensitive detection techniques, including FM and optogalvanic spectroscopy and use of thermionic diode detectors, permit observation of low concentration species in discharges and vapor cells. Typical applications of these data include wavelength standards, detection of trace elements in samples, and laser isotope separation. Facilities include stabilized lasers that are tunable from the near ultraviolet to near infrared and a unique Fabry-Perot wavemeter that is capable of real-time laser wavelength measurements with an accuracy of a few parts in a billion.

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QUANTUM PROCESSES

The NIST quantum processes group is developing new algorithms and theoretical methods for describing the quantum properties of complex systems. These methods are being applied to describe collisional phenomena currently being observed in ultracold neutral atom traps, which ultimately will lead to the next generation of atomic clocks. These interactions also play a crucial role in the formation and stability of Bose-Einstein condensates in nanokelvin atomic gases. The ability to manipulate such condensates is a key to developing atom optics and the proposed atom laser. Developing the theory to quantitatively explain precision NIST spectroscopic measurements in atom traps requires the development of new theoretical algorithms for solving large-scale matrix eigenvalue problems. Such algorithms have widespread applicability to many areas of chemistry and physics and are being used by the group to calculate the optical properties of nanoscale quantum wire laser devices. Implementing these new methods now is feasible due to the development of state-of-the-art massively parallel processing computers.

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X-RAY STUDY OF ATOMIC STRUCTURE OF MATTER

X-ray spectroscopy provides information on electronic structure and on the local atomic structure of atoms in matter. At present, laboratory capabilities at the Gaithersburg site are complemented by a synchrotron radiation beamline at the National Synchrotron Light Source at Brookhaven National Laboratory in New York. It has both high flux and good energy resolution in the X-ray energy range from 500 eV to 5000 eV. Using this line, researchers from NIST and other institutions have applied X-ray emission spectroscopy, X-ray photoelectron spectroscopy, and Auger electron spectroscopy to probe the electronic structure of gas phase and solid targets. The beamline's capabilities are particularly well suited to back-reflection standing wave techniques for finding the precise location of impurities or imperfections within a crystal or at its interfaces. The technique can be used with semiconductors or optical crystals, growth of overlayers on crystals, and the structure of catalysts supported on crystal substrates.

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HIGH-ENERGY X-RAY SPECTROSCOPY

Researchers have developed highly accurate spectroscopic instrumentation for measurements from the keV region to several MeV. This measurement system is connected to the basic SI units of frequency and length by means of X-ray interferometry and a precise lattice comparator. Main applications include accurate secondary standards in the X-ray and gamma-ray region and spectroscopic measurement of high voltage. Several such installations are available at NIST and elsewhere. Collaborative applications of these capabilities are welcomed.

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PRODUCTION AND CHARACTERIZATION OF SYNTHETIC MULTILAYERS

For short-wavelength characterization of multilayer structures intended for larger wavelength X-ray optics, NIST researchers have established a high-performance multiaxis diffractometer. This system provides highly collimated and monochromatic X-ray beams, which, after reflection from the structure under study, can be examined for both specular and non-specular reflection characterization. The normal operating wavelength is 0.154 nm, and the on-scale reflectivity covers a range of six decades.

The researchers also have a thin-film production facility capable of handling a wide variety of materials in the range of thicknesses from near one monolayer to a micrometer. The production process uses ion beam sputtering with simultaneous quasi-neutral beam milling to produce thin layers of exceptional uniformity.

These capabilities currently are being applied to the development and standardization of thin film standards for the semiconductor industry.

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PRE- AND POST-FLIGHT X-RAY CALIBRATIONS

NIST researchers have applied their long-standing experience with the crystal diffraction technique to the production of crystals and/or tunable monochromatic X-ray sources in support of several NASA missions. They provided crystals for the spectrometers flown on the Solar Maximum Mission and P78-1. Post-flight energy calibration was performed for the BBXRT detector as well as pre-flight calibration of the telescope borne by the Japanese satellite Yohkoh (ASTRO-D), which is currently in orbit. More recently, they delivered three double-crystal monochromators for the energy calibration of the AXAF telescope, the proportional counter array for the XTE mission, and the bolometric imager for ASTRO-E. Current capabilities include the design and construction of custom instrumentation and attendant data acquisition and control systems for the production and/or detection of X-rays, X-ray crystal preparation and characterization, and various implementations and techniques of X-ray spectroscopy.

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LUMINESCENCE SPECTRAL RADIOMETRY

Luminescence techniques have broad application in virtually every scientific field, including radiation measurement; remote sensing; analytical chemistry; and characterization of laser, semiconductor, and superconductor materials. The accurate spectral radiometric quantitation of light emission is an exacting task requiring painstaking radiometric measurements and knowledge of the fundamental chemical and physical processes represented by these radiative transitions. Standard lamps, both radiance and irradiance, and silicon detector radiometry provide the accuracy base for the spectral and quantum efficiency measurements. NIST is investigating luminescent phenomena such as photo-, chemi-, thermo-, electro-, and bioluminescences. Researchers are conducting luminescence radiometric research in the near-ultraviolet, visible, and near-infrared spectral regions and are developing accurate standards and measurement procedures for these regions. Facilities available for this research include various laser and lamp sources, a reference spectrofluorimeter, and a low-light-level spectroradiometer.

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PHOTOMETRY

Photometry is the science of radiometric measurement of the response function of human vision. The candela, one of the seven base units of the SI, is the basic unit of photometry. The Optical Technology Division has established a new detector-based candela that has improved the accuracy of these measurements by a factor of two. This improvement has become the basis for improved accuracy of all other photometric measurements offered by the division.

Improved levels of accuracies are needed in industry to ensure the production of higher quality products so U.S. companies can compete in the growing international market. Accurate light measurements are essential to the production of various lighting products such as light bulbs, discharge lamps, lighting fixtures, automobile head lights, and aircraft lamps. Accurate light measurements are also essential in the production of information displays such as cathode ray tubes, flat-panel displays, light-emitting diodes and various other optical components.

Another unit in photometry is the lumen, which is the measure of the total light output of lamps. The lumen is especially important to the lighting industry where millions of lamps are produced every week. The Optical Technology Division recently has established a new lumen unit based on the detector-based candela that provides the highest accuracy levels of lumen measurements.

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HIGH-ACCURACY CRYOGENIC RADIOMETRY

The Optical Technology Division bases many of its radiometric measurement scales, such as detector spectral responsivity, photometry, radiance, and irradiance, on a high-accuracy cryogenic radiometer (HACR). Cryogenic radiometers work on the principle of electrical substitution where the temperature rise in a receiving cavity caused by optical heating is reproduced by electrical heating. Electrical substitution measurements tie the optical watt to electrical standards.

The HACR measures the optical power of single laser lines with an uncertainty of 0.02 percent or better and calibrates transfer detectors to disseminate a spectral responsivity scale. NIST researchers continue to improve the HACR base measurements and the optical transfer devices in different wavelength regions. Optical detector calibrations from the ultraviolet through the infrared are based on HACR measurements and are used in environmental, industrial, defense, and space applications. Cryogenic radiometry reduces the base uncertainty in the optical calibrations transferred to these customers.

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THERMAL RADIOMETRY

NIST researchers are investigating the use of thermal imaging cameras as a temperature-measuring tool. These devices may prove to be very useful in determining the quality of products and in investigating changes in different processes. Research projects involve the development of large-area blackbodies, use of Pt-Si as detector standards, and the characterization of thermal imaging cameras. Equipment available includes several heat-pipe blackbodies, a Pt-Si camera, and an infrared radiometer.

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NEAR ULTRAVIOLET RADIOMETRY

The measurement of terrestrial solar irradiance at ultraviolet-B (UV-B) wavelengths (200 to 400 nm) is being investigated by NIST researchers to provide improved techniques and standards in this spectral region. This work is important to networks that monitor solar UV-B irradiance, to scientists studying the biological effects of ultraviolet radiation, and to researchers investigating the aging of materials. Specific projects include the development of experimental techniques for characterizing instruments that measure UV-B irradiance, spectral irradiance standards for use at field sites, and a transportable reference spectroradiometer. A permanent UV-B monitoring site, equipped with a broad suite of instruments, is maintained at NIST, and researchers coordinate intercomparisons among spectroradiometers from different monitoring networks.

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SPECTRAL RADIOMETRY

Research and development programs at NIST span many activities associated with the measurement of optical radiation, covering the spectrum from 200 nm in the ultraviolet to the far infrared. Included are spectral radiance and irradiance measurements for many varied applications, such as manufacturing process control, remote sensing of the Earth's environment, and defense needs. Researchers at NIST take demanding problems, such as the spectrophotometric measurement of dense optical media, and develop the detector metrology to perform the measurements and relate them to the stable, U.S. radiometric measurement base. Emphasis is placed on solid-state photodiode metrology and its application to all areas of radiometry, especially calibration services.

Several well-equipped laboratories for optical measurements in the ultraviolet, visible, and infared spectral regions are available for use, and new facilities are being developed to enable scientists and engineers to conduct research on detector improvements, detector applications, and optical properties of materials.

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INFRARED SPECTRAL RADIOMETRY

Researchers at NIST are developing devices and techniques for high-precision measurements of radiant power in the 2 µm to 30 µm spectral region to enable characterization of spectral sources, optical components, and detectors. Novel experiments are being planned to investigate physical and chemical processes in materials and molecular structures. State-of-the-art radiometers, a cryogenic blackbody with multiple apertures, lead salt lasers, spectral instrumentation, and solid-state infrared detectors are being acquired. A unique facility called the Low Background Infrared Radiation Facility is dedicated to this research and development effort. An Infrared Detector Comparator Facility, equipped with a prism-grating monochromator and a Fourier transform infrared spectrometer for characterizing detectors at ambient background, is nearing completion.

Related research projects are investigating methods for measuring the optical density of filters using laser heterodyne technology and determining the spatial uniformity and linearity in the response of infrared detectors. Collaborative research opportunities exist in measuring the optical properties of materials and fundamental molecular structures and in developing novel detectors.

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SPECTROSCOPIC APPLICATIONS

The NIST spectroscopic applications group employs advanced spectroscopic methods using state-of-the-art lasers and microwave frequency sources in conjunction with molecular beam techniques to elucidate the details of chemical reactions that are important in a wide variety of industrial processes, including catalysis, combustion, chemical vapor deposition, and drug design. These benchmark studies provide the means for real-time optimization of chemical processes and on-line monitoring for pollution control.

The group also carries out spectral studies of species important in atmospheric processes with particular emphasis on the reaction chemistry of ozone. The work provides spectral data for these species, which are used by scientists modeling the chemistry of the upper atmosphere. A recent thrust of the group centers around the determination of physical and electrical properties of numerous new chemical compounds that are being investigated by industry for use as alternative refrigerants.

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NON-LINEAR OPTICAL MEASUREMENTS AT INTERFACES

Non-linear optical methods are used to measure properties of interfaces that may be found at the surfaces of materials, in thin-film systems, or buried in layered materials. An example is the technique of sum frequency generation (SFG), in which two laser pulses at different frequencies combine to produce light at their sum frequency with an efficiency that depends on the broken symmetry at the interface. With femtosecond laser pulses, SFG provides a time-resolved optical diagnostic uniquely sensitive to interface structure. Measurements include spectroscopic characterization of electronic structure at buried epitaxial interfaces, ultrafast monitoring of carrier dynamics at semiconductor interfaces, assessment of the structure and quality of thin films, and vibrationally resonant SFG of organic films such as self-assembled monolayers. This research is a collaboration with the Chemical Science and Technology Laboratory.

Resources include femtosecond laser sources for generating ultrafast pulses in the infrared through ultraviolet and instrumentation for spectral, directional, and polarization analyses of surface-generated optical signals.

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OPTICAL SCATTERING MEASUREMENTS

Studies are being made of how materials' properties and surface topography affect the distribution of light scattered from surfaces, with an aim to developing standard measurement methods and standard artifacts for use in industry. The description of light scattered from surfaces is a useful metrological tool for appraising performance of optical elements and for evaluating material processing. Applications include evaluation of highly polished optical surfaces, bulk optical materials, surface residues, and diffuse scattering materials. Experiments are under way to correlate the optical scatter from silicon wafers with properties such as haze, surface microroughness and particulate contamination, with a goal to facilitate optical scattering measurements in assembly line applications. The utility of polarization analysis of scattered light also is being investigated. Parallel research in near-field optics is elucidating the connection between microscopic features of the surfaces and the far-field optical scattering pattern. Facilities are available for laser-based measurements of the bidirectional reflectance distribution function of light-scattering materials and surfaces. Work is under way on theoretical modeling of the bidirectional reflectance distribution function. Clean rooms are available for handling optical samples.

The bidirectional characterization of optical scatter from surfaces is a useful diagnostic in evaluating elements contained within large optical systems that require the minimization of scattered light. This information is needed for the development of ring-laser gyroscopes and telescopes. It also is used for the characterization of materials for use in stray light reduction in thermal control and inspection processes in optical manufacturing settings. NIST research projects involve the development of a multi-angle scattering reference instrument and the development of measurement methodologies and Standard Reference Materials for the spectral range from the ultraviolet to the infrared region.

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NEAR-FIELD SCANNING OPTICAL MICROSCOPY

NIST researchers are developing near-field scanning optical microscopy (NSOM) as a quantitative technique for non-invasive optical measurements on previously inaccessible length scales. So far, lateral resolution of the order 20 nm has been achieved with this technique, and vertical resolution of less than 1 nm may be possible. The researchers are building well-characterized microscopes and small light sources and are working on methods to determine the resolution of commercially available near-field microscopes. At a fundamental level, this means understanding the mechanisms that generate contrast in different materials and modeling the fields around small light sources as they interact with various materials and surface features. The group collaborates with other NIST researchers interested in applying near-field microscopy to problems in chemical, optical, and semiconductor technology. Applications include mapping of optical properties of nanostructured materials, investigations of structure in biological membranes, and near-field measurements of photonic structures.

Resources include NSOM measurements in the visible, NSOM tip characterization, theoretical modeling of probe-surface interactions and optical contrast mechanisms, and access to complementary scanning microscopies such as SEM and AFM.

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TIME-RESOLVED INFRARED SPECTROSCOPY

Ultrashort laser pulses are used to observe fast processes that occur in the condensed phase. NIST researchers have developed unique femtosecond infrared spectroscopic techniques to study highly excited vibrational states, vibrational energy transfer, photochemical reactions, and the dynamics of hydrogen bond formation and rupture. The measurements identify transient species and determine energy transfer rates, which serve to improve models of condensed phase chemistry. Current collaborations with industry include measurements on catalytic systems and polymerization reactions. They also are developing sources of femtosecond pulses in the terahertz frequency region to be used to probe directly quantum well electron and solid-state phonon dynamics.

Resources include femtosecond laser sources generating ultrafast pulses in the infrared through ultraviolet; infrared and visible multielement detectors, and instrumentation for capturing transient spectra of samples with single laser pulses.

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ELEMENTARY CHEMICAL REACTION DYNAMICS

Researchers use laser pulses to observe and manipulate fundamental molecular transformations such as bond breaking and bond formation in order to develop an atomic-level understanding of reactions important in combustion and propulsion chemistry, in the chemistry of the upper atmosphere, and in orbital environments. Current efforts emphasize elementary reactions of oxygen atoms with hydrogen, water, hydrocyanic acid, and methane. The experiments use state-resolved nanosecond and time-resolved femtosecond spectroscopic techniques and molecular beam methods to produce data to test quantum chemical models of these benchmark systems.

Resources include intense, narrow bandwidth, tunable laser sources spanning the infrared to vacuum ultraviolet; tunable femtosecond lasers; laser-induced fluorescence and photo ionization mass spectrometric detection of trace gas phase species; and pulsed supersonic jet sampling of gases.

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IONIZING RADIATION

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RADIATION PROCESSING

To enhance quality-control methods used in industrial radiation processing of foods and in the production and use of medical devices, electronic components, and polymers, NIST researchers are developing standardization and measurement assurance methods related to industrial high-dose applications of ionizing radiation. As part of this program, they are investigating radiation chemical mechanisms and kinetic studies applied to chemical dosimetry systems in the condensed phase, including liquids, gels, thin films, and solid-state detectors.

They also plan to examine sensor materials such as doped plastics, solid-state matrices, fiber optics, organic dye solutions, semiconductors, scintillators, amino acids, metalloporphyrins, and organic or inorganic radiochromic and luminescent aqueous solutions and gels. A number of analytical methods will be used, including transmission and fluorescence spectrophotometry and electron spin resonance spectrometry as well as optical waveguide analysis and pulse radiolysis.

Various X-ray and gamma-ray sources and electron accelerators with energies in the 0.1-MeV to 10-MeV range are used in this work. Conventional ultraviolet, visible, and infrared spectrophotometers; high-intensity gamma-ray sources; pulsed and continuous beam electron accelerators; and organic-chemical analytical equipment also are available.

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MEASUREMENT QUALITY ASSURANCE

Credibility of ionizing radiation measurements has been a critical issue for the U.S. radiation medical diagnostics and therapy, occupational safety, industrial, energy, defense, and environmental communities. To this end, NIST scientists disseminate the standards and technology required for reliable measurement of ionizing radiation to federal, state, and local radiation control programs as well as to the medical, industrial, and defense communities. In addition, NIST researchers monitor and evaluate radiation measurements needs; participate in radiation research, metrology development, and quality control activities; and develop methods for improving the accuracy of field measurements through a national system of secondary standards laboratories.

NIST has a strong influence on the design and implementation of measurement quality assurance programs that are accredited under the National Voluntary Laboratory Accreditation Program (secondary calibration laboratories for ionizing radiation and personnel dosimetry programs), the Conference of Radiation Control Program Directors (diagnostic X-radiation), Health Physics Society (private-sector calibration laboratories), and American Association of Physicists in Medicine (therapeutic radiation). Programs currently being developed will address measurement quality assurance needs in sectors that include industrial processing, radio-bioassay, and radioanalyses for environmental remediation and waste management.

In support of the accreditation programs, NIST provides technical expertise for laboratory technical document review and evaluation, traceability to the national physical standards through performance evaluation testing, and on-site assessments. The major research thrust is the development of a wide variety of appropriate transfer standard instruments and materials.

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NEUTRON PHYSICS

NIST researchers are exploring three major areas of fundamental neutron physics: neutron interferometry, laser polarization of neutron beams, and various coupling coefficients of the weak interaction. The Neutron Interferometer and Optics Facility (NIOF) in the cold neutron guide hall has achieved unprecedented levels of phase contrast and stability. Work is under way at this new facility on the development of phase contrast imaging, on a measurement of the neutron-electron scattering length, and on neutron tomography. The NIOF also will operate part-time as a user facility for university and industrial scientists. At another location in the guide hall, development is in progress on neutron spin filters, based on laser polarization of ^{3}He. These neutron polarizers offer advantages over conventional methods in experiments on parity-violating aspects of neutron beta decay and in studies of magnetic materials. This project also is providing assistance to medical researchers who employ polarized ^{3}He for improved magnetic resonance imaging of the lung.

Another major research and user facility is the Fundamental Physics Station. At this station, a beam measurement of the free neutron lifetime has been in progress for several years, and two new experiments are in preparation in collaboration with university physicists. The first of these will be a measurement of parity-non-conserving neutron spin rotation in liquid helium; the second will look for time-reversal asymmetry in neutron beta decay. Further in the future, a potentially much more accurate measurement of the neutron lifetime employing trapped ultracold neutrons will be carried out in collaboration with Harvard University.

In addition, work continues at a much reduced level in the development and evaluation of neutron cross-section standards in the energy range from thermal to 20 MeV. These standards are of value to research in astrophysics as well as to the assurance of accuracy in calculations for nuclear reactor safety.

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NEUTRON DOSIMETRY

NIST physicists develop and maintain standards for neutron dosimetry, both at the very high fluence levels appropriate to materials damage studies for nuclear reactors and at the much lower levels appropriate to standardization of radiation protection instruments. Standard neutron fields at NIST and at the University of Michigan have been characterized to provide test irradiation fields for the neutron dosimetry employed in assurance of materials integrity at nuclear power reactors in the United States. NIST scientists also collaborate with engineers and scientists from industry and the Nuclear Regulatory Commission in drafting regulatory guides for accurate measurements in neutron dosimetry at these reactors. Another set of standard neutron fields at much lower fluence rate levels is maintained at NIST for calibration of radiation protection instruments and personnel dosimeters. Efforts are under way to establish and maintain accreditation of other laboratories so that routine calibrations of neutron radiation protection instruments can be taken over by the private sector and by central military laboratories.

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TIME AND FREQUENCY

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ION STORAGE RESEARCH

This program investigates the applications of ions, such as $^{199}Hg^{+}$, for high-accuracy frequency standards. The ions are stored in ion traps, devices that use electric, or a combination of electric and magnetic fields, to suspend the ions in free space. Laser radiation is used to cool the ions to temperatures on the order of a millikelvin, so the second-order Doppler shift (a serious problem in high-accuracy frequency standards) is extremely small. In some cases, ions are cooled even further, approaching the zero-point motion limit set by Heisenberg's uncertainty principle. It is expected that frequency standards based on laser-cooled, stored ions will be much more accurate than the best current standards, which are based on cesium atomic beams. Research is also under way on related topics, such as the physics of non-neutral plasmas, quantum optics, quantum measurements, laser frequency stabilization, and non-linear optical sources.

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ATOMIC BEAM FREQUENCY STANDARDS

The first atomic frequency standard, based on ammonia, was built in 1950 at NIST (then the National Bureau of Standards) in Washington, D.C. Since then, NIST has constructed a series of seven standards (based on cesium beams) with performances improving at a rate of better than an order of magnitude every 10 years. NIST-7, introduced in 1993, is the most recent in this series. It is based on optical state selection and state detection rather than the more traditional magnetic methods and has an uncertainty of 5×10^{-15}. This should decrease by at least another factor of two with further refinement of the accuracy evaluation process. The atomic fountain concept is being studied as a possible successor to NIST-7. The main advantages of this concept are the reduction in the Doppler shift and the increase in atom observation time. These severely limit the performance of NIST-7. The work in this program involves research on laser pumping of the states of atoms, improvements in atomic-beam ovens, and the development of digital servo-control systems for more reliably controlling critical parameters.

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NOISE IN ELECTRONIC AND OPTICAL SYSTEMS

NIST has developed systems for making phase-noise and amplitude-noise measurements over a broad dynamic range of carrier frequency (into the millimeter range) and Fourier frequency (up to 10 percent of the carrier frequency). The accuracy of measurement is typically 1 dB or better depending on the frequency range. These systems provide the basis for specifications now arising in communication, radar, and other aerospace equipment. Signals at higher millimeter and optical frequencies also can be characterized by beating them against a stable optical reference. A wide range of noise measurement equipment and systems for analyzing the output data is available. Most recently, this unique measurement capability has been applied to the study of PM and AM noise in bipolar-junction-transistor circuits. This work has led to a better understanding of noise processes in these circuits, and design rules for low noise performance have been developed. These rules can provide for a noise reduction (close to a carrier) of as much as 20 dB.

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STATISTICAL ANALYSIS OF TIME-SERIES DATA

Noise processes in high-performance clocks and oscillators are often not white (frequency independent), so the usual variance does not converge. The two-sample variances developed to handle such noise have become standards widely used in the specification of noise in systems demanding high-spectral purity. These measures have been applied with some success to other measurement data. NIST researchers are continuing development of still better variances and have written software for the efficient calculation of a number of these measures. Outputs can be represented in both the frequency and time domains.

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TIME AND FREQUENCY SIGNAL DISTRIBUTION

NIST disseminates time and frequency signals by radio, satellite, telephone, and the Internet. Broadcasts from WWV (Fort Collins, Colo.) and WWVH (Kauai, Hawaii) are at shortwave frequencies of 2.5, 5, 10, and 15 MHz for both stations and 20 MHz for WWV only. Station WWVB operating at 60 kHz provides a useful frequency reference accurate to 1×10^{-11} or better. Time signals accurate to 100 µs also are broadcast from the GOES geostationary satellites providing coverage of most of the western hemisphere. In addition, digital signals delivered by telephone and the Internet are provided to set clocks in computer systems automatically. The time codes for each of these services include advanced alert for changes to and from daylight saving time and advanced notice of insertion of leap seconds. A current focus of the program is the installation of new transmitters at WWB to provide increased broadcast power (6 dB) that should substantially improve the reception of signals, particularly on the east and west coasts of the United States.

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TIME TRANSFER AND NETWORK SYNCHRONIZATION

NIST has broad expertise in time transfer, particularly using satellite methods, that can be applied to synchronization of widely distributed network nodes. Telecommunications and electrical power networks are examples of systems requiring such synchronization. A NIST-developed, common-view method using global positioning system (GPS) satellites provides time transfer accuracy of better than 10 ns, and two-way exchange of signals through telecommunications satellites offers even higher performance. NIST owns and operates a number of specialized GPS receivers and satellite Earth stations needed for such work, and the NIST time scale provides unsurpassed stability as a reference for remote synchronization.

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FAR-INFRARED SPECTROSCOPY

NIST has unique capabilities for high-resolution studies of the spectra of atoms and molecules in the far-infrared region. The methods of tunable far-infrared spectroscopy and laser magnetic resonance (LMR) were developed by NIST, and several of each of these spectrometers currently are providing high-resolution measurements on spectra important in both space studies and studies of the chemistry of the upper atmosphere. Pressure-broadening studies at high resolution also have been performed, providing the basis for locating air pollutants at high altitude. Recent improvements in the NIST LMR systems have improved dramatically their sensitivity, making them especially useful in searches for difficult-to-detect molecular species such as free radicals and molecular ions.

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HIGH-PERFORMANCE DIODE LASERS

Diode lasers are used widely in many applications where spectral and spatial purity is not critical, but they could be used in a variety of other applications if these properties were improved substantially. Such applications include analytical chemistry and sensing of trace impurities or pollutants as well as narrow-line sources for length standards and optical manipulation of atoms and molecules. Recognizing the broad range of measurement applications for high-performance diode lasers, NIST has developed a program aimed at developing methods for controlling the output characteristics of these versatile and inexpensive lasers. The program selects specific practical applications and works on the system designs needed to provide solutions. Current projects include a calcium-stabilized laser for use as a length reference, methods for synthesizing signals in the optical region, and laser-spectroscopy methods for detecting trace impurities.

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QUANTUM PHYSICS

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BOSE-EINSTEIN CONDENSATION

The discovery of Bose-Einstein Condensation (BEC) by JILA scientists in June 1995 has opened up whole new areas of research. JILA (formerly the Joint Institute for Laboratory Astrophysics) is a joint venture of NIST and the University of Colorado. In BEC, atoms cooled to temperatures as low as 10 nanokelvin undergo a phase transition in which a large percentage of the atoms all take on exactly the same quantum wave function, becoming completely indistinguishable from one another.

Preliminary studies on low-lying phonon-like excitations will develop into measurements on vortices and viscosity. Thermal behavior near the critical temperature and the kinetics of condensate formation are also promising topics for study. The implications of condensate formation for precision metrology must be explored as well, including theoretically predicted coherent atom beams, dubbed bosers.

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THIN FILMS

Images of amorphous silicon films taken by an scanning tunneling microscope (STM) at various stages throughout the growth process show particles 3 nm to 5 nm in size forming in the vapor and bonding to the film surface during growth. If these particles can be prevented from forming or reaching the surface, it should be possible to improve the film's ability to convert light into electrical current. A laser scattering system is being developed to detect the silicon/hydrogen clumps as they are forming.

In another project, lines of aluminum as small as 3 nm in width have been deposited on silicon surfaces using the electron beam and electric field produced at the tip of an STM. Independent auger electron spectroscopy studies of the electron-induced deposition of aluminum show nearly pure aluminum deposits.

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LASER DEPOSITION OF THIN FILMS

Evidence suggests that laser-deposited materials can attain better film properties at lower processing temperatures than materials deposited by normal thermal means. The microscopic basis for the effect of kinetic-energy-enhanced epitaxy has been demonstrated at NIST for the first time. An apparatus has been developed to produce a neutral cobalt atom beam with a controlled energy. When cobalt atoms are deposited onto silicon at thermal energy, most of the atoms reside on the surface. However, deposition of cobalt atoms on a silicon(100) wafer at enhanced kinetic energies mimics substrate heating in the 500 K range with thermally deposited cobalt, in which the silicide material forms.

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MOBILITY OF CLUSTER IONS

New methods have been established at NIST to measure the mobilities of ions clustered with water and other molecules important in the upper atmosphere. Ions are produced in a mass-selected ion source and injected into a flow tube where they are converted to clusters by three-body reactions with a solvent molecule. The mobility of the cluster ions is measured by the arrival times of ion "packets" at a mass spectrometer detector, following a pulsed depletion of a small fraction of the ions at two places in the flow tube. The method has been applied for benzene dimer ions, water cluster ions, ammonia cluster ions, and mixed clusters. In general, the size of the cluster ion determines the mobility in helium in a predictable fashion, but for collisions with molecules that have strong dipole moments, remarkably small mobilities are observed. The additional strong attractive forces and internal degrees of freedom of the molecules play a major role, causing the small mobilities.

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STABILIZED LASERS

The remarkable price reduction of diode lasers, taken with cost-effective frequency stabilization approaches, leads to consideration of possible future widespread exploration of frequency-stabilized diode lasers in a vast range of new applications. Traditional interferometric control systems profit from the laser system's increased performance along with its decreased cost and generated heat. A new concept in development will allow stabilization to produce a constant laser wavelength for interferometric applications. Advanced low noise tilt and displacement sensors now can be usefully designed and may become widespread when the stabilized laser system cost is decreased by one order of magnitude or more.

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RESEARCH FACILITIES

SYNCHROTRON ULTRAVIOLET RADIATION FACILITY II

The heart of the NIST Synchrotron Ultraviolet Radiation Facility II (SURF II) is a 300-MeV electron storage ring. The synchrotron radiation emitted is highly collimated, nearly linearly polarized, and of calculable intensity. Seven beamlines are available, and a users' program is in operation. SURF II is well suited for studies in radiometry; atomic, molecular, biomolecular, and solid-state physics; surface and materials science; electro-optics; and surface chemistry and radiation effects on matter. Special facilities are available for developing and testing extreme-ultraviolet (EUV) optical components and systems. Although the primary purpose of SURF II has been the production of EUV radiation (wavelengths above about 4 nm), there are opportunities for using SURF II for applications in the infrared, visible, and ultraviolet spectral regions.

CAPABILITIES

The typical storage ring electron beam current is 200 mA at 284 MeV. The photon intensity in the region 60 nm to 120 nm is about 1.6×10^{12} photons per second per milliradian of orbit for an instrumental resolution of 0.1 nm. Experiments can be conducted conveniently throughout the wavelength range 4 nm to 1000 nm, from the soft X-ray region to the infrared. One normal-incidence, two grazing-incidence, and several toroidal grating monochromators are available to disperse the radiation. A large, ultrahigh vacuum spectrometer calibration chamber, 1.2 m × 1.2 m × 2.5 m and accessible through a clean room, is available for radiometric applications in a clean, vacuum environment. A 6.65-m normal-incidence vacuum spectrometer, with resolving power of about 100,000, is available on a beamline dedicated to high-resolution vacuum ultraviolet radiation research.

APPLICATIONS

The continuous radiation from SURF II is used as a national standard of spectral irradiance for radiometric applications, a spectrometer calibration facility, extreme ultraviolet and infrared microscopy, and for fundamental research in the following areas:

- optical properties of materials;
- electron density of states in solids;
- surface characterization;
- photoelectron spectroscopy;
- atomic and molecular absorption spectroscopy;
- molecular kinetics and excitation and ionization dynamics; and
- radiation interactions with matter (such as lithography, radiation damage, dosimetry, photobiology).

AVAILABILITY

Beam time on SURF II is available to any qualified scientist if beamline vacuum requirements are met and scheduling arrangements can be made. Proposals should be submitted for NIST review before use of the facility is desired. Informal contact also is encouraged.

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B119 Radiation Physics Building

EUV OPTICS FABRICATION AND CHARACTERIZATION FACILITY

The emerging field of high-reflectance, normal-incidence soft X-ray or extreme ultra-violet (EUV) optics has a wide range of applications. The ability to produce high-quality images at wavelengths below 40 nm has allowed construction of EUV solar telescopes with unprecedented resolution, EUV microscopes able to study living biological samples with submicron resolution, and EUV photolithographic systems that are proposed as tools for the next generation of integrated circuits.

NIST has initiated an EUV multilayer characterization facility at the SURF II storage ring, which is available to all researchers on a cooperative basis. The current facility is capable of measuring the reflectance or transmittance of EUV optics such as mirrors, filters, and gratings as a function of wavelength, angle of incidence, and position on the optic. NIST is constructing a new facility that will extend measurement capabilities to larger and more curved optics. A thin-film deposition chamber has been added to the reflectometry facility that allows measurements of films as deposited. From these measurements, the optical constants of important multilayer materials can be determined free from any influences of surface contaminants.

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A253 Physics Building

MAGNETIC MICROSTRUCTURE MEASUREMENT FACILITY

The magnetic microstructure of materials can be measured with very high spatial resolution by a technique called scanning electron microscopy with polarization analysis (SEMPA). An ultrahigh-vacuum electron microscope has been modified so secondary electrons from the sample can be analyzed for their electron spin polarization. This allows for a measurement of the surface magnetism with moments both in the plane and perpendicular to the plane of the sample.

CAPABILITIES

SEMPA allows the simultaneous observation of surface microstructure and surface magnetic domains with a resolution as high as 20 nm.

APPLICATIONS

This unique measurement facility can be used for research in magnetic thin films, high-coercivity magnetic materials, high-density magnetic storage media, and other advanced magnetic materials.

AVAILABILITY

These facilities are available for collaborative research by NIST and outside scientists in areas of mutual interest on a time-available basis.

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HIGH-RESOLUTION UV AND OPTICAL SPECTROSCOPY FACILITY

Accurate atomic data for neutral atoms and ions are required in support of high-technology products and manufacturing processes as well as advanced scientific applications. The primary source of such data is high-resolution optical spectroscopy. Spectrometers in NIST's High-Resolution UV and Optical Spectroscopy Facility are the most powerful in the world for observations of emission and absorption spectra in the soft X-ray to near infrared regions. The 10.7-m grazing-incidence and normal-incidence vacuum spectrographs permit observations from 3 nm to 600 nm with resolving powers of 70,000 to 400,000 and wavelength uncertainties as low as 0.0002 nm. In the visible and near-infrared region, an echelle spectrograph provides resolving powers exceeding 1,000,000. NIST's new high-resolution Fourier transform spectrometer will be capable of observations from 200 nm to 18 µm with unmatched resolution and wavelength accuracy. A variety of discharge sources are used to excite spectra of neutral atoms and ions stripped of up to 20 electrons. Species up to 40 times ionized are observed in plasmas created by ablating samples with a high-power laser. Current NIST research includes development of wavelength standards used for calibration of the high-resolution spectrograph on the Hubble Space Telescope, observations of transitions in highly ionized atoms for plasma diagnostics in tokamaks, development of a promising new scheme for an extreme ultraviolet laser, and precise isotope shifts of mercury wavelengths needed to interpret ultraviolet spectra of stars.

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LOW-BACKGROUND INFRARED RADIATION FACILITY

In the NIST Low-Background Infrared Radiation Facility, radiant background noise levels less than a few nanowatts are attained in a large (60 cm diameter × 152 cm long) vacuum chamber by cooling internal cryoshields to temperatures less than 20 K using a closed-cycle helium refrigerator system. An absolute cryogenic radiometer (ACR) of the electrical substitution type that operates at 2 K to 4 K is housed in the chamber.

CAPABILITIES

The ACR is a broadband detector with a flat response from the visible to the long wavelength infrared spectral region. It can measure power levels of 20 nw to 100 mw at its 3-cm-diameter aperture within an uncertainty of less than 1 percent. The ACR has a resolution of 1 nanowatt, and its time constant is about 20 s.

APPLICATIONS

This unique facility can be used to measure total radiant power from sources such as cryogenic blackbodies. Ongoing improvements will allow measurement of the spectral distribution of radiation from sources and characterization of infrared detectors and optical components.

AVAILABILITY

The facility is operated by NIST staff in support of user infrared calibrations. It is available for collaborative research by NIST and outside scientists in areas of mutual interest.

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B208 Physics Building

CONTROLLED BACKGROUND RADIOMETRIC FACILITY

Infrared radiometry has an important role in space-based civilian, defense, and industrial applications. A facility to maintain an infrared scale for specialized applications was developed with funding from NIST, NASA, and the DoD. In particular, the capability for measurements on large-area, vacuum-operational, blackbody sources operated from 200 K to about 400 K is being established. These measurements will be traceable to NIST via infrared radiometry through the radiance temperature of the source. An example of the type of scientific activity that the NIST facility supports is the use of satellites for the determination of temperature, based on radiance measurements, for the Earth's surface and atmosphere. These measurements are the basis for the study of global warming. A goal of the facility will be the development of infrared radiometers, which will be used to intercompare large-area blackbody sources used by contractors for NASA's Mission To Planet Earth Project.

This facility is not limited to infrared measurements. The capability to make comparisons of large area visible sources also will be possible. For both infrared and visible sources, users are able to bring their sources to NIST for calibration. This facility also is used for hosting intercomparisons of field radiometers, user sources, and training of key personnel. A multipurpose classroom is available where short courses and workshops on radiometry can be held.

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MEDICAL-INDUSTRIAL RADIATION FACILITY

NIST operates an electron accelerator as the heart of a new user facility for the medical and industrial radiation communities. The Medical-Industrial Radiation Facility (MIRF) is based on a rf-powered, traveling-wave electron linac donated by the Radiation Therapy Center of the Yale University New Haven Hospital. This reconfigured accelerator provides electron energies from 7 MeV to 32 MeV at average beam currents of up to 0.1 milliampere. In addition to the original beam-steering system and medical-therapy scanner/collimator head, three additional beam ports and a switching magnet have been added at NIST. The flexibility afforded by access to these four beam lines allows NIST to address issues in radiation metrology, radiation effects, and the uses of electron and high-energy photon beams.

CAPABILITIES

The medical beam line can provide electron doses of up to 5 gray per minute at the patient location and is equipped with a target to produce a 25 MeV bremsstrahlung beam as used in high-energy photon therapy. On other beam lines, dose rates in excess of 1 kilogray per second over a small area have been achieved with electrons, and exposure rates of about 2,500 roentgens per minute can be attained with suitable bremsstrahlung convertors to produce high-energy photon beams used in industrial radiography.

APPLICATIONS

MIRF offers unique opportunities for medical and industrial research. At the facility, a number of organizations are collaborating on a variety of projects, including:

- Medical dosimetry. Medical linacs are used for treating approximately 500,000 cancer patients annually at some 1,300 treatment facilities in the United States. Among the medical dosimetry applications of MIRF are the development and testing of instruments and dosimetry systems for use in clinical facilities as well as investigations into shielding requirements for the radiation scattered from the patient.

- Radionuclide production. Through photonuclear reactions, radioisotopes can be produced with high-energy electron accelerators as an alternative to the use of nuclear reactors. Applications on MIRF include production tests of radionuclides for use in nuclear medicine.

- Radiography. The facility provides for studies pertinent to industrial radiography and computed tomography. In addition, ongoing development on one of the beam lines is aimed at producing quasi-monoenergetic photon beams of channeling radiation and coherent bremsstrahlung suitable for use in digital-subtraction angiography.

- Radiation effects and processing. Current applications include electron-beam treatment of waste water, curing of polymer composites, and radiation effects on electronics.

AVAILABILITY

MIRF is available for collaborative research by researchers from industry, academia, and other government agencies under the supervision of NIST staff.

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ELECTRON PARAMAGNETIC RESONANCE FACILITY

NIST is leading a national and international effort in electron paramagnetic resonance (EPR) dosimetry for measuring ionizing radiation. Paramagnetic centers (molecules or atoms with unpaired electrons) are produced by the action of radiation on materials. In the EPR measurement, irradiated materials are placed in a magnetic field and electron spin transitions are induced by an electromagnetic field of the appropriate frequency (typically in the GHz range). EPR is used as a non-destructive probe of the structure and concentration of paramagnetic centers. The centers created by ionizing radiation are proportional to the absorbed dose and provide a sensitive and versatile measurement method.

CAPABILITIES

The EPR dosimetry facility is supported by three state-of-the-art X-band EPR spectrometers capable of measuring radiation effects on a wide range of materials from inorganic semiconductors to biological tissues. The data acquisition system provides full computer control of all spectrometer functions, including real-time spectral display and rapid acquisition scan to analyze rapidly decaying signals. The data acquisition system is interfaced with an advanced data analysis station for data manipulation and is capable of simulating and deconvoluting multi-component spectra.

APPLICATIONS

EPR dosimetry is operable over many orders of magnitude in absorbed dose (10^{-2} Gy to 10^{5} Gy) and impacts many facets of society and industry. Areas of application include:

- Radiation accident dosimetry. Using biological tissues (bone, tooth enamel) or inanimate materials (clothing), retrospective dose assessment and mapping can be accomplished.

- Clinical radiology. Ionizing radiation doses administered in cancer therapy can be measured for external beam therapy using dosimeters of crystalline alanine (an amino acid) or validated for internally delivered bone-seeking radiopharmaceuticals using bone biopsies.

- Industrial radiation processing. Routine and transfer dosimetry for industrial radiation facilities can be performed using alanine dosimeters as well as post-irradiation monitoring of radiation-processed meats, shellfish, and fruits using bone, shell, or seed.

The EPR facility also serves as a fully functional materials research facility for analyzing radiation effects on semiconductors, optical fibers, functional polymers, and composites.

AVAILABILITY

The EPR facility is available for collaborative research by researchers from industry, academia, and other government agencies under the supervision of NIST staff.

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RADIOPHARMACEUTICAL STANDARDIZATION LABORATORY

Radioactivity measurements for diagnostic and therapeutic nuclear medicine in the United States are based on measurements at NIST. Activity measurements for the gamma-ray-emitting radionuclides are made using the NIST "4π" γ ionization chamber. The calibration process also includes identification of radionuclidic impurities by germanium spectrometry. Recent development work has focused on therapeutic nuclides for nuclear medicine, radioimmunotherapy, and bone palliation.

CAPABILITIES
The radiopharmaceutical standardization laboratory provides calibration services for the gamma-ray-emitting radionuclides and is available for technical users who must make measurements consistent with national standards or who require higher accuracy calibrations than are available with commercial standards. NIST also undertakes basic research to develop new methods of standardizing radionuclides for diagnostic and therapeutic applications. These studies include measurements of decay-scheme parameters, such as half lives and gamma-ray emission probabilities, and identification of radionuclidic impurities.

AVAILABILITY
The customer has no direct use of the facility. NIST staff can provide calibration services for the gamma-ray-emitting radionuclides that comply with the specifications as stated in NIST Special Publication 250-10. Working at NIST, research associates of the U.S. Council for Energy Awareness produce standards that are certified by NIST as Standard Reference Materials for distribution to the radiopharmaceutical user communities.

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NEUTRON INTERFEROMETER AND OPTICS FACILITY

The Neutron Interferometry and Optics Facility (NIOF) located at the NIST Research Reactor is one of the world's premier user facilities for neutron interferometry and related neutron optical measurements. A neutron interferometer splits, then recombines neutron waves. This gives the interferometer its unique ability to experimentally access the phase of neutron waves. Phase measurements are used to study the magnetic, nuclear, and structural properties of materials as well as fundamental questions in quantum physics. Related, innovative neutron optical techniques for use in condensed matter and materials science research are being developed

CAPABILITIES
Neutrons are extracted from a dual-crystal parallel-tracking monochromator system, providing neutron energies in a range of 4 to 20 meV. Neutrons are counted with integrating ^{3}He detectors or by high-resolution position-sensitive detectors (with a resolution better than 50 μm). The sensitivity of the apparatus is enhanced greatly by state-of-the-art thermal, acoustical, and vibration isolation systems. To reduce vibration, the NIOF is built on its own foundation, separate from the rest of the building. The position of the interferometer is maintained to high precision by a computer-controlled servo system. The result is a neutron interferometer facility with exceptional phase stability (5×10^{-3} rad/day)and fringe visibility (>70 percent). The vibration isolation is $< 10^{-7}$ g; the positional stability, 2 μm in translation and 1 μrad in rotation; and the temperature stability, 0.1 K/day.

APPLICATIONS
Among the applications for the Neutron Interferometer and Optics Facility are:

- neutron phase contrast imaging;
- neutron tomography;
- neutron Fourier spectroscopy for surface studies;
- determination of hydrogen content in materials;
- measurement of bound coherent scattering lengths;
- small-angle neutron scattering studies with perfect crystals;
- tests and demonstrations of quantum principles with matter waves;
- measurement of the neutron-electron scattering length; and
- phase transition studies.

AVAILABILITY
Beam time on the NIOF is available to qualified scientists from the United States and abroad, subject to approval and scheduling by the facility oversight committee.

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TIME AND FREQUENCY SERVICES

SHORT WAVE BROADCASTS.
Since 1923 NIST radio station WWV has provided around-the-clock shortwave broadcasts of time and frequency signals. A sister station, WWVH, was established in 1948 in Hawaii. The stations:

- broadcast at 2.5, 5, 10, and 15 MHz; WWV also broadcasts at 20 MHz;
- reliably cover continental United States and the Pacific at time accuracy of $1 \rightarrow 10$ ms; and
- have a frequency accuracy of 1×10^{-7}.

Broadcasts include standard frequencies and time intervals, time of day (both voice and digital code), astronomical time corrections, and public service announcements (marine weather, geophysical alerts, Omega and GPS status information, and radio propagation information).

Telephone access: (303) 499-7111 for WWW and (808) 335-4363 for WWVH.

LOW FREQUENCY BROADCAST.
In 1956 low-frequency station WWVB began broadcasting at 60 kHz. It offers:

- more predictable propagation (at 60 kHz) than that of WWV and WWVH;
- digital time code only;
- time and accuracy of $0.1 \rightarrow 1$ ms;
- frequency accuracy of 1×10^{-11} for measurements over 1 day; and
- good reception in most areas of the continental United States.

GOES TIME CODE SERVICE.
NIST time and frequency services are relayed to most of the Western Hemisphere by satellites positioned high above the equator. This service:

- is cooperative with NOAA using two of their GOES weather satellites;
- has an accuracy of 100 µs limited by information on the location of the satellites;
- covers North and South America plus major portions of the Atlantic and Pacific; and
- includes digital time code and continuously updated satellite locations.

AUTOMATED COMPUTER TIME SERVICE (ACTS).
NIST also offers an Automated Computer Time Service that uses commercial telephone lines to deliver a digital time code for computers and automated systems. The service includes:

- time accuracy of $1 \rightarrow 100$ ms depending on modem and mode used;
- frequency accuracy of 1×10^{-8} for measurements over 1 day;
- telephone-circuit delay measurement and automated compensation for it.

For service call (303) 494-4774. Example user software is available (specify RM8101 - Automated Computer Time Service) at (301) 975-6776.

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MATERIALS SCIENCE AND ENGINEERING LABORATORY

The Materials Science and Engineering Laboratory provides technical leadership and participates in developing the measurement and standards infrastructure related to materials critical to U.S. industry, academia, government, and the public. Materials science and engineering programs at NIST cover a full range of materials issues from design to processing to performance. A unifying aim is to acquire the knowledge and tools needed for intelligent manufacturing methods with real-time automated process controls.

Separate research initiatives address ceramics, metals, polymers, composites, and superconductors. This research supports efforts of U.S. industry to develop reliable, low-cost manufacturing methods for producing tailor-made materials and products with superior properties.

Through laboratory-organized consortia and one-to-one collaborations, NIST's materials scientists and engineers work closely with industrial researchers. Examples include work on improved processing of rapidly solidified metal powders, polymer composites, ceramic machining, aerospace alloys, and non-destructive evaluation sensors for aluminum and steel manufacturing. The laboratory is also strengthening its relationships with manufacturers of high-technology products, the major users of advanced materials.

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COOPERATIVE RESEARCH OPPORTUNITIES

ORGANIZATIONAL STRUCTURE

MSEL is separated into five divisions. Contacts for each division are listed below.

Ceramics Division

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Materials Reliability Division

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Metallurgy Division

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Polymers Division

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Reactor Radiation Division

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COOPERATIVE RESEARCH OPPORTUNITIES

ADVANCED MATERIALS

DENTAL AND MEDICAL MATERIALS

The dental and medical materials program provides basic materials science, engineering, test methods, and standards to sectors of the health-care industry for the development of new or improved materials and delivery systems. The major focus areas of this program are development of dental restorative composites of greater durability and wear resistance, and development of metallic mercury-free alternatives to dental amalgams.

Dental restorative composites are heterogeneous materials having three essential phases: (1) a polymeric matrix that comprises the continuous phase, (2) fillers of various types, sizes, shapes, and morphologies that constitute the disperse phase and (3) an interfacial phase that, in varying degree, bonds the continuous and disperse phases into a unitary material rather than a simple admixture. While all three phases are important in determining the properties of the composites, this program focuses primarily on the interfacial and polymer matrix phases. Resources are allocated to develop high-conversion, low-shrinkage polymeric materials for use in dental resin and composite applications. Because these composites are used in an aggressive, aqueous environment that constantly challenges the vulnerable silane mediated polymer-glass bond, this program also seeks to understand the critical interfacial phase so that strategies can be developed for its improvement.

The occupational and environmental hazards associated with the use of mercury-containing dental alloys are a recurring source of public concern. Since dental amalgams have performed exceedingly well over more than 100 years, the development of a direct filling material still based on the common constituents of dental amalgams, other than mercury, is the objective of this focus. The approach chosen is based on three main premises: (1) the cold-welding of oxide-free silver; (2) the in-situ formation of Ag_xSn_y intermetallics by the room temperature fast diffusion of silver and tin; and (3) the homogeneous precipitation of silver by Sn(II) in solution.

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ELECTRONIC AND PHOTONIC CERAMICS

The objectives of the electronic and photonic ceramics program are to provide data, measurement methods, standards and reference materials, models, and understanding of the fundamental aspects of processing, structure, properties, and performance of electronic and photonic materials. The program supports generic technologies in bulk and thin-film ceramics to foster their efficient and economical use as electronic and/or photonic materials. The research addresses the science base underlying advanced electronic/photonic materials technologies together with associated measurement methodology.

The principal activities of the program are directed toward materials for electronic and photonic technology related to data processing, storage, display, and transmission. Four aspects of this technology being addressed are modulator materials; storage-media materials; materials for microwave transmission; and materials for compact, short-wavelength radiation sources to increase storage density.

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MECHANICAL PROPERTIES OF BRITTLE MATERIALS

Mechanical properties are the source of some of the greatest benefits as well as the most serious limitations of ceramics. With their great strength-to-weight ratio, their relatively inert behavior in aggressive environments, and their ability to withstand much higher temperatures than metals or polymers, ceramics potentially offer major improvements for component design in a wide range of applications. On the debit side, brittle fracture, creep at elevated temperatures, environmentally enhanced failure, and the lack of techniques that can detect and quantify critical flaws before failure occurs, impede their more widespread uses. Problems in controlling failure of ceramics stem from three sources: lack of understanding of the failure processes, limited standard test techniques to permit interlaboratory comparisons of material behavior, and inadequate statistical techniques for reliability and lifetime estimation. The mechanical properties program has components specifically addressing each of these issues.

Basic understanding of mechanical behavior of ceramics is being investigated for both ambient and elevated temperature applications. Effects of cyclic loading and microcrack formation/coalescence are being studied for lead zirconium titanate (PZT), a technologically important actuator material. Mechanical properties and failure processes in fiber-reinforced ceramic matrix composites are being investigated as a function of both temperature and fiber loading. Residual in stresses associated with crack bridging in both fiber-reinforced composites and microstructurally toughened alumina are being measured via micro-Raman techniques. In addition, environmentally enhanced fracture remains an important subject from both an experimental and a theoretical (see Theory and Modeling section) viewpoint. At elevated temperatures, the basic mechanisms responsible for creep in silicon nitride are being investigated.

An important aspect of the program is the development of standards. New standard test techniques for hardness and toughness are being developed and tested in round-robin experiments; these eventually will lead to the American Society for Testing and Materials and the International Organization for Standardization standards. For elevated temperatures, a new creep specimen design has been developed that concentrates more of the applied load in the gage length and reduces the chance of failure from non-gage portions of the specimen.

Finally, techniques to predict lifetimes of ceramics under constant or cyclic loading conditions are being developed. The non-parametric bootstrap approach to lifetime prediction is being applied to a number of materials. A parametric model to predict lifetimes of PZT under cyclic loading also is under development. This latter model does not restrict the material to environmentally enhanced fracture behavior since experimental evidence has demonstrated that other, albeit unknown, processes also are active during cyclic loading.

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THEORY AND MODELING

MSEL theory and modeling efforts focus on the behavior and properties of materials over the range of length scales from atoms to bulk materials. On the atomistic scale, researchers have used molecular dynamics simulations to study fracture in brittle materials, and a new program to model dislocations in metals is under way. On mesoscopic length scales, simulations of phase behavior, stability, separation kinetics, and morphological evolution in alloys, polymer blends, liquid-crystalline polymers, and homopolymer/co-polymer blends complement ongoing experimental efforts in the polymers, metallurgy, and reactor divisions. Simulations of such materials processing problems as, e.g., dendritic growth during solidification and spinodal decomposition of chemically reacting polymers ranged from minute-long calculations on single-processor workstations to week-long calculations on massively parallel supercomputers. On macroscopic length scales, finite-element computer codes have been developed to model a variety of materials processes, such as injection molding for automotive parts, solder geometry in microelectronic interconnects, physical aging in composite materials, and mechanical properties of ceramic microstuctures.

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MEASUREMENTS AND STANDARDS

ELECTRONICS PACKAGING AND INTERCONNECTION

To assist the strategic and rapidly growing U.S. microelectronics industry, MSEL has embarked on a program in electronics packaging and interconnection that addresses industry's most pressing challenges surrounding the utilization of advanced materials and material processes. With a specific mission to develop and deliver to U.S. electronics and electronic materials industries measurement tools and data for materials and processes used in semiconductor packaging, module interconnection, and component assembly, this program:

- develops techniques and procedures for making in-situ, in-process, and in-use measurements on materials and material assemblies having micrometer- and submicrometer-scale dimensions;
- records and quantifies the divergence of material properties from their bulk values as dimensions are reduced and interfaces are approached; and
- develops fundamental understanding of materials needed for future packaging, interconnection, and assembly schemes.

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EVALUATED MATERIALS DATA

The objective of the data technologies program is to develop and facilitate the use of evaluated databases for the materials science and engineering communities. Both research- and application-directed organizations require readily available evaluated data to take advantage of the large volume of materials information developed by public- and private-sponsored programs. This information, particularly numeric data, is available in an ever increasing number of publications published worldwide. The necessity to consolidate and allow rapid comparison of properties for product design and process development underlies the database projects.

Evaluated data projects are conducted in cooperation with the NIST Standard Reference Data Program Office and include compilation and evaluation of numeric data as well as recently initiated efforts directed at more effective distribution and use of data.

Database projects in MSEL include:

- phase diagrams for ceramists, conducted in cooperation with the American Ceramic Society;
- the Structural Ceramics Database, a compilation of evaluated mechanical and thermal data for nitrides, carbides, and oxides of interest to engineers and designers;
- a ceramic machinability database, coordinated with the Ceramic Machining Research Program;
- a high T_c superconductivity database developed in cooperation with the Japanese Agency for Industrial Science and Technology (see superconductivity);
- development and implementation of the STEP protocol for the exchange of materials data, under the auspices of the ISO 10313 activity;
- the NACE/NIST Corrosion Performance Database developed to provide a means to select structural alloys for corrosive applications; and
- the Crystal Data Center, which provides fundamental crystallographic data on inorganic materials.

These projects are developed with the cooperation of the materials community and complement various research programs.

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HIGH-T_C SUPERCONDUCTIVITY

A significant program in high-T_c (critical transition temperature) superconductivity is being conducted in MSEL and other laboratories at NIST. The primary focus of the MSEL program is on bulk superconducting materials for wire and magnet applications. In carrying out this program, researchers in MSEL work closely with their counterparts in other NIST laboratories as well as their collaborators in U.S. industry and other national laboratories.

The primary thrusts of the program are:

- Phase equilibria—A prime objective is the development of the portions of the phase diagram for the Pb-Bi-Sr-Ca-Cu-O system relevant to production of the high T_c materials.
- Flux pinning—This project uses a unique magneto-optical imaging facility to examine flux pinning in a variety of materials.
- Damage mechanisms—The primary tool used is microfocus radiography available at the NIST beamline at the Brookhaven National Laboratory.
- Crystal structure—Thermal neutron diffraction techniques and profile refinement analyses are being utilized to investigate crystal and magnetic structures, composition, and crystal chemical properties.

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METALS DATA AND CHARACTERIZATION

Basic data describing the properties of metals and advanced materials based on metals form an important component of the technological infrastructure that NIST supports. Information of this kind is essential to understanding behavior of metals in different conditions and to the effective design of structures and devices containing metals. The measurement base is an MSEL mission strategic thrust.

This program is focused on the development of techniques to measure various properties of metallic materials and the acquisition of data of technological significance. It includes activities involving measurements of mechanical, magnetic, and optical properties, which impact a number of different technology sectors. For instance, in collaboration with the Copper Development Association, the mechanical behavior of lead-free plumbing solders is being investigated to provide the comprehensive and reliable database needed to establish internal working pressure standards for drinking water pipe joints. In contrast with these traditional measurements involving a widely used material, high-speed optical techniques are being developed in another project to measure selected thermophysical properties of solid and liquid materials at high temperatures. The goals of this work are to generate accurate benchmark data on selected key materials and to develop new high-temperature thermophysical standards. In other work involving a collaboration with ALCOA and USCAR, models are being developed and verified for the press-and-sinter and powder forge processes for metal matrix composites. The goal of this work is to develop lightweight materials for automotive applications. In the area of characterization, a technique is being developed that visualizes stress fields in opaque materials using the acoustic microscope. Work in the past year has included collaborations with DuPont, Libby Owens Ford, and Sonix.

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NANOSTRUCTURED MATERIALS

Nanostructured materials are a new class of materials that provide one of the greatest potentials for improving performance and extended capabilities of products in a number of industrial sectors, including aerospace, tooling, automotive, recording, cosmetics, electric motor, duplication, and refrigeration. Encompassed by this class of materials are multilayers, nanocrystalline materials, and nanocomposites. Their uniqueness is partially due to the very large percentage of atoms at interfaces and partially to quantum confinement effects.

One critical need for use of nanostructured materials is their characterization and measurement science, which is the focus of the NIST program. For many properties, it is not known whether the exciting novel behavior found in these new materials is due to new physics or to a logical extension of large-size behavior to small dimensions. Examples include the deformation and fracture behavior (Do dislocations even exist in these materials?), optical characteristics (Are their properties due to interface or quantum mechanical effects?), magnetic properties (What do magnetic domains look like in nanostructured materials and how they move in response to a magnetic field?), and thermal properties (How do phonons propagate through interfaces?). Consequently, implementation of this new type of material into marketable products is delayed significantly. NIST is providing the measurement science to answer these critical unknowns. Important needs also include the identification of preparation methods for industrial-size quantities of material, extension of the capabilities of conventional measurement tools to the nanometer-size scale, and the development of consolidation methods that retain the nanometer grain size of the initial nanocrystalline powders. For multilayers, understanding the development of epitaxy and control of both composition and interdiffusion at the interface are of critical importance.

By experimentally addressing these issues, by bringing together the industrial and scientific communities through the organization of workshops and conferences in the area, and by developing and preparing appropriate standards, NIST acts to accelerate the utilization of these materials by the industrial sector. Collaborations established in the area with Xerox, General Motors, Nanophase Technologies, Pratt and Whitney, Caterpillar, Lockheed-Martin, Hewlett Packard, IBM, Seagate, and Motorola corporations, for example, enable NIST to leverage its activities with the much larger, but complementary, capabilities of other organizations.

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NON-DESTRUCTIVE EVALUATION

Non-destructive evaluation (NDE) is the determination of product quality using test methods that do not damage the product. At MSEL, the NDE program is directed to the development of model-based methods of physical measurement that characterize the internal geometries of materials, such as defects, microstructures, and lattice distortions. The goal of NDE is to convert these measurement methods into sensors suited for production-line and in-service measurements of materials quality and serviceability.

A primary focus of the NDE program is microstructural characterization of metals and alloys, composite materials, and engineered surfaces. The idea is that models relate microstructure and physical properties. Research is also under way in magnetic, thermal, and radiographic techniques. Modeling advances include Green's function methods for wave propagation in anisotropic materials, obtaining elastic constants from resonance spectra, and determining texture based on ultrasonic measurements.

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POLYMER CHARACTERIZATION

The polymer characterization program provides measurement methods, data, and Standard Reference Materials needed by U.S. industry, research laboratories, and other federal agencies to characterize polymers for processibility, properties, and performance. Molecular weight and molecular weight distribution are the molecular characteristics of polymers that most affect their processing, properties, and performance. Properties and performance also may vary widely depending on the solid-state structure formed during processing. Therefore, the focus of the program is on techniques that measure molecular weight, its distribution, and the solid-state structure of polymers. Primary methods employed for molecular weight are dilute solution light scattering and osmometry. Chromatographic techniques, which require calibration by standards of known molecular mass, provide information on molecular weight distribution. Recent activities seek to exploit advancements in mass spectrometry using mass-assisted laser desorption ionization (MALDI) to determine molecular weights of synthetic polymers. Other spectroscopic methods, solid-state nuclear magnetic resonance (NMR), and infrared, as well as X-ray diffraction, are developed and applied to elucidate the solid-state structure of polymers.

The polymer industry and standards organizations assist in the identification of current needs for Standard Reference Materials. Based on these needs, research on characterization methods and measurements is conducted, leading to the certification of Standard Reference Materials. Standards are produced for calibration of gel permeation chromatographs, the principal method used by industry for assessing molecular weight and molecular weight distributions, and melt flow standards are developed for use in the calibration of instruments used to determine processing conditions for thermoplastics.

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VISCOELASTICITY OF POLYMERS

The goals of the viscoelasticity of polymers program are to develop measurement strategies that produce mechanical properties data in efficient ways and concurrently to build methodologies that can be applied in the design and development of finished polymers. This approach uses the theoretical frameworks of continuum constitutive equations and micro- to meso-scale physical models to interrelate the mechanical responses under different loading conditions and to test model predictions using available measurement methods. The work involves the first major effort to measure the mechanical and rheological responses of a single class of solid polymer in multiple geometries of deformation and modes of loading as well as in different temperature histories. The combination of experiment and modeling results in both improved models and the development of new experimental methods for measuring material property parameters. Furthermore, the measurement and modeling requirements are renewed continuously by coordinating the efforts through collaborations with and support activities for other programs in the Polymers Division, including polymer characterization, polymer theory and modeling, and electronic packaging and interconnects as well as other agency and miscellaneous projects that result from the program's activities.

In addition, the program works actively with industrial research programs. Activities such as workshops and special symposia that improve the interaction of the program with outside industry and the general technical and scientific communities also are fostered.

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ADVANCED PROCESSING

CERAMIC COATINGS

The ceramic coatings program is a measurement and characterization effort that addresses the processing reproducibility and performance prediction issues associated with, primarily, thermal-spray deposited ceramic coatings. The program focuses on plasma-spray-deposited ceramic thermal barrier coatings used in aircraft gas turbines and expected to be used in land-based turbines and diesel engines. Research also is conducted on the processing and properties of chemical-vapor-deposited diamond films and on physical-vapor-deposited ceramic coatings.

The approach taken in the plasma-spray (PS) research has been to build on the analytical capabilities at NIST and the material processing capabilities of collaborators. The program has the following elements:

- development of techniques for characterization of physical and chemical properties of stabilized zirconia feedstock to provide data for increased processing reproducibility as well as data required for production of a Standard Reference Material suitable for calibration of light-scattering size distribution instruments used in industry for analysis of PS powder;
- development of scattering techniques to determine the quantity, size, and orientation of porosity and microcracks in PS ceramic coatings suitable for use in modeling the thermomechanical behavior of these materials;
- development of methods to measure chemical, elastic modulus, and thermal properties on a scale suitable for use in microstructural models of behavior;
- development of techniques to model thermomechanical behavior of thermal-barrier coatings to enable more reliable performance prediction; and
- development of techniques for accurate measurement of the thermal conductivity of PS coatings by use of the guarded hot-plate technique suitable for incorporation in ASTM standards and to provide a method for comparison with routine industrial techniques.

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CERAMIC PROCESSING

The ceramic processing program is focused on the improvement of measurement quality in ceramic powders processing. This is accomplished by providing the U.S. ceramics community the ability to control ceramic powder properties so that cost-effective manufacturing can be achieved. The current program continues to emphasize structural ceramics with application of silicon nitride to automotive engines. The specific elements of the program are as follows:

- ceramic powder characterization techniques, measurement science, sensors, and models for intelligent processing, standard methods, and Standard Reference Materials;
- powder processing science to understand interrelationships between powder characteristics and their processing environment; and
- novel processing and synthesis methods as applied to nanosize and ultra-pure powders.

Ceramic processing projects address the development of standard procedures and Standard Reference Materials, improvement of the scientific basis for powder dispersion measurements in slurries and in overall measurement accuracy, and leadership in national and international standardization activities, including the ISO and ASTM. The powder characteristics of interest include physical and surface chemical properties and phase composition. In addition, grain-boundary characterization, and crystallographic texture investigations are carried out using advanced characterization tools. In powder processing, efforts have been focused around high-energy agitation milling of powders, textured Al_2O_3 microstructure, and hot-isostatic-pressing of silicon nitride.

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INTELLIGENT PROCESSING OF MATERIALS

The intelligent processing of materials (IPM) program makes important contributions to three MSEL strategic thrusts: advanced processes, advanced materials, and measurement technology. The central elements of IPM are process understanding expressed in terms of a process model, real-time information on processing parameters and material conditions obtained with on-line process sensors, and a model-based sensing and control strategy to achieve the desired characteristics in the finished product. IPM projects advance each of the elements, and joint projects with industry are integrating these elements into improved processing capabilities.

Advanced materials are those with microstructures designed and controlled to provide superior properties and performance for specific functions. Hence, microstructural control is perhaps the most important application of IPM. The idea is to model microstructural evolution during processing, sense microstructural changes in real time, and use a model-based system to ensure the final product has the desired microstructure. Microstructural consistency is essential to the commercialization of advanced materials because it assures reliable properties and performance of the material.

The IPM program also contributes to MSEL's measurement technology goal. A major focus of IPM projects is process sensors, which our industrial collaborators repeatedly identify as a crucial need. Sensor technology is a core competence of MSEL, which has its roots in sensor development for nondestructive evaluation of materials.

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MACHINING OF ADVANCED MATERIALS

The goal of the NIST ceramic machining program is to assist U.S. industry, through a joint research program, in the development of precision machining technology for the manufacture of reliable and cost-effective products made from advanced ceramics. Specific projects address grinding optimization, machinability database, nano-precision grinding, mechanisms of material removal, characterization of machining damage, and chemically assisted machining. Current research materials include those intended for structural applications, such as silicon nitride, and dental materials, such as machinable glass.

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METALS PROCESSING

The properties of metals and their alloys depend strongly on their processing history. The conditions under which materials are processed and fabricated into useful items determine the distributions of phases, grains, and defects in the final products. These distributions are crucial in determining alloy strength, ductility, magnetic response, homogeneity, and other properties important for commercial applications. The metals processing program focuses on measurements and predictive models needed by industry to provide improved process control, develop improved alloy properties, tailor material properties for particular applications, and reduce costs.

Three main approaches are being pursued:

- assisting in the design of materials production processes;
- measuring properties of the final materials and relating them to the process conditions to evaluate the adequacy of process models; and
- performing measurements under dynamic conditions to monitor materials' properties during production.

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POLYMER COMPOSITES

The polymer composites program seeks to facilitate the introduction of lightweight, corrosion-resistant composite materials into commercial applications by expanding the essential science base and generating test methods, reference data, and standard materials. The outstanding properties of composites mean they can be used to make products that are superior and more competitive in international markets. Industries as diverse as transportation, construction, marine, offshore oil, medical devices, and sporting goods can benefit significantly from the use of these materials. For this to happen, however, two barriers must be addressed: the lack of rapid, reliable, cost-effective fabrication methods; and the poor understanding and predictive capability for durability. In response to these challenges, the composites program initiated two tasks: one on processing science and the other on long-term performance.

The goal in the processing science task is to develop the technology required to monitor, understand, model, and control the events that occur during composite fabrication. The program's primary interest is in liquid composite molding since this fabrication method is of great interest to all industry sectors and is the consensus choice of the automotive industry as the method with the most promise for making structural automotive parts. The approach in this task involves three steps: (1) development of measurement tools to characterize materials properties that control processing, (2) formulation of sophisticated process simulation models to ultimately optimize processing parameters, and (3) development and utilization of process monitoring sensors.

The work on performance focuses on composite characterization tools and environmental durability. The goals are: (1) to develop measurement methods that can determine the state of the material, (2) to identify the chemical and physical mechanisms of environmental attack, and (3) to formulate reliable predictive models for long-term behavior. The environmental durability projects focus on glass fiber materials since they are the primary candidates for automotive applications. Work is beginning on graphite reinforced composites since these systems are important for marine and infrastructure applications.

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POLYMER BLENDS AND PROCESSING

Applications of polymer blends and alloys have enjoyed steady growth over the last decade in terms of market share, consumption, and employment within the plastics industry. This growth has challenged materials suppliers to respond quickly to customer needs by reducing their new product development cycle.

The goals of the polymer blends and processing program are to establish expertise in static and kinetic aspects of phase behavior in polymer blends, effects of shear flows on mixing and separating, and reactive processing to promote compatibility. Current program objectives use the knowledge base and measurement expertise to develop tools needed by industry to process polymer blends more effectively. Accordingly, the program works on development of measurement methods using fluorescence, light scattering, neutron scattering, and microscopy to aid in monitoring polymer blend processing.

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RESEARCH FACILITIES

COLD NEUTRON RESEARCH FACILITY

The NIST Cold Neutron Research Facility (CNRF) is the first in the United States devoted exclusively to cold neutron research. The facility provides U.S. researchers prime access to a key tool of modern materials science with capabilities unavailable elsewhere in this country.

The facility is focused on a novel liquid hydrogen cold source operating at 20 K. The cold source is viewed by one port inside the reactor hall and seven neutron guide tubes. The guide hall and associated office and laboratory space have more than tripled the workspace available at NIST for neutron beam researchers.

CAPABILITIES

Instruments currently in operation include:

- Small-Angle Neutron Scattering (SANS) Instruments. The NIST/Exxon/University of Minnesota and the NSF/NIST Center for High Resolution Neutron Scattering (CHRNS) 30-meter SANS instruments combine long flight paths and variable collimation to provide flexibility, angular resolution, and beam intensities that compare favorably with any SANS instruments in the world. Large-area position-sensitive detectors provide exceptional sensitivity to materials structures ranging from roughly 1 nm to 500 nm. An 8-meter SANS instrument also is available. Computer-automated equipment is available for maintaining samples at temperatures from 4 K to 700 K and in magnetic fields up to 20 kilogauss. To extract structural information from the data, the researchers analyze SANS patterns with an interactive color graphics system and related programs. Polarized neutron capabilities are planned for both 30-meter instruments.

- Depth-Profiling Instrument. With a measured chemical sensitivity 20 times that of the existing NIST thermal-beam instrument, this station features automated sample handling, near real-time spectral processing, goniometer positioning of sample and detectors, and sample temperature control. Increased signal intensity will permit multi-dimensional imaging of elemental distributions and profiling of nuclides with absorption cross-sections for charged particle emission of less than 1 barn.

- Prompt-Gamma-Ray Activation Analysis. Providing much greater sensitivity for this method than any existing thermal-beam instrument in the world, this equipment provides unique measurements of chemical elements, such as hydrogen (detection limit $\leq 2\ \mu g$), that are difficult to detect by other means.

- Medium Resolution Time-of-Flight Spectrometer. The energy resolution of this instrument, 40 to 600 μeV, is suitable for a broad range of studies of diffusional motions and magnetic and vibrational excitations. A combination of double-crystal monochromator and Fermi chopper, with a detector array covering a large range of scattering angles, allows incident energies from 2.2 to 15.5 meV and (elastic) momentum transfers from 1 to 49 nm^{-1}.

- NIST/IBM/University of Minnesota Cold Neutron Reflectometer. This instrument exceeds the sensitivity of the NIST thermal neutron instrument—already among the best in the world. In addition, the CNRF reflectometer incorporates vertical scattering-plane geometry and a horizontal sample plane that allows examination of liquid surfaces. Independent movement of sample and detector allows measurement of off-specular scattering. This reflectometer is clearly at the forefront worldwide and provides unique capabilities to U.S. researchers.

- Fundamental Physics Station. Available for use only in collaboration with the NIST fundamental physics research group, an end guide position physics station currently is instrumented for a new measurement of the lifetime of the neutron. A second fundamental neutron physics station, a neutron interferometer, is also operational.

- Neutron Optical Bench. This station is available for testing and calibrating neutron devices such as focusing capillary tubes.

- Triple-Axis Spectrometer. A spin-polarized inelastic neutron spectrometer is operational, with intensity and resolution unmatched in the United States. Among other features, this instrument includes novel transmission polarizers providing excellent polarization analysis, and a horizontally focusing analyzer providing much higher fluxes for inelastic scattering.

At press time (mid 1996), three other instruments are in the process of being installed: a high-resolution time-of-flight spectrometer, a spin-echo spectrometer, and a back-scattering spectrometer. These instruments will become available during 1996-1997.

APPLICATIONS

The unusual sensitivity and range of measurements possible at the NIST CNRF provide applications in materials structures, materials dynamics, chemical analysis, and neutron physics. Currently operational instruments are used to study microstructures in metals, ceramics, and colloidal mixtures; thin films, layered structures, and interfacial properties; magnetic properties and shear-induced phenomena; molecular geometry of polymer and biological macromolecules; chemical composition of semiconductors, high-tech materials, air-pollution filters, and other samples; and neutron decay rates.

AVAILABILITY

The CNRF operates as a national facility open to all qualified researchers. NIST develops experimental stations for use by the general U.S. research community. Two-thirds of the available time on these stations (three-fourths on CHRNS instruments) will be allocated by a Program Advisory Committee (PAC) on the basis of scientific merit of written proposals. The second mode involves Participating Research Teams (PRTs), which are developing the remaining stations. The PRTs are responsible for design, construction, and maintenance of the facilities in return for three-fourths of the available time. The remaining time will be allocated by the PAC. For all instrumental stations, instrument-responsible scientists will be designated to assist users in performing their experiments.

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NIST RESEARCH REACTOR

The NIST research reactor is a national center for the application of reactor radiation to a variety of problems of national concern. A wide variety of internal and external programs have benefited from the broad range of capabilities available to researchers from industry, universities, and government laboratories.

CAPABILITIES

The NIST reactor is an enriched-uranium, D_2O cooled and moderated reactor, with a peak thermal core flux of 4×10^{14} neutrons/cm^2-s. The core comprises 30 fuel elements of a unique, split-core design, in which nine radial beam tubes look at a 17-cm gap between fuel-element halves. A large-volume cold source, two tangential and one vertical beam tube, a thermal column, several vertical thimbles, and four “rabbit” tubes complete the configuration. The reactor operates continuously, 24 hours a day on monthly cycles, followed by approximately a week of shutdown for refueling and maintenance.

The reactor utilizes the flux available in a very efficient manner through relatively short core-to-instrument distances and large-diameter beam tubes. As a result, the flux on the sample for certain instruments is comparable to that at other major research reactors of higher power and peak core flux.

The experimental facilities in the reactor hall are used for neutron scattering and diffraction, neutron radiography, trace analysis and depth profiling, neutron dosimetry and standards development, irradiations, and isotope production.

Sample environments for low and high temperature, low and high pressure, and high magnetic fields are routinely available. Online graphics, plotting, and data fitting are available via personal computers, Macintoshes, Micro-VAXs, and a DEC 5810.

- Elastic Scattering. Four beam ports are dedicated to elastic scattering studies.

A new high-resolution powder diffractometer is installed at beam tube 1 (BT-1). It is a 32-detector instrument that provides three monochromator positions, each set at 0.154-nm wavelength but at different take-off angles to allow maximum flexibility in selecting the optimal resolution function for a given measurement. Collimations down to 7′-20′-7′ are available.

A deflection instrument dedicated to the measurement of residual stress is now operational at BT-8. This diffractometer is optimized for such measurements and provides great flexibility.

A triple-axis spectrometer with a four-circle goniometer is installed at BT-6 and is used primarily for residual stress and texture measurements, although inelastic scattering experiments also can be performed. This spectrometer is typically operated in the elastic scattering mode without an analyzer for texture studies and with the analyzer for residual stress measurements. Incident energies are continuously variable with 2 ΘM's from 20′ to 75′ available. Beam sizes up to 30×50 mm^2 and down to 2×2 mm^2 (for residual stress studies) are utilized. Single-crystal structure determinations are performed on this instrument while a new residual stress/texture/single-crystal diffractometer is being completed on BT-8.

A new thermal-neutron reflectometer, in which the incident beam can be polarized and the spin state of the reflected beam analyzed, is operational on BT-7. In this reflectometer, a pyrolytic graphite (PG) filtered beam is incident on the vertically focusing PG monochromator set for a principal wavelength of 0.235 nm. For collimations of ~1′ preceding and 1 following the monochromator, respectively, the wavelength resolution is $\delta l/l \sim 0.01$ and the actual flux on the sample is $\sim 5 \times 10^5$ neutrons/cm^2-s. Two ^{3}He detectors are incorporated—one for reflectivity measurements; the other is for grazing-angle-diffraction experiments.

Polarization of the incident beam is accomplished in transmission by one or more polarizing Fe-Si supermirrors deposited on single-crystal Si substrates. Reflectivities down to about 2×10^{-7} with a signal-to-noise ratio of about 1 have been measured.

- Inelastic Scattering. Three triple-axis inelastic scattering spectrometers are operational. The BT-4 instrument employs two remotely selectable, vertical-focusing monochromator crystals (PG and Cu), which provide incident energies from 3 meV to 300 meV continuously. It is capable of elastic-peak resolution down to 0.04 meV and also can be used in the inverted-filter mode for energy-loss spectroscopy of vibrations in the 15-meV to 280-meV range. The BT-9 spectrometer offers variable incident energy in the 5-meV to 50-meV range and collimations down to 10′-12′-12′-16′.

- The BT-2 instrument has both triple-axis and polarized-beam (up to 96 percent) capabilities. Either a PG or a Heusler-alloy monochromator, each vertically focused, are available, with remotely insertable cold beryllium or PG filters. Built-in guide fields and spin rotators and collimation as low as 10′-5′-5′-20′ are available.

- Elemental Analysis. Neutron activation analysis is performed utilizing the clean room for sample preparation, the reactor irradiation facilities, semi-hot and warm radiochemistry labs, and state-of-the-art radiation-counting labs. Development of methodology has aimed at accuracies and sensitivities over concentrations of 10^{-10} percent to 100 percent.

Radiochemical separations for specific elements and multielement analysis at the ultratrace level are available. A thermal neutron-capture prompt-gamma activation analysis facility is operational, with a neutron fluence of 5×10^8 n/cm^2-s in a 2-cm-diameter beam.

A thermal neutron-depth-profiling facility is installed on BT-3 for non-destructive determination of near-surface elemental depth distributions in a variety of materials. Sensitivities approaching 10^{13} atoms/cm^2 with a spatial resolution of better than 30 nm for depths of 5 mm to 20 mm are achievable.

- Neutron Standards and Dosimetry. A number of neutron fields for standards and dosimetry are available. These include a Cf fission source; a ^{235}U cavity fission source; the thermal column beam, an intermediate energy standard neutron field; and 2-, 24.5-, and 144-keV filtered beams.

- Irradiation Facilities. Four pneumatic tubes for 40-cm^3 rabbits with fluence ranges of 3×10^{11} to 2×10^{14} n/cm^2-s for irradiations of seconds up to hours are available. The cadmium ratio range for these facilities is 4 to 3000 (Au). For long irradiations 6-cm- and 9-cm-diameter in-core thimbles are used. These are D_2O filled with fluences of 2-4 $\times 10^{14}$ n/cm^2-s.

- Neutron Radiography. Radiography facilities are available at a highly thermalized beam of the thermal column. Fluences range from 10^5 to 10^7 n/cm^2-s, depending on resolution, with a Cd ratio of 500:1 and an L/D ratio adjustable from 20:1 to 500:1. The beam is 25 cm in diameter at the image plane, 2 m from the reactor face. Facilities for autoradiography also have been developed.

APPLICATIONS

Many of the principal applications have been described elsewhere in this report. Others include:

- Structural and Spectroscopic Studies of Magnetic Materials. Recent efforts have focused on rare-earth compounds, amorphous magnets and spin glasses, superconductors, magnetic bilayers, and hydrogen in metals.

- Elemental Analysis Programs. Examples include studies in environmental chemistry, nutrition, biomedicine, energy and electronic devices—with emphasis on Standard Reference Materials for these applications.

- Neutron Dosimetry Studies. Specific projects include neutron fluence standards for power reactor pressure vessel irradiation surveillance, ultralight mass assay for commercial track recorder detectors, absolute fission-rate measurements, and development of thermal neutron beam monitors.

AVAILABILITY

There are 25 thermal neutron facilities at the reactor, which provide about 125,000 instrument hours per year. In 1992, over 700 researchers from 14 NIST divisions, 28 other government organizations, 114 U.S. industrial and university laboratories, and 65 foreign laboratories utilized the facilities, either collaboratively with NIST staff or independently.

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MATERIALS SCIENCE X-RAY BEAMLINES

NIST operates two beam stations on the X23A port at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory in New York. The light source provides an intense continuous-spectrum beam of collimated and polarized X-rays many orders of magnitude brighter than the beams provided by conventional laboratory sources. These two beam stations offer access to dedicated instrumentation for small-angle X-ray scattering, X-ray diffraction imaging (topography) and X-ray absorption fine structure (XAFS).

CAPABILITIES

Small-angle X-ray scattering can be carried out in the photon energy range from 5 keV to 11 keV. The minimum wave vector is 4×10^{-3} nm^{-1} and the wavelength resolution is $\Delta\lambda/\lambda = 10^{-4}$, enabling anomalous small-angle scattering with excellent resolution. Diffraction imaging of single crystals and powders is carried out with monochromatic photons between 5 keV and 30 keV. An energy-tunable X-ray image magnifier enables imaging of microstructures down to less than 1 mm. The energy-scanning experiments, primarily XAFS, also are performed over an energy range from 5 keV to 30 keV.

APPLICATIONS

Small-angle scattering measurements on ceramic and metallurgical materials are used to characterize microstructure in the 2-nm to 1-μm size range as a function of starting chemistry and processing parameters. Scattering from a particular entity can be separated from other scatterers in a complex material using anomalous small-angle X-ray scattering. Diffraction imaging is used to study imperfections and strains in single crystals and powder compacts. The structure of strained semiconductor interfaces and metal multilayers can be studied using XAFS. A combination of XAFS and diffraction will provide a capability for site-specific local structure determination in crystals.

AVAILABILITY

Beam time is available to qualified scientists provided safety requirements are met and scheduling arrangements can be made. Proposals for collaborative use of the facility are reviewed at NIST; proposals for independent use of the facility should be submitted to the NSLS.

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SMALL-ANGLE X-RAY SCATTERING FACILITY

Small-angle X-ray scattering (SAXS) is a technique in which a highly collimated beam of X-rays (wavelength range 0.07 nm to 0.3 nm) is used to probe the structure of materials on the size scale of 0.1 nm to 100 nm.

Materials exhibiting structure in this size range include polymers, biological macromolecules, ceramics, metals, and alloys. The small-angle scattering patterns can be analyzed to characterize the size and shape of the scattering centers as well as their spatial distribution and surface area. Data obtained from these experiments are complementary to data obtained from other diffraction studies and from morphological studies using electron microscopy.

CAPABILITIES

The NIST 10-m SAXS camera uses a 12-kW rotating anode X-ray generator as a source of X-rays. The target is usually copper $\lambda(K\alpha) = 1.54$, but additional wavelengths are available. The collimation path is defined so as to permit 10^{-2} nm^{-1} resolution in reciprocal space at the surface of a two-dimensional position-sensitive proportional detector. The collimation path and the scattered beam path are evacuated, and all elements of vacuum operation, X-ray optical configuration, sample selection, and calibration are computer controlled. Image data are collected by a minicomputer, and a complete collection of software is available for displaying, analyzing, and modeling the results.

Sample chambers are available for measurements at high temperatures and to deform specimens during measurement.

APPLICATIONS

The SAXS technique is used to study molecular conformation, microphase domain structures, crystallization phenomena, network formation, craze initiation, void distribution, and similar phenomena resulting from fluctuations in electron density within a material. Such studies are currently of broad interest in all areas of materials science.

AVAILABILITY

This facility is operated by members of the NIST staff in support of their active research program in polymeric materials. It is available for use by researchers from industry, academia, and other government agencies on either a collaborative or independent basis.

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POWDER CHARACTERIZATION AND PROCESSING LABORATORY

Advanced ceramics are manufactured by the consolidation of fine powders. Researchers at NIST are working to develop the scientific foundation needed for improving reproducibility and reducing the cost of producing ceramic components. The powder characterization facility offers specialized instrumentation for measuring physical properties, phase composition, and surface chemical properties. In addition, facilities exist for processing and synthesizing ultrapure powders.

CAPABILITIES

- Physical Properties Measurement. Particle-size distribution, specific surface area, specific gravity, and porosity are some of the major physical properties for which instrumentation is available. Powder-size distribution can be determined by gravity sedimentation followed by X-ray absorption, centrifugal sedimentation, light diffraction, and photon correlation spectroscopy. The size range of these instruments covers 0.03 µm to 200 µm. Each instrument works in a specific range and provides the data in the form of a discrete size range. The particles are examined directly by the application of scanning and transmission electron microscopy of particles as small as 0.001 µm.

- Surface and Interface Chemistry Measurements. The surface and interface characterization of powders contributes to the knowledge base of the surface interactions of particles in contact with dispersants and binders. As the particles become smaller, their surface characteristics become more significant. MicroRaman and Fourier transform infrared spectroscopy are used to study surface composition, and electrophoretic mobility and acoustophoretic mobility are used to study modification to the powder surface as a result of an interaction with dispersants and binders.

- Phase Composition. Since most of the ceramic powders undergo phase transformation during densification, understanding the phase changes in specific densification environments is an active part of NIST research. The Siemens high-temperature X-ray diffractometer has a temperature range from room temperature to 3000 K and a position sensitive detector. In addition, sintering can be carried out in oxygen-free argon or nitrogen environments.

- Solid-State Imaging. The solid-state nuclear magnetic resonance (NMR) spectrometer/imager carries out measurements in chemical shift, nuclear spin density, relaxation times, and imaging of NMR active nuclear distribution. Ceramic powder slurries, green bodies, and dense ceramics can be analyzed for identification of impurities, chemical state, and composition distribution by non-destructive evaluation. In addition, the NMR can determine amorphous phase content of the powders.

- Powder Synthesis. The ability to synthesize powders of controlled characteristics is necessary for development of a powder-processing knowledge base. The fine-powder synthesis facility consists of a chemical flow reactor for controlled synthesis and inert atmosphere chambers. A solution atomizer is available to generate polydisperse aerosols in the range of 0.001 µm to 1.0 µm, as is a spray dryer to form monodisperse agglomerates in the range 0.5 µm to 100 µm.

- Collodial Suspensions Preparation. Colloidal processing of ceramic powders has emerged as an attractive technology for producing defect-free ceramics. However, some major issues still remain to be addressed, including the lack of characterization techniques for slurries that contain high concentrations of solids and scientific understanding of limitations in the preparation of such slurries. The powder processing laboratory consists of an acoustophoresis instrument, a rheometer, a high-energy agitation ball mill, and slurry consolidation equipment. These techniques are used to study interface chemistry, flow behavior, size reduction, morphology modification, and densification of polydisperse particles and similar processes resulting from interactions between the particles and their environment.

AVAILABILITY

These facilities are used primarily to support NIST research programs using ceramic powders. They are available for collaborative or independent work by qualified government, industry, or university personnel with preference given to projects related to ceramics research.

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A256 Materials Building

BUILDING AND FIRE RESEARCH LABORATORY

The Building and Fire Research Laboratory (BFRL) enhances the competitiveness of U.S. industry and public safety through performance prediction and measurement technologies and technical advances that improve the life-cycle quality and cost effectiveness of constructed facilities. BFRL's efforts are closely coordinated with industry, professional and trade organizations, academe, and other agencies of government.

Major BFRL goals are to improve the productivity of U.S. industries of construction, which now face stiff competition from overseas firms, and to reduce the human and economic losses resulting from fires, earthquakes, winds, and other hazards. Laboratory research includes fire science and fire safety engineering; building materials; computer-integrated construction practices; structural, mechanical, and environmental engineering; and building economics. Products of the laboratory's research include measurements and test methods, performance criteria, and technical data that are incorporated into building and fire standards and codes. Staff members are involved in more than 100 activities to develop voluntary standards.

The laboratory conducts investigations at the scene of major fires and structural failures due to earthquakes, hurricanes, or other causes. The knowledge gained from these investigations guides research and is applied to recommendations for design and construction practices to reduce hazards.

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COOPERATIVE RESEARCH OPPORTUNITIES

COOPERATIVE RESEARCH OPPORTUNITIES

STRUCTURES

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STRUCTURAL, EARTHQUAKE, AND WIND ENGINEERING

Under the National Earthquake Hazards Reduction Program, NIST performs research and development work used in standards for the seismic safety of structures. Experimental and analytical research under way at NIST contributes directly to the development of design and construction standards for new and existing buildings and lifeline structures. Other structural research involves determination of limit states and identification of mechanisms of failure and establishing criteria to ensure structural safety and serviceability.

The results provide designers and constructors with improved methods to predict and assess the resistance of buildings and structures to seismic and wind loads, guidelines for strengthening new and existing structures, and technologies to revise civil engineering related standards and codes.

Current research addresses:

- a rational procedure to determine the ultimate shear strength of partially reinforced masonry walls;
- strength and ductility of connections in precast concrete structures;
- evaluation criteria for base-isolation systems and test procedures for evaluating the response of structures subjected to seismic loading;
- strengthening methodologies for concrete frame structures; and
- performance of non-structural components.

Other structural research includes:

- non-destructive testing methods to detect internal flaws and discontinuities in structural members;
- studies of structural performance for developing standards and test methods for high-performance concrete in major construction applications;
- response of low-rise structures and cladding to extreme wind loads;
- techniques and instrumentation for assessing the properties of existing structures and for developing technical criteria and methodologies for strengthening and repairing existing structural members and systems;
- analytical and experimental methods for identification of dynamic response characteristics of flexible members and structural networks;
- response measurements of full-scale structures; and
- reliability of compliant offshore structures.

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BUILDING MATERIALS

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CEMENT AND CONCRETE

NIST researchers are developing a fundamental understanding of the relationship between chemistry, microstructure, performance, and service life of conventional and high-performance concrete and other inorganic building materials. Their goal is to develop tools for predicting the behavior of these materials and their service lifetimes. Because the service life of concrete largely depends on the transport of water, dissolved salts, and gases in the pore system of the concrete, researchers are developing mathematical representations of the microstructure of concrete and models for use in predicting its diffusivity and permeability.

Models are being developed to consider service conditions, including the chemistry of the environment; the transport rate of reactants by diffusion, convection, and capillarity; and reaction mechanisms.

Research projects include development and validation of models for simulating microstructure development in cement pastes as the cement hydrates and the degradation of concrete. Artificial intelligence systems are being developed for optimizing the selection of materials and for diagnosing the causes of material degradation. The research is performed using a variety of techniques, including scanning electron microscopy, computerized image analysis, X-ray diffraction, and thermal analysis.

This work helps the U.S. construction industry to be competitive by providing a strong technical basis for standards for concrete and concrete materials. The research is coordinated with industry and voluntary standards organizations and trade associations, the National Science Foundation's Center for Advanced Cement-Based Materials, and federal and state government agencies.

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ORGANIC BUILDING MATERIALS

NIST is conducting basic and applied research to develop methods for predicting the performance and service life of organic building materials such as protective coatings for steel, polymer-matrix composites, and roofing materials. Researchers are investigating degradation mechanisms, improving characterization methods, and developing mathematical models of the degradation processes. Stochastic models, which are based in reliability theory and life-testing analysis, are included in the modeling efforts for all three of these materials.

To help in understanding the mechanisms of degradation and provide data for models, materials are characterized in many ways, including Fourier transform infrared spectroscopy, thermal analysis, scanning electron microscopy/energy dispersive X-ray, and visual and infrared imaging. Researchers also are developing improved ways to characterize atmospheric environments to which these materials are exposed. Characterization of environmental parameters that cause degradation is needed to link material properties with service life.

The NIST research strengthens the scientific and technical basis for engineering standards for organic building materials developed by voluntary consensus standards organizations. Sometimes, as in the Coatings Service Life Prediction Consortium and the Consortium for Performance of Tape-Bonded Seams for Elastomeric Roofing Membranes, the research is carried out in close collaboration with, and support from, industry and other federal agencies.

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HIGH-PERFORMANCE CONSTRUCTION MATERIALS AND SYSTEMS

NIST's High-Performance Construction Materials and Systems Program is a BFRL-wide research program. It supports the national program, CONMAT, which the Civil Engineering Research Foundation and 10 industry groups established "to develop the high-performance construction materials and systems necessary for America's well-being and international competitiveness in the 21st Century." The NIST program involves four of BFRL's divisions—Structures, Building Materials, Fire Sciences, and Fire Safety Engineering—and its Office of Applied Economics. The program encompasses high-performance concrete, steel, polymer-matrix composites, organic coatings, and roofing materials and is developing rational methods for evaluating, by measurement or prediction, all major aspects of performance—structural, durability, and fire resistance, and providing a testbed for collaboration with industry in development of a computer-integrated knowledge system (CIKS) for high-performance construction materials and systems. The results of the NIST program will facilitate acceptance of new and improved construction materials by the construction industry.

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CONSTRUCTION MATERIALS REFERENCE LABORATORIES

NIST's Construction Materials Reference Laboratories (CMRL), managed by BFRL, comprises the ASTM-sponsored Cement and Concrete Reference Laboratory (CCRL) founded in 1929 and the AASHTO (American Association of State Highway Transportation Officials)-sponsored AASHTO Materials Reference Laboratory (AMRL) founded in 1965. The laboratories provide a reimbursable, voluntary, quality assurance service for more than 1,200 commercial and other laboratories that test construction materials for compliance with standards—ASTM standards for cements and other concrete materials in the case of CCRL, and AASHTO standards for almost the full range of highway construction materials in the case of AMRL. The services of both laboratories comprise laboratory inspections by CMRL's staff of inspectors and operation of large proficiency sample programs. CMRL has been described as "an outstanding example of government-industry collaboration" for its contributions to the quality of construction.

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INDOOR AIR QUALITY AND VENTILATION

Computer simulation programs and measurement procedures are being developed and applied by NIST researchers to better understand the phenomena of air and contaminant transport in buildings and to support industry efforts to improve environmental conditions in buildings in a cost-effective manner. The results of this research are providing reliable methods to design buildings and HVAC systems and to evaluate ventilation characteristics and indoor pollutant concentrations in buildings.

The modeling efforts include the development and application of multizone airflow and indoor air quality models, specifically the CONTAM series, which predicts airflows and contaminant concentrations in multizone building systems. CONTAM has been used at NIST to study the indoor air quality impacts of HVAC systems in single-family residential buildings, ventilation in large mechanically ventilated office buildings, and radon entry and transport in large residential, office, and school buildings.

Measurement procedures are being developed and demonstrated to evaluate building ventilation and indoor pollutant concentrations. These procedures range from sophisticated tracer gas methods used predominantly in building research efforts to less involved procedures that can be employed by building operators. NIST researchers are developing new test procedures and demonstrating them in the field to evaluate their feasibility and reliability. The efforts in which these procedures are demonstrated in the field have resulted in the development of an important database of building ventilation and indoor air quality performance in the field.

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REFRIGERATION MACHINERY

NIST researchers identify and characterize refrigerant and refrigerant mixtures to improve the efficiency of refrigeration cycles and replace harmful chlorine-containing refrigerants that were implicated in the destruction of the upper-atmosphere ozone layer. The researchers evaluate alternative refrigerant cycles, systems, and components that will operate efficiently with new refrigerants. Working with industry, they improve capabilities in determining the performance of alternative refrigerants and help refrigeration equipment manufacturers in designing refrigeration systems.

The researchers evaluate alternative refrigerants and a wide variety of refrigeration cycles by using a breadboard heat pump to which different components and circuits can be "plugged" and "unplugged." These breadboard modifications are based on theoretical and simulation studies conducted to find the optimal combination of mixtures and appropriate refrigeration cycle for the best and most versatile performance. Fluorocarbon and hydrocarbon refrigerants are studied in novel applications like a water-to-water heat pump or a heat pump with evaporative cooling of the high-pressure refrigerant. In addition to simulation and laboratory studies, pool-boiling and flow-boiling heat-transfer coefficients are measured for alternative refrigerants and refrigerant mixtures, including tests with pool-boiling additives.

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HEAT TRANSFER

Buildings account for over 60 percent of all electricity used in the United States and almost 40 percent of all natural gas consumed within the United States, at an annual cost that exceeds $170 billion. A significant portion of this energy is used to provide space heating and cooling. Researchers at NIST are developing basic data and simulation models for heat, air, and moisture transfer through building envelope components. They are enhancing the capabilities of MOIST, a widely used computer model for predicting moisture transfer within the building envelope. They are developing a Standard Reference Material (SRM) that will be used to calibrate private-sector facilities for measuring thermal performance of windows while maintaining the supply of three other SRMs used to calibrate insulation manufacturers' "in-house" instrumentation. In addition to conducting measurements for industry on conventional building insulation products, researchers within the heat transfer group are developing measurement techniques to assess the thermal performance of new insulation products with superior thermal performance. A study currently is being conducted to determine the energy-savings potential of reflective roofing materials.

A 1-m guarded hot plate is used to develop SRMs; to determine thermal conductivity values for various materials, such as CFC-blown insulation; and to provide measurement services to manufacturers and researchers. A calibrated hot box is used to measure the steady-state and dynamic performance of full-scale wall systems. A calorimeter and finite-element models are used to characterize the performance of advanced insulation systems such as gas-filled and vacuum insulation panels.

This work provides the national "meter bar" for the thermal insulation industry. All advertised thermal insulation product performance is traceable to measurements made in this program.

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BUILDING CONTROLS

NIST research is fostering the development of more intelligent, integrated, and optimized building mechanical systems. A dynamic building/heating, ventilating, and air-conditioning control system simulation program is used to study HVAC/control system dynamics and interactions. An expanded building management and controls laboratory is used to assist the building controls industry in the development, evaluation, and testing of communication protocol standards for the open exchange of information. NIST technologies serve as a basis for ASHRAE standards to assist the control system manufacturers to develop interoperable systems and methods for testing conformance to the standard.

The application of "smart" control systems to buildings is a relatively new area of research. Plans call for exploring how real-time models, on-line system identification, optimal control, and fault detection and diagnostics can be combined to improve control system performance, make control strategy decisions that optimize building operations, and advise the building operator or manager on building operations, equipment problems, or maintenance requirements. Research on smart building control systems will be performed by simulation and emulation studies, laboratory testing, and field studies in real buildings.

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COMPUTER-INTEGRATED CONSTRUCTION

NIST researchers are developing rational techniques for defining and testing computer representations of information needed throughout the building process, from the conception of a building to its demolition. The goal of the program is to develop validated neutral data representations for use in standards for accessing, exchanging, and archiving information. As a corollary, the program seeks to develop testing methods that assure consistency, completeness, and correctness of information. The research draws on evolving information technologies, including knowledge engineering and semantic modeling. Subject areas for research include standards and codes, engineering drawings, and product data.

Past research has resulted in methodologies for representing, analyzing, and expressing standards and for interfacing standards to computer-aided design systems. Recent results are being applied in the development and validation of national and international standards for product data. This work led to the improved 3D Piping IGES Application Protocol (AP) to meet a high-priority data exchange requirement of industry and government. It also has produced a prototype AP framework to provide a structure to classify APs and to plan DOD Computer-Aided Acquisition and Logistics Support Program APs and the work of the International Organization for Standardization's project on developing the Standard for the Exchange of Product Model Data.

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FIRE MODELING AND APPLICATIONS

The United States has one of the worst fire records in the industrialized world. NIST researchers are helping to reduce the losses and the cost of fire safety by providing scientific and engineering bases needed by manufacturers and the fire safety community. This work involves the development of predictive, analytical methods that permit the quantitative assessment of hazard and risk from fires. Researchers base these methods on numerical modeling but also include hand-calculation methods for estimating hazards and design curves/tables to be used by architects and engineers. To ensure widespread use, the necessary data must be readily available, and data input and presentation must be in terms readily understandable by the average professional. This research includes strong emphasis on state-of-the-art computer graphics and computer-aided design techniques. The results of this work help manufacturers, purchasers, designers, code officials, fire investigators, and practitioners evaluate the fire hazard implications of the products and fire protection strategies they use.

The expedient transfer of scientifically based technology from NIST to the professional user community and the creation of a link between NIST computer-based activities and others doing similar or complementary work can enhance fire safety and reduce its costs. Over the past decade, NIST researchers developed many computer models of various aspects of fire. These researchers develop engineering systems for design application and fire investigation, collect supporting data and programs, and operate training programs and user workshops.

In addition, NIST maintains the Fire Research Information Service (FRIS) consisting of national and international fire research literature and FIREDOC, the automated database of fire research literature. FRIS is the only comprehensive national library resource for the fire community.

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LARGE FIRES

Large fires result from industrial or transportation accidents, natural disasters, arson, or when fire protection systems in constructed facilities fail to perform adequately. While these fires present a hazard to building occupants, firefighters, and the surrounding area, little is known about their characteristics, their growth and control, and methods of mitigating their impact. NIST is performing research and developing techniques to measure and predict the behavior of large fires and the action of building fire protection systems. Large building fires involve the interaction of strongly buoyant gas flows and thermal radiation with complex structures and, in some cases, automatic fire suppression systems. Experiments to evaluate room-size fire behavior and the performance of existing fire suppression systems are being conducted to provide information that can be used to reduce the vulnerability to large fires.

NIST also is measuring smoke plumes from large, open-air fires to help develop computer models that can predict their size and movement. Computational fluid dynamics models based on large eddy simulation technology have been developed to assess the local impact of large fires. These methods are being used by industry in preplanning analysis for potential accidents or as technical support for emergency response. In addition, NIST operates a large-scale fire research facility that is capable of detailed measurements of fire behavior for room size fires. Among its many uses, this facility provides data on the burning characteristics of fuel packages for use as input data to fire models.

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ADVANCED FIRE SENSING

The damage from fires that are detected quickly can be kept small. NIST researchers are studying new "fire signatures" that would enable the development of a new generation of detectors. The signals from these detectors would be analyzed electronically to alert occupants or suppression devices, perhaps even before flames exist. The research also is intended to understand and provide technology for avoiding the high false-alarm rate of current detectors. In addition, advanced concepts for fire suppression chemicals, reduced explosion potential, and minimizing collateral damage from the application of the suppressant are being explored.

NIST also is developing a first-generation, fire-emulator/detector-evaluator. Identified by industry as a principal stimulant to the development and commercialization of new fire alert devices, the emulator will provide a well-controlled environment in which fire sensors can be exposed to highly reproducible, time-varying concentrations of combustion products at predetermined temperatures and flow velocities. This will provide accurate determination of the sensitivity and utility of new detector designs.

Using this device will demonstrate the response of discriminating detector systems to early fire events and will enable improved fire protection with reduced cost and losses.

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B356 Polymer Building

ADVANCED FIRE SUPPRESSION

Rapid, effective response to a fire is essential to improve life safety and avert major property loss. Halon fire suppressants have long been used to protect the most important, sensitive, and irreplaceable facilities. Production of these chemicals has now been halted due to their deleterious effect on stratospheric ozone.

In performing leading research into replacements for the halons, NIST is working closely with the industries and federal agencies that need alternative suppression capability, the potential manufacturers of advanced fire suppression technologies, and other researchers in the field. NIST research includes studying the mechanisms of highly efficient flame extinguishants to help identify new chemicals for practical use, investigating the transport properties of gaseous and liquid suppressants to optimize their effectiveness, and developing performance measures for new fire suppression technologies.

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SMOKE AND TOXIC GAS PREDICTION

Most people who perish in fires die from smoke inhalation. Many are exposed to this smoke for longer periods because the blackness of the smoke impedes their escape from the burning building. NIST research is developing the scientific base and the predictive methods for the yields of carbon monoxide (the predominant toxicant) and soot. These require improved knowledge of the chemical and physical processes in flames, combined with the fluid mechanical processes that dominate air entrainment into fire plumes and the flow fields within a compartment.

The results of this research have been used to formulate a global model of soot formation and oxidation processes, improve strategies for incorporating chemistry into turbulent flow fields, and extend optical investigations into flames where the effects of chemistry-turbulence interactions can be probed effectively.

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B360 Polymer Building

POLYMER COMBUSTION RESEARCH

The materials industry is seeking products that are both low in flammability and will not pose environmental hazards over their life cycle. NIST is working on several key research areas needed to produce natural and synthetic polymers and composite materials that can meet these goals. One area is the measurement of flammability properties by bench-scale methods, directly relevant to real fires, and the development of mathematical models that use the measured flammability properties as inputs to predict fire performance of materials in the conditions of actual use.

Another research area concerns approaches to environmentally acceptable, char-forming flame retardant treatments for flaming and smoldering combustion. This effort includes studying the physical and chemical nature of char and how its properties can be enhanced. Theoretical modeling using molecular dynamics and quantum mechanics complement the experimental work to develop a technical basis for the design of a new generation of fire resistant materials, which, while retaining their intended-use properties, will be low in combustion toxicity and safe for the environment.

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APPLIED ECONOMICS

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B226 Building Research Building

MICROECONOMIC ANALYSIS

The Office of Applied Economics (OAE) conducts research and provides technical assistance in the field of microeconomic analysis. It provides information to decision makers in the public and private sectors who are faced with choices among new technologies and policies relating to manufacturing, industrial processes, the environment, energy conservation, construction, law enforcement, and safety. It also develops and conducts prototype training programs in applied economics for scientists and engineers.

Benefit-cost analysis, life-cycle costing, multicriteria decision analysis, risk analysis, and econometrics are techniques the OAE uses to evaluate new technologies, processes, governmental programs, legislation, and codes and standards to determine efficient alternatives. Research areas include energy conservation in buildings, fire safety, automation, seismic design, and building economics. Products include reports of research findings, standard methods and guidelines for making economic evaluations, audiovisuals that teach and illustrate methods in practice, and decision support software with documentation.

Current research includes developing and automating a decision support system, BEES, for evaluating the environmental and economic performance of buildings; developing models and software for evaluating the life-cycle cost effectiveness of composites and other new technology materials in construction; constructing an optimization model for determining the appropriate prices and levels of production for NIST's Standard Reference Materials; and providing economic software tools for evaluating the long-term cost effectiveness of capital investments in buildings and building components.

RESEARCH FACILITIES

LARGE-SCALE STRUCTURES TESTING FACILITY

The NIST large-scale structures testing facility consists of a universal testing machine (UTM) that may be used with a 13.7-m-high reaction buttress equipped with a horizontal hydraulic ram of 4.5-MN capacity. A combination of horizontal and vertical forces may be applied to large-scale specimens.

CAPABILITIES

The UTM portion of the facility is a hydraulically operated machine of 53.4-MN capacity and is one of the largest in the world. It tests large structural components and applies the forces needed to calibrate very large capacity force-measuring devices. It can apply compression forces to column sections or fabricated members up to 18 m in height. The reaction buttress will resist horizontal forces to 4.5 MN from floor level to 12.2 m high. Flexure and tension specimens may be subjected to forces up to 18 MN and 26 MN, respectively. Two-meter-thick test floors east and west of the machine may be used to tie specimens in place.

A servo system has been added to the original manual controls of the UTM. It can be programmed by function generator or computer to create any desired loading function using force, strain, or displacement as the variable.

Loads may be applied to a specimen by both the UTM and horizontal ram. A four-rail track system equipped with low-friction rollers has been used for concrete column tests. An "A" frame was used to resist horizontal reaction forces generated by the ram and was attached to the buttress at the desired height.

APPLICATIONS

A testing program was conducted to evaluate the performance of concrete columns 1.5 m in diameter and up to 9.1 m high. Another test series evaluated fracture propagation in steel plates 1 m wide and 0.1 m and 0.15 m thick. A third experiment used the servo-control system, programming repeated loads applied to composite specimens.

Low-cycle fatigue tests, destructive or ultimate loads, earthquake simulation in two dimensions, and complex loading of components may all be accomplished in this facility. Servo operation of this machine creates a unique potential for precisely controlled very large forces applying to test components.

AVAILABILITY

This facility, which NIST staff must operate, is available for cooperative or independent research. Tests should be arranged as far in advance as possible as special hardware may be needed for attaching specimens.

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B168 Building Research Building

TRI-DIRECTIONAL TEST FACILITY

The tri-directional test facility at NIST is a computer-controlled apparatus capable of applying cyclic loads simultaneously in three directions. It is used to examine the strength of structural components or assemblages under the application of a variety of loading phenomena, such as an earthquake or wind. This is one of the largest such facilities in the world, in terms of both its high load capacity and its capability to handle large, full-scale specimens.

CAPABILITIES

The facility can apply forces and/or displacements in six directions at one end of a specimen. The other end of the specimen is fixed. Specimens up to 3.3 m high × 3 m in length or width may be tested. The six degrees of freedom are translations and rotations in and about three orthogonal axes. Six closed-loop, servo-controlled hydraulic actuators that receive instructions from a computer apply the forces. Operating under computer control, the facility simultaneously maintains control of the load and/or displacements in each of the three orthogonal directions. Loads may be applied up to 2,000 kN in the vertical and about 890 kN in each of the two horizontal directions.

APPLICATIONS

The test facility is limited only by the size of the test specimen. Loads may be cyclic or unidirectional depending on the type of loading condition being simulated. The facility is used to study masonry shear walls subjected to reverse cyclic lateral loading and precast concrete connections also subjected to reversed cyclic lateral loading. This facility supports NIST's role in conducting research for seismic design and construction standards in the National Earthquake Hazards Reduction Program.

AVAILABILITY

The tri-directional test facility is used by NIST staff in a variety of NIST research projects and in collaborative projects with other agencies. It also is available for independent research but must be operated by NIST staff.

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LARGE ENVIRONMENTAL CHAMBER

The large environmental chamber is 14.9 m × 12.8 m × 9.5 m high. It has an earth floor and may be excavated as needed for building construction. The chamber is one of the largest of its kind, capable of accommodating two-story houses under simulated environmental conditions. This chamber has been used for thermal performance, heating and cooling load measurements, and energy consumption studies of buildings of different kinds.

CAPABILITIES

The chamber is capable of automatically maintaining steady and/or dynamic temperature profiles from -45 °C to 65 °C and humidity from 50 percent relative humidity (rh) at 1.7 °C up to 35 °C dewpoint at 49 °C. A wider range of rh (15 percent to 80 percent) may be obtained manually. Air circulation maintains the temperature variation within the chamber to within ±1 °C. Damper-control return ducts in all four corners of the chamber permit good air distribution. Supply air is furnished by ceiling diffusers.

APPLICATIONS

The chamber is used to measure indoor temperature fluctuation, heat loss and heat gain through building envelopes, energy conservation and moisture condensation studies, and air infiltration under simulated and dynamically fluctuating outdoor temperature cycles. The chamber has been used to test a variety of conventional and special structures and equipment, including military hardware (such as inflatable life rafts, relocatable air-inflatable hospital units, and portable walk-in coolers) under extreme climatic conditions.

AVAILABILITY

This facility, along with several smaller chambers (including one designed for vehicles), has substantial potential for use by researchers in industry and universities. Collaborative programs and individual research can be arranged.

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CALIBRATED HOT BOX

The NIST calibrated hot box measures the heat transfer coefficient of full-scale building wall sections. Designed according to ASTM Standard C976, it consists of two large, heavily insulated chambers—an environmental chamber and a climatic chamber—each with one open side. Indoor and outdoor conditions are simulated in the chambers. The open test section measures 3 m × 4.6 m. A well-insulated frame supports the wall specimen clamped between the open sides of the two chambers.

CAPABILITIES

This facility is the only one of its kind designed to perform simultaneous dynamic transfer measurements of air, moisture, and heat during simulated winter and summer conditions under steady-state and dynamic climatic conditions. While the environmental chamber temperature and humidity are maintained to simulate a relatively steady and narrow range of indoor conditions, the climatic chamber can attain temperatures ranging from –40 °C to 65 °C. The apparatus measures the performance of homogeneous or composite walls having a range of thermal resistance from 0.35 m^2 to 8.8 $m^2 \cdot C/W$. It accommodates wall specimens up to 0.6 m thick and up to 700 kg/m^2 in weight per unit area.

APPLICATIONS

NIST researchers use the facility to develop standard test methods to evaluate dynamic thermal performance of full-scale walls under cyclic temperature conditions. The building industry and government agencies are seeking reliable evaluation techniques for wall thermal mass, especially to predict energy consumption of buildings with heavy mass effects in comparison to standard wood-frame buildings.

NIST has participated in round-robin test activities with domestic and overseas thermal insulation laboratories.

AVAILABILITY

The facility provides a unique opportunity to measure simultaneous transfer of air, moisture, and heat through wall and roof specimens with openings for windows and doors. While available for use by those outside NIST, this apparatus must be operated by NIST staff.

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B320 Building Research Building

LINE HEAT-SOURCE GUARDED HOT PLATE

The 1-meter guarded hot-plate apparatus measures thermal conductivity of building insulation materials. The thermal resistance of all insulation products sold in the United States is traceable to this apparatus. NIST researchers use the hot plate to provide calibration specimens for guarded hot plates in other laboratories. The hot plate also is used to investigate edge heat loss from thick thermal insulation materials. This facility is the only one of its kind in the world that will permit low-density thick insulation to be measured with an uncertainty of less than 0.5 percent.

CAPABILITIES

This apparatus has a test temperature range of 80 °C for the hot plate and -20 °C for the cold plates. The apparatus permits measurement of vertical and horizontal heat flow to simulate heat transfer through ceilings and walls, respectively. This apparatus operates within its own carefully controlled temperature and humidity environment shielded by an insulated enclosure. This facility provides for absolute measurement of thermal resistance of thick and low-density test specimens used as transfer standards. These standards are used to calibrate or verify heat flowmeter (ASTM C518) or guarded hot-plate (ASTM C177) equipment.

AVAILABILITY

This apparatus is available for use by those outside NIST, but it must be operated by NIST staff. Collaborative programs may be arranged.

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ADVANCED INSULATION FACILITY

The advanced insulation facility consists of experimental apparatus and analytical tools to assess the thermal performance of advanced insulation systems. These systems include gas-filled, powder-filled, and metal-clad vacuum panels. The facility consists of a calorimeter facility to measure the thermal resistance of advanced insulation panels, a state-of-the-art infrared thermography system to characterize thermal anomalies, and finite element software.

CAPABILITIES

The maximum panel size that can be accommodated by the calorimeter facility is 0.9 by 0.9 m. The maximum thickness that can be accommodated is 0.1 m. The temperature of one side of the panel may be varied from -15 °C to 10 °C. The other side of the panel, encased by a calorimeter, is maintained at laboratory ambient temperature. The infrared thermography system consists of both short-wave and long-wave scanners and advanced software that permits analysis of both real-time and stored images. The finite element software is applicable to all classes of advanced insulation systems.

APPLICATIONS

The facility is used to measure the thermal resistance of advanced insulation systems including, but not limited, to gas-filled, metal-clad vacuum, and powder-filled panels. The facility is well suited to measure non-homogeneous insulation systems but could be utilized to measure the thermal performance of conventional insulation materials.

AVAILABILITY

This facility has substantial potential for developers of advanced insulation systems in industry and academia. Cooperative Research and Development Agreements are used to establish research projects within this facility.

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FIRE RESEARCH FACILITIES

As the federal government's principal fire research laboratory, NIST maintains some of the country's best and most extensive fire testing facilities. A substantial portion of NIST's fire tests are performed in a specially equipped fire research building, which measures 27 m × 57 m and is designed for large-scale fire experiments. Smoke abatement equipment permits large fire tests to be conducted safely without polluting the environment.

In addition to several individual burn rooms, which are modified from time-to-time to accommodate special NIST testing requirements, the facility houses several specially designed calorimeters for measuring the rate of heat release from materials and large samples, a room/corridor facility for studying smoke and toxic gas transport, pilot furnaces, and reduced-scale model enclosures. Also, a two-story "townhouse" is used to study fire spread from a burning room, smoke transport between levels, and sprinkler performance. The townhouse features a living room that is continuously weighed, allowing the burning rate of finish materials to be measured.

A new computer-based data acquisition system provides state-of-the-art data collection capabilities for all large-scale fire testing. Up to 300 instruments with scanning rates of more than 100 channels per second can be dedicated to a single test. During an experiment, real-time, full-color graphics present the data as collected, with automatic conversion to engineering units for gas analysis, rate of heat release, temperature, and other measurements.

CAPABILITIES

- Heat-Release-Rate Calorimeters. NIST pioneered and developed the oxygen consumption methodology for measuring the rate of heat release and has used it longer and in more devices than any other laboratory. The major benefit of this technique is the independence of the apparatus in measuring enthalpy responses to changes in heat release rate.

NIST has two calorimeters available for measuring the rate of heat release of free-standing items, such as pieces of furniture. The smaller one has a capacity of 0.5 MW; the larger, 7 MW. Provisions for measuring smoke production and gas species yield are available with both instruments.

- Room/Corridor Facility. NIST researchers have constructed and used a room/corridor facility to evaluate an analytical model that predicts the transport of smoke and toxic gases from the room of fire origin into the corridor and secondary target rooms. The design of this facility makes it possible to measure the hazards associated with the burning of wall linings or room furnishings by evaluating the rate of heat release, smoke production, and toxic gas generation. The facility is available in its present form or with design modifications for evaluating a variety of building contents and furnishings.

• Burn Rooms. A standard burn room built to ASTM specifications, 2.4 m × 3.7 m × 2.4 m high, adjoins a large overhead hood that collects the exhaust products from the room fires. The exhaust collection system is calibrated to measure the rate of heat release and the generation rates of smoke and other combustion products from the fire. The burn room is available for developmental and validation studies of mathematical models and for studies of fire performance of furnishings and interior finish materials.

The room fire environment can be characterized in terms of temperature and pressure gradients and the spatial distribution of thermal flux, gaseous combustion products, and smoke. Other measurements permit the calculation of thermal losses to the room boundaries and mass and energy flows from the room. Smaller burn rooms also are available.

• Pilot Furnaces. A pilot furnace for evaluating the fire endurance of wall assemblies or floor/ceiling assemblies is available. This furnace, capable of handling specimens 1 m × 1 m, may be used for research purposes only and cannot be used for code acceptance testing. Typically, fire exposure similar to that specified by ASTM E119, under carefully controlled conditions of furnace pressure and oxygen concentration, can be carried out. Depending on the parameters required, a variety of other exposure conditions can be applied.

• Reduced-Scale Models. NIST facilities are available for reduced-scale modeling of full-scale fire configurations. Physical models offer an economical means of achieving sufficient variation of physical parameters for a generalized understanding of fire behavior. Based on the results of reduced-scale experiments, limited full-scale verification then can be performed.

AVAILABILITY

Industry, university, and government representatives are encouraged to use these fire testing facilities on a collaborative or independent basis, with certain restrictions. For safety reasons, NIST staff must closely supervise all use of the facilities.

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INFORMATION TECHNOLOGY LABORATORY

About 60 percent of all U.S. workers have jobs that depend on the information they generate and receive on advanced information networks. Innovations in computer hardware, software, and digital communications will challenge managers to apply new technology for productivity increases throughout the American economy in the coming years and will have pervasive effects on industry structure as well as on the quality of government services. The merging of computer and telecommunications technology heightens the importance of an integrated approach to developing and using computer and related telecommunications systems. As the technology changes, it will be essential to find ways to enable organizations to preserve their investments in applications systems, to upgrade existing systems, and to improve the portability of staff skills, data, and software. Also, since computers will be distributed throughout society, both at home and in the workplace, computer integration, interoperability, usability, reliability, and security will become even more important.

To rise to this challenge, NIST has consolidated the activities of the Computer Systems Laboratory (CSL) and the Computing and Applied Mathematics Laboratory (CAML) into a new Information Technology Laboratory.

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COOPERATIVE RESEARCH OPPORTUNITIES

COOPERATIVE RESEARCH FACILITIES

SOFTWARE DIAGNOSTICS AND CONFORMANCE TESTING

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SOFTWARE QUALITY

Growing dependence on computers requires assurance that critical systems will operate reliably and exactly as intended without adverse effects, even when outside circumstances cause other systems to fail. NIST researchers are studying problems and potential solutions in building and operating high-integrity systems and are looking at life-cycle methodology, risk management, formal methods, object-oriented design, software reliability, clean-room techniques, and formal verification.

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CONFORMANCE TESTING

NIST researchers are designing and developing test methods for conformance tests and using these methods to produce test metrics and test suites for evaluating the quality and correctness of information technology products. Several conformance test metrics and test suites have been produced for evaluating implementations of language compilers (C, COBOL, Ada), computer graphics metafile, database language SQL, Information Resource Dictionary System, Remote Database Access, and POSIX. In collaboration with industry, the user community, and various testing laboratories, NIST researchers work to identify new technologies and to develop measurement schemes, test collections, reference implementations, test suites, and tools necessary to advance the technology and produce usable, reliable implementations.

Past research has resulted in a method for minimizing subjectivity in the evaluation of visual results in graphics testing. This method is implemented by a customizable interface, randomized self-explanatory displays, and automatic capture of results. Recent activities focus on providing conformance test services and test metrics electronically via the Internet. One test service automatically routes test data received via email through series of tests that evaluates the data and generates a report describing the test results. A prototype implementation for testing conformance of distributed relational databases is being developed using the World Wide Web to provide the access, connectivity, and interface between the remote databases.

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FUTURE STANDARDS FOR SOFTWARE

For the past several years, NIST has recognized the need to increase its involvement in technology specifications used in the development of high-technology software. In today's information processing environment it is becoming increasingly common for these new technology specifications to quickly become de facto standards. NIST researchers are seeking to become involved with organizations that are developing pivotal, forward-looking technology specifications in all areas related to high-technology software. This involvement will emphasize the development of appropriate metrics, measurement technology, and techniques for testing conformance to new high-technology software specifications.

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GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems (GIS) technology allows users to collect, manage, and analyze large volumes of spatially referenced and associated data. New research directions are emerging from the interdisciplinary uses of GIS technology through studies integrating computer graphics standards, database management standards, expert systems technology, and Global Positioning Satellite technology to support GIS applications. This group's research is focused on providing GIS compatibility through standards and conformance testing for GIS standards, such as the Spatial Data Transfer Standard (FIPS PUB 173). Because the activities of many governmental and private organizations are land- or location-based or both, GIS technology will be important in integrating existing spatial data to administer, manage, and monitor people, money, and activities in accomplishing the objectives of these organizations.

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SECURITY TECHNOLOGY

Research and development efforts focus on common, interoperable cryptographic security technology, such as algorithms, functionality, and interfaces, and on protocols; public key infrastructure for managing public key certificates needed to facilitate data integrity, authentication, access control, non-repudiation, and data confidentiality services in global applications; and application interfaces for cryptographic modules. Development efforts include standards, guidance on the use of cryptographic technology, and conformance tests so that strong cryptographic mechanisms will be available for the protection of sensitive information. Cryptographic standards promote interoperability and an acceptable level of security. Testing of products which were built to conform to the standards verifies that the provisions of the standard were implemented correctly. NIST has begun testing of more complex cryptographic modules through accredited, private-sector laboratories and plans to promote testing of entire systems in the future. The Cryptographic Module Validation Program encompasses testing for cryptographic modules (Federal Information Processing Standard (FIPS) 140-1), the Data Encryption Standard and its modes of operation (FIPS 46-2 and 81), the Secure Hash Standard (FIPS 180-1), and the Digital Signature Standard (FIPS 186). For details, see the Computer Security

Resource Clearinghouse, which may be accessed at http://csrc.nist.gov/cryptval/.

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SYSTEMS AND NETWORK SECURITY

Research, development, and application efforts focus on secure, interoperable systems to protect the integrity, confidentiality, reliability, and availability of information and systems. R&D efforts addresses technical areas such as advanced countermeasures (for example, intrusion detection, firewalls, and scanning tools); vulnerability analysis and mitigation, access control, and incident response; security criteria and metrics; assurance methods; role-based access control to network resources and Internet security (such as key management).

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ADVANCED NETWORK TECHNOLOGIES

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HIGH-SPEED NETWORKS

NIST researchers are working with industry in the development of protocols for the Broadband Integrated Services Digital Network (B-ISDN) or Asynchronous Transfer Mode (ATM) networks, and Hybrid Fiber-Coaxial (HFC) systems. The goal is to expedite the development and deployment of high-speed, interoperable communications systems and services. NIST provides leadership at the ATM Forum in developing test suites for ATM product interoperability and standards conformance testing.

Research projects include ATM network simulation and modeling, evaluating the completeness and correctness of ATM routing protocols, evaluating proposals for the Media Access Protocol for HFC systems, and developing test and measurement methods for interoperability and conformance.

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MULTIMEDIA AND DIGITAL VIDEO

NIST researchers are working with industry to promote the development of cost-effective, interoperable, distributed multimedia applications and to enable the development of digital video technologies for broadcast, interactive television, video-on-demand, and video conferencing. Research emphasizes measurement techniques for characterization of distributed multimedia technologies and digital video devices and services; techniques for integrating multi-media services with network technologies; and industry-driven standards for multimedia technologies and digital video devices and services.

Research projects involving video teleconferencing technologies include close collaboration with the International Multimedia Teleconferencing Consortium to define and conduct interoperability testing for T.120 and H.324 standards-based products and research and development activities related to teleconferencing technologies over multicast. The latter includes the definition of a convergence layer between T.120 and transport multicast and fast track improvements to the T.120 International Telecommunications Union standard. Research projects involving resource sharing in a multimedia environment include the development and implementation of mechanisms for sharing applications among participants on different platforms through a collaborative Java-based application.

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NEXT-GENERATION INTERNET

NIST researchers are working to remove barriers to the next generation of reliable and secure internetworking technologies and integrated network services. The focus of research is on testing methods and reference implementations for next-generation internetworking technologies; interoperability among next-generation internetworking products; and measurement techniques and performance characterizations for network services that integrate voice, video, and data.

Research projects include investigating changes to the Internet architecture that will support guaranteed bandwidth and quality of services for real-time applications, such as audio, video, and synchronized data. This project focuses on the scalability of the proposed enhancements, interoperability issues, and methods and metrics to characterize the digital data streams.

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HUMAN-MACHINE INTERFACE TECHNOLOGIES

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SPOKEN LANGUAGE TECHNOLOGY

Recent advances in automatic speech recognition (ASR) technology have enabled the development of automatic dictation and spoken language understanding systems and prototype spoken language interfaces to information technology. Interdisciplinary efforts involve the natural language processing, information retrieval, and cognitive engineering (for example, usability testing and human factors) communities.

Much of the relevant research is "corpus-based" and relies on shared use of spoken language databases and standard test methods.

NIST works closely with researchers, other government agencies (such as the Defense Advanced Research Projects Agency), and the Linguistics Data Consortium in the collection, processing, characterization, and distribution of spoken language corpora. Approximately 150 CD-ROMs have been produced by NIST for use within the ASR and spoken language research community. NIST also develops and implements periodic benchmark tests to define the state of the art for research ASR systems. The scope of these tests includes several forms of large vocabulary continuous speech, including speech read from prepared texts, conversational speech, goal-directed spontaneous speech, and, most recently, radio broadcasts. Research facilities include Sun workstations, speech-signal-processing software tools and peripherals, and CD-ROM production tools. Areas of interest include characterization of spoken language data, ASR, natural language understanding and information access, and usability testing.

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TEXT SEARCH AND RETRIEVAL

NIST is working to accelerate the transfer of better text search and retrieval technology into commercial systems. One approach is to conduct a conference attracting international participation from more than 50 research groups in text retrieval, both from industry and academia. The Text Retrieval Conference (TREC) is now starting its fifth year. Participating groups work with a large, diverse test collection built at NIST, submit their results for a common evaluation, and meet for a 3-day workshop to compare techniques and results. The conference is starting to serve as a major technology-transfer mechanism in the area of text retrieval.

NIST also has developed a public domain prototype retrieval system (the PRISE system) capable of handling over 3 gigabytes of data. This system uses natural language input and state-of-the-art statistical ranking mechanisms. The prototype serves as a research vehicle within NIST and as a starter kit for groups outside NIST interested in working with these new types of search engines or with the Z39.50 (ANSI/NISO) protocol for search and retrieval, which is used for communication between the PRISE client and server. The PRISE server is especially designed to isolate the search engine from the details of the Z39.50 protocol and to minimize the effort needed to interface the server to natural language search engines other than PRISE. More information is available on http://potomac.ncsl.nist.gov/

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VISUAL IMAGE PROCESSING

The visual image processing group develops test methodology and testbed systems and publishes test data for evaluating image based systems used in optical-character recognition (OCR), document conversion to electronic form, fingerprint classification, and face recognition. These evaluation methods are designed to include a wide variety of statistical and neural network algorithms and system architectures. The methods being developed are used for automated fingerprint classification, automation of data entry from images of handprinted forms, automation of conversion of machine-printed documents to electronic form and measurement of recognition systems on realistic applications. Data sets, evaluation software, and prototype OCR and fingerprint classification systems are distributed on CD-ROM. More information is available on http://www.nist.gov/itl/div878/878.03/vip.html

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THREE-DIMENSIONAL VISUALIZATION

The visualization group conducts research to demonstrate the utility and feasibility of three-dimensional visualization and computer graphic techniques to access, manipulate, and exchange complex information. Information visualization is a process of transforming data and information that are not inherently spatial into a visual form allowing the user to observe and understand the information.

NIST is developing an interactive visual interface to a statistical text retrieval system. The objective is to demonstrate the utility of visual interfaces for supporting access to large collections of complex documents. Evaluation methodologies and test corpora for measuring scalability and usability of visual interfaces, which are being constructed to support this endeavor, will be made available to the research community. In the manufacturing domain, NIST is collaborating with industrial partners to investigate how the application of three-dimensional visualization can speed up the manufacturing process. This effort includes the use of commercial off-the-shelf software to create visualizations of factory floor assembly lines and support for parts design and assembly. NIST researchers are analyzing usability and performance capabilities of a number of virtual environment and World Wide Web visualization tools for these and other related applications. More information is available on http://speckle.ncsl.nist.gov/~jacki/vvrg.htm

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APPLIED AND COMPUTATIONAL MATHEMATICS

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MATHEMATICAL MODELING

Mathematical and computational problems are becoming more elaborate as measurement techniques, physical understanding, and computational capability improve. Solving these problems requires innovative combinations of the methods of modern applied and computational mathematics. With the collaboration of other scientists and engineers, mathematicians of the Applied and Computational Mathematics Division develop and analyze mathematical models of phenomena; design and analyze computational methods and experiments; transform these methods into efficient numerical algorithms for modern, high-performance computers; and validate and extend the models by comparing them with experiments. Major research interest areas include crystal growth, fluid flow, electromagnetic waves, magnetic materials, molecular dynamics, foams, and polymers. Frequently occurring mathematical areas include partial differential equations, random processes, and inverse problems.

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MATHEMATICAL SOFTWARE

The increasing prevalence of computation in science and engineering has generated an acute need for accurate and robust computer software to solve frequently occurring mathematical and statistical problems. NIST mathematicians and computer scientists are actively involved in the development of algorithms for the solution of such problems, as well as in the reliable and maintainable implementation of these algorithms on modern high-performance computers. Division researchers undertake specific projects in response to both internal NIST needs and the needs of the computational science community in industry and academia. Recent efforts address such problem areas as the evaluation of mathematical functions, the adaptive solution of partial differential equations on distributed memory multiprocessors, and the design of high-performance software for large sparse linear systems.

Such research has fostered associated efforts in improving the environment for mathematical software research, development, and use. Areas of concern include highly reliable arithmetic systems, object-oriented software design, test and evaluation methodology, automated distribution mechanisms, and expert advisory systems. Examples of these efforts include the Guide to Available Mathematical Software—a virtual mathematical software repository—and the Matrix Market—a source of test data for evaluating sparse matrix algorithms. Both are operated as publicly available network services.

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OPTIMIZATION AND COMPUTATIONAL GEOMETRY

The use of optimization techniques is increasing in design, process modeling, and broad areas of science and engineering, economics, and management. Examples include the use of optimization models in curve and surface fitting, parameter estimation, maximum entropy, minimum energy, maximum likelihood as well as in newer areas such as performance improvement in production systems and advanced design and control. Improved algorithms and computational power have led to the consideration of multidisciplinary optimization models that pose significant new challenges in all areas of optimization. Division researchers design, analyze, and implement large-scale optimization algorithms and use these methods to develop and solve optimization models in many areas. Current concentration is on large-scale algorithms for non-convex, nonlinear programming problems using interior-point methods and sequential quadratic programming.

Computational geometry is a rapidly emerging field with applications in robotics, statistical mechanics, cartography, computer graphics, materials science, and molecular dynamics. NIST researchers are developing robust and efficient computational schemes for large-scale terrain modeling, molecular beam epitaxial simulations, and related problems. Algorithms and software are in wide use at NIST and many other scientific and commercial centers.

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IMAGE COMPRESSION

A recurring theme in information science is the need for efficient encoding of stored and transmitted information. Common information encoding schemes are typically ill-suited to computers and to data networks and, as a result, can be improved substantially. Image compression is an important emerging concern because the infrastructure does not meet the user demands for still images, sequences of still images (for example, in exploratory surgery), and video. More importantly, the trends indicate that the demand will increase while the systems of the future, by being highly mobile, will rely on inherently limited communications and storage technologies (for example, wireless communications and storage media of minimal weight).

Division scientists perform applied and reference implementation research in areas including the development of efficient image compression techniques with emphasis on wavelets, on adapting generic compression techniques for image compression, and on error correction codes that are tuned to the needs of image compression. The group also develops reference software and data that facilitate algorithm development and the testing of such algorithms for performance and correctness of output (for example, compliance testing). Finally, metrics for quantifying the quality of the images produced by lossy compression schemes are being developed.

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STATISTICAL ENGINEERING

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INDUSTRIAL EXPERIMENTATION

NIST's collaborations with industry and its projects to support industrial research and development typically involve the conduct of experiments, generation of data, and analysis of the results. NIST statisticians participate in these collaborations by contributing strategies for experimentation, graphical and numerical data analysis, stochastic modeling of empirical phenomena, uncertainty evaluation, computationally intensive methods, and reliability modeling.

Ongoing collaborative research projects include the following:

- improving measurements of lithographic overlay on semiconductor wafers by using hybrid electrical-optical test structures;
- developing certification and uncertainty analysis methodology for Charpy V-notch measurement machines;
- developing a non-contact sensor for measuring the temperature of hot-rolled aluminum;
- working with an industry consortium to compare various methods for machining ceramic components;
- applying robust regression to optical fiber dimensional quality control;
- developing a practical protocol for reliable measurement of solderability using a wetting balance;

- working with an industry consortium on predicting the service life of metals coatings;
- error modeling and correction for improving metrology characteristics of coordinate measuring machines; and
- evaluating the effects of various processing methods and formulations on strength and durability of concrete.

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MEASUREMENT PROCESS EVALUATION

Measurement is the backbone for advancing scientific research and creating new technologies. NIST statisticians collaborate with subject experts in developing techniques for evaluating measurement processes, tying measurement processes to accepted standards, and assuring the quality of measurements. Expertise in the design of experiments, modeling, estimation of components of variance, interlaboratory studies, quality control, and uncertainty analysis, coupled with a strong research focus, brings statisticians into contact with leading researchers in measurement science, both at NIST and elsewhere. This expertise also provides opportunities for contributing to the measurement science base for emerging technologies.

In the initial phases of such programs, experiments at NIST and with industrial partners are conducted to evaluate the status of measurements in the user community. Problems are identified, and models for describing the error structure of the measurements are developed and validated. The initial characterization, which may require several rounds of experimentation and produce refinements to the measurement process, is followed by the development and dissemination of artifact standards, test methods, and procedures for the measurement technology of interest.

For example, statisticians have worked with other NIST scientists in cooperation with the FBI to develop standards to assure the quality of DNA measurements that are introduced as physical evidence in legal proceedings.

Statisticians are working with scientists from NIST's Electronics and Electrical Engineering Laboratory on the development of artifact standards for measuring the sheet resistance of silicon wafers. In cooperation with the semiconductor industry, a new measurement method was developed and interactions between probing instruments and wafers were studied.

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SCIENTIFIC VISUALIZATION

Researchers at NIST are developing and applying advanced methods for using state-of-the art, computer-based scientific graphics for rendering complex experimental, computational, and analytical results in physics and chemistry. Researchers use a collection of vector and raster workstations, photographic and video hardware, high-speed networking for transmitting large graphics data sets between computers and graphics devices, and computational geometry algorithms and software for the analysis of two- and three-dimensional data sets. Techniques also have been developed to manipulate dynamic objects in automated design and manufacturing systems; to display quasicrystal structures with icosahedral symmetries and scanning electron tunneling microscopy data with polarization analysis; and to study models of turbulent combustion showing the dependence of solutions on time and fuel-oxidizer mixture parameters.

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PERFORMANCE OF MODERN-ARCHITECTURE COMPUTERS

NIST researchers in the area of computer-systems performance are promoting the effective evaluation and efficient use of advanced computers by the federal government. Their areas of interest include characterization of new computer architectures to identify improved technology for applications, exploration of economical programming methods that standardize across classes of architecture, and design of coherent evaluations that economically and reliably characterize the machines.

These NIST researchers also are involved in the development of instrumentation and related management techniques for gigabit networks of workstations and computers used for scientific calculation and visualization-based applications.

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CONTINUAL UPGRADES

The laboratory maintains a central scientific computing environment for NIST staff at Gaithersburg and Boulder. It procures and operates computer and communications facilities and maintains them at state-of-the-art levels suited to the needs of a highly diverse scientific and engineering research and development community. The continuing program of upgrading responds to advances in hardware, software, and communications technologies as well as to changes in the kinds of tools used in modern scientific research.

NIST specialists log and analyze the use of the components of the facilities—hardware, software, operating systems, and networks—to determine what changes or new equipment will be most useful. They take steps to acquire them where possible or to develop them internally. They design interfaces as needed for users to gain access to the resources best suited to their needs. This work proceeds with a broad view of the overall operation of the computing environment and its interactions with external environments as well as detailed understanding of the progress of hardware and software capabilities and of the roles of visualization and networking in the design and execution of scientific computing projects.

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RESEARCH FACILITIES

COMPUTER AND NETWORK SECURITY FACILITY

The NIST Computer and Network Security Facility is used to improve the current security posture of federal computer and telecommunication systems and to provide security for these systems as they migrate toward open system environments. Research performed in the facility is aimed at applying methods to protect the secrecy and integrity of information in computer systems and data networks, evaluating personal identification and authentication techniques to control access to information resources, and developing computer and network security architectures to determine proper implementation of controls for integrity and confidentiality of information and authentication of users.

CAPABILITIES

The facility is equipped with desktop computers and workstations, security devices, terminals, personal identification systems, and access to supercomputers through local-area, national, and global networks. Several communications technologies and applications environments are available for research efforts for developing and testing security protocol standards.

Operational capabilities include a computer emergency response team to facilitate identification and response to acute computer and telecommunications security incidents involving self-replicating computer viruses.

Test and evaluation capabilities range from specific functionality tests of cryptographic modules to test methodologies for network security protocols to the specific criteria used to evaluate the trustworthiness of systems that handle unclassified, but sensitive, data.

A laboratory is available for research in risk management techniques and methodologies and evaluation of risk management software to determine applicability to environments at different agencies. Several computers support the development of advanced computer access control systems based on smart-token technology and the virus laboratory for research in multiuser environments. A small systems security laboratory completes the Computer and Network Security Facility.

APPLICATIONS

The facility is used primarily to develop and test federal standards for computer and network security. Support is provided to other federal agencies and industry where the protection of unclassified data is required.

AVAILABILITY

Collaborative research programs can be arranged.

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ADVANCED NETWORK FACILITY

The facility is equipped with desktop computers, workstations, protocol analyzers and simulators as well as ATM, ISDN, Internet, and satellite communications facilities and switches.

APPLICATIONS

Facilities are used to develop and assess design alternatives, evaluate performance, and test standards for advanced communications and distributed multimedia systems, which include the following:

- ATM Network—The testbed consists of an ATM switch and several workstations. The testbed is connected to the NIST ATM network and a wide-area ATM testbed.

- Digital Video Interoperability Testbed—The testbed consists of facilities for testing the video-on-demand application conforming to the Digital Audio/Visual Council specification, including MPEG2 video source and server, Digital Storage Management Command and Control system, and set-top units. Various network access mechanisms, in addition to ATM networks, are being planned.

AVAILABILITY

Collaborative research programs with government, industry, and academia can be arranged.

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SUBJECT INDEX

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NIST Special Publication 858
September 1996 edition

Prepared by Public and Business Affairs
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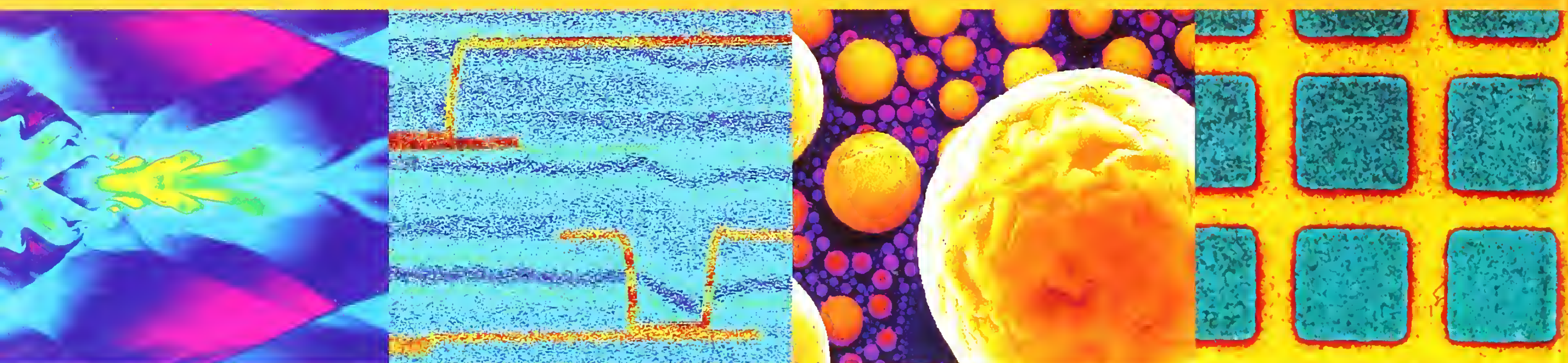

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