Collaborating With Our Customers

# NIST Building & Fire Research Laboratory

U.S. Department of Commerce

Technology Administration

National Institute of Standards and Technology

**U.S. Department of Commerce**
Ronald H. Brown, Secretary

**Technology Administration**
Mary L. Good, Under Secretary for Technology

**National Institute of Standards and Technology**
Arati Prabhakar, Director

August 1993
Developed by Noel J. Raufaste
NIST SP 838-3

# Director's Message

The competitiveness of all U.S. industries and the quality of life of all people depend on the quality of the constructed facilities that shelter and support most human activities. Construction also is of great direct economic importance. Annually, in excess of $600 billion is spent in the United States on the design, construction, maintenance, repair, and renovation of constructed facilities, according to statistics from the U.S. Department of Commerce. New construction alone employs 6 million people.

Safety is essential to quality and competitiveness. Fire losses and costs of fire safety are in excess of $100 billion annually. A single major earthquake of the magnitude of the Loma Prieta earthquake of 1989 close to any major urban center would cause estimated losses of $60 billion to $100 billion. Wind damage to constructed facilities exceeds $4 billion per year; damages from Hurricane Andrew in 1992 were more than $20 billion.

The Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST) is dedicated to the life cycle quality of constructed facilities. NIST's primary mission is to help U.S. industry to strengthen its international competitiveness. 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 of constructed facilities. Its products are used by those who own, design, construct, supply, and provide for the safety or environmental quality of constructed facilities.

BFRL works closely with its customers to identify needs for improved practices, conduct the needed research and development, and transfer research results to practice. BFRL reaches out to its customers through participation in professional, trade, and standards organizations. In its research and development activities, BFRL encourages the participation of its customers as guest researchers, in consortia, and in cooperative research and development agreements.

Major themes of BFRL's work are the performance concept and open systems for the products and services of constructed facilities. The performance concept is to make explicit, quantitative, predictable and measurable the users' needs for the performance of the materials, components, and systems of constructed facilities. For instance, how much time does an occupant need to evacuate a burning building, and does the fire safety system provide that time reliably?

Open systems allow improved materials, components or practices to be introduced into constructed facilities and the construction process without excessive cost or extensive modifications to other elements. BFRL supports open systems by making the performance of the system predictable from the properties of its components, and providing the interface criteria and measurement methods needed for acceptance of components.

This "Perspective" describes how BFRL's projects respond to needs of the principal classes of its customers in the construction and fire safety communities: owners, designers, and constructors; producers and suppliers; standards and codes interests; and the fire services. Our projects address major needs and opportunities for improving the life cycle performance of constructed facilities, including:

- high-performance concrete and steel
- "green" building technologies
- integrated, automatic control systems for operation of constructed facilities
- computer-integrated, effectively automated design and construction practices
- reduction of losses from unwanted fires, earthquakes, and extreme winds

We invite you to read this "Perspective" and to contact us to gain access to our results or to explore collaborative activities. We encourage you to join with us in working to improve the competitiveness of the construction industry, the quality of constructed facilities, and the safety and quality of life of their users.

Richard N. Wright
Director

**Typical of BFRL's research is development of improved measurement methods which provide the technical basis for standards for design and construction practices. Shown here is Steven Nabinger, mechanical engineer, measuring airborne concentrations of volatile organic compounds which were collected during indoor air quality investigations. Chromatographic analysis is used to identify specific organic compounds in the air sample. This work advances the Administration's thrust in environmental quality.**

# Building and Fire Research Laboratory at a Glance

## BFRL's Resources

- over 90 years of experience
- unique facilities
- staff of more than 200
- $24 million annual budget
- expertise in structures, building materials, mechanical systems, building environments, fire science, and fire safety
- access to advanced technologies
  - –mathematical modeling
  - –high-speed instrumentation
  - –non-destructive testing and diagnostics
  - –information technologies
  - –modeling environmental processes
  - –advanced fire detection and suppression

## BFRL's Opportunities

- laboratory visits to share information
- cooperative research and problem solving, access to unique resources
- cooperative proprietary research to achieve customer's technology mission, with industry partner holding rights to intellectual property
- guest researcher assignments for collaborative research
- research consortia to solve industry-wide problems
- licensing inventions

## BFRL's Divisions

**The Structures Division** provides the construction community with technologies to increase the productivity and safety of construction. The Division:

- provides technical bases for improved structural, earthquake, and wind design criteria;
- conducts laboratory, field, and analytical research in structural engineering, including investigations of important structural failures, characterization of building loads during construction and service, and structural response analyses;
- produces evaluation methods and criteria leading to safer and more economical construction practices; and
- determines engineering properties of soils and foundations and develops non-destructive evaluation methods and criteria for increasing structural properties.

*Contact:*
Dr. H.S. Lew
301-975-6061

**The Building Materials Division** performs research to advance construction materials science and technology. The Division:

- conducts analytical, laboratory, and field research, including the development of methods to measure and predict service life of construction materials; and
- develops technical bases for improving criteria and standards used to evaluate, select, use, and maintain construction materials and for improving tools to make decisions in selecting construction materials, including high-performance concrete and steels.

*Contact:*
Dr. Geoffrey J. Frohnsdorff
301-975-6706

## BFRL's Divisions *(continued)*

**The Building Environment Division** provides technologies to improve performance and reduce costs of designing, constructing, and operating constructed facilities.
The Division:

- develops data, measurement and test methods, and modeling techniques to determine building air leakage, the performance of the building envelope and its insulation systems, and the release, movement, absorption of indoor air pollutants, the performance of building mechanical and electrical equipment, and the quality of the indoor environment; and
- develops performance criteria, interface standards, and test methods to help the nation's building industry make better use of computer-aided design hardware and software.

*Contact:*
Dr. James E. Hill
301-975-5851

**The Fire Safety Engineering Division** develops methods to predict the behavior of fire and smoke and to assess ways of mitigating their impact on people, property, and the environment.
The Division:

- develops and demonstrates the application of analytical tools to building fire problems and quantitative prediction of threats to people and property from fires, as well as the means for assessing the accuracy of the models;
- develops techniques to predict, measure the behavior of, and mitigate the impact of large fires;
- maintains and advances the Fire Research Information Service (301-975-6860); and
- operates BFRL's large-scale fire test facility.

*Contact:*
Dr. Andrew J. Fowell
301-975-6863

**The Fire Science Division** develops metrology for fire research and understanding of the scientific and engineering aspects of fire phenomena. The Division:

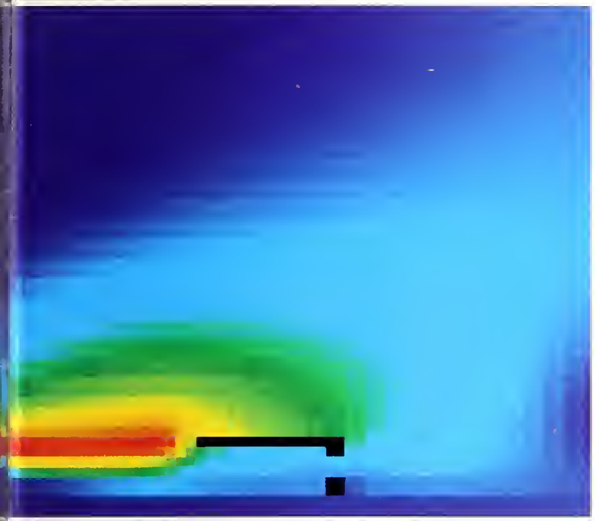
- produces principles, metrology, data, and predictive methods to evaluate the smoke components in flames and the burning of polymeric materials;
- generates science and predictive methods for the development of high-performance fire detection and control systems; and
- develops understanding of and information about new fire suppressants and their use.

*Contact:*
Dr. Richard G. Gann
301-975-6864

**Right: Measurements are critical to the producers of building-related products. William Pitts, research chemist, is making real-time measurements of scalar values (such as concentration) in turbulent flows. These measurements are used to validate computational fluid dynamics codes and to develop models for industry's chemical reacting turbulent flows, combustion systems, and mechanical systems.**


BRIGHTNESS
CONTRAST
DEGAUSS

# Owners, Designers, and Constructors



**Computer scientist Glenn Forney develops computational models to determine the flow characteristics in different structural geometries. Such models are used by designers to plan more fire-safe facilities. Shown here are thermal gradients induced by fires and their effect on the structure and surrounding environment.**

BFRL provides the analytical tools, procedures, and practices needed for improved design, construction, and operation of constructed facilities. Better methods to test, measure, and predict the performance of materials, systems, and processes will lead to increased productivity and comfort of building occupants and reduced construction, operating, and maintenance costs. Improved fire hazard modeling, materials, and fire detection and suppression systems save lives and reduce losses from fires. Safer facilities reduce human and economic losses from disasters.

### Open Systems

BFRL researchers take an open systems approach to permit products or components manufactured by different companies to be used in the same building. With open systems, owners can consider alternative suppliers for the components of the initial system, combine manual and automated functions cost effectively, modify their system to respond to new requirements, and upgrade the system incrementally as technologies and needs evolve.

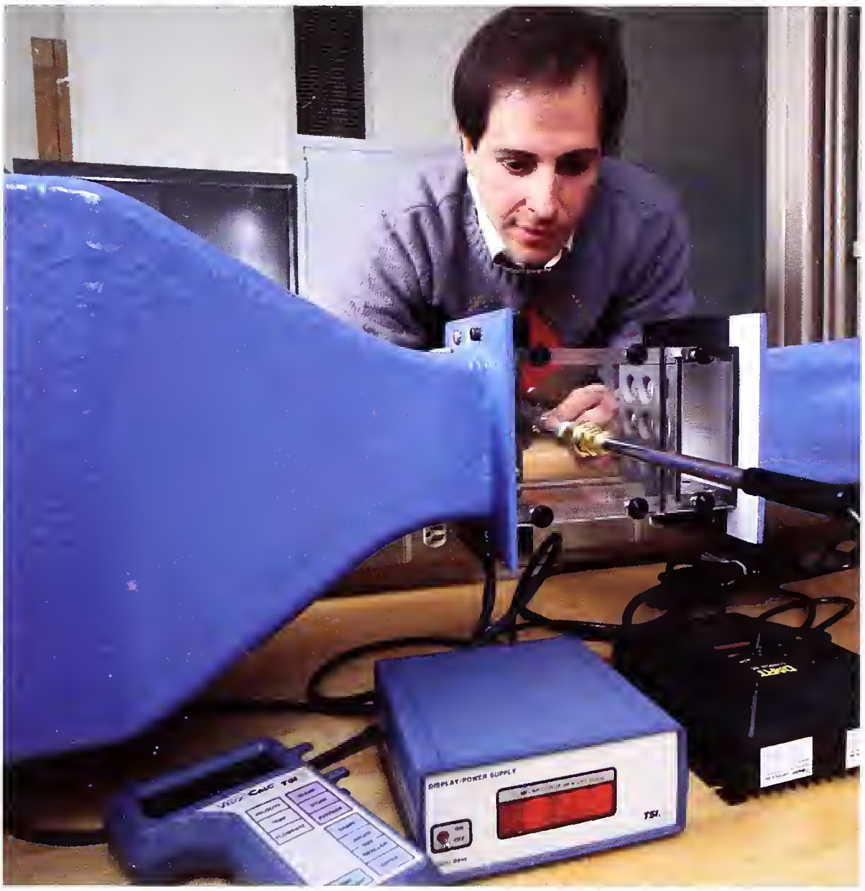
For example, in cooperation with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, BFRL has developed a standard communication protocol—called BACnet (Building Automation and Control Networks)—for direct digital control of building control systems.

BFRL researchers also are working to standardize information formats so architects, engineers, manufacturers, contractors, and owners can exchange automatically drawings and data generated on different computer-aided design systems. This work is part of an international standardization effort known as STEP (Standard for Exchange of Product Data) that includes all industries. This standardized information exchange project is part of BFRL's effort to advance computer-integrated construction.

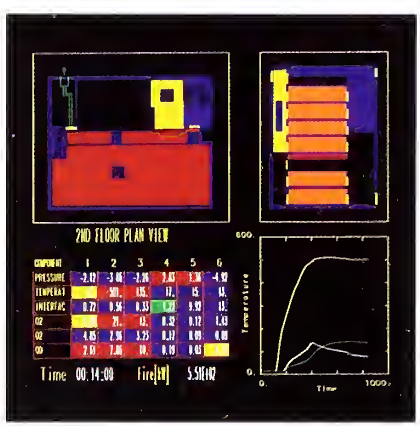
### Computer Models for Decision Making

Advances in computing hardware permit BFRL to offer its customers vastly improved methods for predicting, testing, and measuring the performance of systems and materials. The Lab develops, evaluates, and tests communication protocol standards so building mechanical and electrical systems can be increasingly integrated and automated. A major part of this work involves the development, verification, and refinement of dynamic-simulation models for heating, ventilating, and air conditioning (HVAC) and control components and systems. In addition, BFRL researchers are conducting theoretical and experimental studies on building/HVAC/control system dynamics. Simulation models are being developed that will predict the transfer of moisture through walls, movement of pollutants from materials and equipment throughout a building, and spread of fires throughout buildings. With these tools, architects and engineers can design facilities to minimize the risk from such events.

HAZARD I, an advanced computer model, makes it possible to assess the fire safety of a specific building and the change in the safety level that will result from changes in building design or composition of building components or furnishings. Using data about the building design, materials and furnishings, room arrangements, door and window configuration, and the nature of a fire, HAZARD I predicts temperature, smoke and toxic gas concentrations in each room, and the likely loss of life and injuries.




**Stuart Dols, mechanical engineer, is calibrating an air velocity probe in preparation to assess the performance of ventilation systems of large buildings, leading to development of advanced techniques for evaluating indoor air quality.**




**Computer models make it possible for building owners, designers, contractors, and others to improve fire safety at reduced costs. Using BFRL's HAZARD I, they can predict the spread of smoke, toxic gases, and heat from a fire in a room to other parts of a building without having to burn a room or building.**

Architects and builders can use HAZARD I to gain approval of building designs by code authorities. With the model, they can calculate the most cost-effective design trade-offs in selecting materials and fire-control technologies to meet building code requirements.

BFRL and the Portland Cement Association, working through a Cooperative Research and Development Agreement (CRADA), are examining the effect a fire has on concrete building components such as walls, ceilings, and floors. They will use this information to produce an advanced version of HAZARD I that will apply to a wider range of fires, building types, and materials.

### New Techniques to Improve Work Quality

The Lab develops guidelines and expert systems that provide decision tools to improve the quality of work in the construction industry and contribute to the rehabilitation of the U.S. infrastructure. For example, the expert system on highway concrete (HWYCON), developed by BFRL and sponsored by the National Academies' of Science and Engineering, National Research Council's Strategic Highway Research Program (SHRP), assists highway inspectors and engineers to diagnose problems on site and select appropriate concrete materials for the construction or repair of pavements and highway structures such as bridge decks and columns. The portable expert system contains facts, accepted practices, and guidelines from concrete experts and professional associations as well as pictures and drawings that facilitate its use. It was successfully pretested by users from more than 10 state Departments of Transportation and universities. HWYCON now is distributed by SHRP to state highway departments, engineering firms, and material specialists.

### Improved Building Operations

A major thrust of BFRL research is to improve the safety, comfort, and productivity of building occupants through the development and application of energy conservation and environmentally "friendly" technologies. This work focuses on energy efficient and color corrected lighting systems: automated and integrated building control systems for heating, cooling, ventilation, illumination, fire control, communication, improved indoor air quality, and energy efficiency of appliances and materials.

BFRL researchers provide building managers and operators, designers, indoor air quality consultants, and industrial hygienists with tools to assess the impact of indoor air contaminants on the performance of ventilation systems. For example, BFRL pioneered tracer gas techniques for evaluating ventilation system performance and determining contaminant levels in mechanically ventilated office buildings. This research led to a better understanding of indoor air quality, particularly the relationship between ventilation and indoor air pollution levels. Advanced measurement techniques are being developed to more accurately measure ventilation system performance, assess the reliability of existing measurement techniques, provide prototype automated equipment to monitor ventilation system performance in the field, and produce advanced computer simulation tools that will allow designers to better estimate the effectiveness of ventilation systems before construction.

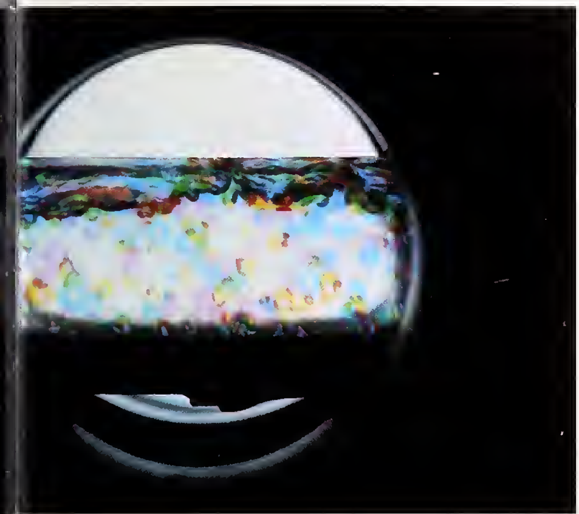
**Below: Computer scientist Lawrence Kaetzel and chemist James Clifton, HWYCON developers, evaluate the interactive expert system designed to help highway inspectors and engineers diagnose problems, select materials for construction, and repair highways and highway structures.**

**Center: Steven Bushby, electrical engineer, develops, evaluates, and tests communication protocol standards for the open exchange of information between equipment from different control vendors and between different control levels in hierarchical and distributed building management systems.**

The drive to conserve energy through tighter construction and better insulation often results in excess moisture in walls and roofs. Under sponsorship by the Department of Energy (DoE), BFRL developed a personal computer program, MOIST, that predicts the transfer of heat and moisture in building envelopes. The computer program, using hourly outdoor weather data, predicts the moisture content and temperature of the envelope layers as a function of time of year. This program is used by architects and engineers to predict damaging moisture accumulation in building walls and flat roofs, thus improving the performance of the envelope. Using MOIST, BFRL researchers assisted HUD by developing moisture control guidelines for walls and ceilings/roofs of manufactured housing. The guidelines have been incorporated into HUD's Manufactured Home Construction and Safety Standards.

**Cheol Park, mechanical engineer, develops simulation models to help designers accurately predict and improve the performance of heating, ventilating, and air conditioning systems and building controls. These models are validated using experimental data, documented through users' manuals, and publicized through technical talks and publications.**

# Producers and Suppliers



**Mark Kedzierski, mechanical engineer, takes photographs and measurements of the nucleate boiling heat transfer characteristics on refrigerants being tested as alternatives to chlorofluorocarbons.**

The Lab helps producers and suppliers develop, more economically, construction materials and products with improved performance, safety, and economy. BFRL develops test methods and conducts performance research for construction-related materials and systems ranging from concrete, steel, and paints to heating and cooling equipment. The Lab provides producers and suppliers with measurement and test methods, traceable to an authoritative national reference source, for accurate and cost-effective methods of quality assurance.

### Better Materials

In collaboration with the private sector and federal agencies, the Laboratory developed a national program to exploit the potential of high-performance concrete and steel. Concrete is the most widely used manufactured material; over 230 million kg (500 million tons) of concrete are placed in the United States each year, about 1000 kg (1 ton) for every U.S. citizen. With an annual cost of $20 billion, concrete for construction is targeted for performance improvements and cost reductions. Possibilities of greater strength, improved durability, and easier placement are driving BFRL work to predict and optimize concrete performance.

Precise characterization of concrete materials and better performance measurements will lead to better designs for concrete mixtures, which are now largely based on trial and error. Four major universities and BFRL comprise the National Science Foundation's (NSF) Center for Advanced Cement-Based Materials, a consortium investigating the chemistry, physics, and microstructure of concrete and related materials to generate the knowledge for improving their performance. Work is under way to produce concrete with compressive strengths of 170 to 200 million Pa (25,000 to 30,000 psi) — a fivefold increase in strength over today's conventional good concrete.

A BFRL-developed analytical tool predicts strength development in fresh concrete as a function of time and temperature. These predictions help increase the speed and safety of construction projects, such as high-rise buildings, where concrete must gain sufficient strength before formwork can be removed safely.

The Lab is conducting a comprehensive research effort to find and exploit refrigerant mixtures to replace harmful chlorofluorocarbons (CFCs) refrigerants, which are depleting the Earth's ozone layer. Even before the 1987 international agreement to phase out CFCs, BFRL researchers screened nearly 1,000 fluids in search of refrigerant replacements. This work revealed some fluorocarbons, which do not have ozone-destroying chlorine atoms, as candidates for replacement refrigerants.

In 1988, BFRL launched its current research effort to provide industry with the information needed to identify promising alternatives to CFCs, to retrofit existing equipment, and to design new equipment. As part of this work, BFRL has CRADAs with several firms. In association with the Electric Power Research Institute, the research and development arm of the electric utility industry, and with the Trane Co., an equipment manufacturer, BFRL is determining the performance characteristics of alternative refrigerants and providing technologies for the redesign of heat pumps and chiller systems to optimize performance using mixtures of alternatives/refrigerants.

**Full-scale fire tests are used to validate small-scale test procedures and models developed to predict the behavior of manufactured products for heat release rates and other data important for minimizing fire hazards.**

### Testing the Tests

Much of BFRL's work involves developing new test and measurement methods. To help industry assure that its tests are performed properly, the Lab develops reference materials for calibrating industry testing equipment. The Lab's Line Heat Source Guarded Hot Plate serves as a reference device to calibrate the accuracy of other hot plates. Standard Reference Materials, a fibrous-glass blanket (SRM 1451) and a fumed silica board (SRM 1449 and 1459), characterized using BFRL's hot plate are used by other laboratories to calibrate their devices. The apparatus is capable of measuring insulation 1-meter (39 in) in diameter and up to 400 mm (16 in) thick. Devices used previously could measure only samples about 25 mm (1 in) thick or less. This device is now an ASTM and ISO standard.

Besides providing Standard Reference Materials and techniques for the construction industry and fire community, BFRL administers two reference laboratories. The Cement and Concrete Reference Laboratory (CCRL) is sponsored by the ASTM and the Army's Corps of Engineers. The AASHTO Materials Reference Laboratory is sponsored by the American Association of State Highway and Transportation Officials (AASHTO). CCRL inspects cement and concrete testing laboratories and distributes proficiency test samples on cement and pozzolans (mineral admixtures), aggregates, and concrete for quality assurance in private and public construction materials testing laboratories that use ASTM standards. The AASHTO Materials Reference Laboratory provides similar services for soil and bituminous testing laboratories that use AASHTO standards.

BFRL fire research for producers and suppliers includes modeling combustion and flammability of materials ranging from engineered polymers and thermoplastics to composites to cellulosic materials. The work focuses on producing mathematical models to predict burning rates and flame resistance and on understanding fire ignition, flame spread, and flame retardant treatments. In parallel work, researchers are developing new fire safety technologies such as advanced fire detection systems and automatic fire suppression systems. For example, BFRL and E.I. du Pont de Nemours & Co., through a CRADA, are testing the effectiveness of a fire-blocking barrier on the flammability of upholstered furniture.

Degradation of the protective ozone layer has been accelerated by the effects of the halogenated fire suppressants (halons). BFRL is studying suppression mechanisms and screening potential alternatives to halon 1301 for in-flight fire suppression in its work for the Air Force, Army, Navy, and the Federal Aviation Administration. BFRL is a leader in the search for new suppressants and in optimizing ways to incorporate them into efficient systems.

### More Energy Efficient Building Systems

Residential buildings consume approximately 21 percent of all U.S. energy, costing the United States more than $100 billion annually. Space conditioning, water heating, and food storage account for 80 percent of this energy use. BFRL, in response to the National Appliance Energy Conservation Act, develops testing and rating procedures for central air conditioners, heat pumps, furnaces, water heaters, refrigerator/ freezers, and other residential appliances. A study by DoE's Lawrence Berkeley Laboratory, *The Regional Energy and Economic Impacts of the National Appliance Energy Conservation Act of 1987*, showed that mandated DOE minimum efficiency level standards that use BFRL's test procedures will result in $17 billion in energy savings for appliances purchased between 1990 and 2015. Also, the American Council for an Energy Efficient Economy reported that BFRL's work contributed to an average efficiency increase of 96 percent for refrigerator-freezers, 35 percent for central air conditioners and heat pumps, 30 percent for room air conditioners, and 18 percent for gas furnaces during the period from 1972 to 1986.

**BFRL researchers have characterized the flammability of alternative refrigerants under ambient conditions. In this example, an unacceptable level of flammability, evident by the blue horizontal flame, was found.**

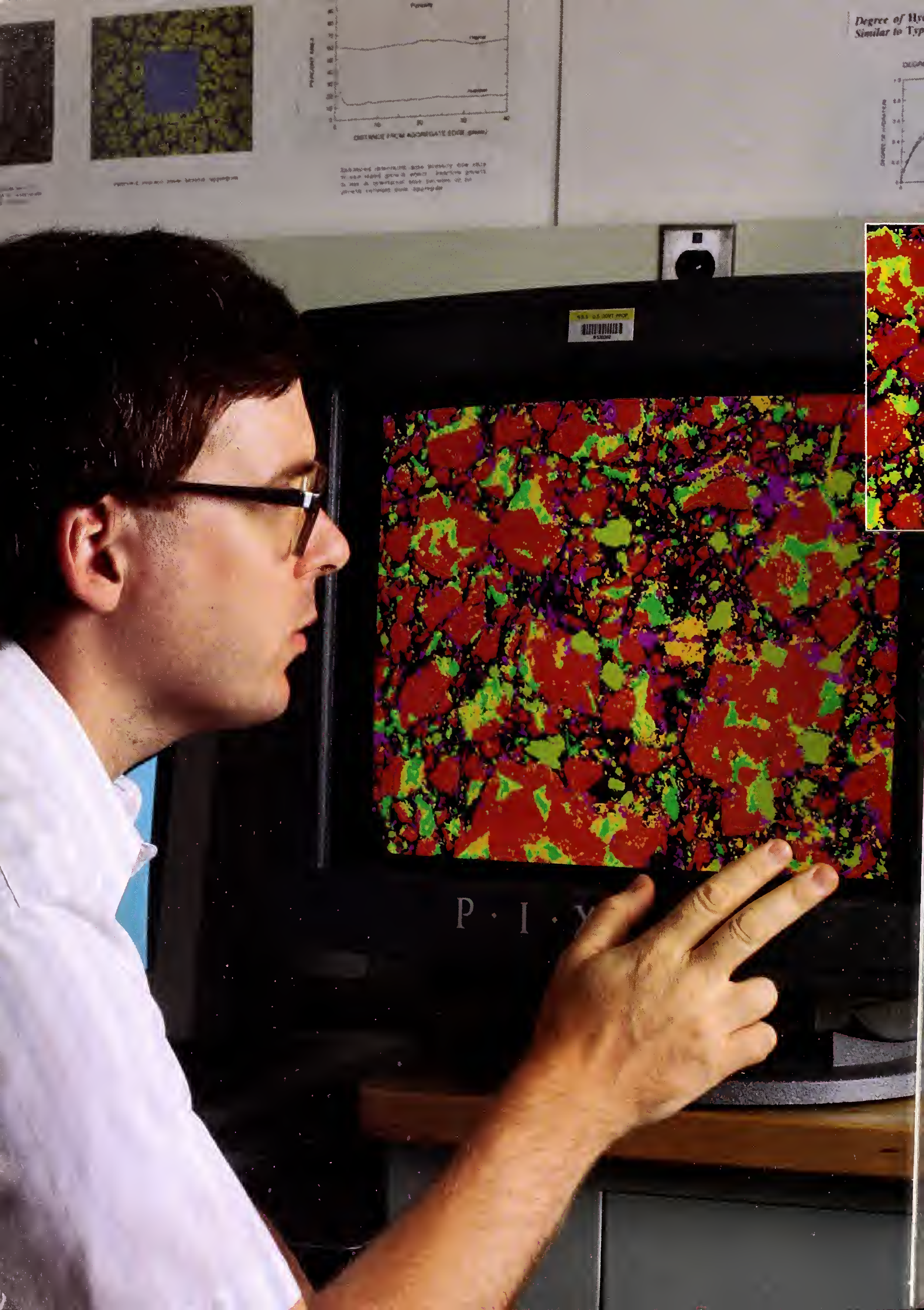

**BFRL researchers use computer models to characterize the molecular dynamics of thermal degradation of polymers. These computer models and the resulting data are used by manufacturers to make polymers more stable and fire resistant.**

### Less Flammable Materials

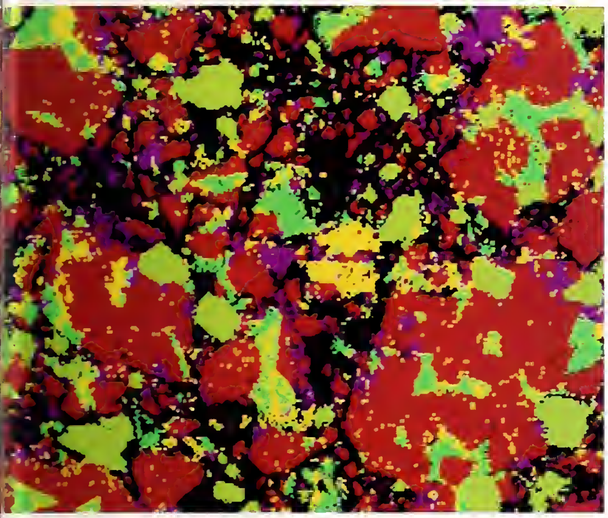
Losses from fires in buildings would be greatly reduced if furnishings did not burn or were less flammable. BFRL is developing advanced technologies that permit the design for fire safety of the materials used in furniture and interiors found in building and transportation systems. Lab researchers have developed methods to reduce the flammability of high impact and other commonly used polymers. For example, researchers found it was possible to cut the flame spread of an acrylic in half. With BFRL's polymer molecular dynamics modeling, researchers also are able to use computer simulations to develop new materials with improved fire resistance. With these tools, BFRL researchers are working with industry to help manufacturers design less flammable synthetics and to verify accurately the results.

**Nicholas Carino, civil engineer, tests high-strength concrete specimens to establish the technical basis for characterizing their mechanical properties.**

**Stanley Liu, mechanical engineer, helps to develop new procedures for measuring the energy consumption of residential equipment. Test procedures are used by manufacturers to determine the annual operating costs of their products.**



# Standards and Code Developers



**Edward Garboczi, physicist, develops computer models that simulate the development of the microstructure of concrete during the setting process. Models like this are used to predict concrete performance, strength, and durability.**

BFRL's findings influence the way buildings are designed and constructed, components are fabricated, and materials are manufactured and used. Its research results form the technical basis for many of the specifications, standards, and codes used by designers, constructors, producers, suppliers, and others serving the construction industry.

Although BFRL has no standards or code writing authority, 90 organizations that produce the standards cited in the nation's building codes rely on BFRL's research findings. BFRL staff participate in more than 150 domestic and international committees that develop standards for the construction and fire safety communities.

The Lab's study of plumbing loads and the hydraulics of drainage and venting provided the technical basis for revisions in plumbing provisions of the One and Two Family Dwelling Code, a model code widely used in the regulation of single-family dwellings. These changes are estimated by the National Association of Home Builders to save about $500 per dwelling, for a nationwide savings of about $500 million annually. BFRL's research also supports standards and codes for solar heating, energy conservation, building rehabilitation, mobile homes, structural serviceability, and fire safety of materials such as furniture and carpeting.

### Natural Hazards

In 1990, the Reauthorizing Act of the National Earthquake Hazards Reduction Program gave NIST the responsibility for research and development to improve standards, codes, and practices for new and existing buildings and lifelines (gas and liquid fuels, water and sewage systems, power and telecommunications, and transportation). BFRL's research includes determining the seismic behavior of masonry and precast concrete structures and the residual strength and energy absorbing capacity of damaged structures. In cooperation with other organizations, BFRL contributes to "recommended provisions" that provide the basis for the seismic provisions of national standards and the model building codes.

BFRL conducts earthquake engineering investigations as part of its effort to reduce human and economic losses from natural hazards. Some examples of earthquake investigations and subsequent improvements to practice include:

- San Fernando, Calif., 1971 – improved design provisions for highway bridges;
- Miyagi-ken-oki, Japan, 1978 – calibration techniques to evaluate the liquefaction potential of soils;
- Imperial County, Calif., 1979 – models that predict inelastic deformation and failure mechanisms in structures;
- Mexico City, 1985 – models that showed the importance of site amplification and duration of strong shaking on seismic performance of buildings;
- Loma Prieta, Calif., 1989 – practices for site hazard assessments and for seismic safety of new and existing buildings and lifelines.

**Max Peltz, technician, evaluates innovative precast beam-column connections undergoing earthquake motion tests.**

**BFRL performs post-disaster investigations to develop the most probable technical causes of failures. A failure of supporting columns resulted in the major collapse of the bi-level I-880 Viaduct during the 1989 Loma Prieta earthquake in the San Francisco area.**

In research performed for the Federal Highway Administration, the California Department of Transportation, and NSF, BFRL evaluated the effectiveness of bridge design specifications that were revised following the San Fernando Earthquake. Based on their model and full-scale structural tests of bridge columns, BFRL researchers determined that the revised specifications were adequate for seismic resistance. They also showed how the specification could be improved to reduce construction costs.

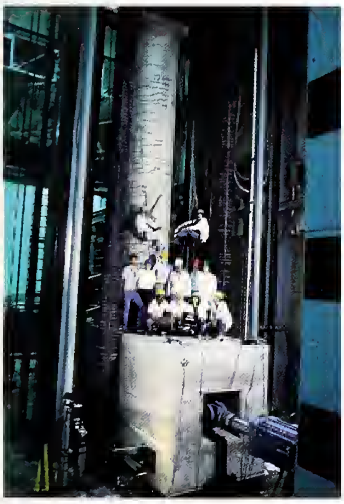
### Failure Investigations

As a neutral third party, BFRL investigates and reports on the physical causes of major structural failures. The research results provide technical bases for improved standards and construction practices and procedures.

For example, after the Lab identified the cause of the collapse of a suspended walkway in a Kansas City hotel in 1981 that killed 113 guests, the American Society of Civil Engineers and other organizations developed a manual to improve quality in design and construction. As a result of the BFRL investigation into the 1988 collapse of a large oil tank south of Pittsburgh that polluted the Monongahela and Ohio rivers, the American Petroleum Institute improved its standard for existing tanks.

**A 15,000 m$^3$ (4 million gallon) capacity oil storage tank cracked as a result of brittle fracture that initiated at a flaw in the tank's wall.**

**Vytenis Babrauskas, fire protection engineer and developer of the cone calorimeter, is collecting data critical to predicting the fire hazard of a product using a small sample of material. This test replaces time-consuming and expensive full-scale tests. ASTM and ISO adopted a voluntary fire hazard test method based on the instrument.**



**Testing is conducted to evaluate the seismic performance of concrete columns 1.5 m (5 ft) in diameter and 9.1 m (30 ft) high. Other tests have evaluated fracture propagation in steel plates 1 m (3.3 ft) wide and 90 mm (3.6 in) and 150 mm (6 in) thick.**

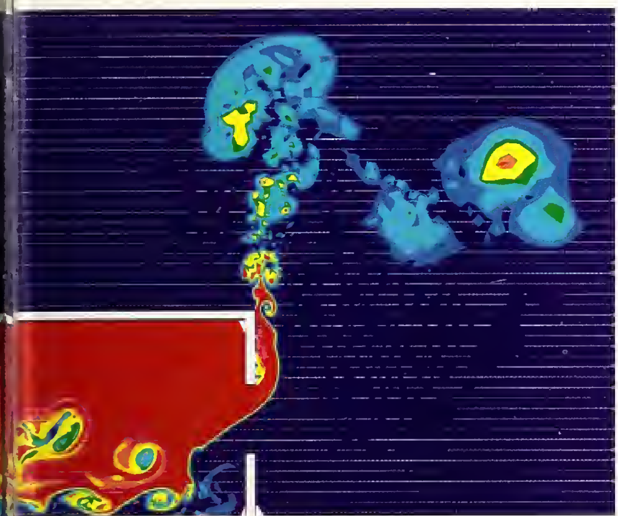
## New Testing Technologies for Industry

BFRL invented the cone calorimeter to measure the burning behavior of materials. The device measures the rate at which a small sample of a product releases energy by measuring the oxygen consumption. Rate of heat release is widely accepted as the most important property of a product in assessing its fire hazard and risk. It capitalizes on the principle that heat release is proportional to the amount of oxygen consumed and the constant of proportionality is nominally independent of the chemistry of the fuel. The device accurately represents the way that materials perform in fires. The cone calorimeter provides the basis for national and international standards for fire testing of materials. As a result, more than 100 cone calorimeters are used in federal, industrial, and university laboratories around the world.

The cone calorimeter enables product manufacturers to obtain data for assessing the degree to which a new or existing product contributes to a fire hazard. It, along with BFRL's HAZARD I model, is supporting a worldwide movement to performance-based fire standards and the creation, evaluation, and specification of a new generation of more fire resistant products.


SiliconGraphics

# Fire Safety Officials



Kevin McGrattan, computational fluid dynamicist, is using numerical techniques to evaluate the flow of smoke and hot gases released by fires.

BFRL is the primary U.S. source of new knowledge about the science of fire and a major player in the development of advanced fire safety technologies. The Lab's research generates scientific data and analytical tools that help fire safety officials prevent fires, reduce the damages of fire fighting, limit damage when fires do occur, and understand why and how they happen. The Lab focuses on developing the data and analytical techniques to predict fire hazard, tools that fire safety officials can use to estimate the risk of fire in facilities and to identify cost-effective ways to reduce that risk.

BFRL staff work closely with organizations that represent state and local fire safety officials, as well as all major fire service organizations in the United States and in several countries abroad. For example, the International Society of Fire Service Instructors, which represents local fire department training officers, transfers BFRL technologies to fire departments through state and local training programs.

BFRL works with the National Association of State Fire Marshals, which represents the 50 state fire marshals responsible for code enforcement, public fire safety education, and fire investigations, to investigate the cause of fires and to define fire research needs and priorities. Together, BFRL and the fire marshals are developing a networked computer database containing technical information necessary to run fire models such as HAZARD I. The National Fire Protection Association (NFPA) and the Society of Fire Protection Engineers advance fire protection engineering and develop fire standards. BFRL staff serve on many of the committees of these organizations that develop standards, codes of practice, handbooks, and other educational materials.

### Predicting Fire Hazard

BFRL research helps fire protection engineers design buildings against fires, fire safety officials assess innovative fire safety designs, and fire investigators determine the causes of fires during post-fire investigations. BFRL fire simulation methods help reconstruct the path of a fire to learn where, when, and how it started and the factors that led to the level of loss suffered. For example, using the Lab's computer models for fire growth and engineering formulas addressing mass burning rate, rate of heat release, smoke temperature, smoke layer depth, velocity of smoke/flame front, oxygen concentration in the smoke layer, sprinkler and smoke detector response, and fire duration, BFRL demonstrated the probable course of a fire in 1986 that raced through the lower floors of the Dupont Plaza Hotel in Puerto Rico and killed 98 people.

In another fire investigation, the 1988 Los Angeles First Interstate Bank Building fire, BFRL's investigation revealed the important relationship between the rate of burning material and the availability of air. Here, the availability of excess combustion air assured complete burning. Too, it showed the vulnerability of continuous glass construction used in many modern buildings and the potential value of sprinkler protection. BFRL's fire models are invaluable to fire investigators as they reconstruct fire events. These and other BFRL investigations have contributed to revisions in the fire safety provisions of local building codes to require sprinklers in all hotels and high-rise buildings. The investigations also led to major changes in fire services and fire safety education.

**This blowout fire near East Timbalier Island, La., provides a natural laboratory field site for evaluation of measurement techniques for burning rate and emissions from industrial fires. Information from these field measurements are used by local authorities responsible for making hazard response decisions.**

BFRL researchers work to understand fire spread in buildings; the fire itself, and the smoke and hot gases released. The Lab's experimental facilities help answer some of the questions about small-scale combustion and large-scale convection phenomena. For example, BFRL's work in computational fluid dynamics is illustrated in the red and blue computer graphics on page 18. Shown is a compartment (left), which is filled with smoke and hot gases (red) from a fire when a window is broken (center) and fresh air (blue) pours into the room from the right. This phenomenon is called backdraft. The intermediate colors denote the temperature of the mixing fluids. This scenario concerns firefighters because often a fire in an initially sealed compartment exhausts the available supply of oxygen and appears to die, only to be explosively re-ignited when fresh air enters the room through an opened door or broken window. Using computer simulations, it is possible to quantify certain aspects of problems such as the time to replenish the diminished oxygen level and the amount of mixing that takes place. The findings provide guidelines to assist firefighters in identifying potentially dangerous situations.

BFRL pioneered the Fire Safety Evaluation System (FSES) to identify alternative methods of providing the equivalent levels of fire safety to that specified in prescriptive codes. FSES uses a numerical grading system to evaluate the relative value of design features and safety systems in limiting the threat to building occupants. FSES was developed for use in a variety of occupancies such as health care, board-and-care, detention, correctional, and business facilities. As a recognized means of establishing compliance with the life safety code, FSES was included in the NFPA's

## Oil Spill Fires

The Lab is helping government officials find more efficient ways to rapidly clean up large oil spills. BFRL developed methods to measure the distribution of smoke and oil residue to determine if burning an oil spill would cause less environmental damage than other clean-up options. Working with the Department of Interior's Minerals Management Service, the U.S. Coast Guard, and the American Petroleum Institute, BFRL researchers studied the process during burning, the residue after the oil has burned, and air emissions. Researchers produced a simulation model that predicts, in three dimensions, the airborne concentration of smoke particles from a major oil fire. Simulations such as this one are used to evaluate the environmental impact of such fires, addressing issues like the height of the plume and the location of unhealthy amounts of particulate matter tens of kilometers downwind. In a related area, BFRL is helping the oil industry and the Minerals Management Service predict oil flow from spills and oil well platform blowouts. By using data from on-site flame radiation measurements with the Lab's data to predict oil flow, authorities can plan for spill response and oil recovery and predict damage to coastal areas.


**Emissions from a large crude oil fire are collected using mini-blimps to understand possible environmental impacts of intentionally burning oil as a response method to performing oil clean-up after accidental oil spills.**

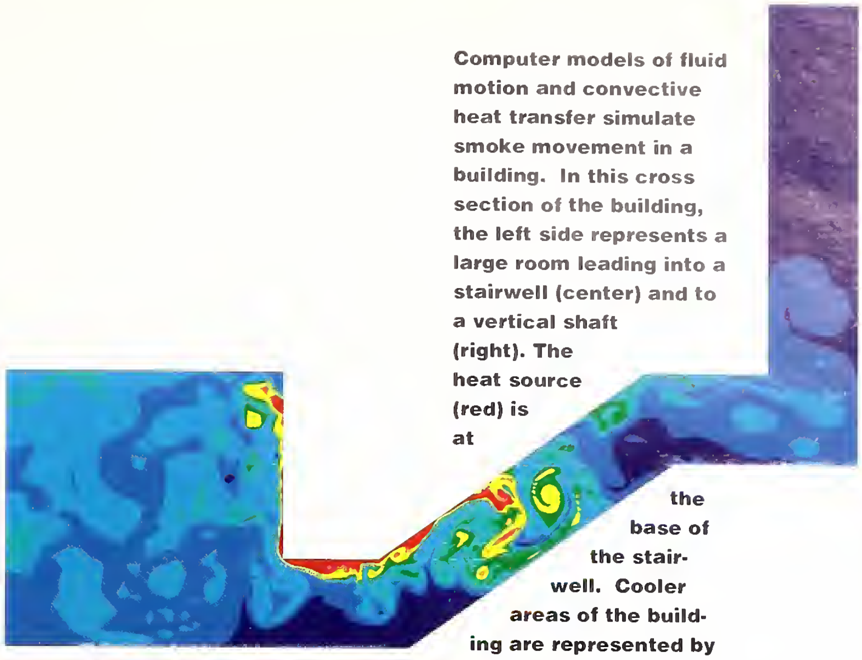
Alternative Approaches to Life Safety 101M 1992. This approach helps users identify lower cost alternatives for code compliance in new and existing buildings.

**Fire Control Technologies**

BFRL is developing better fire detection, suppression, and smoke management methods by characterizing the combustion processes in fires, predicting smoke formation and dispersion, calculating the effects of fire suppressants on electrical systems, and developing principles for the response of advanced detection systems. Working with the Department of Veterans Affairs and the Architect of the Capitol, BFRL investigated the use of smoke control systems to mitigate fire conditions in tall buildings. The old Plaza Hotel, Washington, D.C., was used to collect measurements on smoke transport, stairwell pressurization, natural ventilation, and the interactions of sprinklers with the fire under smoke control conditions. The results provided a basis for evaluating smoke control system designs based on computer and laboratory models.

Using this and other Lab-developed information, BFRL verified its computer model that predicts the course of fires in buildings. The Consolidated Fire and Smoke Transport model uses the rate of heat release from the fire to predict room pressure and temperature, the height of the smoke layer, inter-room air flow, and concentrations of oxygen, carbon monoxide, and carbon dioxide.

BFRL is working to identify methods for detecting fires in the early stage of development. The Lab is studying the use of unique fire "signatures" to trigger detectors, a technique that would reduce false alarms which often occur in conventional fire detection systems.



**Computer models of fluid motion and convective heat transfer simulate smoke movement in a building. In this cross section of the building, the left side represents a large room leading into a stairwell (center) and to a vertical shaft (right). The heat source (red) is at the base of the stairwell. Cooler areas of the building are represented by various shades of blue. The smoke and hot gases concentrate at the center of the stairwell, a concern for fire safety professionals. This simulation also is important to designers of HVAC systems as they consider a heat source occurring in a duct.**

Acoustic emissions from materials provide unique signatures of early stage fires. Piezoelectric transducers mounted on materials, such as wood, plastic, and gypsum board, detect ultrasonic emissions which result from the relief of stress created by changing temperatures. The rate of acoustic emissions and the cumulative energy, released when the material is exposed to a flame, provide a good measure of the overheated state of many materials. This occurs well before a temperature increase registers at the same location. For example, wood is particularly susceptible to acoustic emission. A solid fir board produces more than 1,000 events per minute; other products produce fewer emissions per minute, yet many more than background activity.

If research shows that this fire-induced frequency of acoustic emission is not confounded by frequencies emitted by other mechanical sources, it may lead to the development of devices that can detect small fires reliably. It further may provide greater assurances that building occupants will not disconnect the detector.

**The consolidated fire growth and smoke transport computer model predicts the temperature, smoke, and level of gases in a room. The model will be incorporated into HAZARD I to improve its predictive capabilities to duplicate real fires without having to burn a room or building.**

# Research Facilities

BFRL is a national resource for the science and technology underpinning the construction and fire industries. Its facilities are world-class. Some are unique, and several serve as reference sources for equipment in other organization's laboratories. All facilities can be used for collaboration by researchers in industry, government, and academia.

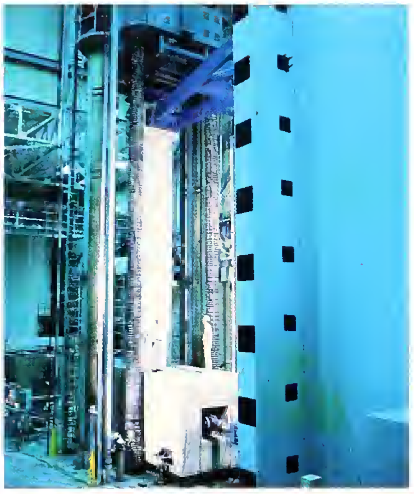
Information about using these facilities is available from Noel J. Raufaste, Head, Cooperative Research Programs, BFRL, 301-975-5905.

**1. Large-scale structures test facility.** With its 53 MN (12-million pound) universal structural testing machine—the largest in the world—this facility can test structural components up to 17.7 m (58 ft) in height.

**2. Tri-directional structural test facility.** This computer- controlled apparatus—the only one of its kind—applies forces or displacements in three directions simultaneously to test structural components up to 3.4 m (11 ft) high and 3.1 m (10 ft) in length or width.

**3. Guarded hot plate.** This is a large-capacity device for measuring the thermal resistance of insulation and other low-density materials up to 400 mm (15 in) thick and 1 m (39 in) in diameter. It provides calibrated specimens for guarded hot plates in other labs.

**4. Calibrated hot box.** This facility uses an environmental and climatic chamber to simulate indoor and outdoor conditions. It is used to develop standard test methods to evaluate the dynamic performance of full-scale walls up to 3 m by 4.6 m (9.8 ft by 15 ft) under cyclic temperatures ranging from -40°C to 65°C (-40°F to 150°F). The facility also is used to develop standard measurement methods for use in other laboratories.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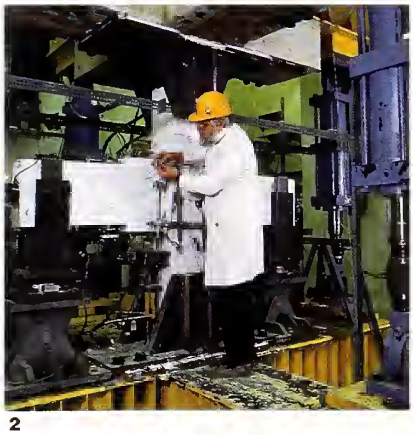
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**5. Cone calorimeter.** This is the primary apparatus for small-scale measurements of the burning behavior of materials. It measures the rate of heat and smoke release by burning materials. Through connection to a Fourier Transform Infrared Spectrophotometer, the calorimeter can continuously measure water vapor, hydrogen chloride, and other gases released. The calorimeter is a national and international standard test method.

**6. Lateral ignition and flame spread apparatus.** This apparatus determines properties related to piloted ignition of a vertically oriented material sample under constant and uniform radiant heat flux up to 6.5 W/cm$^2$ and to lateral flame spread on a vertical surface due to an externally applied radiant flux. The data generated are used in fire growth models and as component elements in fire hazard and fire risk assessments.

**7. Large burn facility.** One of the few of its kind in the world, this multiroom facility is used for conducting experimental fires in full scale to validate mathematical models and to study the fire performance of furnishings and interior finish materials. Two large heat-release rate calorimeters are available with capacities of 1/2 million W and 7 million W. Up to 300 instruments with scanning rates over 100 channels per second can be dedicated to a single test.

**8. Environmental chambers.** BFRL has one large and six smaller environmental chambers with temperature ranges of -40°C (-40°F) to 65°C (150°F) and relative humidity ranges from 15 to 85 percent. They are used to test simulation models for a variety of conventional and special structures and equipment. The largest is 14.9 m × 12.8 m × 9.5 m (49 ft × 42 ft × 31 ft). It can accommodate a two-story building and has an earthen floor that can be excavated for construction of experimental structures. Shown here is one section of a three-section, two-story townhouse entering BFRL's largest environmental chamber.

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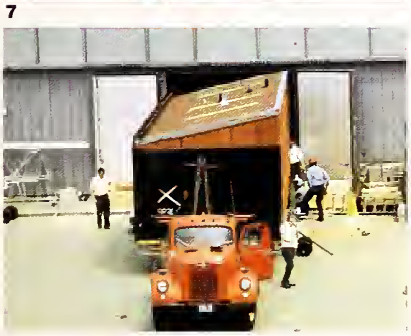

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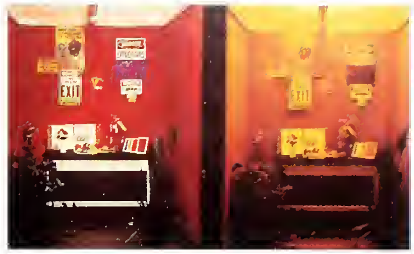
**9. Lighting research facilities.** The facility provides a basis to better understand the interactions between the occupants and the illumination/daylighting systems of a building. It provides a realistic environment for studying color rendering (distortion) of energy-efficient lighting systems.

**10. Controls laboratory.** With the aid of a computerized energy monitoring and control system, this lab performs fundamental research on HVAC control systems, on controls dynamics, and on adaptive optimization techniques. It uses a computerized energy monitoring and control system with BFRL software, which controls an air handler, a building, a heating/cooling plant, and a laboratory test facility for evaluating the performance of standard and advanced HVAC/control systems.

**11. Microstructure laboratory.** The laboratory is equipped with a digital scanning electron microscope with X-ray powder diffractometer and petrographic and stereo microscopes. The facility provides for microstructural characterization of cement clinkers, high-performance concrete, and mortars, and it is used to characterize expanded foam insulation, roofing materials, paints, and other protective coatings.

**12. Interactive graphics and structural analysis laboratory.** This facility supports finite-element modeling and analysis of complex three-dimensional structures. It has a high-performance Silicon Graphics 4D/210 workstation, a Convex C120 minisupercomputer, two Vax minicomputers, a high-resolution color raster display device, and a color hardcopy device.

**13. Outdoor energy conservation laboratory.** A passive solar house and six one-room buildings constructed of different materials with varying amounts of insulation are used to test the thermal performance of solar building features and provide data on dynamic mass effects and heat exchange with the surrounding earth.

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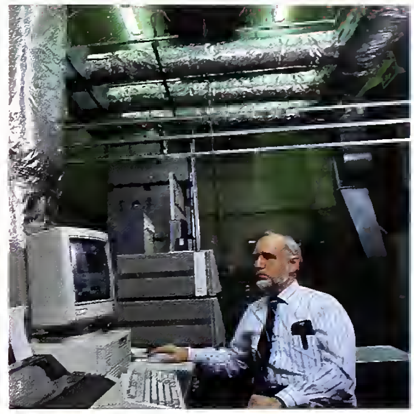

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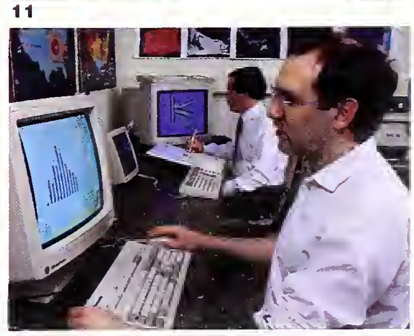

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## Staff Highlights

One of the great strengths of the Laboratory is the excellence of its staff. Their competence and contributions are consistently recognized by peers in professional societies. Examples of some recent staff awards include:

*Nicholas Carino*, 1993 Delmar L. Bloem Award, American Concrete Institute, for leadership in developing specifications for cold weather concreting;

*Steven Glazer*, 1993 Basic Research Award, U.S. National Committee for Rock Mechanics, for a paper on the application of acoustic emission in fracture mechanics in rock;

*Edward Garboczi*, 1992 Robert L'Hermite Medal, International Union of Research and Testing Laboratories for Materials and Structures, for development of computer simulation models of microstructure and properties relationships for cement-based materials;

*James G. Gross*, 1992 American Society of Civil Engineers President's Medal, for leadership in providing ASCE with a growing standards program and developing ASCE's five-year standards plan;

*Nora Jason*, 1992 Directors' Award, Society of Fire Protection Engineers (SFPE), for Outstanding Committee Service on the inFIRE Advisory Committee;

*John Klote*, 1992 ASHRAE Symposium Paper Award, for design of elevator smoke control systems for fire evacuation;

*Mary McKnight*, 1992 William T. Pearce Award, ASTM Committee D-1 on Paints and Related Coatings and Materials, for outstanding contributions to the science of testing paint and paint materials;

*Katharine Notarianni*, 1992 SFPE Hat's Off Award, Society of Fire Protection Engineers, for representing SFPE on the National Coalition of Engineering Societies for Precollege Mathematics and Science Education and as active participant in the coalition's Engineers for Education;

*Paul Stutzman*; 1992 American Society for Testing & Materials P. H. Bates Award from Committee C01 on Cement, for outstanding paper and presentation on cement clinker characterization by scanning electron microscopy;

*Steven Treado*, 1992 Taylor Technical Talent Award, Illuminating Engineering Society of North America, for outstanding research in lighting and HVAC;

*Howard Baum*, 1991 2nd International Symposium on Fire Safety Science Medal of Excellence, for best paper on fire induced flow field-theory and experiment;

*John Klote*, 1991 ASHRAE Best Paper Award, for fire experiment of zoned smoke control at the Plaza Hotel in Washington, D.C.;

*Vytenis Babrauskas*, 1990 Interflam Award at the Fifth International Conference on Fire Safety, for development of heat release rate measurement and accelerating adoption of this technology worldwide;

*Nicholas Carino*, 1990 American Concrete Institute Leonard G. Wason Award for Materials Research, for co-authored paper on the feasibility of the impact-echo method for reliably detecting delaminations in reinforced concrete slabs;

*Richard Marshall*, 1990 National Hurricane Conference Engineering Award, for work on wind load measurements and post-disaster assessments of hurricane wind speeds and structural damage;

*Mary McKnight and Jon Martin*, 1990 Corrosion Committee Publications Award, Federation of Societies for Coatings Technology, for the best corrosion-related paper published in the *Journal of Coating Technology* in 1989;

*Harold E. Nelson*, 1990 Standards Medal by the National Fire Protection Association's Standards Council, for development of the fire protection engineering technologies;

*Andrew Persily*, 1990 Young Engineer Award, District of Columbia Council of Engineering and Architectural Societies, for developing measurement and testing procedures for indoor air quality in large commercial buildings;

These awards are supplemented by many other awards for technical excellence by the Department of Commerce and NIST management and for leadership by virtue of election as chairs of professional society committees and of government technical panels and committees.

## Collaborations

### Collaboration with Other NIST Labs

BFRL works closely with NIST's other laboratories and draws on their expertise to support its own research such as:

**Chemical Science and Technology Laboratory** to develop a Standard Reference Material for lead in paints; develop mathematical models that describe degradation processes of protective coatings on metals; provide measurement protocols for sampling airborne asbestos; and establish the thermal and physical properties and performance potential of candidate alternative refrigerants.

**Computing and Applied Mathematics Laboratory** to formulate probabilistic distributions of extreme wind in hurricanes and extratropical storm regions; generate structural identification and non-linear dynamical systems; model flow patterns of smoke particulates; and design experiments and analyze results statistically.

**Computer Systems Laboratory** to develop mathematical models of expected penetration of concrete security barriers based on various threat scenarios.

**Electronics and Electrical Engineering Laboratory** to evaluate fire resistance of microwave absorbers in acoustic anechoic chambers and to develop electrical and fire protection methods for power transformers containing PVC fluids.

**Manufacturing Engineering Laboratory** to assess the quality of plasma sprayed coatings and to develop finite element modeling to formulate the manufactured process.

**Materials Science and Engineering Laboratory** to develop methods to measure the photon efficiency of ultraviolet light in degrading polymers; develop electromicroprobe characterization methods for corrosive products at the polymer coating/metal interface; and provide non-destructive testing capabilities, such as X-ray analysis of welds and metal failures during investigations of buildings and structures.

**Physics Laboratory** to determine laser magnetic resonance for flame chemistry and perform microprobe analyses to predict corrosion on metals.

## Collaborative Research

BFRL lends its expertise and facilities for some proprietary research and for the development of generic and precompetitive technologies that benefit the construction and fire safety industries. Research opportunities include:

*Guest Researchers*
The Laboratory usually has around 70 visiting scientists from industrial, university, federal, and foreign labs; typical assignments average 12 months.

*Cooperative Research*
BFRL frequently works with other organizations to share costs and resources in solving problems whose solutions often have industry-wide application. Through Cooperative Research and Development Agreements, industry partners can be granted proprietary rights to intellectual property resulting from the collaboration.

*Research Consortium*
BFRL encourages and supports the formation of consortia by firms and organizations to solve industry-wide problems.

## More Information About BFRL

BFRL publishes several brochures and booklets that give more detailed descriptions about specific areas of the Lab. They include:

*Building and Fire Research Project Summaries:* a detailed description of the current year's research.

*BFRL Impacts:* a sample of the Lab's technical contributions and their impact on its customers.

*BFRL List of Publications:* an annual listing of the Lab's publications.

*About BFRL:* a brief overview of the Lab.

*BFRL Facilities:* a technical description of the Lab's facilities and their capabilities.

*BFRL Guest Researcher Opportunities:* a review of the guest researcher programs available for assignments to BFRL.

To order a copy of these free publications or to discuss the Lab's research reports, contact Nora Jason, BFRL Information Service, at 301-975-6862.

*Inventions, Patents, and Licenses:*
Several Lab inventions are available for licensing. For a list of inventions and other details, contact Dr. Bruce Mattson, Chief, Technology Development and Small Business Program, 301-975-3084.

## Visit the Lab

We encourage potential collaborators to visit the Laboratory when in the Washington area. To schedule a visit, contact Noel J. Raufaste, Head, Cooperative Research Programs, 301-975-5905.

## BFRL Consultation

If you have general questions about BFRL programs or are interested in working with BFRL, contact:

Dr. Richard N. Wright
Laboratory Director
301-975-5900

Dr. Jack E. Snell
Deputy Director and
Manager for Fire Research
301-975-6850

James G. Gross
Assistant Director
301-975-5903

Noel J. Raufaste
Head, Cooperative Research Programs
301-975-5905

Questions about specific programs should be directed to BFRL's Management listed on pages 3 and 4.

The mailing address for all BFRL personnel is:
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-0001
FAX: 301-975-4032

## National Institute of Standards and Technology

The National Institute of Standards and Technology is dedicated to helping U.S. industry strengthen its international competitiveness. NIST also aims to advance science and engineering and to improve public health, safety, and the environment.

Created in 1901, NIST is the nation's premier measurement laboratory. It is a major source of technical expertise for U.S. businesses—large and small—seeking to use the latest technologies to improve their products and processes.

NIST laboratory researchers work with industry to develop new technologies, devise new measurement methods, and provide materials, data, and calibrations for quality assurance. Through its Advanced Technology Program, NIST awards direct grants to industry for development of generic, precompetitive technologies. To assist small and mid-sized manufacturers in modernizing their production capabilities, NIST is building a Manufacturing Extension Partnership that will be made up of Manufacturing Technology Centers, Manufacturing Outreach Centers, the State Technology Extension Program, and LINKS—a support, coordination, and linking/networking infrastructure. The Malcom Baldrige National Quality Award, managed by NIST, recognizes continuous improvements in quality management by large manufacturers, large service companies, and small businesses. NIST researchers work at the frontiers of science and technology in the following areas: electronics and electrical engineering, manufacturing engineering, chemical science and technology, physics, materials science and engineering, building and fire research, computer systems, and computing and applied mathematics.

For more information on NIST programs, call 301-975-3058.


NIST