Building & Fire Research Laboratory

Activities,

Accomplishments

& Recognitions

National Institute of Standards and Technology

Technology Administration

U.S. Department of Commerce

Contents

BFRL *at a Glance*

BFRL Mission

BFRL partners with our customers to provide the measurement technologies, performance prediction methods, and technical advances needed to enhance the competitiveness of U.S. industry, public safety, environmental safety, and to assure the life cycle quality and economy of constructed facilities.

BFRL Vision

- Leader in performance prediction and measurement technologies;
- Focal point for advances in key areas of technology;
- Partner with customers to exploit the benefits of these technologies.

BFRL Goal

BFRL aims to meet the critical measurement and standards infrastructure needs of the construction and fire safety communities.

BFRL Resources

- 170 world-class staff
- unique facilities
- $30 million annual budget
- expertise in
  - measurement
  - material and system performance
  - mathematical modeling
  - non-destructive testing and diagnostics

To take advantage of BFRL Resources

- visit web site to access reports and download software (*www.bfrl.nist.gov*)
- visit laboratory to share information
- participate in cooperative research to access to unique resources
- send guest researchers to work with our staff
- participate in research consortia to solve industry-wide problems

Director's *Message*

Jack Snell, Director, Building and Fire Research Laboratory

This is the 1999 annual report of the NIST Building and Fire Research Laboratory, BFRL. It presents the impacts, accomplishments, recognition and activities of our staff. The focus of our work is to provide the communities we serve with the measurement and prediction tools they need to prosper. These communities include those who design and build facilities and the many products of which they are constructed; those who own, occupy, operate and maintain them; and those who oversee them for fire, life safety and risk management.

At BFRL, our most valuable asset is our staff. We have a highly diversified technical staff with a broad range of technical and academic backgrounds and industry, research, government and academic experience. Our staff are known for their integrity and openness, their attentiveness and responsiveness to the needs of those we serve, their dedication to quality and excellence in their work, and their commitment to stay at the forefront of measurement and prediction technologies relevant to the changing needs of our customers. They are also committed to partnering with the intended users of their results so that together with our partners, we can assess the real consequences of our work. Therefore, as you read through this report, you will discover it presents a rich array of individual and team efforts many of which are already having significant benefits.

In 1999, we maintained our focus on 10 technical objectives and have made substantial progress on each of them as noted in the following pages. Major drivers facing our customers are international competition, globalization of standards, reduced cycle times and costs, improved quality, and rapidly advancing technologies. Each of our technical objectives is aimed at providing tools and technologies to facilitate innovation for public and corporate benefit. I am particularly excited about the progress we are making in bringing the fruits of advances in information, computing, sensing, and materials technologies to beneficial applications for the design and construction, building materials, and controls industries, and for the fire services and building regulatory community.

This is my first year as Director. In the past year we have experienced a number of other changes in the management of the laboratory (see pages 51-52 for new management team). We are taking advantage of this time of change to lead a series of conversations – within BFRL, with our partners, and with those we serve – to reassess the direction and priorities for the Laboratory. Our intent is to assure we are making the most effective use of our resources, and, in the process, make BFRL a delightful place in which to work.

These are times of transforming change and opportunity for many of the communities we serve, and no less so for BFRL. We look forward to working with and serving you. For more extensive information, please visit our web site – *www.bfrl.nist.gov*. We value your comments, I look forward to hearing from you.

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Building & Fire Research Laboratory

1999 Activities, Accomplishments, and Recognitions

BFRL's research is focused and linked with collaborative private- and public-sector activities to help achieve the National Construction Goals (NCGs) developed with industry by the National Science and Technology Council's Subcommittee on Construction and Building (C&B). In 1996, groups of industry leaders representing the residential, industrial, public works, and commercial/institutional sectors developed industry strategic plans for achieving the NCGs in cooperation with federal agencies. These industry plans, direct discussions with industry leaders and federal agencies such as the U.S. Fire Administration, helped shape the direction of BFRL research.

BFRL's 10 Objectives

BFRL's 1999 research program was sharply defined under 10 key areas:

- FIATECH: Fully-Integrated and Automated Project Process Systems and Technologies
- Cybernetic Building Systems
- Fire Safe Materials
- Industrial Fire Simulation
- Partnership for High Performance Concrete Technology
- Performance Standards System for Housing
- Service Life of Building Materials
- Metrology for Sustainable Development
- Earthquake, Fire, and Wind Engineering
- Advanced Fire Measurements and Fire Fighting Technologies

The 10 areas comprise six major products plus four focused project areas that address the NCGs and industry plans. About 50 percent of BFRL's direct appropriations fund the first six BFRL objectives. Each is focused on a product that will bring immediate economic benefits. Objectives 7 through 10 are focused areas funded by direct NIST appropriations and by other federal agencies. This research is smaller in scale and includes projects aimed at solving problems with high economic impact and others focused on fundamental research for the next generation of technologies.

I

FIATECH: Fully-Integrated and Automated Project Process Systems and Technologies

Background and Intended Outcome.

The construction industry faces special challenges in reaping the full benefits of the information technology revolution that has brought and continues to bring rich rewards to many industries. These challenges include low R&D investment, fragmentation, and its unique project-oriented character. Recognizing this issue, the Construction Industry Institute (CII) – an organization with more than 100 members representing the Nation's largest owners, contractors, and suppliers of constructed facilities – has made the accelerated development of Fully Integrated and Automated Project Processes, FIAPP, a top priority.

CII, with the support of BFRL, has created the FIATECH Consortium. This CII-affiliated, collaborative, not-for-profit consortium will conduct leveraged research and development in partnership with suppliers, with firms in the software/information technology industries, and with the public sector. Simply stated, both CII's FIATECH Consortium and BFRL's FIATECH major product, collectively referred to as FIATECH, are needed to accelerate the delivery of FIAPP products and services to the construction industry.

FIATECH will enable significant cycle time and life-cycle cost reductions in the delivery of capital projects by achieving breakthrough, technology-intensive

process changes. These changes will be brought about, first, by enabling the seamless integration and management of project information within the context of an entire life cycle and enterprise wide resource planning system, and second, by bringing live wireless data from the construction site into the project management information loop. Drawing upon documented economic success in industries such as manufacturing, FIATECH will develop and adopt open interoperability and communication standards to achieve cycle time and life-cycle cost reductions.

CII has achieved reductions of 20 percent or more in project delivery time, costs, and worker injuries and is dedicated to redoubling these gains. FIAPP is an essential ingredient in achieving these additional gains. Specifically, FIATECH will:

- reduce design changes and rework through concurrent engineering;
- enable better control of project schedule and cost;
- improve supply chain management, including tracking of materials, equipment, and labor;
- rapidly detect and rectify differences between intended design and actual construction; and
- capture the "as-built" status of the project for later use in facility operation, maintenance, and renovation.

NIST is partnering with CII to provide the measurement systems, standard communication protocols, and information technology tools to enable FIATECH, along with economic assessments to quantify its impact. FIATECH-developed systems and technologies are being tested and demonstrated in a modular (plug-and-play) testbed environment that is configured from an end-user view point.

The first generation prototype FIAPP system, targeted for completion in 2002, will demonstrate feasibility, focusing on innovative process changes based largely on the integration of robust/proven technologies. The second generation prototype system, targeted for completion in 2004, will integrate advanced functional capabilities, building on new measurement systems and innovative uses of information technology. Key FIAPP *components* will be field tested on the $6 million Building 205 emissions control system (ECS) project on the NIST campus in FY 2000. In the following year, the focus will be on *sub-systems*, viz.: earthwork, foundation, structural (steel) delivery process; and pipe spools and piping systems delivery process.

Interoperability Protocols for Construction Site Measurement System

Unlike modern manufacturing plants (and our most complex laboratory experiments) the every day construction site represents a highly unstructured environment. Stated simply: there can be no wires leading to the hundreds of sensors, displays, and machines which must be integrated to make the system work. Dr. Lawrence Pfeffer and colleague DeWitt Latimer are developing a communications framework for the construction industry that will ultimately permit "plug-and-play" capability between site sensors, communications equipment and third party software vendors. The framework will consume live data from the construction site and provide useful project management information and, ultimately, the downlink information necessary to bring automation to the construction

site. Known as LiveView the new interoperability framework began where simulation protocols (such as DIS-VRML-Java) and sensor interface standards (such as IEEE-1451) leave off. New items being developed from this protocol include: the ability to seamlessly substitute GPS position sensors and laser-based spatial positioning systems; the ability to utilize a variety of RFID tags and barcodes using a standard software interface; the ability to handle scanner data (such as the 2-1/2D data that originate from fast scanning and flash LIDAR systems); and ultimately, machinery diagnostics. Highly promising prototype tests were conducted in FY 1999, in which excavation and component tracking tests were remotely monitored using wireless job site uplink with LiveView. Full-scale field tests of the initial LiveView framework are scheduled for FY 2000 on the Building 205 project site at NIST.

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Product Data Standards for the Process Plant Industries

Mr. Mark Palmer, research engineer, has led the development of the first international standard for the representation and exchange of process plant design information. The International Organization for Standardization (ISO) approved ISO 10303-227, Application Protocol for Plant Spatial Configuration, for publication as an International Standard this year. This standard addresses a long-standing problem shared by the process, power, engineering and construction industries as they seek to improve the design and delivery of constructed facilities. The existence of standard, neutral information representations and exchange methods will allow system vendors to retain their proprietary technologies and yet allow users to exchange and share plant information among the systems automatically – thereby improving the project delivery process and reducing cost. In NIST workshops and industry meetings, process plant owners, engineers and constructors, information technology providers, and part fabricators agreed to use the evolving international standard ISO 10303-Product Data Represen-tation and Exchange as the baseline technology for development. Known familiarly as STEP (Standard for the Exchange of Product Model Data), this standard delivers industrial capabilities in a series of parts called application protocols. NIST worked with industry and the Construction Industry Institute to establish PlantSTEP, Inc., a consortium composed of major plant owners, plant engineering and construction contractors, and vendors of computer-aided plant design systems. In collaboration with PlantSTEP, NIST developed the first STEP application protocol for the process plant industries, ISO 10303-227. Trial implementations of the application protocol have been demonstrated at NIST and at international conferences in the United States, Europe and Japan. A major system vendor has announced the first commercial translator product based on the standard, and several other vendors have announced translator developments. Pilot industry projects to use this new standard are getting under way.

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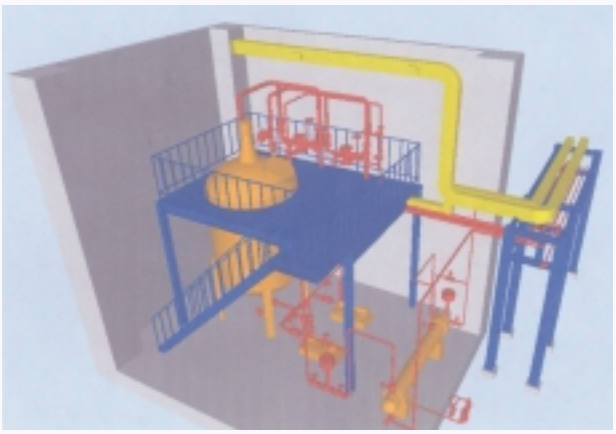

Computer generated picture of chemical plant

Economic Impacts of FIATECH

Improved methods for measuring economic impacts are needed to help BFRL focus its FIATECH-related research where it will produce the greatest value to key construction industry stakeholders. This project addresses that need. In 1999, researchers identified industries affected by BFRL's FIATECH-related research and classified the benefits and costs of that research. During 2000, BFRL will complete a prospective economic impact assessment that will estimate and document the economic impacts anticipated from BFRL's FIATECH-related research.

A key component of this impact assessment is BFRL's collaboration with the Construction Industry Institute (CII). This collaboration will produce information documenting the benefits and costs of using design/information technologies. The CII Benchmarking and Metrics Database, which is composed exclusively of actual project execution experiences, is the product from which the information is being developed. Two complementary efforts are being used to develop the data necessary to analyze the economic impacts of design/information technologies. The first effort is a statistical analysis of a broad cross-section of projects from the CII Benchmarking and Metrics Database; it focuses on establishing baseline measures of performance and indicators of economic value. The second effort is a case-by-case analysis of "exemplary" projects selected from the CII Benchmarking and Metrics Database; it focuses on documenting a series of lessons learned, which will lead to a better understanding of how to successfully integrate design/information technology practices into the project delivery process. In-depth analyses of both data sets are being conducted to estimate the incremental benefits and costs associated with the extensive use of the design/information technologies that are central to BFRL's FIATECH-related research.

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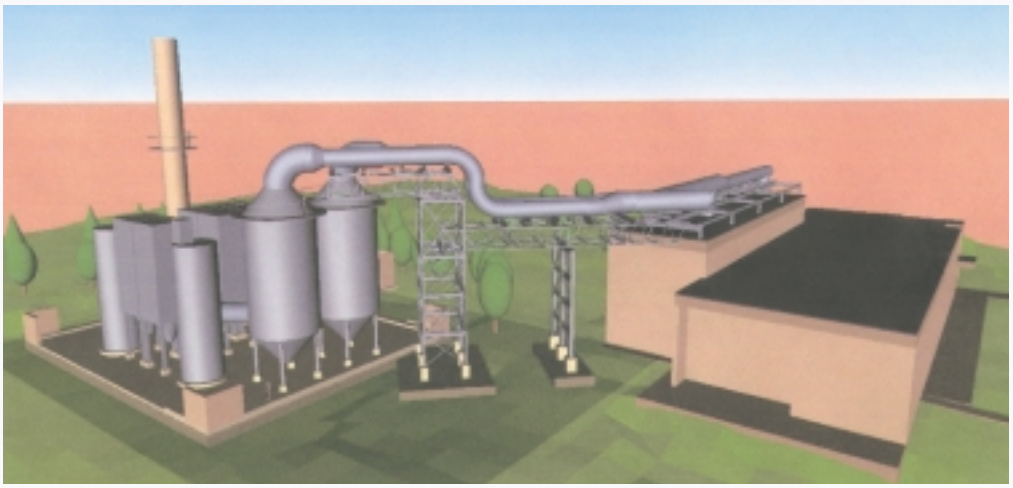
Graphical User Interfaces for Construction Information Systems

Mr. Robert Lipman has developed a prototype graphical user interface that demonstrates the use of three-dimensional web-based technologies for managing, accessing, and viewing construction project information. Basing his work on the open-standard Virtual Reality Modeling Language (VRML), Mr. Lipman created a modeling prototype that allows the simple specification of construction objects and encapsulates the details of implementation. In experimental studies, models were built of the emissions control system that is to be added to the NIST Fire Research Facility and of a simulated construction site. With the Fire Research



Computer generated image of emissions control system for the BFRL Fire Research Facility. This project will serve as a major field test for the LiveView framework and integrated wireless metrology systems in 2000.

Facility model, the graphical user interface was used to demonstrate not only typical walk-through surveys of the proposed project, but also a visualization of the construction sequence. In addition, the use of links in the three-dimensional visualization model to external project information such as traditional two-dimensional drawings and specifications was demonstrated. With the construction site simulation, the graphical user interface was used to demonstrate how a remote user with only a simple web browser and access to the Internet can track construction equipment operations based either on planned sequences or on external field sensor data.

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Prototype of the "strap down" construction machinery status system. The position and orientation of the vehicle are relayed to the project database in real-time.

Real-time Construction Component Tracking

Inordinate amounts of time are spent on construction sites in efforts to locate and identify components, sub-assemblies, and tools. Knowledge of component status, in a quick and accurate fashion, would dramatically improve productivity and reliability on the construction site.

Ms. Karen Furlani, and her collaborators Dr. Lawrence Pfeffer and DeWitt Latimer, are developing new technology, software tools, and standards to change the way components are tracked on the typical construction site. The new approach uses a customized interactive website operating on a wireless, handheld computer as the field agent interface. Peripherals, such as a laser-based real-time spatial positioning system, a bar code and RFID (radio frequency identification) scanning system, and a wireless data link, are integrated seamlessly through the website. The field inspector scans a parts ID to retrieve information from the project database, including CAD-based models with fiducial point locations. 3D coordinate data for at least three points are collected and automatically sent to a Virtual Site Simulator that allows contractors, engineers, and owners to independently view the job site in 3D and to observe the status of construction, including the current position and orientation of every component. In this fashion, an automated "as-built" database can be constructed in the course of routine quality control tracking. The system can be adapted to permit real-time tracking of construction machinery as well as other mobile capital assets. Initial full-scale tests of key system components are scheduled to take place on a construction site at the NIST Fire Research Facility in the fall of 1999 and throughout 2000.

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Non-intrusive Scanning Technologies for Construction Status Assessment

Recent evaluations by the construction industry indicate that timely knowledge of project status – where things are, what has been done, what needs to be done – is the single most important issue facing construction managers today. A broad class of construction status monitoring tasks are complicated by the *amorphous* nature of the item to be tracked. Amorphous objects are the antithesis of manufactured components where a small number of geometric attributes are sufficient to completely describe the object. Concrete placement, paving operations, and earthmoving represent complex situations where traditional metrology techniques are simply not effective, due to the massive quantities of data needed to describe the environment.

Ms. Geraldine Cheok, along with collaborators Dr. Christoff Witzgall of NIST's Information Technology Laboratory and Mr. Robert Lipman, are developing new techniques for using laser ranging technologies and three-dimensional analysis to automatically, and non-intrusively, scan a construction site and to extract useful information for project planning purposes. LIDAR (for Light Detection and Ranging) is a new tool that is just now being brought to bear on construction measurement problems. Ms. Cheok's work has been focused on the development of an automated system for the assessment of earthmoving activities at a construction site. The information can be used to derive precise, timely cut and fill requirements, quantities of material placed or removed, and rates of material removal, all of which are of significant interest to contractors, subcontractors and owners. Although laboratory demonstrations in 1999 utilized a small sand pile, the same technology and algorithms will be modified in 2000 for use on a live construction site measuring hundreds of meters on a side. This technology has drawn international interest and collaborative projects are planned with several companies during the next year.

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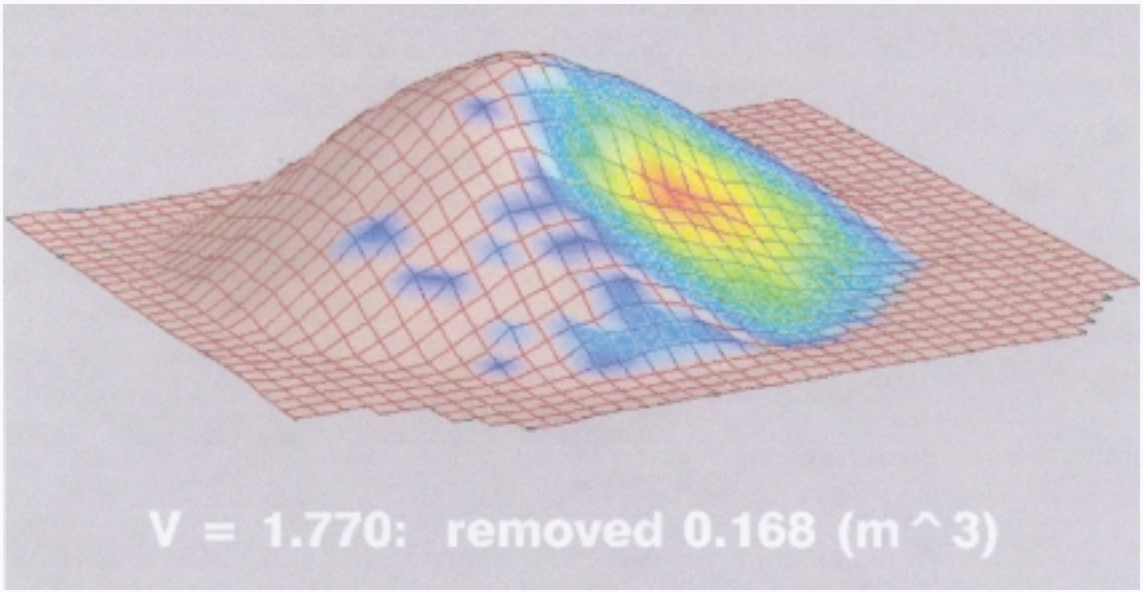

Following material removal with a front end loader, a sand pile is re-scanned with lidar and the new consumables stockpile is calculated, along with the billable amount removed by the subcontractor. The removed material leaves behind the easily visible collapse on the right side of the pile.

II

Cybernetic Building Systems

Background and Intended Outcome

During the next 10 years, the building controls industry in the United States is expected to undergo a radical change from one with a vertical structure to one with a horizontal structure. Building control companies, equipment and system manufacturers, energy providers, utilities, and design engineers will be under increasing pressure to improve performance and reduce costs by developing "cybernetic building systems" that integrate more and more building services. These services include energy management, fire and security, transportation, fault detection and diagnostics, optimal control, the real-time purchase of electricity, and the aggregation of building stock. If cybernetic building systems are to be successful, and if the U.S. is to obtain a significant share of the developing global market for such systems, we need to address, on an industry-wide basis, the way these systems communicate, interact, share information, make decisions, and perform in a "synergistic" and reliable manner.

During the next several years, BFRL will work with industry, building professionals, ASHRAE and trade organizations, university researchers, and other government agencies to develop and demonstrate a Cybernetic Building System (CBS). The work will involve the following tasks and culminate in full-scale demonstration of a Cybernetic Building System:

- **Develop standard building communication protocols that will facilitate the open exchange of information.**
- **Develop enabling technologies, such as fault detection and diagnostic (FDD) methods.**
- **Develop advanced measurement technologies, including smart multifunctional sensors.**
- **Develop performance evaluation tools for protocol compliance testing, real-time monitoring, and the evaluation and documentation of interactions among cybernetic building systems.**
- **Develop a standards-based program infrastructure supporting the design, analysis, specification, procurement, installation, operation and maintenance of HVAC systems.**
- **Construct a Virtual Cybernetic Building Testbed (VCBT) in the laboratory to facilitate the development and evaluation of new CBS products.**
- **Conduct basic research on the dynamic interactions of a fire, HVAC/distribution and the zones in commercial buildings.**
- **Develop a consortium consisting of manufacturers and service providers interested in producing, testing, demonstrating and selling Cybernetic Building Systems.**
- **Conduct a full-scale demonstration of a Cybernetic Building System in a government owned office building complex. This will involve the integration of energy management, fire detection, smoke control, smart fire panels, multifunctional sensors, building transport, fault detection and diagnosis, aggregation of multiple building loads, and real-time communication with energy providers, the local utility, an aggregator, and numerous service providers.**

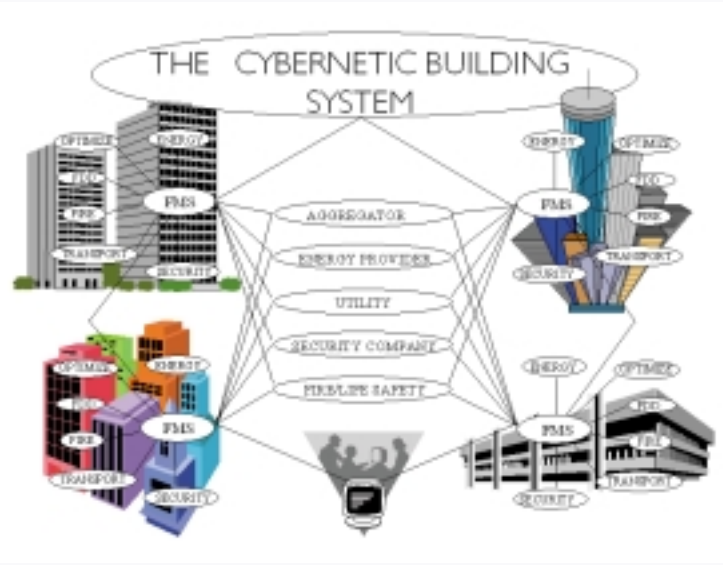

Diagram of a Cybernetic Building System (CBS)

BACnet™ Communication Protocol Enhancement

BFRL is working with industry partners to expand the capabilities of the BACnet™ communication protocol, ANSI/ASHRAE Standard 135-1995. Significant advancements this year include the formal adoption of Addendum 135a (BACnet/IP), which provides new flexibility for integrating BACnet devices with networks using the Internet Protocol. Additional addenda have been approved for pubic review that include new BACnet objects and one new service that will facilitate the use of BACnet with fire, life safety, and security systems. These BACnet enhancements model the functionality of life safety devices such as fire alarm panels, pull stations and smoke detectors, and provide a way to consolidate groups of such devices into "zones." The new service will allow users to interact with both devices and zones to the extent desired or permitted by fire and life safety regulations and codes. The effect of these enhancements should be to further improve the acceptance of BACnet as the protocol of choice for integrating fire, life safety and security systems with HVAC and other building systems.

A third major accomplishment was the approval of a companion standard, ASHRAE Standard 135.1 Testing Conformance to BACnet, for public review. Proposed Standard 135.1 describes in detail how to test devices to make sure their claimed BACnet functionality has been correctly implemented. It is likely to be used both by BACnet manufacturers seeking to verify their own implementations and by third party testers as part of a BACnet certification program.

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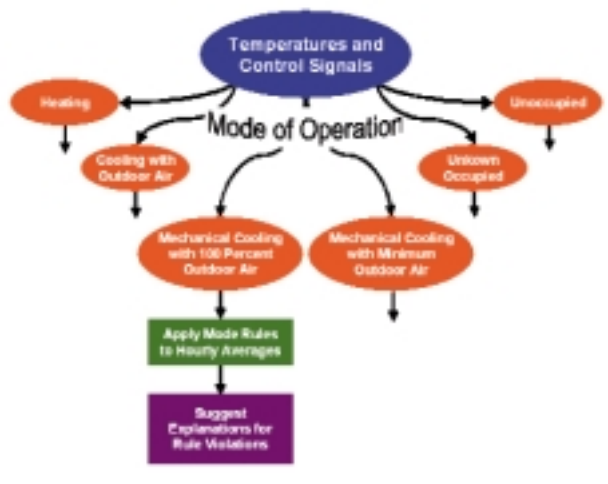
Rule-based FDD Method for Air-Handling Units

Air-handling units (AHUs) transition between numerous discrete modes of operation to maintain comfortable building conditions. NIST has collaborated with the French Scientific and Technical Building Centre (CSTB) and Montgomery College in Germantown, Md., to develop and test a fault detection and diagnostic (FDD) method that uses this behavior to simplify the diagnostic process. The FDD method is based on rules derived from typical operating strategies and commonly available measurements. Control signals and occupancy status are used to identify the particular mode of operation of an AHU, thereby identifying a subset of the rules that are applicable in its current state of operation. Because the rules are based on common control practices and sensors, it is anticipated that the method can be applied with only limited modifications relating to the characteristics of a specific AHU. Typical faults that are expected to lead to rule violations under certain operating conditions include: 1) stuck or leaking mixing box dampers, 2) stuck or leaking heating coil and cooling coil valves, 3) temperature sensor faults, 4) design faults such as undersized coils, 5) sequencing logic errors, 6) central plant faults that affect supply conditions at the AHU coils and 7) inappropriate operator intervention.

Flow diagram highlighting the main steps in the rule-based fault detection and diagnostic method for air-handling units.



A stand-alone prototype tool that implements the rules has been developed and tested on simulation data in collaboration with the French Scientific and Technical Building Centre (CSTB). In addition, field-testing has been performed using data from a building on the Germantown, Md., campus of Montgomery College. NIST, CSTB and Montgomery College plan to continue to collaborate to refine and test the rule-based diagnostic tool for AHUs with the common goal of having the technology transferred to industry partners.

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First Generation Virtual Cybernetic Building Testbed

The Virtual Cybernetic Building Testbed (VCBT) is a real time emulator consisting of real state-of-the-art and prototype BACnet speaking control systems interfaced with simulation models running over a network. NIST researchers, control manufacturers, service companies, and software developers can use this unique hybrid software/hardware testbed to develop and evaluate control strategies and products.

The first generation of the VCBT has been built, tested and demonstrated. It serves as a proof of concept and basis for future VCBT development. Components of the VCBT include a HVAC mechanical system simulation, a fire simulation, a set of real BACnet speaking air-handling unit and variable air volume box controllers, and a sophisticated Virtual Reality Modeling Language (VRML) user interface. The Common Object Request Broker Architecture (CORBA) provides the communication infrastructure between the different components that run on different computer platforms.

The next step towards the development of a second generation VCBT is enhancing the VRML user interface to allow viewing over the Internet. Currently, basic research is being done to understand the fundamental physics associated with fire/HVAC system/building zone interactions in commercial buildings. With this knowledge, a more sophisticated VCBT building modeling scheme will be developed that also uses product data information represented by Industry Foundation Classes (IFCs). In addition, work is being done to add fault-containing models of the HVAC systems to the VCBT.

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Diagram of First Generation Virtual Cybernetic Building Testbed.

Multielement, Multifunction Fire and Indoor Air Quality Sensor Research

Current test protocols and certification procedures have been developed to accommodate specific fire sensor technologies. The "sources" used in these test methods are optimized for a unique fire or smoke property to quantify detector response. However, in the case of indoor air quality sensors, very little has been done to determine the impact of test methods or nuisance sources on sensor response. To improve detection sensitivity and reduce inappropriate responses, manufacturers are developing new sensors to measure different aspects of a fire source. To help distinguish a real fire or air quality threat from an interfering background signal, the sensors are used in combination with other environment sensors. Existing test methods are unable to evaluate and quantify the performance of these new sensing systems that are needed for monitoring and predicting the changing environment in cybernetic building systems. To bridge this gap, a fire emulator/

detector evaluator (FE/DE), which consists of a laboratory wind tunnel that reproduces fire and non-fire environments, was developed to quantify sensor response to environmental change.

During this past year, a modern multielement detector was used to demonstrate the utility of the FE/DE for evaluating sensor response to fire and non-fire aerosols. In addition to smoke formed from flaming hydrocarbon combustion, the detector was exposed to clouds of dust and cooking oil in air flowing at speeds typical of room currents. It was demonstrated that the FE/DE is useful for comparing the performance of various smoke sensors exposed to a specific type of aerosol and for comparing the relative response of a given sensor to different types of aerosols. Environmental conditions (including smoke build-up, temperature rise and increase velocity) were reproduced in the FE/DE to assess the multielement detector's response to realistic fire environments. Additionally, the FE/DE was used to determine the response of different CO_2 sensors upon exposure to changing gas concentrations at rates typical of diurnal building concentration variations. These results were then contrasted with their response to the more rapid change associated with the early stages of a fire.

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III

Fire Safe Materials

Background and Intended Outcome

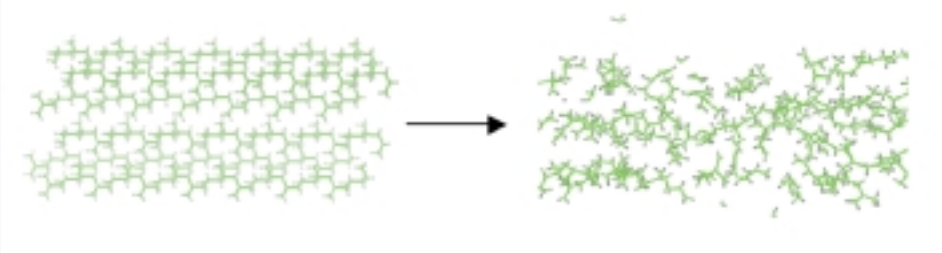
The United States produces about one-third of a trillion dollars worth of polymer products annually. For typical plastic end products with their complex formulations, the traditional trial-and-error method of achieving satisfactory fire retardancy is too expensive, time-consuming, and limited in its application by the narrow product line of an individual company.

Validated technology for the U.S. plastics industry is needed to assure that modifications to their products will manifest the intended fire performance without significant reductions in their physical properties (preferably improving them), resulting in new/improved U.S. products for domestic and international markets. A first example of an end product will be demonstrated in FY 2000, and a general protocol will be completed by the end of FY 2002. The BFRL product will be a model of the burning of a bench-scale sample of a material based on scientifically sound principles that are capable of implementation by industry and demonstrated to be accurate at predicting improvements in fire performance at the real, end-product scale.

Molecular Dynamics Model of Thermal Degradation in Polymers

Dr. Marc Nyden, a research chemist, has used his unique molecular dynamics model MD_REACT to identify factors that affect the flammability of polymer-based materials. The basis of MD_REACT is molecular dynamics (MD), which involves solving the equations of motion for the 3N (where N is the number of atoms in the polymer) degrees of freedom associated with the model polymer. The forces are obtained as the negative gradient of a potential energy function (force field) which describes the variation of the molecular energy with changes in the internal degrees of freedom (*i.e.*, bond distances, bond angles, and dihedral angles). The feature that distinguishes MD_REACT from other MD codes is that it allows for the formation of new bonds from free radical fragments that are generated when bonds in the polymer break and, thereby, accounts for the chemical reactions that play a major role in the thermal degradation process. During the past year, the predictive capability of MD_REACT was tested by comparing computed rate constants to experimental values for molecular systems ranging from small gas phase radicals to polymers. In all cases, there is reasonable agreement between the computed and experimental results, with a maximum error of about a factor of four

Still frames from computer simulations of the thermal degradation of isotactic polypropylene showing the progression from the ordered crystal (left) to amorphous polymer and decomposition products (right) obtained after about 50 x 10^3 MD time steps (50 x 10^{-12} s).



over the temperature range of interest for burning polymers (500 K - 1000 K). Additional simulations were performed as part of a survey of the effect of fire retardant additives on the thermal degradation of polypropylene. Included in this survey were blends of polypropylene with silica gel, representative bromine-containing fire retardants, and a polymer-layered nanocomposite. In all cases, the results of the simulations are consistent with experimental findings and, at the same time, provide new insights into the mechanisms by which these additives effect a reduction in the flammability of polymers.

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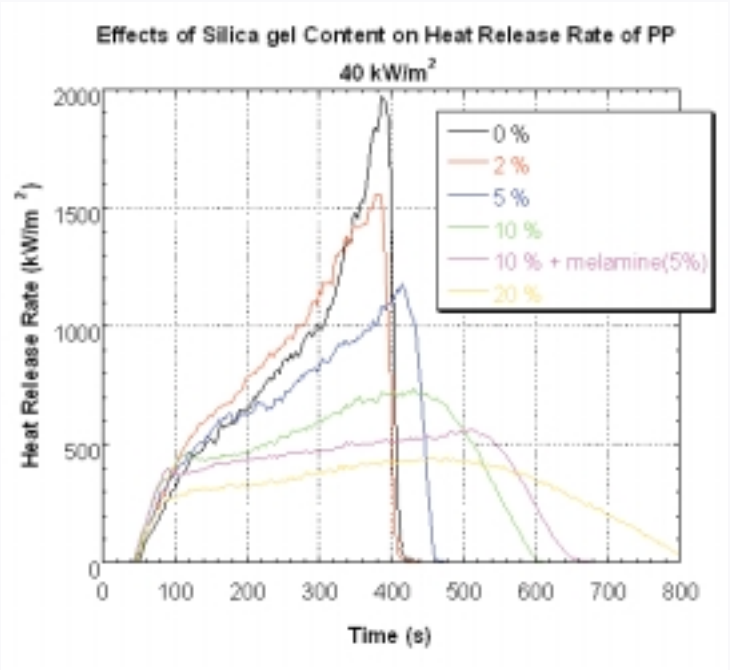
Silica Additives Effects on Flammability of Thermoplastics

A team led by Dr. Takashi Kashiwagi has found that the addition of small amounts of silica gel into polypropylene (PP) reduced its heat release rate significantly without increasing the formation of soot and CO. They also determined that the mechanism is based on physical processes in the condensed phase: an increase of melt viscosity, which reduces the transport rate of thermal degradation products to the surface, and the formation of a thermal insulation layer of accumulated silica near the surface, which further blocks the release of volatile products. As shown in the figure, the amount of reduction in heat release rate measured in a Cone Calorimeter is proportional to the silica gel content. The specific heats of combustion of all the samples are about the same, which indicates that the flame retardancy is affected in the condensed phase. This hypothesis was tested in several ways. The mass loss rates of these samples at the same external flux but in a nitrogen atmosphere, that is, without any gas phase chemical reactions, are about the same as those obtained during burning. Fourier Transform Infra-Red and Nuclear Magnetic Resonance analyses of collected polymer sample residues show no formation of new chemical bonds. Neutron activation analysis shows the accumulation of SiO_2 at/near the sample surface during a test. Video pictures taken during the test in a nitrogen atmosphere show molten PP with vigorous bubbling without any silica gel addition. However, the liquid-like behavior accompanied by bubbling disappears gradually with an increase in silica gel content. Above a mass fraction of



5 percent silica gel in PP, the sample appears to be more or less solid-like and the degradation products generated inside the sample appear to be transported to the surface by capillary motion through the solid-like layer. Thus, the team has established that the reduction in burning rate is achieved by changing from the rapid transport of the degradation products by bubbling to the slow capillary transport of the products and also by the thermal insulation of the accumulated silica layer near the surface.

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Nanocomposites: a New and Effective Approach to Fire Retardancy

Dr. Jeffrey Gilman, Dr. Takashi Kashiwagi and the Materials Fire Research Group have demonstrated that polymer-clay nanocomposites fulfill the requirements for a high- performance additive type flame retardant system for polymers, that is, one that reduces flammability while improving the other performance properties of the final formulated product. Dr. Gilman, collaborating with Dr. David VanderHart of NIST's Materials Science and Engineering Laboratory (MSEL), has developed NMR methods for better characterization of nanocomposites. Dr. Gilman and NRC postdoctoral associate Dr. Alex Morgan, collaborating with Air Force Research Lab scientists have filed a patent on a new method to prepare nanocomposites. Dr. Gilman and Dr. Morgan collaborating with Dr. Catheryn Jackson of MSEL, have found that certain nanocomposite parameters have very strong effects on the flammability of nanocomposites. Reactive treatments, which tether the polymer to the clay, can work in opposition to the nanocomposite's flame retardant effect; while larger clay plate size (or higher aspect ratio) is not necessarily better either. This work has generated international interest and a consortia of eight companies and three government agencies – Flammability of Polymer-clay Nanocomposites Consortium – has been formed to study the nanocomposites' flame retardant mechanism.

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The Role of Polymer Melt Behavior in Flammability

Quantitative probing techniques are now in hand for determining the role of polymer melt behavior in flammability. Thermoplastic polymers such as polypropylene or polystyrene are formed into useful objects by using heat but, when they burn, heat once again changes their form, complicating their burning process. The flow behavior of the polymer melt, particularly its effective viscosity, is the most important property needed to predict these changes in shape. BFRL recently acquired a rheometer with which to evaluate the effective viscosity of polymer melts. These materials are non-Newtonian in behavior with viscosities that depend both significantly on shear rate and strongly on temperature. The dependence of the viscosity of each polymer of interest on these two parameters is now being measured to provide a vital input to first cut models that predict the flow which will result from fire-level heat fluxes impinging on a simple vertical slab polymer geometry. At the same time, an apparatus has been constructed with which to check these model predictions. The apparatus permits quantitative study of the behavior of a polymer slab subjected on one surface to a uniform radiant flux of varied intensity. Melt flow velocity, melt surface temperature and overall weight loss measurements are being made for comparison with the model predictions. The

A TEM of a polypropylene-montmorillonite nanocomposite made at NIST

materials chosen have a wide range of melt flow properties. Thermal stability is also varied since it too can affect melt viscosity. Burning experiments with these same materials are planned as a prelude to modeling the burning process.

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Polymer Burning Model

To help plastics formulators improve the fire behavior of their products, a model of burning behavior needs to relate the material chemistry and the physical changes to the tested properties, most importantly the rate of heat release. For polymeric materials, such complex physical phenomena as melting, dripping, bubbling, charring, and barrier effects due to additives may play a critical role in the development of a fire. Dr. Kathryn Butler, physicist, has completed one-dimensional models that determine temperature profiles and mass loss rate of pyrolyzing thermoplastic materials in the presence of melting, internal absorption of radiation, and temperature dependence of material properties. Models of a composite material and of a thermoplastic material containing an inert additive are nearing completion. The thermal properties of the sample holder are included in each model, as are radiative loss at the surface. By combining a condensed phase model with the cone calorimeter model developed by Dr. William Mell, a preliminary model of a burning bench-scale sample has been demonstrated. The gas phase model provides the incident radiant flux, from both the flame and the hot cone, on the surface of the condensed phase. This flux is an input to the condensed phase model and drives thermal degradation and the subsequent production of gaseous fuel. The rate of gaseous fuel production, in turn, is put into the gas phase model and controls flame development.

The gas phase calculation is based on a large eddy simulation approach developed by Drs. Howard Baum and Kevin McGrattan of BFRL for the simulation of large fires. This approach simplifies the governing equations by approximating the flame as a large number of burning thermal elements. Thermal radiation transfer from the flame and hot cone is computed using a flux tracing method. The effects of radiative absorption in the gas phase can be included. The incident radiant flux on the sample surface is mostly due to the hot cone.

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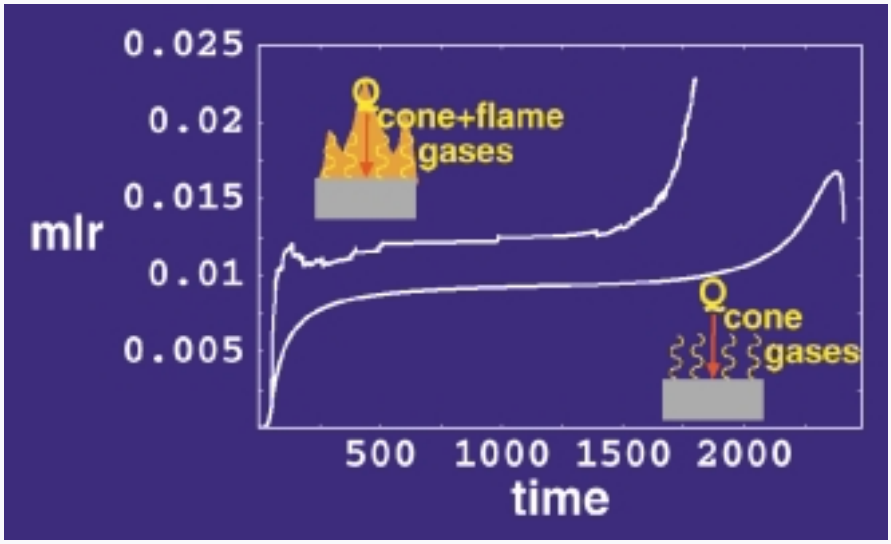

The Cone Calorimeter model is used to calculate the mass loss rate (kg/m²s), or mlr, vs. time(s) for a burning polypropylene sample (upper plot). Radiative/convective feedback from the flame causes more rapid mass loss rate than for the pyrolyzing sample (lower plot) heated solely by incident radiation of 40 kW/m² from the Cone heater.

IV

Industrial Fire Simulation System

Background and Intended Outcome

A shift from fire safety determined predominately by information from large scale testing to reliance on information from verified computer simulations of industrial fire events is taking place. Accurate, accessible, and easily understood fire simulations will create for the first time a means to routinely demonstrate the relationship of fire safety costs and expected losses on an individual facility and specific fire scenario basis. Drawing on experience with large eddy simulation (LES) technology used to predict the characteristics of smoke plumes from industrial fires, a new industrial fire simulation (IFS) system will be developed to generate predictions of fires in facilities protected by automatic fire sprinklers. An IFS system includes a fire simulation and a system to gather electronically input data from data bases and deliver the results of the simulation. An IFS system for fire sprinklers is expected to be in use by industry by the end of 2000. In pursuing this objective, BFRL has formed a consortium of industrial partners from the sprinkler and insurance industries. Research in supportive measurement tasks is also being conducted on grants to the University of Maryland, Northwestern University, and the University of Michigan.

Industrial Fire Simulation

Dr. David Evans, Chief, Fire Safety Engineering Division and coordinator of BFRL's research in this area, and industrial partners have formed a BFRL lead research consortium to quantify the interaction of fire sprinklers with industrial fires. Problems of interest to the consortium are the design of sprinkler systems for specific applications, the interaction of sprinklers and standard commodity fuel arrangements used in standardized testing, and investigation of sprinkler skipping phenomena. Previous research sponsored by the National Fire Protection Research Foundation has shown the effectiveness of the Industrial Fire Simulation (IFS) model to predict the major features of the interactions of sprinklers, draft curtains, and heat and smoke roof vents in controlled tests involving the burning and suppression of a high piled boxed plastic commodity. Results of the study are published in the NIST report, *Sprinkler,Smoke and Heat Vent, Draft Curtain Interaction — Large Scale Experiments and Model Development*, NISTIR 6196-1, by Kevin McGrattan, Anthony Hamins, and David Stroup. For well-controlled gas burner tests, fire simulations based on BFRL's industrial fire simulation (IFS) model were capable of predicting the activation times for the first ring of four sprinklers directly above the ignition point to within 15 percent of the measured time and 12 additional sprinklers in the second ring to within 25 percent. The goal of developing a simulation capable of predicting whether an industrial fire would be controlled by the activation of a large or small number of sprinklers was satisfied. Results of the IFS calculations can be viewed as full motion video simulations of the fires. Such simulations are building wide spread acceptance and excitement for the technology.

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Box fire tests at UL

Courtesy of King TV

TV news photograph of the freighter New Carissa *taken immediately after intentional ignition of fuel on board.*

Smoke Aloft-FT™ Application in Coos Bay

Predictions from a computer program developed by BFRL's Mr. William Walton and Dr. Kevin McGrattan were used to evaluate the impact of intentionally igniting the fuel on the *New Carissa*, a freighter grounded on the coast of Oregon. Igniting the fuel on the ship could reduce the quantity of oil reaching the water and impacting natural resources and wildlife in the area. The National Oceanic and Atmospheric Administration response team on site requested predictions from BFRL using ALOFT-FT™, which was developed specifically for situations involving the intentional burning of oil spills. The predictions gave authorities confidence about the limited spread of the downwind smoke plume over populated areas. ALOFT-FT provides detailed three-dimensional predictions of the downwind distribution of smoke particulate and combustion products from large outdoor fires. The ignition of the fuel on the ship was the first use of intentional burning of oil at sea off the coast of the continental United States and the first use of ALOFT-FT in response to an incident. Photographs of the smoke plume from the ship fire agree favorably with the predictions from the model. This model can be downloaded from the World Wide Web site http://fire.nist.gov/aloft/.

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New Zone Fire Model JET

A new zone fire model, JET, was developed Dr. William Davis, physicist, with support from the National Aeronautics and Space Administration. This zone fire model predicts plume centerline temperature, ceiling jet temperature, and sprinkler activation in high ceiling situations. The impact of ceiling vents, forced ventilation, and draft curtains on the development of a hot smoke layer and on detector activation are included in the model predictions. The model contains a new ceiling jet correlation, which includes the impact of a hot smoke layer on the radial dependence of the temperature as measured from the plume centerline. The computer model JET provides a tool to perform reliable predictions for detector activation in high ceiling structures. The model and comparisons of predictions and experiments are contained in the report *The Zone Fire Model JET: Model for the Prediction of Detector Activation and Gas Temperature in the Presence of a Smoke Layer*, NISTIR 6324.

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Fire test in a Navy aircraft hanger to evaluate detector activation fire model JET

V

Partnership for High Performance Concrete Technology

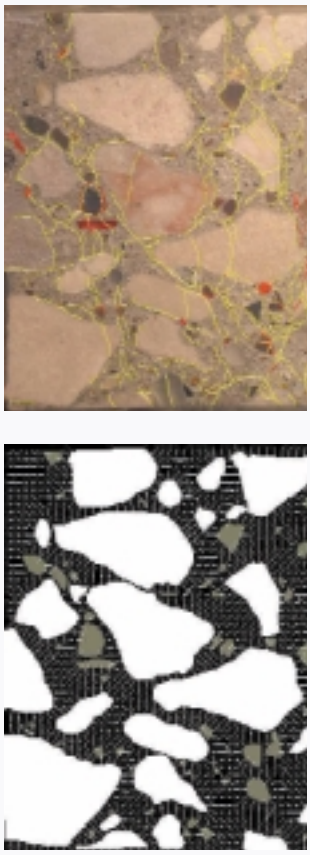
Background and Intended Outcome

In partnership with industry, BFRL will enable the reliable application of high-performance concrete (HPC) in buildings and the civil infrastructure by developing, demonstrating, and providing assistance in implementing a computer-integrated knowledge system, HYPERCON, incorporating verified multi-attribute models for prediction and optimization of the performance and life-cycle cost of high-performance concrete. The BFRL product will be the deployment of the computer-integrated knowledge system, HYPERCON, in a commercial HPC construction project by 2002. BFRL partners with many organizations in this objective, including the National Ready-Mixed Concrete Association, the Portland Cement Association, Master Builders, Inc., W.R. Grace Company, the Federal Highway Administration, the U.S. Army Corps of Engineers, the Nuclear Regulatory Commission, and the Center for Science and Technology of Advanced Cement-Based Materials.

Concrete is made in larger quantities than any other man-made material of construction. Recent advances in knowledge of the materials science of concrete have shown that there are substantial opportunities for improvement in its flow properties, durability, and strength, if appropriate measurement methods and predictive tools can be developed, standardized, and applied to optimization of concrete mixtures to meet high-performance requirements. Computer-integration of knowledge of concrete technology is essential if optimization is to be made practical and, at the same time, responsive to demands for sustainable construction. BFRL researchers are providing the technical basis for the measurement methods and predictive tools that will help the construction industry exploit the opportunities. Examples are given below.

Micro- and Macrostructural Characterization of High-Performance Concrete

Methods for quantitative characterization and mathematical description of the micro- and macrostructures of high-performance concrete (HPC) are being developed by Mr. Paul Stutzman. The methods are being applied in HPC-related projects investigating curing, the effects of processing on structure and performance, and the response of HPC to fire. Combining petrographic studies with computer simulations has advanced understanding of degradative processes. For example, the probable cause of premature cracking of a concrete box beam was determined by combining petrographic analysis with simulations involving the use of finite element elastic algorithms. In the first of the accompanying figures, cracking can be seen to be associated with both the coarse aggregate (carbonate) and chert in the coarse sand fraction. In the second, crack patterns modeled by a simulated aggregate expansion show good agreement with those in the actual specimen.



(Top) Cracking associated with both the coarse aggregate (carbonate) and chert in the coarse sand fraction. (Bottom) Crack patterns modeled by a simulated aggregate expansion show good agreement with those in the actual specimen.

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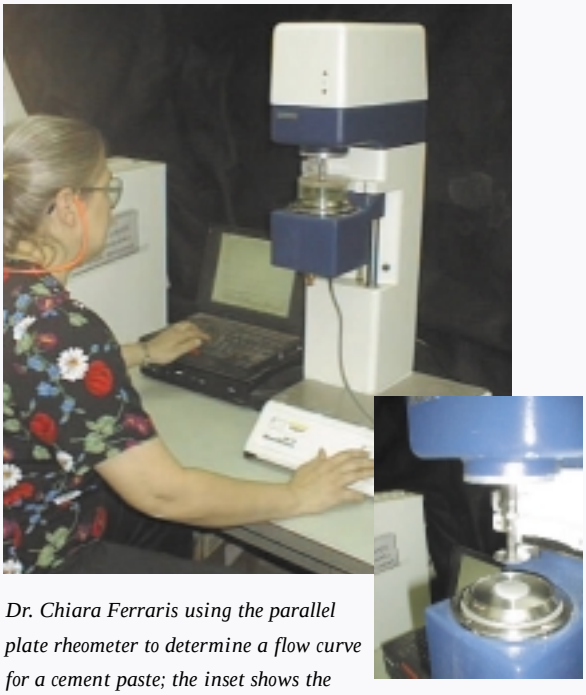
Flow Properties of Fresh High-Performance Concrete

The flow properties (rheological properties) of concrete must be understood if the performance of the concrete is to be optimized. Drs. Chiara Ferraris and Nicos Martys, research physicists, are developing a method to predict the flow behavior of concrete from the properties of the cement paste



Dr. Chiara Ferraris using the parallel plate rheometer to determine a flow curve for a cement paste; the inset shows the plates separated to show the paste sample.

matrix and the aggregate gradation and volume concentration. The goal is to develop a validated computer simulation of the flow of concrete – aggregates in a cement paste medium. Flow properties of cement pastes are measured under shear conditions intended to be similar to those that occur in the mixing of concrete. The use of a parallel plate rheometer allows varying the distance between the plates so that studies can be made of effects related to the distance between aggregate particles in concrete (which is a function of the content of cement paste). Results have shown how to select mineral admixture dosages to improve concrete flow, and the method is being applied in studies of the compatibility of cement with chemical admixtures.

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Curing of High-Performance Concrete

Dr. Nicholas J. Carino, research structural engineer, and Dr. Kenneth W. Meeks, a former graduate student, completed a report on curing of high-performance concrete (*Curing of High-Performance Concrete: Report of the State-of-the-Art*, NISTIR 6295). From their review, the authors concluded that the prescriptive curing provisions routinely used in the United States are lagging those of other nations. To ensure that in-place concrete will meet its strength and durability requirements at minimum cost, they recommend fundamental studies to develop rational curing provisions for high-performance concretes.

Drs. Meeks and Carino also completed the first series of tests aimed at understanding the required duration of moist curing to ensure that concrete in a structural member reaches its design strength at the depth of the reinforcement (taken to be 25 mm). Mortar specimens were cured under water for 1, 3, and 7 days and then allowed to undergo unidirectional drying under controlled conditions of 50 percent or 70 percent relative humidity at 25 °C. At 28 days, the tensile strength was measured as a function of distance from the drying surface. A novel testing technique (see the accompanying figure) was developed for this purpose. Results indicated that, for the conditions studied, 1 day of moist curing was sufficient for adequate strength development at a depth of 25-mm.

In a related study, Mr. Dale Bentz, research chemical engineer and computer scientist, measured, with a 0.1 mm spatial resolution, the moisture distribution in cement paste specimens using a unique x-ray scanning apparatus and environmental chamber at the Danish Technical University. Such data such will be used to verify moisture migration models required to predict cement hydration under realistic curing conditions.

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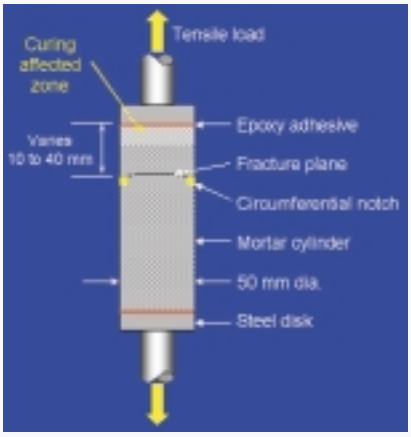
Testing technique to measure the tensile strength as a function of distance from the drying surface.



Left: Mr. Frank Davis, Structures Division, is setting up a high-temperature load test of HPC specimen.

Below: Remnants of an exploded HPC cylinder and rendering of the fracture formation. The sudden, dramatic spalling failure occurs when the concrete core temperature exceeds 250°C.

Fire Performance of High-Performance Concrete

Dr. Long Phan, research structural engineer, and colleagues have completed the first phase of an experimental program to study the effects of elevated temperature exposure on engineering properties of high-performance concrete (HPC). A high-temperature testing facility that permits simultaneous application of load and high temperature was made operational. Experimental results show that, compared with conventional concrete, the engineering properties of HPC are more adversely affected by high temperature. HPC is also more prone to a sudden, dramatic failure mode, commonly referred to as "explosive" spalling, at temperatures well within the range of a normal building fire. The experimental program was designed to facilitate a fundamental understanding of factors contributing to the spalling of HPC, and to develop proven and practical techniques for mitigating the spalling. The results of this experimental program will be used to support modification of existing design provisions for fire-exposed concrete, which were developed based on results of conventional concrete and are therefore unsuitable for HPC given its significantly different behavior under fire exposure. Dr. Phan is also working with the Portland Cement Association (PCA) under a NIST-PCA Cooperative Research and Development Agreement to provide experimental data for enhancing the existing PCA heat-and-mass transfer model to include the capability to predict conditions for the spalling of HPC.

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Simulating the Performance and Service Life of High-Performance Concrete

It is known that adding organic fibers to high-performance concrete (HPC) can often prevent the sometimes rapid spalling that HPC can undergo during a fire. However, the mechanism by which the fibers perform this function has been a subject of speculation. By computationally adding fibers to an existing model of concrete (available on the Web at *http://ciks.cbt.nist.gov/garboczi/, Chapter 6, Section 8*), Mr. Dale Bentz, research chemical engineer and computer scientist, has been able to gain insight into the process. His model calculations have shown how cement paste matrix pores can percolate with pores resulting from the melting of the fibers to give relief to the otherwise high pressures of steam that would build up in a fire situation. The model will be tested in the project on the fire performance of HPC led by Dr. Long Phan.

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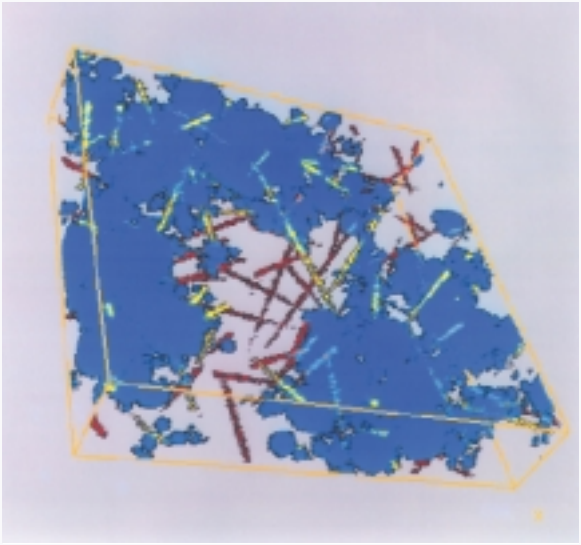

Illustration depicting the three-dimensional microstructure of a fiber-containing concrete. Aggregates with interconnected, percolated interfacial transition zone (ITZ) regions are blue. Fibers connecting these percolated aggregate clusters are yellow and remaining fibers are red.

VI

Performance Standards System for Housing

Background and Intended Outcome

BFRL's Performance Standards System for Housing (PSSH) program is designed to increase opportunities for innovation, enhance competitiveness, and support the attainment of the goals of two important federal housing programs – the Partnership for Advancing Technology in Housing (PATH) and the Healthy Homes Initiative (HHI). PATH is a multi-agency public/private partnership that seeks to accelerate the creation and widespread use of advanced technologies to radically improve the quality, durability, environmental performance, energy efficiency, and affordability of our nation's housing. HHI is a program of research and demonstration projects that will address multiple housing-related problems affecting the health of occupants, especially children. Both PATH and HHI activities are being funded through the U. S. Department of Housing and Urban Development (HUD).

PSSH will attain its objectives by:

- **developing performance standard guides for housing both nationally and internationally;**
- **conducting research to advance housing technology and industry's capabilities in setting performance criteria and evaluating, measuring and predicting performance; and**
- **coordinating and partnering with the U. S. housing industry in the application of the performance approach and the tools for measuring such performance.**

Within the American Society for Testing and Materials (ASTM), BFRL is leading the development of standard guides on structural safety and serviceability, functionality, durability, indoor air quality, and economics. The first ASTM standard guide is targeted for completion in 2000. The PSSH program is supporting efforts in durability within the International Organization for Standardization (ISO).

BFRL is participating in important research activities being initiated in 2000, which include:

- **PATH-D, a national durability research effort aimed at attaining the PATH goal of improved durability and reducing the cost of maintenance by 50 percent, and**
- **PATH Cooperative Research Program, a government/industry cooperative research program aimed at stimulating innovation and accelerating its rate of market acceptance.**
- **HHI suite of research projects such as advanced work in modeling of indoor air quality and heat and moisture transfer, monitoring of moisture content, enhanced performance of fire/CO detectors, and evaluation of fire safety measures.**

On going and recent BFRL accomplishments in the PSSH program area follow:

Predicting Indoor Environments

Mr. Steven Emmerich is validating methods for predicting specific air-borne contaminant distributions and thermal comfort parameters. Because measuring ventilation rates, contaminant concentrations, and thermal comfort parameters in any significant number of buildings is prohibitively expensive, compliance with indoor environmental criteria will involve the use of predictive methods. The predictive methods will use building ventilation and indoor air quality models based on the Building Environment Division's CONTAM model. Before a CONTAM-based compliance approach can be incorporated into a performance standard, its predictive reliability must be demonstrated through experimental validation, and the program must be made accessible to those implementing the performance standard. A test facility was instrumented, and a pilot phase testing program for volatile organic compounds and humidity control equipment was completed. Instrumentation of a multizone test building and a second phase testing program will be implemented in 2000 to obtain additional data needed to validate the CONTAM-based evaluation method.

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Structural Performance of Housing Systems

Dr. Fahim Sadek and Dr. Michael A. Riley are developing methodologies for measuring, predicting, and evaluating the structural performance of single family dwellings. The near term objective is to establish baseline performance criteria for wood-frame houses under seismic and wind excitations, and, in the long-term, the study will consider non-traditional construction materials such as concrete, light gage steel, and composites. BFRL has published a comprehensive state-of-the-art report, *A Summary of the Structural Performance of Single Family Wood Frame Housing*, NISTIR 6224. Detailed finite element computer models for wood stud shear walls, floors, and roofs have been developed and verified against available experimental data. In FY 2000, testing of roof truss-to-wall connections under monotonic and cyclic loading will be conducted and wall-to-foundation and wall-to-wall connections will be tested in later phases. Such testing will support research to develop models for inter-component connections.

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Improvements in Residential Fire Safety

Mr. Daniel Madrzykowski is developing test protocols for determining the utility of passive and active fire protection methods that could be economically implemented by residents to increase the level of fire safety in the home. Fires in residential properties represent 74 percent of the estimated 428,000 structure fires and accounted for more than 4,000 deaths and more than 25,000 injuries in 1996. Other than smoke detectors, few options exist for retrofitting fire safety systems into a home and this effort is intended to develop alternatives. Characterization experiments of kitchen fire hazards have been completed and a report is to be issued in 1999. In 2000 test protocols for passive and active systems will be completed and work will begin with industry groups, standards organizations and other government organizations to support the implementation of project results.

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VII

Service Life of Building Materials

Background and Intended Outcome

In the construction materials industry, like all other industries, the time-to-profit for a new construction material and the warranty costs are of foremost concern to industrial decision-makers and the consumer. These time-competitive issues can only be resolved reliably through the availability of accurate and reliable estimates of the service life of a material exposed in its intended operating and service environment. Generating service life estimates using the conventional methodology – the methodology used in the construction industry over the last 100 years – requires long field exposures. For example, cumulative exposure times for materials having life-safety implications (e.g., structural composites) and high initial cost (e.g., protective coatings for bridges) can easily exceed a decade or more. Such long-exposure testing is expensive, time consuming and a major barrier to product innovation. In contrast, the electronics, medical, aeronautical, and nuclear industries have been successful in obtaining accurate service life estimates for their materials and products in much shorter periods of time. These industries approach service life prediction differently and use reliability theory and life testing analysis. Unlike the conventional methodology, this methodology has a strong theoretical and scientific basis and, hence, consumers are more willing to trust the reliability of the generated service life estimates. Also, it has had a long and successful history of application to a wide-range of materials, components and systems over the last 50 years.

The goal of BFRL's Service Life of Building Materials Program is to apply the reliability-based methodology to construction materials. Previously, most of the effort has been directed toward applying it to organic coatings, the selected model construction material. Over the last year, however, the number of materials being investigated has increased and includes coatings, composites, sealants, and asphalt roofing shingles. Products from this research program, which will involve industry/university/government consortia, will include computer-integrated knowledge-based systems and other software, consensus standards, symposia, workshops, patents and other publications.

Larry Masters (President of Atlas Weathering Services Group), Jack Martin (Atlas), Larry Kaetzel (consultant), and Jonathan Martin (NIST) at Atlas' Miami exposure site standing next to a Smithsonian Institution filter-wheel solar radiometer. Four exposure sites have been equipped with this radiometer which breaks the solar ultraviolet spectrum into ten nanometer increments.

Methodology and Metrologies for Predicting the Service Life of Coatings Systems

Dr. Jonathan W. Martin, and Dr. Tinh Nguyen have initiated a second 3-year phase of an industry/university/government consortium on the service life of coating systems. The goal of the program is to link field and laboratory exposure results for coatings. During the first 3-year phase, the following were accomplished:

■ An exposure apparatus was designed and constructed in which the three major weathering factors – spectral ultraviolet radiation, temperature, and relative humidity – could be spatially and temporally controlled within narrow tolerance limits.

■ A software package was written that computes ultraviolet radiation dosage and spectral quantum yields using spectral ultraviolet absorbance and changes in infrared absorption spectra in the study coating.

■ A web site was created displaying the solar spectral radiant flux at four field exposure sites.

Three research projects have been initiated. The first project investigates deviations from the reciprocity law in polymeric coatings exposed to very high spectral ultraviolet radiation fluxes. The second project is aimed at modeling and estimating the bulk and surface moisture contents of coatings exposed in the field using environmental and material moisture property data as input. The third project investigates the distribution and temporal stability of photostabilizers and photoabsorbers in weathered coating films.

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Drs. Lipiin Sung, Mary McKnight and Geoffrey Frohnsdorff view a confocal microscopic image of an optical slice through the thickness of a coating. The confocal microscope has an optical resolution down to 200 nm and is a major research tool in assessing the microstructural properties of coatings.

Service Life of Structural Polymeric Composite Materials

Dr. Joannie Chin and Prof. Bruce Ellingwood of the Johns Hopkins University have joined with researchers from industry, professional societies, universities, and other Federal government laboratories in providing technical input into a Load and Resistance Factor Design (LRFD) code for structural polymeric composite materials. Ellingwood and Chin have co-authored a report outlining the history of LRFD design and, in the process, have highlighted materials data that must be generated to satisfy the demands of an LRFD design code. Of particular interest and importance are long-term weathering data for these materials. Such data are required by the structural design community due to the expected long life of structures made from these materials. Over the last year, Chin and her colleagues have modeled the fatigue behavior of composites and have performed experiments on the mechanical and chemical properties of composites exposed to water, salt water and simulated concrete pore solutions. In early 2000, Chin will host a meeting with the industry and other interested parties in an effort to establish an industry/university/government consortium to generate material weathering data required to complete an LRFD design code for composites.

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Appearance

Dr. Mary McKnight, senior scientist, leads a team of researchers from four NIST Laboratories (BFRL, Physics, Information Technology, and Manufacturing Engineering) on advancing measurements and predictions of the reflective properties of materials that govern human perception of appearance. The appearance of an object greatly influences a customer's judgment of the quality of

the object. This is not only true for building materials but also for all products from almost every industry. The objective of the appearance program is to initiate a systems approach to appearance metrology utilizing recent advances in optical metrology, mathematical modeling, and computer rendering. BFRL's role is to lead the effort and to develop advanced textural, spectral, and goniophotometric measurements for quantifying light scattering from a coating and its constituents. These measurements will then be used to validate physical models describing the optical scattering from a coating and the relationships between its microstructure and its goniophotometric properties. The measurements and models will also be used in making a virtual computer representation of a finished product. The computer representation could, potentially, be used as a design tool for the virtual formulation of coatings and for predicting the initial and weathered appearance of coated objects.

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Drs. Mark R. VanLandingham and Xiaohong Gu, an Air Force Office of Scientific Research Post Doc, examine a freshly fabricated chemically modified atomic force microscope (AFM) tip. When installed in the AFM, the tip acts like a chemical sensor having nanoscale resolution. Resolution at this scale is required in studying the interfacial and interphasial properties of materials.

Interfaces and Interphases of Polymeric Materials and Systems

Drs. Tinh Nguyen and Mark VanLandingham have initiated, along with colleagues from NIST's Chemical Science and Technology Laboratory and Materials Science and Engineering Laboratory, a collaborative effort to study the interfacial and interphasial properties (the chemical and physical properties of a material within 100 nanometers of an interface), for polymeric materials. A fundamental understanding of the interfacial and interphasial properties is required to better understand the degradation mechanisms controlling the service life of a product and to improve the service life estimates. Over the last two years, Nguyen and VanLandingham, along with their NIST colleagues, have explored the possibility of joining with industry in establishing an Interface/Interphase Consortium. The meeting to establish this consortium was held in November, 1999.

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VIII

Metrology for Sustainable Development

Background and Intended Outcome

President Clinton has called global climate change one of the most pressing challenges of the 21st century. Scientific opinion on this matter varies significantly, from the view that contributions to global warming are negligible, to those that say man-made carbon emissions are a disaster in progress and require immediate substantial reductions in the emission of the so-called greenhouse gases, principally carbon dioxide. The International Kyoto Climate Change Conference was held in Japan from December 1-10, 1997. The purpose was to accelerate the pace of international action on climate change. Officials from 160 countries agreed on a legally binding protocol where industrialized countries would reduce their collective emissions of six greenhouse gases 5.2 percent below their 1990 levels by 2010. For the United States, this translates into a 7 percent reduction within the same time period. The U.S. building sector shares almost equally with the industrial and transportation sectors in U.S. carbon emissions. Monumental strides must be made by the U.S. building sector to achieve the 2010 goals.

Beyond regulated carbon emissions, the "green movement" is sweeping the building industry. All major building product companies, building designers, and building operators need measurement methods, test methods, fundamental data, and life cycle environmental and economic analysis tools to objectively promote their approaches and products to achieve sustainability.

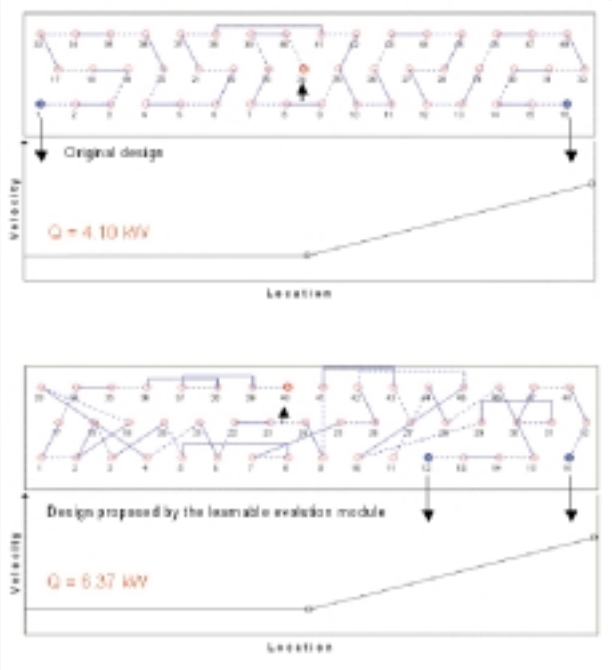
To meet these needs, BFRL staff will apply their expertise in refrigeration systems, thermal insulation, building integrated photovoltaic systems, indoor air quality, and life cycle economic and environmental analysis methods to support the widespread use of sustainability and assist them in achieving carbon-reduction goals. A wide range of data, measurement methods, test methods, simulation models, and analysis tools will be developed. These include: Building for Environmental and Economic Sustainability (BEES); performance data on flammable and natural refrigerants; artificial intelligence-aided design procedures for refrigeration heat exchangers; new apparatuses/test methods/standard materials for advanced thermal insulation/low temperature insulation/high-temperature insulation; validated design models for building integrated photovoltaic systems; and contaminant-based design procedures for indoor air quality.

Software Tool for Optimized Heat Exchanger Design Using Genetic Algorithms

The goal of a heat exchanger design engineer is to obtain the maximum capacity for specified general heat exchanger parameters. One of the important tasks in designing a finned-tube heat exchanger is designing the refrigerant circuitry, that is, specifying the refrigerant path through the heat exchanger. Designing an optimized circuitry is particularly challenging when a zeotropic mixture is used as a refrigerant or when the air entering the heat exchanger has a non-uniform velocity profile.

Piotr Domanski of BFRL in cooperation with Ryszard Michalski and Ken Kaufman of George Mason University demonstrated the feasibility of designing an optimized refrigerant circuitry without designer's input using a dedicated software package. The package consists of NIST's detail tube-by-tube evaporator model, EVAP5, and a newly developed "learnable evolution module" that implements Genetic Algorithms and Symbolic Learning. During a refrigerant circuitry design run, the module generates a population (set) of proposed circuitry architectures, which EVAP5 evaluated as to the obtained capacity. The results guide the module in generating the next population for evaluation by EVAP5. This process can be

Effect of poorly distributed air flow on coil capacity for a normally designed coil (top) and a coil designed using a learnable evolution module (bottom).



repeated hundreds of times and leads to an optimized design.

The figure shows two side-view schematics of an evaporator indicating the refrigerant path through the heat exchanger and the air velocity profile. Each circle represents a tube in the assembly. The solid lines connecting the tubes denote returning bends located on the near (visible) side, and the dotted lines denote the returning bends on the far side. In the upper example, the refrigerant enters the evaporator through tube #24. After passing through tube #25, the refrigerant splits into two branches (to tubes #10 and #42), which causes the refrigerant to the exit tubes #1 and #16, respectively. The air flows from the bottom up. The upper example of evaporator design obtained 6.33 kW capacity with the uniform inlet air velocity profile and only 4.10 kW capacity with the non-uniform air velocity profile indicated in the figure. The lower design, optimized by the learnable evolution module, obtained the capacity level that corresponds to that of the upper original design operating with the uniform air distribution. This result demonstrates that the learnable evolution module can develop optimized circuitry designs that account for poorly distributed air and eliminate performance degradation.

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BFRL Director Jack Snell, NIST Deputy Director Karen Brown, NIST Director Ray Kammer and BFRL researcher Hunter Fanney dedicate NIST's Solar Tracking Test Facility.

Solar Tracker Facility

The widespread use of building integrated photovoltaics appears likely, as a result of the continuing decline in photovoltaic module costs, the relative ease in which photovoltaics can be incorporated within a building's exterior shell, and the fact that buildings account for 40 percent of the U. S. energy consumption. Examples of building integrated photovoltaics are photovoltaic shingles that replace conventional three-tab residential roofing shingles and walls constructed of photovoltaic cells that replace commercial building's opaque walls.

A recent survey found that 88 percent of building professionals would consider the use of building integrated photovoltaics, if high-quality performance data were available. BFRL's Building Integrated Photovoltaic program will provide the needed high-quality experimental data needed by both the building professionals and researchers attempting to develop predictive models. To assist in this research, a mobile solar tracker facility was recently constructed by Dr. Hunter Fanney, Mr. Brian Dougherty and Mr. Stanley Morehouse.

The solar tracker facility will be used to characterize the performance of building integrated photovoltaic modules. Parameters that will be determined using the solar tracker are:

- influence of angle-of-incidence,
- influence of solar spectrum,
- temperature coefficients for voltage, current, and power; and
- module operating temperature as a function of meteorological conditions.

The solar tracker is capable of tracking the sun to minimize the solar incident angle, to perform azimuth or elevation only tracking, and to track the sun with prescribed offsets in the azimuth and/or elevation angles. An "on-board" meteorological station measures the total,

beam, and diffuse solar radiation as well as the wind's direction and velocity. A spectroradiometer is used to measure solar radiation as a function of wavelength, and the open circuit voltage, short circuit current, maximum power point, and the current versus voltage characteristics of the photovoltaic modules are measured.

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Investigation of the Well-Mixed Zone Assumption in Calculation of Indoor Air Motion and Contaminant Dispersal

Reliable modeling of contaminant dispersal within buildings is fundamental to many types of design and analysis. To understand and predict contaminant migration, both the mixing of air within rooms and the distribution of contaminants between rooms must be properly modeled. This requires the combination of a macroscopic, whole-building model that can predict contaminant migration between zones and a microscopic room airflow model that represents airflow patterns within individual rooms.

Multizone network airflow models, such as CONTAM, take into account weather conditions and building leakage characteristics to calculate airflow and contaminant migration between building zones that are assumed to be at a uniform contaminant concentration. They provide fast, reliable calculations for many types of building contaminant analysis. However, the uniform-concentration assumption is inappropriate for some situations, and detailed room airflow modeling is required. This is typically done using computational fluid dynamics (CFD), which produces detailed results at the expense of considerable computational resources. Therefore, there is a need to combine network airflow and CFD models to achieve greater detail where it is needed while maintaining manageable computing times.

This project investigates the impact of coupling a multizone network airflow model with computational fluid dynamics. Sets of connected rooms are modeled, first using only computational fluid dynamics and then using the multizone model to represent one of the rooms, providing boundary conditions for CFD modeling of the other room. Comparison of contaminant concentrations predicted using the two strategies would identify situations in which it is appropriate to use a combined model to reduce computing time. This enhances the ability of multizone models, which are better suited to modeling entire buildings, to represent buildings in which complex spaces or innovative ventilation technologies result in imperfectly mixed indoor air. Expanding the application of multizone models in this manner will improve the cost effectiveness and accuracy of analyzing these types of buildings using computational methods.

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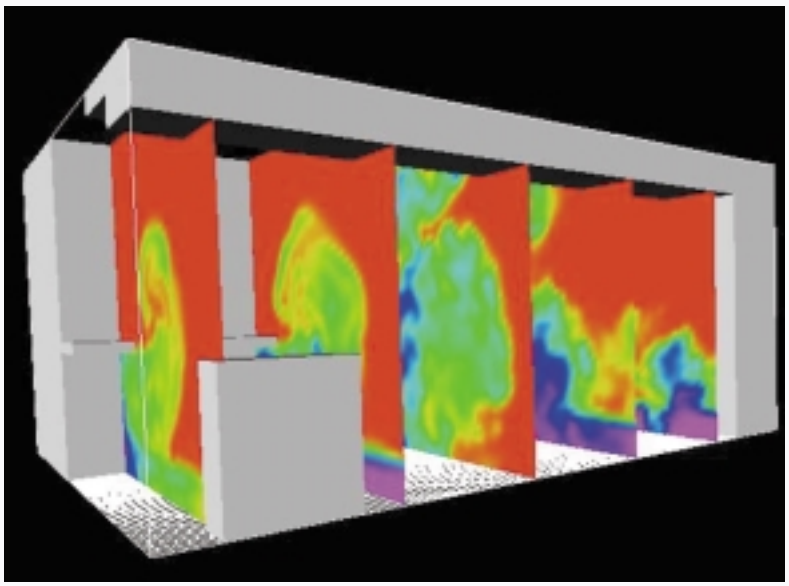

Fresh air entering an atrium through first floor windows.

IX

Earthquake, Fire and Wind Engineering

Background and Intended Outcome.

Costs due to disaster-related damages are being driven up sharply by increasing population density in high risk regions that have increasingly vulnerable and costly-to-repair infrastructures based on advanced technology. Economic losses to the nation from recent natural disasters exceed $100 billion per year. Reducing disaster-related losses – life, injuries, and economic – is a complex problem because of the breadth and diversity of these systems, their inherent independence, the varied nature of the threats from disasters, and the multiplicity of sources of vulnerabilities.

NIST seeks to reduce economic losses from earthquakes, extreme winds, and post-disaster fires and increase public safety through the development and adoption of next-generation technologies and practices for disaster mitigation, response, and recovery. It provides measurement, evaluation, and performance prediction technologies to enable cost-effective improvements to increase the disaster-resistance of new and existing construction. The technologies encompass structural control for extreme loads, performance-based seismic design, next-generation standards for wind loads and computational wind engineering, enhanced fire control for post-disaster and urban wind-driven fires, non-destructive evaluation for condition assessment and quality control, high-performance disaster-resistant materials and systems, structural performance of housing systems, and the strengthening and rehabilitation of structures.

BFRL is partnering actively with the U.S. materials, architecture, engineering, and construction industries, government agencies (especially the Federal Emergency Management Agency and the National Oceanic and Atmospheric Administration), building standards and codes organizations, and the fire services and disaster response communities.

Courtesy of Charles Pankow Builders

Architect's drawing of a 39-story apartment building which will use a hybrid precast concrete moment frame system.

Hybrid Precast Concrete Moment Frame System

An innovative connection system for precast concrete buildings in seismic regions will be used in a $128-million, 39-story apartment building in San Francisco. The connection system was developed by Dr. William Stone, Ms. Geraldine Cheok and Dr. H. S. Lew in partnership with Charles Pankow Builders, the American Concrete Institute (ACI) and the University of Washington. This new building has more floors than the current concrete-frame record holder, a 32-story office building in Burbank, in an active seismic zone. By using this system, an estimated savings of $4 million to $6 million (equivalent to 5 to 7 percent of construction costs) can be achieved over the use of what would ordinarily be a steel-frame structure. Additional savings are expected due to reduction of the project delivery time by three to four months and the commensurate shortening of the length of the construction loans. This connection system has been used previously in parking garages in Eugene, Ore. and in Garden City, NY.

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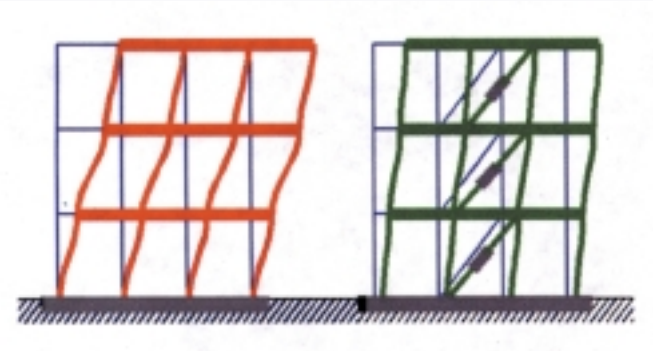

A computer simulation illustrates how structural dampers (right building) reduce inter-story drifts and minimize damage to the structure during strong earthquakes.

Seismic Rehabilitation of Welded Steel Frame Buildings

Dr. John Gross, partnering with the American Institute of Steel Construction (AISC) and three leading U.S. universities, has published *Modification of Existing Welded Steel Moment Frame Connections for Seismic Resistance*. This document provides the first comprehensive guidance for the seismic rehabilitation of existing welded steel frame buildings. Conceived in response to the large number of beam-to-column connections that failed at the weldments during the 1994 Northridge, Calif., earthquake, this project addresses a critical public safety problem. Use of the guidelines, published by AISC as Design Guide No. 12, will assure the safety of tens of thousands of similar buildings located in the United States and throughout the world. Rehabilitation of 50 percent of the existing steel frame buildings in "high" seismic regions of the United States alone is estimated to cost $2 billion to $5 billion. The guidelines provide experimentally-validated response prediction models and design equations for three connection modification concepts that shift loading from the brittle weld joints into the beams, thus enabling the structure to absorb the earthquake's energy in a ductile manner.

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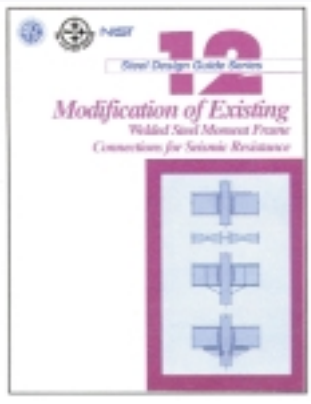

Design Guide No. 12, published by the American Institute of Steel Construcion, provides the first comprehensive guidance for the seismic rehabilitation of existing welded steel buildings.

Structural Control for Extreme Loads

Structural control devices, which include seismic isolators and structural dampers, can protect structures and their occupants during large earthquakes and extreme winds. Installation of these devices in numerous structures throughout the world has proven that they can effectively reduce structural response to strong vibrations, and help structures achieve their expected levels of performance in a reliable and cost-effective manner. Although these devices must be tested before installation, consensus standards for all types of control devices do not yet exist.

Dr. Michael Riley and Dr. Fahim Sadek have developed testing guidelines for passive energy dissipation devices, a major class of control devices. These guidelines detail a complete series of quality control and prototype tests. The recommended test procedures were developed with the assistance of a technical review committee. A workshop involving leading experts in the field of structural control, including device manufacturers, structural engineers, representatives of government agencies and academic researchers, was held to review and comment on the recommended procedures. The draft version of the test procedures was well received by the workshop participants, and their recommendations were used to improve the final version. BFRL is working closely with manufacturers, designers, and researchers to encourage the use of the test procedures in practice and will recommend adoption of the test procedures as a consensus standard by the American Society of Civil Engineers.

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Dr. Dat Duthinh, research structural engineer, examines the condition of a carbon FRP strip used to strengthen a reinforced concrete beam. The beam has been instrumented to permit measurement of inelastic rotation in the maximum moment region.

Fiber-Reinforced Polymer (FRP) Composites in Construction

Much of the U.S. infrastructure is in need of repair or replacement because of deterioration caused by heavy use and exposure to the environment. Moreover, some of the nation's infrastructure requires retrofit to either increase its load capacity or to improve its seismic performance. FRP composites provide attractive alternatives to traditional methods of infrastructure rehabilitation owing to their corrosion resistance, high strength and low density. The goal of Structures research on FRP composites is to provide the technical bases for design standards that will facilitate wider use of these materials in construction.

Dr. Dat Duthinh is investigating the ductility of reinforced concrete beams externally strengthened with carbon FRP strips. Ductility is the ability of a structure to continue to deform while sustaining a load close to its ultimate, and is desirable for safety. In contrast to traditional steel-reinforced concrete beams, where ductility is provided by yielding of the steel reinforcement, FRP composites are incapable of plastic deformation and the ductility of FRP-strengthened beams is questionable. A series of eight reinforced concrete beams with various ratios of steel to FRP reinforcement were tested to failure. The results are being analyzed with a view toward recommending a measure of ductility and a limiting ratio of FRP to steel reinforcement to ensure adequate ductility of the rehabilitated member.

The above work responds, in part, to critical industry needs identified in the NIST Workshop on Standards Development for the Use of Fiber-Reinforced Polymers for the Rehabilitation of Concrete and Masonry Structures held in January 1998 in Tucson, Ariz. The workshop proceedings (NISTIR 6288) are available upon request.

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Electronic Standards for Wind Loads

The development of electronic provisions for wind loads has been made possible by recent technological developments in the areas of measurement, computation and data processing. The development has been initiated by NIST for use in design of large aerodynamic databases containing time series of pressures measured in the wind tunnel at a large number of points on the building surface. Such use is now accepted by the ASCE 7-98 Standard (1999) as an alternative to the use of wind pressure tables and plots. Because electronic provisions can make full use of vast amounts of information in a user-friendly format, they can result in structures that are far more risk-consistent and therefore can be both safer and more economical than structures designed in accordance with conventional provisions patterned to suit slide-rule era constraints.

The methodology to be used in electronic standards was recently employed in a NIST/University of Maryland cooperative study aimed at assessing the procedure used in the ASCE 7-98 Standard to account for wind directionality effects. This procedure is shown to result in significant numbers of buildings being potentially subjected to larger loads than those intended by the Standard. The study provides information that can be used to correct this state of affairs.

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Natural Disaster Investigations

This year, BFRL researchers investigated structural damage resulting from two natural disasters to gain a better understanding of how buildings respond to extreme wind and earthquake loads. Dr. Michael Riley investigated damage to engineered structures caused by the May 3, 1999, tornado outbreak in Oklahoma City, Okla. This outbreak, which included one of the largest tornadoes to ever strike an urban area, damaged or destroyed thousands of homes and hundreds of businesses. The damage reconnaissance identified several engineered structures that provide a unique opportunity to conduct in-depth studies of how such buildings respond to tornado loads. Two of these buildings are being analyzed to estimate the wind loads that were required to cause the observed damage and to determine how these structures and others should be designed or retrofitted to ensure life safety during a tornado of similar intensity. To enhance public safety, the study will recommend needed improvements to existing wind load standards, building codes, and construction practices for existing and new construction.

Dr. John Gross and Dr. Long Phan conducted reconnaissance and documented damage to buildings and highway structures in the August 17, 1999, Kocaeli (Turkey) earthquake. Reinforced concrete frame construction similar to that used in the United States suffered extensive damage and, in many instances complete collapse, and there were numerous cases of soil failure (liquefaction). The vulnerability of such construction and risk to residential occupants emphasize the importance of careful site characterization to avoid the potential for soil failure, proper design and construction practices, and rigorous code enforcement.

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Performance-Based Seismic Design of Structures

Recent earthquakes in the United States and abroad have resulted in significant loss of life and enormous economic loss due to structural damage, loss of function, and business interruption. Such consequences are avoidable. Dr. H.S. Lew and his colleagues are studying alternative approaches to seismic design that permit performance-based design at multiple performance and hazard levels, with due consideration given to the use of seismic isolation and control devices. Both energy-based and displacement-based approaches are being studied. Computer-based nonlinear dynamic analyses are being carried out on structures that have instrumentation data from recent earthquakes. Validated computer models are used to evaluate global response modification factors used in current codes and design procedures for structures with seismic isolation and energy dissipation devices. Four

Kelley Elementary School in Moore, Oklahoma was destroyed by a direct hit from an F-5 rated tornado.

analytical procedures (linear static, linear dynamic, nonlinear static and nonlinear dynamic) have been evaluated against the acceptance criteria for seismic response of buildings established by the NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA-273). The four analytical procedures yield results that are not consistent with the expected seismic demands. The differences in the acceptance criteria for the linear and nonlinear methods indicate that it is possible that the demands estimated by one method may meet FEMA-273 acceptance criteria while demands estimated using a different method for the same building may fall short of the criteria. The analyses also show that the use of inter-story drift demands in developing acceptance criteria appears to be promising.

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X

Advanced Fire Measurements and Fire Fighting Technologies

Background and Intended Outcome.

BFRL will add new capabilty for corporate or commercial testing laboratories to measure a product' s fire behavior in the laboratory and in the field, and improve fire fighter safety and effectiveness through new measurements, test methods, predictions and fire ground information technology. The BFRL products will be improved measurement methods for the performance of products and fire control technologies and real-time measurement and predictive tools for command and control of emergencies. In pursuing this objective, BFRL actively partners with the U.S. Fire Administration and the National Institute for Occupational Safety and Health for fire fighter safety; also BFRL cooperates with the Montgomery County Fire Department and the New York City Fire Department.

Predicting How Hot is "Hot"

Nearly every fire test or research study employs thermocouples to measure gas temperatures because they are affordable, easy to install, and robust and they produce an output that is easy to read. However, a thermocouple's output is influenced by the thermal and flow conditions in its surroundings, often leading to significant deviation from the true gas temperature. Thus, producing accurate temperature measurements in and near fires requires including the effects of the severely inhomogeneous environment.

As one part of a broad program to improve fire measurements, the BFRL Fire Science Division is modeling the uncertainties associated with using thermocouples in and around fires. Performed by Dr. Linda Blevins, mechanical engineer, and Dr. William Pitts, group leader, the research is intended to improve methodology for recognizing, avoiding, and accounting for thermocouple uncertainties during fire testing and research.

This photograph was taken during a fire test at NIST using a 40%-scale model of a standard fire-test room having a single doorway. The fire is burning underventilated with the result that flames extend out of the doorway. An array of aspirated thermocouples, which can be seen in the doorway, are used to record local temperatures.

The team has developed steady-state computer models of the response of bare and aspirated thermocouples to thermal environments characteristic of a room fire. The models show major differences in the temperature reading errors (up to tens of percent low) for bare thermocouples placed in the hot, upper layer of a room fire compared to those placed in the cooler, lower layer (up to hundreds of percent high). Measurements of the coolest lower layer temperatures are particularly sensitive to radiative transfer from even modestly warmer surroundings. The models also showed that measurements using aspirated thermocouples are more accurate in both the upper and lower layers of a room fire, but are still in need of correction.

The results have been published in *Fire Safety Journal*. Vol. 33, November, 1999.

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Cooling Fire Suppressants

The classic *fire triangle* is composed of three components – fuel, air, and heat necessary to sustain a fire – and extinguishment occurs when one or more of these are removed. Inclusion of a fourth component, the free radicals (hydrogen atoms and hydroxyl radicals that propagate combustion) leads to expansion to a *fire tetrahedron*. Brominated fluorocarbon suppressants such as halon 1301 (CF_3Br) and halon 1211 (CF_2ClBr) derive much of their high efficiency by removing these free radicals from combustion zones. In addition to their many desirable properties and their widespread use for protecting a variety of high-value assets such as aircraft and telecommunication facilities, these halons are effective destroyers of stratospheric ozone. As a result, the production of halons has been banned by international treaty and domestic legislation.

Under Department of Defense sponsorship, Dr. William Pitts is working with Dr. Jiann Yang and Dr. Linda Blevins of BFRL and Dr. Marcia Huber of the NIST Chemical Science and Technology Laboratory to identify fire-fighting agents which have the desirable properties of halons, but which do not harm the atmosphere. The focus is on thermal agents, which attack other sides of the fire tetrahedron, extracting thermal energy and cooling the fire and/or fuel surfaces.

A three-pronged approach has been utilized in the search. First, extensive NIST molecular property data bases have been searched to identify potential fire-fighting agents capable of absorbing large amounts of heat and which have other favorable properties for fire-fighting applications. Second, detailed chemical kinetic combustion modeling has been used to provide an understanding of how thermal agents interact with and extinguish a flame. The modeling has led to a predictive method for the amount of a candidate gaseous thermal agent required to extinguish flames. Third, the molecular properties that control cooling of fuel surfaces (to lower the fuel generation rate) by condensed-phase agents with fuel surfaces have been identified.

The findings have been used to rank potential thermal agents, that have desirable properties for halon replacement. One of the highest rated compounds is a commercially available, environmentally friendly fluorinated ether. This compound, along with others, is currently being tested using a screening apparatus developed at NIST for evaluating the fire-fighting effectiveness of fire-fighting agents.

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Heat Flux Measurement Standards

Heat release is the single most important variable in determining fire growth and the resulting human injury and property damage. Thus, quantifying heat transfer (by radiation, convection, and conduction) is pivotal in assessing fire hazard. Since many fire test methods measure combustibility under external radiation, accurate calibration of flux meters affects the acceptance or rejection of commercial products. Accurate heat flux measurements are also essential for validation of computational fire models.

Heat transfer is a derived quantity, which must be inferred from

measurements of temperature gradient (conduction) or the flux of photons (radiation). Studies have indicated that the uncertainty associated with a heat flux gauge calibrated in a radiant field can be as high as 40 percent when it is exposed to a strongly flowing environment such as occurs in the neighborhood of a fire.

Under the leadership of William Grosshandler a multi-Laboratory NIST team has performed research to address industrial needs for improved range and accuracy of then-current heat flux measurement apparatus. The results have been improved understanding for interpretation of heat flux measurements and advanced facilities for calibrating heat flux gauges in pure conduction, convection and radiation modes with reduced uncertainty. The new convective heat transfer tunnel, shown in the photograph, can evaluate the performance of heat flux gauges of different designs at levels up to 5 kW/m^2. A second apparatus, also with application to flowing environments, enables conductive heat flux measurement at levels up to 75 kW/m^2.

These facilities will now be used to develop a better understanding of the performance of heat flux measurement devices in the complex environments of real-scale fire tests and will lead to traceable calibration standards.

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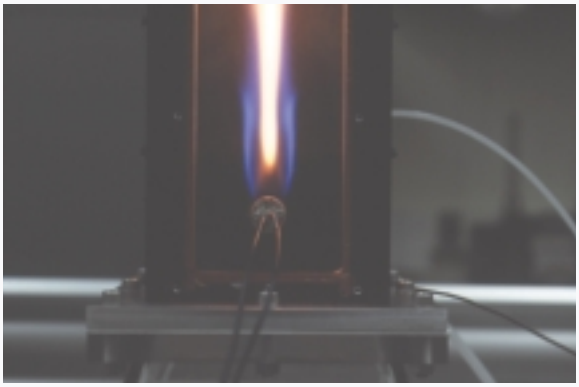

Transition from a stable enveloped flame (top) to a wake flame (right)

Ms. Carol Womeldorf preparing for a heat flux gauge calibration.

Screen Test for Liquid Fire Suppressants

The 1994 ban on production of halon 1301 (CF_3Br) production has resulted in an extensive search for its replacements and alternatives. With the wealth of new chemicals being considered, it is critical to be able to obtain values of flame suppression efficiency quickly, at low cost using a small sample. While the conventional screens are designed primarily for evaluating gaseous fire suppressing agents, many candidate agents are fluids of low volatility. Therefore, there is a need for the development of a reliable screening method for liquid aerosols.

Sponsored by the Department of Defense's Next Generation Fire Suppression Technology Program, a

team led by Dr. Jiann C. Yang of the Fire Science Division has designed and built an apparatus for screening liquid aerosols. The apparatus includes a propane-fueled, water-cooled, sintered stainless steel cylinder burner located in the test section of a vertical wind tunnel. A nebulizer is used to create liquid droplets (< 100 µm) and inject them into the air stream. The performance of the nebulizer was characterized using a Phase Doppler Particle Analyzer. The apparatus is robust and easy to operate. At the extinguishing concentration, flame blow-off occurs, with an abrupt and obvious transition from a stable enveloped flame to a wake flame, as shown in the accompanying two flame photographs.

Flame extinction in this burner has now been extensively characterized with conventional inert gases, halons, and fluids with a range of thermophysical properties, as well as a variety of common and exotic candidate halon replacements. Powders can also be tested when a particle delivery system has been added.

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Protecting Fire Fighters

For more than 20 years the protective clothing worn by fire-fighters has improved dramatically, giving the firefighter greater protection from fire, heat, and moisture.

Yet, firefighters continue to suffer burns at a stubbornly constant rate. With support from the U.S. Fire Administration and the National Institute of Occupational Health,

Mr. James Randall Lawson, physical scientist, and colleagues have developed a new apparatus for measuring the thermal performance of fire fighter protective clothing. As part of this process, he has examined the broad range of fire conditions and events that lead to burn injuries during structural firefighting. Study results are found in *Fire Fighter Protective Clothing and Thermal Environments of Structural FireFighting*, NISTIR 5804. Many firefighter burn injuries are not caused by flame contact, but by factors such as contact with hot surfaces, excessive exposure to high thermal radiation and/or insufficient protection provided by protective clothing. Moisture from perspiration or fire hose wetting causes significant changes in protective clothing's thermal performance. These changes often lead to serious burn injuries caused by hot vapors or steam. These phenomena are explained in detail in the Mr. Lawson's paper, "Thermal Performance of Bunker Gear", which appeared in the August 1998 issue of *Fire Engineering*.

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BFRL apparatus for measuring the thermal performance of fire fighter protective clothing.

The activities of the National Science and Technology Council (NSTC) Subcommittee on Construction and Building (C&B) have a strong effect on the BFRL program. BFRL co-chairs the C&B and maintains its secretariat. NSTC, a cabinet-level group charged with setting federal technology policy, coordinates R&D strategies across a broad cross-section of public and private interests. C&B defines priorities for federal research, development, and deployment related to the industries that produce, operate, and maintain constructed facilities, including buildings and infrastructure. These priorities, and related collaborations with industry and government, guide the focus of BFRL programs.

The C&B Program focuses on developing technologies and practices that can be used to achieve the following goals and making them available for general use in the construction industry by 2003. The goals, based on 1994 business practices and endorsed by industry leaders, are:

- 50 percent reduction in delivery time from the decision to construct a new facility to its readiness for service;
- 50 percent reduction in operation, maintenance and energy costs;
- 30 percent increase in productivity and comfort of building occupants;
- 50 percent fewer occupant illnesses and injuries related to building conditions;
- 50 percent less waste and pollution at every step of the delivery process, from raw material extraction to final demolition and recycling of the shelter and its contents;
- 50 percent more durability and flexibility; and
- 50 percent reduction in construction work illnesses and injuries.

C&B Activities in 1999

Partnership for Advancing Technology in Housing (PATH)

C&B organized the Partnership for Advancing Technologies in Housing (PATH), which became a Presidential initiative announced in 1998. PATH brings together government and industry to develop, demonstrate, and deploy housing technologies, designs, and practices that can significantly improve the quality, durability, energy efficiency, environmental performance, and affordability of new and existing houses. The Department of Housing and Urban Development is leading the PATH program. The government's primary role in the partnership is to act as catalyst and facilitator, to coordinate and promote individual agency programs that contribute to PATH goals, and to help remove unnecessary regulatory barriers to innovation.

C&B provides the secretariat for the PATH federal agency-working group and, as such, works in collaboration with the director of PATH to provide technical support from the federal agencies. C&B coordinates the federal R&D effort in all sectors of construction and building and, therefore, can identify federal R&D that is in support of the PATH goals. C&B will stimulate and encourage federal agencies to provide supporting technology for industry partners in response to their expressed needs.

C&B agencies also explore and promote industry/government collaborations that respond to the research needs of the housing industry.

Streamlining the Building Regulatory System

C&B continues to provide financial support for the National Conference of States on Building Codes and Standards' (NCSBCS) project on streamlining the building regulatory system. The purpose of the project is to develop and gain the adoption of a package of model reforms which when

adopted by federal, state, regional, or local governments will enhance public safety, economic development, and environmental quality while reducing by as much as 60 percent the amount of regulatory processing time it takes to move projects from the initial step of zoning approval through to the last step of issuance of the certificate of occupancy.

NCSBCS has collected over 100 case studies of streamlined regulatory processes, analyzed them, modified some, and offered them as model processes to jurisdictions interested in improving their own systems. These model processes are described on the NCSBCS Web site at www.ncsbcs.org/. NCSBCS is working with public and private groups to develop training seminars in the use of model regulatory procedures such as the one developed for the state of Oregon. NCSBCS plans to develop a streamlining model guidebook, which will include a legislative guide for state and local governments.

Partnership for Advancing Infrastructure and its Renewal

C&B supported the further development of the Partnership for Advancing Infrastructure and its Renewal (PAIR). PAIR is conceived by its secretariat, the Civil Engineering Research Foundation (CERF), as a partnership of existing and future government, private sector, and academic programs to develop the innovative technologies needed to revitalize and advance the nation's physical infrastructure. "Infrastructure" comprises transportation, energy, telecommunications, water supply and sewerage, and key public institutional resources such as schools, hospitals, and prisons. This year's effort has focused on the development of a draft detailed roadmap/implementation plan for transportation physical infrastructure and educational facilities, and the development of increased public awareness of PAIR to broaden programmatic and financial support.

Working with the Industries of Construction

C&B agencies participate in and support the CONstruction MATerials (CONMAT) Council, which consists of 12 different material groups (aluminum, coatings, concrete, fiber-reinforced composites, geo-synthetics, masonry, plastics, roofing materials, smart materials, stainless materials, steel, and wood) and liaison members from public and private agencies. These groups joined forces in a $250 million effort to plan and implement a national program of research development and deployment.

C&B worked with the American Society of Mechanical Engineers to develop a joint government/industry forum, similar to CONMAT, for mechanical and electrical systems industries. This forum involves organizations representing heating and air-conditioning systems, lighting security systems, fire alarm systems, electrical systems, and elevators and escalators.

C&B supports a National Academy of Sciences study to document the relationships between the workplace environment and worker productivity and health.

Through active participation and leadership in many Standards Development Organizations, BFRL staff contribute significant time and technical expertise to the process of developing national and international standards.

For example, BFRL staff serve, on behalf of the American National Standards Institute (ANSI), as the U.S. participant on the International Organization for Standardization (ISO), Technical Management Board's Technical Advisory Group 8 – Building. In addition, BFRL staff work within specific organizations including the American Concrete Institute (ACI), American Society of Civil Engineers (ASCE), American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), American Institute of Steel Construction (AISC), International Code Council (ICC), National Fire Protection Association (NFPA) and ASTM.

Among the committees that BFRL staff participate on within ACI are ACI 235 and ACI 235-A , ACI 236-A, ACI 318, and ACI 126, Formats for Concrete Materials Property Data. Dr. Chiara ("Clarissa") Ferraris, research physicist, Building Materials Division, serves as secretary to ACI 126. She played a major part in the drafting and editing of the 70-page committee document that is to be published in ACI's Manual of Concrete Practice in 2000. It will be the first ACI guide devoted to the important topic of database formats.

Dr. H. S. Lew, senior research engineer in the Structures Division, working closely with the ACI Technology Transfer Committee, proposed to the American Concrete Institute a provisional standard on *Post-Tensioned Moment Frames Composed of Discretely Jointed Precast Concrete Members*. The provisional standard is based on a multiyear research program on hybrid precast concrete connections conducted with Structures Division colleagues Dr. William Stone and Ms. Geraldine Cheok in cooperation with industry. A 39-story building is being constructed using hybrid precast concrete connections in the San Francisco area, a high seismic region. Other high-rise buildings are being designed using hybrid precast concrete connections. (See also page 30)

In ASTM alone, BFRL is active on the following committees: C01-Cement; C09-Concrete and Concrete Aggregates; C16-Thermal Insulation; D01-Paint and Related Coating Materials; D04-Road and Paving Materials; D08-Roofing, Water-proofing and Bituminous Materials; D09-Electrical and Electronic Insulating Materials; D20-Plastics; D22-Sampling and Analysis of Atmospheres; D30-High Modulus Fibers and Their Composites; E05-Fire Standards; E06-Performance of Buildings; E12-Appearance of Materials; E36-Conformity Assessment; and G03-Durability of Non-metallic Materials.

Dr. Nicholas J. Carino, leader, Structural Evaluation and Standards Group, of the Structures Division prepared a draft revision to ASTM C 900 (Test Method for Pullout Strength of Hardened Concrete) that was adopted by Committee C 09. The revision covers the use of post-installed pullout inserts and broadens the application of this reliable method for measuring the strength of concrete in structures. Dr. Carino serves as chairman of ASTM Subcommittee C09.64 on non-destructive and in-place testing of concrete.

Dr. Richard Gann, senior scientist, working within ASTM E05, Fire Standards, was instrumental in effecting key revisions to the recently developed Standard Test Method for Measuring Smoke Toxicity for Use in Fire Hazard Analysis (E1678). Based on the research results of a BFRL project led by Dr. William Pitts, research chemist, the standard was amended to reflect the large amount of carbon monoxide (CO) produced in postflashover fires, where the combustion is severely under-ventilated. This high CO yield is independent of the nature of the combustibles in the room and dominates the lethality of the smoke produced. A second upgrade of the Standard was the inclusion of the accuracy of the method in predicting the lethality of smoke from real-scale room fire tests. The combination of these changes will enable fire hazard analyses to show that the lethality of the smoke that causes most fire deaths is not fuel-specific, reducing the likely levels of fire regulation and product liability.

Dr. William Grosshandler, chief, Fire Science Division, chairs a task group of the NFPA 2001, Standard on Clean Fire Extinguishing Systems, which is looking into problems that result from electrical equipment that cannot be de-energized prior to applying a fire suppressant. Working under a cooperative research and development agreeement with 3M, Dr. Grosshandler and his research team are quantifying the additional amount of clean agent that must be applied when substantial sources of electrical heating may be present. The NFPA standard is currently being revised based upon some of the information developed by the task group.

Dr. Andrew Persily, leader, Indoor Air Quality and Ventilation Group, chairs the committee charged with revising ASHRAE Standard 62. This committee is developing HVAC system and building design and operation requirements for providing acceptable indoor environments. The committee's work has focused on system design requirements and calculation methods for determining design ventilation rates. The committee's effort has resulted in the publication of the first revision of the standard in 10 years, Standard 62-1999. This new version of the standard contains information on ventilation and indoor carbon dioxide resulting directly from BFRL research.

Mr. Joel Zingeser, manager, Codes and Standards Services, was named chair of ASTM E06.66, Performance Standards for Dwellings. This subcommittee is preparing a suite of standard guides written in performance language to facilitate performance-based design and procurements of housing. Mr. Zingeser is also chair of a related U.S. Technical Advisory Group (ASTM E06.92.15) to ISO TC/59/SC15, Performance Criteria for Single Family Attached and Detached Dwellings.

Also, BFRL serves on the National Manufactured Home Advisory Council, which provides technical advisory services to the Secretary of Housing and Urban Development about the preemptive federal code for manufactured housing. BFRL, through its involvement with ANSI, is supporting the development of a strong U.S. position in regional and international standards activities.

BFRL is active internationally and participates in many international scientific and technical organizations. BFRL staff are often invited speakers at international meetings and serve as guest researchers to foreign national laboratories. Data and information, shared between BFRL and our foreign collaborators, influences BFRL's research.

Turkey

On August 17, 1999, a severe earthquake (magnitude 7.4) occurred in Kocaeli, Turkey causing considerable loss of life and a large number of structural failures. On August 20, 1999 Drs. John Gross and Long Phan of the BFRL Structures Division arrived in Istanbul to conduct reconnaissance of damage to engineered structures located in the region. NIST actively monitors earthquake events worldwide and participates in post-earthquake investigations for the purpose of advancing earthquake research and providing public service. This particular effort was coordinated on the ground with representatives of the U.S. Geological Survey (USGS) and investigators from the Earthquake Engineering Research Institute (EERI). The NIST team recorded numerous examples of failures fitting into a broad range from partial damage to complete collapse. Of greatest interest to the NIST engineers were the buildings that were not totally destroyed. These examples presented the best insight as to the modes of failure, the possible causes of failure, and the lessons to be learned for next generation construction, both in Turkey and in the high-seismic areas of the United States. The NIST reconnaissance team presented their findings and recommendations for possible follow-on activities to the U.S. Agency for International Development (USAID), the U.S. Department of State, the U.S. Department of Housing and Urban Development, and the NIST staff.

Kingdom of Saudi Arabia

Mr. Joel Zingeser, manager, Codes and Standards Services, leads a joint BFRL and NIST Technology Services Program aimed at helping the Kingdom of Saudi Arabia (KSA) develop and adopt a building code based on U.S. practices. This bilateral work will help the U.S. construction industry in major developing markets avoid technical barriers to trade and promote the application of U.S. technology in international construction markets through the development and adoption of appropriate building and construction practices, codes, specifications, and standards. Work with KSA is being conducted under two Memoranda of Understandings between NIST/ BFRL and the National Conference of States on Building Codes and Standards and with the Saudi Arabia Standards Organization (SASO). The Saudi Building Code Coordination Committee and its four technical committees are coordinating this work in Saudi Arabia. In addition to SASO, participants in the KSA code review and development process represent private sector organizations, universities, and other key departments of government. U.S. technical support for the KSA efforts has come principally from the International Conference of Building Officials,

whose Uniform Building Codes are the basis for the Saudi effort. It is expected that drafts of the first editions of the KSA Building Code and the KSA Fire Code will be published early in 2000.

Japan

Dr. S. Shyam Sunder, chief of the Structures Division, was named U.S.-side chairman of the United States-Japan Cooperative Program in Natural Resources (UJNR) Panel on Wind and Seismic Effects. The UJNR was founded in 1964 in response to the need for improved engineering and scientific practices through exchange of technical data, information, and research personnel between the United States and Japan. The Panel on Wind and Seismic Effects is composed of 19 federal agencies that participate in 11 task committees focusing on specific bilateral issues such as earthquake hazards reduction, passive and active structural control systems, repair and retrofit of structures, and wind and earthquake engineering for offshore structures. Dr. John Gross, leader, Structural Systems and Design Group, was named U.S.-side Secretary General of the Panel on Wind and Seismic Effects. A joint panel meeting is held every year, alternating between the United States and Japan, and features information exchange through technical presentations and site visits to research laboratories and civil works projects.

Multilateral Activites

International Council for Research and Innovation in Building and Construction (CIB)

BFRL is a full member of CIB and actively participates in many of its task groups and working commissions. CIB is concerned with fostering international cooperation and information exchange in building construction and research, technology development, and documentation and provides an important channel for international pre-standardization activity in this field. CIB priorities include sustainable development, performance-based standards, construction process re-engineering, better serving the needs of members in the Americas and Asia, and expanding its role as a pre- standardization body. Dr. Jack Snell, BFRL director, is CIB's vice president and a member of the Board of Directors and the Program Committee.

Mr. Richard Bukowski, research engineer, represents BFRL on CIB W14 on Fire. W14 provides a vehicle for cooperative efforts among international researchers and provides input directly to ISO TC21 and TC92. These efforts serve to coordinate evaluation methods and technical approaches to compliance with building fire regulations, thus contributing to the elimination of non-tariff barriers to trade. Mr. Bukowski also represents BFRL in CIB TG11 on Performance Building Codes.

Federation International du Beton (FIB)

Ms. Geraldine Cheok, research structural engineer, was invited to join Working Groups (WG) 3 and 4 of the International Federation of Structural Concrete - FIB (Federation International du Beton) Commission 7 Seismic Design based on her research on hybrid precast connection systems. The commission was formed in 1998. The objective of WG 3 is to develop a state-of-the-art report on prefabricated structures designed for earthquake resistance. The objective of WG 4 is to develop a state-of-the-art report on prestressed concrete structures designed for earthquake resistance. The committee met for the first time in Kyoto, Japan, in April 1999, and the reports will be completed by 2002.

International Organization for Standardization (ISO)

The ISO subcommittee on Design Life (TC59/SC14) chaired by Dr. Geoffrey Frohnsdorff, chief, Building Materials Division, is continuing the drafting of a multipart standard/guide, Buildings: Service Life Planning. Part 1, General Principles, is now a Draft International Standard (DIS) and Part 2, Service Life Prediction Methodology, is expected to achieve DIS status before the end of 1999. Other parts being drafted address audit and maintenance, database formats, life-cycle costing, and life-cycle analysis. For the future, consideration is being given to the need for parts concerning environmental characterization, condition assessment and concrete.

BFRL continues work with the ISO TC92/SC1/WG10 on Fire-Testing – Calibration and Use of Heat Flux Meters. This work is aimed at providing an economical radiation calibration chain for heat-flux sensors that connects the calibration of sensors used daily in fire-testing laboratories to a designated primary standards laboratory, usually through a national fire laboratory's secondary calibration facility.

We are continuing to evaluate the ISO scheme in terms of its applicability to U.S. needs, assuming that, for U.S. purposes, the NIST Optical Technology Division would provide the primary-standard facility, and BFRL would provide the secondary facility in this chain.

Mr. Mark Palmer participates in ISO TC184 (Industrial Automation Systems and Integration) / SC4 (Industrial Data) and leads the development of ISO 10303 application protocols for the process plant industries. In collaboration with the industrial consortium PlantSTEP, BFRL developed and demonstrated the first ISO 10303 application protocol (AP 227) for exchanging CAD/CAE information for process plants.

Mr. Steven Bushby, electronics engineer, is convener of ISO TC 205 WG 3 Building Control System Design. The Working Group is developing a multipart international standard that addresses several issues related to building control systems issues including control system functionality, communication protocols, system specifications and project management. ANSI/ASHRAE Standard 135-1995 was adopted as the working draft for the communication protocol portion of this standard.

ISO's Technical Committee (TC)86, Refrigeration and Air-conditioning is composed of eight subcommittees that address topics such as terms and definitions, safety, and testing and rating methods for refrigeration and space-conditioning equipment. BFRL participates as a member of the U.S. Technical Advisory Group for ISO TC86. BFRL also is represented on WG1 and WG5, within Subcommittee (SC)6, factory-made air-conditioning and heat pump units. WG1 is working to revise testing and rating standards that apply to unitary air-conditioners and heat pumps. WG5 is developing testing and rating standards that cover three categories of multisplit air-conditioners and heat pumps.

Mr. Joel Zingeser, manager - Standards and Codes Services, is NIST's representative on ISO Technical Advisory Group (TAG)8 on Building. TAG8 is appointed by ISO's Technical Management Board. Approximately 12 countries are represented. TAG8 focuses on advancing and streamlining building sector activities within the relevant ISO technical committees and their subcommittees.

International Union of Testing and Research Laboratories for Materials and Structures (RILEM)

RILEM promotes progress in the design, testing, manufacture and use of building materials. Its membership includes specialists from 80 countries involved with construction and research.

Mr. James Pielert, manager, Construction Materials Reference Laboratory, is a delegate to RILEM and is a member of the Bureau, the management committee of RILEM. He was actively involved with revising RILEM's strategic plan through participation in the RILEM 2000 Workshop in Madrid and the 1999 annual meeting in Stockholm.

Mr. Dale Bentz, chemical engineer, was elected at the 1999 annual meeting of RILEM to the Coordinating Committee which is one of the three standing committees of RILEM. The Coordinating Committee is responsible for overall coordination and monitoring of the technical committees of RILEM which is where specific scientific and technical problems are addressed. Mr. Bentz is also a member of the Technical Committee on Engineering of the Interfacial Transition Zone in Cementitious Composites.

Dr. Long Phan, research structural engineer, is a member of RILEM Committee 129-MHT, Test Methods for Mechanical Properties of Concrete at High Temperatures. He attended the 13th TC 129-MHT meeting in Wismar, Germany (May 1999) and worked with other committee members on developing a draft recommendation for test methods for mechanical properties of concrete at high temperatures.

Dr. Walter Rossiter, research chemist, chairs RILEM/CIB Joint Committee on Roofing Materials and Systems. The committee's objectives are to develop a methodology for assessing the condition of in-place flexible roofing membranes and determine the state-of-the-art design, application, and maintenance of sustainable membrane roofing systems.

Other BFRL members of RILEM Technical Committees include Dr. Edward Garboczi, leader, Inorganic Building Materials, on the Technical Committee on the Interfacial Transition Zone in Cementitious Composites; and Mr. Ken Snyder, physicist, on the Technical Committee on Internal Damage of Concrete Due to Frost Action.

Process Industries Executive for Achieving Business Advantage using Standards for Data Exchange (PIEBASE)

PIEBASE is an international umbrella organization for process and construction industry consortia active in the development of ISO STEP (Standard for The Exchange of Product model data) application protocols and other international standards for exchanging and sharing industrial data. Mr. Mark Palmer, research engineer, participates in the PIEBASE Executive and leads the PIEBASE Working Group. PIEBASE coordinates the standards development programs of the participating consortia and provides a forum for international collaboration on developing and using information technology standards for the benefit of the global process industries.

International Energy Agency (IEA)

Eleven countries participate in the International Energy Agency Annex 34. Members of the U.S. team, in addition to Dr. John House, Mechanical Systems and Controls Group, include Johnson Controls Inc., the Honeywell Center,

Massachusetts Institute of Technology, Purdue University and Field Diagnostic Services, Inc. Annex 34 works with control manufacturers, industrial partners and/or building owners and operators to demonstrate the benefits of on-line performance evaluation in real building applications. The fault detection and diagnostic (FDD) methods developed in an earlier Annex (Annex 25) are being combined into a robust performance evaluation systems and incorporated into a future generation of smart building control systems.

Forum for International Cooperation on Fire Research (FORUM)

The Forum for International Cooperation on Fire Research (FORUM) comprises heads of public and private sector fire research laboratories and organizations sponsoring fire research around the world. Dr. Jack Snell, BFRL director, is the Forum chair and Mr. Richard Bukowski, research engineer, is secretary. The group meets annually at the facilities of one of the member organizations to discuss mutual interests, encourage cooperative undertakings and promote the advancement of fire safety engineering. The 1999 meeting was held at the facilities of Fire Research Station (FRS) in the United Kingdom. Topics of discussion included opportunities for enhanced collaboration among member institutions, especially in the area of enhanced measurement technology and sharing of fire performance data. Further information on FORUM and its members and activities is found on BFRL's web site at http://www.bfrl.nist.gov/info/forum/forum.html.

Thermal Insulation Reference Materials

The Building Environment Division and NIST's Information Technology Laboratory are organizing a three-year effort to examine regional thermal insulation reference materials in Canada, France, Japan and the United Kingdom. In the first phase, the participating laboratories have approved the test protocol, identified candidate regional reference materials, obtained the materials and prepared test specimens. In accordance with test protocol, measurements of thermal conductivity are to be conducted with guarded-hot-plate apparatus conforming to either ASTM Test Method C177 or ISO 8302. The measurements are to be conducted from 280 K to 340 K at a temperature difference of 20†K across the specimen. Replicate measurements at 297 K also are required. In phase two, which began in 1999, the material variability characterization and actual test measurements will be performed.

8th International Conference on Durability of Building Materials and Components

The 8th International Conference on Durability of Building Materials and Components (8DBMC), held in Vancouver, Canada, in June 1999, was attended by over 400 persons.

Dr. Geoffrey Frohnsdorff served on the Steering Committee and Dr. Jonathan Martin served on the Organizing Committee. The series of triennial conferences, of which NIST is a sponsor, was initiated by NIST and the National Research Council of Canada (NRCC) in 1978, with the goal of generating a body of literature on the durability of materials to complement the already extensive literature on corrosion of metals. The 4-volume, 2950-page, conference proceedings contained 281 papers on durability-related subjects including asset management, maintenance management, life cycle costing, life cycle analysis, information technology in construction, product modeling, process modeling, and virtual reality and human-computer interaction.

One of BFRL's great strengths is the excellence of its staff. Their competence and contributions are consistently recognized by peers in professional societies. Examples of recent staff awards, other recognitions and key appointments are listed below.

Dr. David Didion Wins Gustav Lorentzen Prize

Dr. David Didion, NIST Fellow, was awarded the first Gustav Lorentzen Prize. The presentation took place at the 20th International Congress of Refrigeration, which will be held in Sidney, Australia. The Gustav Lorentzen Prize is the most prestigious recognition for research in the refrigeration field. The International Institute of Refrigeration established this award in 1997 to honor the memory of Professor Gustav Lorentzen who occupied a pre-eminent position in the world of refrigeration for almost a half century. Starting with the presentation to Dr. Didion, the Gustav Lorentzen Prize will be awarded every four years.

By awarding its highest honor to Dr. Didion, the International Institute of Refrigeration recognized his immense contributions to research benefiting the air-conditioning and refrigeration industry. His contributions included rating procedures, detailed simulation models of refrigeration equipment, refrigerant heat transfer studies, and, most profoundly, his pioneering and world-renowned work in searching for alternative refrigerants as substitutes for ozone-depleting working fluids. In this last research area, Dr. Didion's work was of particular importance because in an early stage of alternative refrigerant research he described the alternative fluid options consisting of single-component refrigerants and proposed refrigerant mixtures as additional options.

DOC/NIST Engineer of the Year

Dr. Hunter Fanney of the Building Environment Division was selected by the National Society of Professional Engineers as the DoC-NIST Engineer of the Year. He was honored with a plaque during an Awards Ceremony at the Crystal Gateway Marriott in Arlington, Va., February 25, 1999. He was cited for his contributions in the fields of solar energy and heat transfer engineering. His achievements included the development of a unique laboratory for the evaluation of super thermal insulation, a patented technology for using solar photovoltaic modules to heat stored water, and data and test procedures for solar thermal equipment. Dr. Fanney was

also recognized for his achievements by Maryland Governor Parris Glendening during a State House ceremony, February 24, 1999, where he was awarded a Governor's Citation.

The Arthur B. Guise Medal

NIST Fellow, **Dr. Howard Baum** received the Arthur B. Guise Medal from the Society of Fire Protection Engineers (SFPE). Dr. Baum was recognized for his research in the fluid mechanics of fires, turbulent combustion and large eddy simulation computational methods for fire phenomena. The SFPE Guise Medal recognizes eminent achievement in advancing the science of fire protection engineering.

The Bronze Medal Award recognizes work that has resulted in more effective and efficient management systems and the demonstration of unusual initiative or creative ability in developing and improving methods and procedures and recognizes significant contributions affecting major programs, scientific accomplishment within NIST, and superior performance of assigned tasks for at least five consecutive years.

ACI Henry Turner Medal

Dr. H. S. Lew, senior research engineer received the Henry Turner Medal from the American Concrete Institute (ACI) at its annual meeting, March 1999. Dr. Lew was recognized for his distinguished service to the concrete industry through his contributions to improved performance and safety of structures. A Fellow of ACI, Dr. Lew is currently a member of several ACI technical committees, including the Building Code Committee. Dr. Lew has investigated numerous failures of concrete structures during construction, and his findings have been incorporated in ACI building code and standards, the Construction Safety Standards promulgated by the American National Standards Institute and the mandatory construction safety standards regulated by the U.S. Occupational Safety and Health Administration.

Bronze Medal

Dr. Jeffery Gilman of the Fire Science Division was a recipient in 1999 of a Department of Commerce Bronze Medal for his pioneering research in applying nanotechnology to reduce the flammability of commodity polymers. Fire performance determines the marketability of U.S. products at home and abroad, yet key traditional fire retardant additives are losing favor because they compromise other product properties and they have an adverse environmental impact. Dr. Gilman's innovative use of nanometer-scale clay additives is yielding materials with improved environmental, physical *and* flammability properties. U.S. firms have recognized the commercial value of this work by joining a consortium which Dr. Gilman organized and is directing to develop this new technology toward new and better, U.S.-produced, fire-safe products for the world market.

Bronze Medal

Mr. Brian P. Dougherty of the Building Environment Division was a recipient in 1999 of a Department of Commerce Bronze Medal for his superior performance over the past decade in the development of testing and rating procedures for central air conditioners and heat pumps. The U.S. heating, ventilating and air-conditioning industry is currently a $28 billion a year industry. Mr. Dougherty provided this industry with evaluation techniques needed to test and rate these increasingly complex systems with a high degree of confidence. He is a leader in the field within both the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and the International Organization for Standardization. His current collaboration with the American Refrigeration Institute and the Department of Energy, addressing the metrification of the U.S. heat pump and air-conditioning standards, will eliminate potential trade barriers to the U.S. industry.

Bronze Medals

Dr. Glenn Forney, computer scientist, and **Ms. Nora Jason**, supervisor of BFRL's Fire Research Information Services, were awarded the NIST bronze medal. Dr. Forney and Ms. Jason were recognized for developing and implementing a world wide web-based fire information system with access to literature, data, images and fire models. The innovative use of the internet as a mechanism for global dissemination of BFRL reports and data has impacted the fire safety community. The resulting FIREDOC/Fire on the web site is unique in the world in that it contains data integrated with models, images integrated with data, and reports that document everything. It has made BFRL the definitive source of quality data and information needed to perform modern fire safety engineering calculations.

Dana Chase Memorial Award

Ms. Natascha Castro of the Building Environment Division received the Dana Chase Memorial Award for the Best Paper at the International Appliance Technical Conference held May 10-12, 1999, at Purdue University. Her paper, entitled *Test Procedure Development for Residential Dishwashers*, proposed changes to the Department of Energy's test procedure to obtain

reliable energy efficiency factors that consumers could use in making purchasing decisions. This work included the development of a new method to test soil sensing dishwashers and the calculation of an energy factor that can be compared to conventional models. The results of this research have been adopted into the Notice of Proposed Rulemaking for Dishwashers at DOE, and this paper was published in the August 1999 edition of *APPLIANCE* magazine.

SFPE Fellow

Dr. David D. Evans, P.E., Chief of the Fire Safety Engineering Division, was elected to the grade of Fellow in the Society of Fire Protection Engineers (SFPE). Dr. Evans has performed research directed toward the needs of the user of scientific fire safety knowledge. He was one of the developers of DETACT, one of the most used computational programs in fire protection engineering field. Along with Dan Madrzykowski, leader of the Large Fire Research Group, developed the first correlations of the impact of sprinkler discharge on burning rates. Dr. Evans has been a longtime member of the SFPE Board of Directors and is now serving as President of SFPE.

SFPE Fellow

Richard W. Bukowski, P.E., leader of the Fire Safety Systems Group was elected to grade of Fellow in the Society of Fire Protection Engineers (SFPE). Mr. Bukowski was recognized for his significant contributions to several areas of fire protection engineering. In particular, his study of residential smoke alarms has resulted in improved technology and widespread use. He is co-author of the *Fire Alarm and Signaling Systems Handbook*, and was also team leader for HAZARD I, the world's first comprehensive fire hazard assessment methods for PC's.

ACI Distinguished Chapter Member Award

Dr. Nicholas J. Carino, leader of the Structural Evaluation and Standards Group, Structures Division was the recipient of the 1999 Distinguished Chapter Member Award from the National Capital Chapter of the American Concrete Institute (ACI). The award was established to recognize and honor eminent chapter members who have made exceptional contributions to the objectives of the chapter and ACI. Dr. Carino has held numerous leadership positions within ACI and is a three-time recipient or co-recipient of the ACI Wason Medal for Materials Research. One award was for research on the maturity method and the other two were for research on the impact-echo method. He was instrumental in the development of two ASTM standards dealing with these two methods of testing concrete.

Interagency Committee on Seismic Safety in Construction

NIST Director Ray Kammer appointed **Dr. S. Shyam Sunder**, chief of the Structures Division, as chair of the Interagency Committee on Seismic Safety in Construction (ICSSC) upon the January 1999 retirement of BFRL Director Dr. Richard Wright from federal service. The ICSSC, established by the Earthquake Hazards Reduction Act of 1977, makes recommendations to its 32 constituent member-agencies on practices and policies to reduce earthquake hazards in the more than 500,000 federally owned, leased, assisted, and regulated buildings. **Mr. Stephen Cauffman**, who joined the Structures Division as research engineer, was appointed to serve as the ICSSC Technical Secretariat. **Dr. John Gross**, leader of the Structural Systems and Design Group, was appointed co-chair of ICSSC Subcommittee 5 on Post-Earthquake Investigations.

BFRL Communicator Award

Dr. Robert Chapman, economist, Office of Applied Economics, received BFRL's 1998 Communicator Award for a series of five publications that developed and applied performance metrics for program evaluation and improvement. In support of the Construction and Building Subcommittee, Bob demonstrated in two reports how measures of current construction industry practices could provide a

well-defined baseline against which new construction industry practices and technologies can be evaluated. In two additional reports he developed standard methodologies for measuring economic impacts of research and provided case studies of three BFRL projects. His fifth report described how to use data envelopment analysis to assess and improve the economic performance of 51 Manufacturing Extension Centers associated with NIST's Manufacturing Extension Partnership.

BFRL Communication Award

Ms. Barbara Lippiatt, economist, Office of Applied Economics, received BFRL's 1998 Communication Award for her software and user guide, Building for Environmental and Economics Sustainability (BEES). The software helps persons who choose building materials make selections based on a balanced, comprehensive, life-cycle approach to measuring both economic performance and multiple environmental impacts. BEES is a science-based tool that encourages cost-effective environmental innovation. It permits manufacturers to market the environmental value of their innovations and customers to recognize environmental value in their purchases.

ASCE Structures Congress 2001

Dr. S. Shyam Sunder, chief of the Structures Division, was named chair of the 2001 Structures Congress, sponsored by ASCE's Structural Engineering Institute. NIST is hosting the congress to coincide with its centennial celebrations in 2001. **Dr. John Gross**, leader of the Structural Systems and Design Group, was named to the Congress Steering Committee. **Dr. Michael Riley and Mr. Steven Cauffman** are providing the technical secretariat for the congress. The Structures Congress is held annually and attracts over 800 participants representing researchers and practitioners from industry, government, and academia.

Composites Research Advisory Boards

Dr. Dat Duthinh, research structural engineer, represents NIST which is an associate member of the NSF Industry-University Cooperative Research Center for the Repair of Buildings and Bridges with Composites at the University of Missouri-Rolla. He is also working on a pilot project with the Advanced Engineered Wood Composites Center at the University of Maine as part of the NIST-Maine Technology Partnership Program announced in June 1999. In addition, Dr. Duthinh was invited to serve on the External Advisory Board of the Composites Education Research Center at the Georgia Institute of Technology.

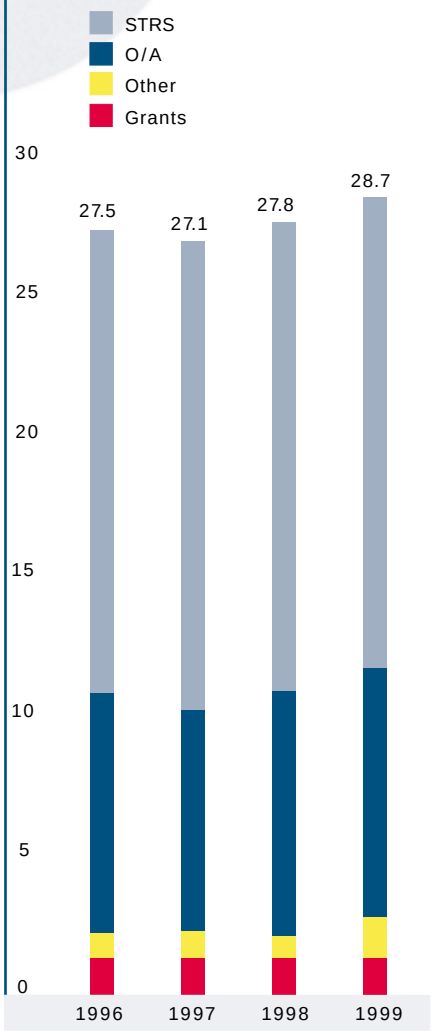
Fire Research Experiments Featured on the Learning Channel and the History Channel

During the past year, film crews have been following the events of BFRL's Large Fire Research group. Footage collected at full-scale fire experiments conducted in Delaware, Pennsylvania and Maryland, as well as footage taken in the Large fire Research Facility at NIST has been featured. Two programs were produced for the Learning Channel, "Fire-Nature of the Beast" and "Into the Flames, Fire in the City". The History Channel featured NIST fire experiments in a "Modern Marvels" program entitled "Crash Testing", which focused on product testing. All of the programs highlight experiments resulting in flash over. These experiments not only demonstrate NIST's leadership in the field of fire dynamics and large-scale fire experiment capabilities, but also provide a fire safety message to the public.

BFRL Fire Researcher Included in SFPE Career Guide

The Society of Fire Protection Engineers has recently developed a career guide aimed at high school students, which is being distributed to high school guidance departments across the country. **Mr. Dan Madrzykowski** of BFRL's Fire Safety Engineering Division was interviewed by SFPE, and his work history at NIST has been included in the guide. The article describes what a fire protection engineer working in the field of fire research might do. In addition, photos of examples of NIST fire research, including water spray from a sprinkler, a full-scale house fire experiment, and graphical output from the NIST industrial fire simulator, are on the guide's cover.

BFRL Resources 1996-99 ($ millions)

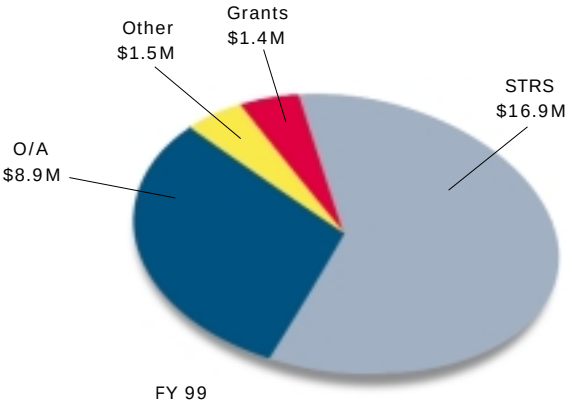


STRS — In-house research, NIST congressionally appropriated funds

O/A — In-house research, other agency funds

Other — Other funds including industry and private sector

Grants — Grants to other organizations including academia



FY 99

Organizations Funding BFRL's Research

Funding from other federal agencies and industry supports about one-third of BFRL's overall research during FY 1999. We are proud to serve our federal and industry customers with measurement technologies. They are recognized in the following list:

FEDERAL AGENCIES

- **Department of Agriculture**
- **Department of Defense Agencies**
- **Department of Energy**
- **Department of Health and Human Services**
- **Department of Housing and Urban Development**
- **Department of Interior**
- **Department of Justice**
- **Department of Labor**
- **Department of State**
- **Department of Transportation**
- **Department of Treasury**
- **Environmental Protection Agency**
- **Federal Emergency Management Agency**
- **General Services Administration**
- **National Aeronautics and Space Administration**
- **National Science Foundation**
- **Nuclear Regulatory Commission**

PRIVATE SECTOR

- **Air-conditioning and Refrigerating Technology Institute**
- **American Association of State Highway & Transportation Officials**
- **ASTM**
- **Northwestern University**
- **Virginia Department of Transportation**
- **Coating Consortium**
- **Dow Chemical Company**
- **Fire Safe Materials Consortium**
- **General Motors Corporation**
- **Nanocomposites Consortium**
- **Johnson Controls, Inc.**
- **Sleep Product Safety Council**
- **Trane Company**

BFRL Organization at a Glance

The **Structures Division** promotes construction productivity and structural safety by providing measurements and standards for key technologies supporting the design, construction and service ability of constructed facilities including infrastructure lifeline systems. Work includes:

- performing and supporting laboratory, field and analytical research in structural evaluation and standards, structural systems and design, and construction metrology and automation;
- non-destructive structural evaluation; high-performance materials for new construction and repair and rehabilitation of existing structures;
- performance of structural systems; structural control and performance based seismic design; wind loads on structures; structural fire endurance; specialized testing of structural components, connections and systems; performance standards for structural design and improved construction practices; and
- developing construction site metrology and data telemetry standards for construction simulation and 3D visualization, machinery/vehicle monitoring and control, and automated component placement and robotics;
- providing technical support to the National Earthquake Hazards Reduction Program (NEHRP) and to standards and code development organizations for constructed facilities.

Contact: Dr. S. Shyam Sunder
Chief, Structures Division
(301) 975-6713
sunder@nist.gov

The **Building Materials Division** performs research to advance construction materials science and technology and disseminates improved techniques and data to make more informed decisions about the performance of construction materials. Work includes:

- conducting analytical, laboratory and field research;
- developing measurement and prediction methods of service life to serve as the technical bases for improved criteria and standards for evaluation, selection, use and maintenance of construction materials, and improved tools to aid the making of decisions concerning construction materials;
- providing technical support to national and international standards-writing organizations such as ASTM and the International Organization for Standardization; and
- conducting cooperative programs with other research organizations, professional societies, standards-writing groups, testing laboratories and educational institutions.

Contact: Dr. Geoffrey J. Frohnsdorff
Chief, Building Materials Division
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The **Building Environment Division** provides technologies to reduce the cost of designing and operating buildings and increase the international competitiveness of the U.S. building industry. This includes:

- providing modeling, measurement and test methods needed to use advanced computation and automation effectively in construction and to improve the quality of the indoor environment and the performance of building equipment;
- conducting laboratory, field and analytical research on building mechanical and control systems;
- developing data, measurement methods, and modeling techniques for the performance of the building envelope, its insulation systems, building air leakage, the release,movement and absorption of indoor air pollutants; and
- developing software performance criteria, interface standards, and test methods needed for the nation's building industry to make effective use of modern computer-aided design hardware and software and database management systems.

Contact: Dr. George E. Kelly
Chief, Building Environment Division
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george.kelly@nist.gov

The **Fire Safety Engineering Division** develops, verifies, and utilizes measurements and predictive methods to quantify the behavior of fire and means to reduce the impact of fire on people, property and the environment. This effort includes:

- integration of laboratory measurements and verified methods of prediction,
- use of large scale fire experiments to develop and verify fire models,
- development of data and methods to advance the practice of fire safety engineering,
- development of new measurements, models and information systems to improve the safety and effectiveness of fire fighting, and
- operation of the Fire Research Information Service and the Large Fire Research Facility.

Contact: Dr. David D. Evans
Chief, Fire Safety Engineering Division
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dave.evans@nist.gov

The **Fire Science Division** performs research on and develops scientific and engineering understanding of fire phenomena and metrology for fire research. This includes:

- developing metrology for fire research;
- producing principles, new technology, data and predictive methods to characterize the burning of polymeric materials and their effluents; and
- developing the science and predictive methods to enable high-performance fire detection and suppression systems.

Contact: Dr. William L. Grosshandler
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The **Office of Applied Economics** supports BFRL's research by providing standardized economic methods, economic models, training programs and materials and expert technical consulting in support of resource allocation decisions; and uses techniques such as benefit-cost analysis, life-cycle costing, multicriteria decision analysis and econometrics to evaluate new technologies, processes, government programs, legislation, and codes and standards to determine efficient alternatives.

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More Information About BFRL

■ Publications 1998

An annual listing of BFRL's publications with indexes for abstracts, authors and keywords is available as hard copy and on 2-CD-ROMs, NIST SP938, May 1999. Also, full text of publications with art from 1994 to present are available from BFRL Publications On-line at *http://fire.nist.gov/bfrlpubs/*.

To order a copy of the above publications on CD's or to discuss BFRL's research reports, contact Nora Jason, BFRL Information Service, 301-975-6862, nora.jason@nist.gov.

Visit the Laboratory

Potential collaborators are encouraged to visit BFRL when in the Washington area. To schedule a visit, contact Dr. James Hill, deputy director, Building and Fire Research Laboratory, james.hill@nist.gov

BFRL Inquiries

Questions about specific programs should be directed to BFRL's Management listed in the Chapter, BFRL Finances & Organization. If you have general questions about BFRL programs or are interested in working with BFRL, contact:

■ Dr. Jack E. Snell, BFRL director, jack.snell@nist.gov

■ Dr. James Hill, BFRL deputy director, james.hill@nist.gov

The mailing address for all BFRL personnel is:

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National Institute of Standards and Technology

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 Commerce's Technology Administration, NIST strengthens the U.S. economy and improves the quality of life by working with industry to develop and apply technology, measurements, and standards. It carries out this mission through a portfolio of four major programs:

■ **Measurement and Standards Laboratories**, that provide technical leadership for vital components of the nation's technology infrastructure needed by U.S. industry to continually improve its products and services;

■ the **Advanced Technology Program**, which accelerates the development of innovative technologies for broad national benefit through R&D partnerships with the private sector;

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

■ a highly visible quality outreach program associated with the **Malcolm Baldrige National Quality Award** that recognizes business performance excellence and quality achievement by U.S. manufacturers, service companies, educational organizations and health care providers.

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NIST SP 838-16

February 2000