NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

BFRL

BUILDING & FIRE RESEARCH LABORATORY

**Activities,
Accomplishments
& Recognitions**

Contents

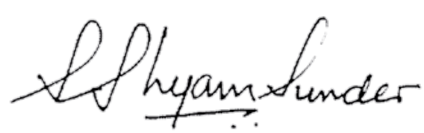
Message from the Director

BFRL is involved in a wide range of scientific, engineering, and investigative work for the building and fire safety communities. We address technical challenges in response to critical national needs, with a particular mission focus on measurement science. The term measurement science refers to the development of performance metrics, measurement methods, predictive tools, and protocols as well as reference materials, data, and artifacts. Measurement science also includes the conduct of intercomparison studies and calibrations; the evaluation and/or assessment of technologies, systems, and practices; and the development and/or dissemination of technical guidelines and the technical basis for standards, codes, and practices—in many instances via testbeds, consortia, and/or other partnerships with the private sector and academia.

BFRL measurement science research has led to many successes in our mission to advance overall performance and safety of built facilities. This report outlines BFRL's five strategic goals focused on achieving net-zero energy, high-performance buildings; advances in infrastructure delivery; sustainable infrastructure materials; innovative fire protection; and disaster-resilient structures and communities under multi-hazards (such as hurricanes, earthquakes, and fires). This report also provides details of BFRL's research activities and the impacts of our results, which often include changes to building and fire safety standards and codes.

We recognize that BFRL is but one of a number of players involved in advancing the performance, productivity, and cost-effectiveness of built facilities. Increasingly, we see ourselves as a node in a larger network of organizations dedicated to better, more efficient, safer, and less costly facilities.

We are constantly looking for opportunities to extend our impact through partnerships and collaborations, and encourage you to send us your thoughts and suggestions on how, working together, we may be an even greater influence for beneficial change and growth. I hope that reading the information contained in this report will motivate you to develop even closer relationships with us. I encourage you to visit our Web site *(http://www.bfrl.nist.gov)* and look forward to hearing from you *(bfrl@nist.gov)*.



Dr. S. Shyam Sunder
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Building and Fire Research Laboratory (BFRL)

BFRL MISSION

To promote U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of the U.S. building and fire safety industries in ways that enhance economic security and improve the quality of life.

BFRL VISION

To be *the* source for creating *critical solution-enabling tools*—metrics, models, and knowledge—and promoting *performance-based standards* that are used by the U.S. building and fire safety industries in establishing competitive leadership in domestic and international markets. Our programs are identified, developed, carried out, the results implemented, and consequences measured in partnership with key customer organizations.

WHAT BFRL DOES

BFRL promotes U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of the U.S. building and fire safety industries (builders, suppliers, owners and operators, codes and standards organizations, building and fire safety officials/professionals, and insurers) in ways that enhance economic security and improve the quality of life.

BFRL's programs are focused on five strategic measurement science goals:

- **Net-Zero Energy, High-Performance Buildings:** reducing building energy-use through in-situ performance measurements, embedded intelligence in building controls, emerging building energy technologies, and metrics and tools for sustainability performance.
- **Advancing Infrastructure Delivery:** improving construction productivity through tools to measure jobsite and offsite productivity and at scales ranging from a project task to the entire economy, real-time process sensing and control, automated access and integration of diverse information systems, and intelligent and automated construction testbed.
- **Sustainable Infrastructure Materials:** increasing sustainability through multi-scale models to predict life-cycle performance of construction and building materials, advances that exploit the unique properties of nanomaterials,

and scientific knowledge of materials degradation, flammability, and nanoparticle release.

- **Innovative Fire Protection:** reducing the risk of fire spread in buildings and in wildland-urban interface communities, ensuring effective and safe use of emerging fire service technologies, and deriving lessons from post-fire investigations.

- **Disaster-Resilient Structures and Communities:** enhancing the resilience of structures and communities to disasters (earthquakes, hurricanes and windstorms, and fires) through tools to predict structural performance and estimate losses at the community-scale in extreme events, tools for performance-based design of new buildings and rehabilitation of existing buildings, and post-disaster and failure investigations.

BFRL carries out major statutory responsibilities assigned to it by the Fire Prevention and Control Act (1974), the National Earthquake Hazards Reduction Program Reauthorization Act (1977, amended 2004), the National Windstorm Impact Reduction Act (2004), and the National Construction Safety Team Act (2002).

IMPACTS

In the United States, construction and building is a $1.2 trillion per year industry, represents 5 percent of the gross domestic product, and employs nearly 12 million workers.

- The construction industry directly affects as much as 12% of the U.S. economy when manufacturing of construction materials and components, building contents and furnishings, and renovation and maintenance are included.

- The vast majority of construction firms are small (including about 1.8 million self-employed workers), and do not have the resources to conduct the in-depth research needed to improve building practices.

- Buildings represent the single largest end-user of energy (40%) and electricity (73%) and contributor of carbon dioxide emissions (39%) when compared with the transportation and industrial sectors.

- The estimated cost of renewing the nation's aging physical infrastructure exceeds $2 trillion.

- The U.S. costs due to natural and technological disasters are $55 billion per year and growing, with future catastrophic events possibly causing mega-losses in excess of $100 billion.

- Fire is a major problem in the United States, which has one of the worst fire fatality rates of the world's industrialized nations. Even with improvements in fire protection and safety, in 2006, 3,245 lives were lost in fires, 16,400 more were seriously injured, direct property loss was almost $12 billion, and fire cost the U.S. economy in excess of $250 billion.

BFRL's research addresses the key *drivers* for change in construction: sustainability, energy independence, and environmental security; demand for better quality, faster, and less costly construction; competition due to globalization and offshoring; renewal of the nation's aging physical infrastructure; and homeland security and disaster resilience.

BFRL's research also addresses the key *barriers* to change in construction: declining industry level productivity with pockets of improvement and significant waste; industry fragmentation; minimum first-cost mindset, which precludes lower-cost investment options based on life-cycle performance; prescriptive standards and codes which stifle innovation and competitiveness; and very low investment in research and development.

MEASUREMENT SCIENCE FOR

Net-Zero Energy, High-Performance Buildings

What is the problem?

Buildings account for 40 percent of U.S. energy use and a similar percentage of carbon dioxide emissions, more than the transportation or industrial sectors. Emissions associated with buildings and appliances are projected to grow faster than those from any other sector. In order to ensure adequate supplies of energy and to curtail the projected growth of CO_2 emissions, it is essential that building energy consumption be significantly reduced. One way this can be achieved is through the introduction of innovative building technologies enabled by new measurement science.

In addition to energy issues, building operation practices face pressure to improve safety, security, and occupant comfort and health. Building control companies, equipment and system manufacturers, energy providers, utilities, and design engineers are under increasing pressure to improve performance and reduce costs by developing cybernetic building systems that integrate more and more building services, including energy management, fire and security, transportation, fault detection and diagnostics, optimal control, the real time purchase of electricity, and the aggregation of building stock. Measurement science is lacking to enable these systems to communicate, interact, share information, make decisions, and perform in a synergistic and reliable manner. Specific needs include standard data models, communication protocols, user interface standards, security procedures, testing tools, and performance metrics. Overcoming these barriers is critical if cybernetic building systems are to be successful and if the United States is to obtain a significant share of the developing worldwide market for such systems.

Why is it hard to solve?

Buildings are complex systems of interacting subsystems. Past improvements in the energy performance of individual components/systems have not resulted in the expected reductions in overall building energy consumption. The industry is very sensitive to the first cost of new technologies, and performance goals, such as energy efficiency, indoor air quality, and comfort often conflict. Because a mismatch exists between who invests (builders and manufacturers) and who benefits (public), public sector involvement is necessary to overcome the initial barrier of developing the measurement science.

Performance measurements made on individual components in carefully controlled laboratory test environments are idealized and capture neither the complexities of actual building installation nor the dynamic interactions of multiple subsystems. An integrated portfolio of measurement science capabilities is needed that not only supports innovation in the design and manufacturing of individual components and systems, but also captures the system complexities and interactions seen in a real building. Each individual measurement capability presents technical challenges, and the overall goal of significantly improved energy performance can only be achieved by applying an integrated portfolio of such measurement science capabilities.

Why BFRL?

The Building and Fire Research Laboratory (BFRL) is in a position to leverage its strong ties to industry stakeholders, academia, and standards organizations. BFRL has the needed technical expertise and an international reputation for excellence in the technical areas relevant to cybernetic building systems as a result of more than two decades of technical work and collaboration. The energy-related research within this program supports BFRL's core competency in *Measurement Science for Building Energy Technologies*, and BFRL staff members have leadership positions on the key U.S. and international committees that will make use of the research results.

BFRL plans to enable and promote the use of open cybernetic building systems with embedded intelligence for energy efficient building operations, new integrated functionality for building systems, and improved occupant comfort and safety by developing the measurement science needed to develop, test, integrate, and demonstrate the new technology. In addition, this research will provide the measurement science that will enable the development, deployment, and use of building energy technologies that will move the nation towards net-zero energy buildings while maintaining a healthy, productive, and safe indoor environment.

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The Building Environment and Indoor Air Quality Test House is being used to study residential indoor air quality issues including exposure to ultrafine particles from common household activities, carbon monoxide poisoning associated with the operation of emergency generators, and whole house performance of air cleaning systems.

Improved Building Energy Performance

Numerous technologies are emerging to reduce energy consumption in buildings, but it is often difficult to determine the performance of buildings as they are constructed. This performance not only relates to energy consumption, but it also applies to the level of indoor environmental quality and economics of the energy measures.

The goal of the Improved Building Energy Performance program is to improve the as-constructed performance of high-performance buildings by developing and implementing the measurement science to assess the energy consumption, CO_2 emissions, indoor air quality, and cost effectiveness of buildings. The program addresses building energy, greenhouse gas emissions, and indoor air quality measurement science in a holistic, integrated manner that considers system interactions involving weather, the building envelope, control systems, and space conditioning equipment. Research efforts are focused on the development of cost-effective building energy monitoring systems, improvements in the efficiency of space conditioning equipment through self diagnostics and enhanced design tools, providing accurate metrics to capture the performance of thermal insulation, improved measures of CO_2 emissions from facilities, and development of tools to enhance indoor air quality (IAQ) through measurement science advancements to address volatile organic compounds (VOC) emissions and advanced ventilation schemes. Metrics to assess the sustainability of buildings and to quantify the carbon footprint of buildings are an integral part of the program.

This program will transform U.S. innovation and competitiveness in the building sector by developing the means to assess next-generation building technologies needed to achieve net-zero energy buildings. Additional impacts of this program include significant reduction in the nation's CO_2 emissions and reduced stress on the electrical power grid. Previous impacts of this program have included methods of testing and rating procedures that are used exclusively throughout the appliance and solar thermal industries, leadership in the formation of the U.S. Green Building Council, and providing the technical foundation for energy and indoor air quality standards adopted by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE.)

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The Guarded-hot-plate Apparatus has been used to develop Standard Reference Materials for thermal resistance, as well as to provide measurement services to the public.

ACTIVITIES AND ACCOMPLISHMENTS

Thermal Insulation Standard Reference Materials (SRMs®)

BFRL began providing thermal insulation SRM 1450, Fibrous-Glass Board, to the public in 1978. In subsequent years, BFRL has renewed four series of SRM 1450 and, additionally, developed four other thermal insulation SRMs. These certified reference materials are typically used for calibration of equipment used to determine the thermal performance of insulation, thereby providing important quality assurance and metrological traceability for both U.S. and international thermal insulation manufacturers and thermal measurement user communities. Currently, BFRL is developing the fifth series of Fibrous-Glass Board, SRM 1450d, to ensure an adequate supply for customers.

Most of the current NIST thermal insulation SRMs were developed for temperature applications at or near 300K. BFRL has recently fabricated a new guarded-hot-plate apparatus for the development of reference materials at extended temperature ranges. The new apparatus will handle specimens 500 mm in diameter and is designed for operation from 90K to 900K, a range that covers the application range of several industrial insulations. Working with members of ASTM International Committee C16 on Thermal Insulation, BFRL has identified several candidate reference materials and, subsequently, completed preliminary measurements of these materials for future SRM development. The availability of a certified reference material for high temperature applications will help industry by reducing the large levels of uncertainty in measured thermal resistance values that exist at high temperatures. This improvement in measurement capabilities provides potential for energy savings for end users of high-temperature thermal insulation.

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Carbon Monoxide Exposure from Emergency Generators

While observing that gasoline-powered portable electric generators are useful in emergencies, the U.S. Consumer Product Safety Commission (CPSC) warns consumers not to use a generator inside homes, garages, crawlspaces, sheds or similar areas, even when using fans or opening doors and windows for ventilation. Deadly levels of odorless and invisible carbon monoxide can quickly build up and linger for hours, even after the generator has shut off, according to the CPSC, which received reports that at least 65 people died from carbon monoxide (CO) poisoning associated with portable generators in 2006. It is also dangerous to use a generator outside if it is too close to a home's open doors, windows, or air vents. CPSC and the Centers for Disease Control and Prevention (CDC) have enlisted the National Institute of Standards and Technology (NIST) to help quantify the CO emissions of portable gasoline-powered electric generators and evaluate possible technical solutions to the problem.

BFRL researcher Steven Emmerich adjusts a multi-gas analyzer that will measure carbon monoxide, oxygen, carbon dioxide and hydrocarbons concentrations produced by such a generator located, against safety advice, in a garage.

To accomplish these goals, BFRL researchers are measuring and modeling potential CO generation and exposure and oxygen depletion in homes resulting from portable generators operating in attached garages and in locations outside of homes. The measurement effort includes testing in both a stand-alone shed and a test house with an attached garage. The experimental results will also be used to validate a model of the test house in CONTAM, NIST's indoor air quality modeling software. The model will enable prediction of CO concentrations under conditions not measured. Additionally, a computational fluid dynamics model will be used to predict indoor CO concentrations resulting from generator operation outdoors but near a house.

Significant accomplishments to date include development of the test facility for measuring CO emissions and oxygen usage from emergency generators; completion of testing to determine emission rates as a function of building ventilation rate and electrical load on the generator, measurement of the entry of CO from an attached garage into the living space of a test house, and completion of simulations to help develop guidance on safe distances for generator placement outside a home. Through its agency partners, NIST's efforts will lead to safer operation of emergency generators and decreases in CO poisoning events.

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Improving the Reliability of Chemical Emissions Testing of Products Used in Buildings

BFRL is developing reference materials to validate measurements of volatile organic compound (VOC) emissions from building materials and products (e.g., floor coverings, paint, and furniture). VOC emissions from building materials and products have been linked to occupant illness, reduced worker productivity, and increased requirements

BFRL's small chamber test facility is being used to assess the performance of a reference material for building product VOC emissions testing.

for ventilation/air cleaning, leading to increased energy consumption. As a result, low VOC emitting products are being used more widely in buildings to help achieve a healthy and sustainable indoor environment. However, existing product labeling programs for ranking and certifying building products and materials as low emitting are not yet supported by reliable VOC emission rate measurements.

In 2007, BFRL began working with Virginia Tech to develop a prototype reference material for emissions testing. A polymer film was selected as a substrate that could be loaded with a representative VOC through a diffusion process. A loaded polymer has an emission profile similar to a typical "dry" building material (e.g., sheet flooring) that can be measured in a small chamber commonly used for emissions testing. The polymer film emission rate can also be independently determined by measuring key material properties and using a fundamental emission model. In 2008, BFRL used its stainless steel chambers to characterize the emission properties of the reference material and found good agreement between the chamber and emission model results. As a result, BFRL is currently moving forward to develop the capability to produce these reference films at NIST with an interlaboratory study planned for late 2009. If successful, the project will be expanded to include more material types and VOCs with mass production and distribution by 2013.

Reference materials have the potential to build consensus and confidence in emissions testing as well as level the playing field for product testing laboratories and manufacturers. With improved measurement science in place, there is also the potential for substantial growth in the sustainable building products market.

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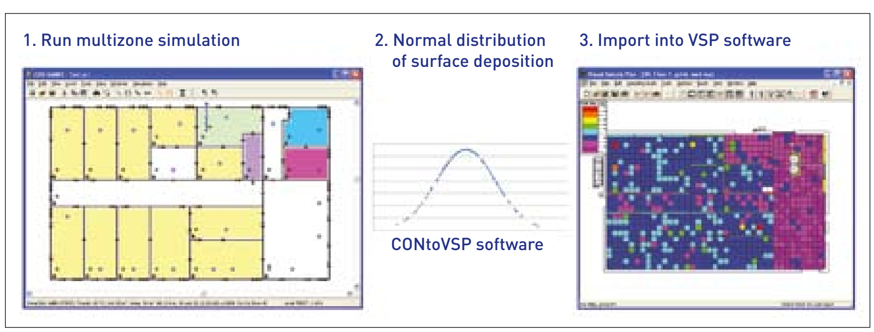
Analysis of Bio-Sampling Strategies Using Multizone Modeling

The CONTAM airflow and contaminant dispersal simulation program is being used to model bio-agent release scenarios in an office building of moderate complexity. The software is designed to include the major features of building layout, vertical shafts, weather effects, and ventilation system operation. The modeled contamination of the building is then overlaid with judgmental and probabilistic sampling plans generated using the Visual Sampling Plan (VSP) computer program developed by Pacific Northwest National Laboratory. By applying this approach differing sampling strategies can be evaluated under specific release scenarios.

The use of CONTAM in conjunction with VSP will provide agencies responding to a biological agent event with a tool for assessing and predicting adequate sampling strategies. The end users in the immediate future will be the



CONTAM model of study building as a multizone building airflow system and its conversion into the VSP software to enable the development of bio-agent sampling plans.

Validated Sampling Planning Workgroup (VSPW), a multi-agency group led by the Department of Homeland Security for the validation of sampling strategies in conjunction with the Joint Program Executive Office for Chemical and Biological Defense. In the future, end users of the VSP program (5,000 users worldwide) will be able to enhance their decision process with modeling of the expected contamination of a site based on release information and fit sampling strategies to predictive models, thus decreasing cost and laboratory confirmatory burden.

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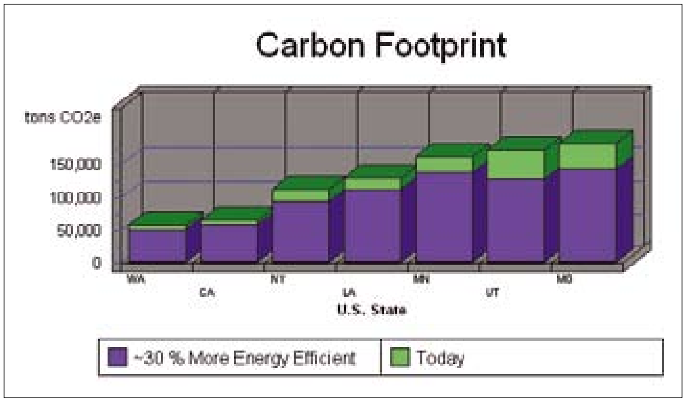
Metrics and Tools for Sustainable Buildings

Building stakeholders need compelling metrics, tools, data, and case studies supporting major investments in sustainable building designs and technologies. Proponents of green building widely claim that these buildings are cost-effective, but often these claims are based on incomplete, anecdotal evidence that is difficult to reproduce and defend. Buildings upon which claims are based are not necessarily "green" in a science-based, life-cycle assessment (LCA) sense, and their measures of cost-effectiveness often are not based on standard life-cycle cost (LCC) methods for measuring economic worth. Yet the building industry demands compelling metrics to justify sustainable building designs. The problem is hard to solve because it requires an integrated design approach, which considers all building components and subsystems together in an effort to optimize overall building performance.



The "carbon footprint" of a 16-story office building, measured over 40 years of operation, depends on its location and energy efficiency.

In 2008, BFRL started tackling this important problem by extending to whole buildings its popular metrics and tool for sustainable building products known as Building for Environmental and Economic Sustainability (BEES). Since then, it has developed whole-building sustainability metrics based on innovative extensions to LCA and LCC approaches and using whole-building energy simulations. These new metrics assess the "carbon footprint" of buildings as well as 11 other sustainability metrics, including fossil fuel depletion, smog, water use, habitat alteration, indoor air quality, and human health. Carbon-efficiency ratios and other eco-efficiency metrics are established to yield science-based measures of the relative worth, or "business case," for green buildings. Business cases are customized to account for the investor's time horizon, the building type and size, and the local climate, prices, and fuel mixes.

Over the next several years, BFRL plans to disseminate these metrics in a web-based software tool for developing business cases for green building known as BusiBEES. The idea is to bring performance metrics and tools to sustainable building decisions through life-cycle-based assessment. Only by directly linking building design and technology innovation with economic and environmental benefits and costs will investors be motivated to finance new building technologies with measurable sustainability improvements, consumers be confident in adopting them, and policymakers be informed of the trade-offs inherent in meeting national goals.

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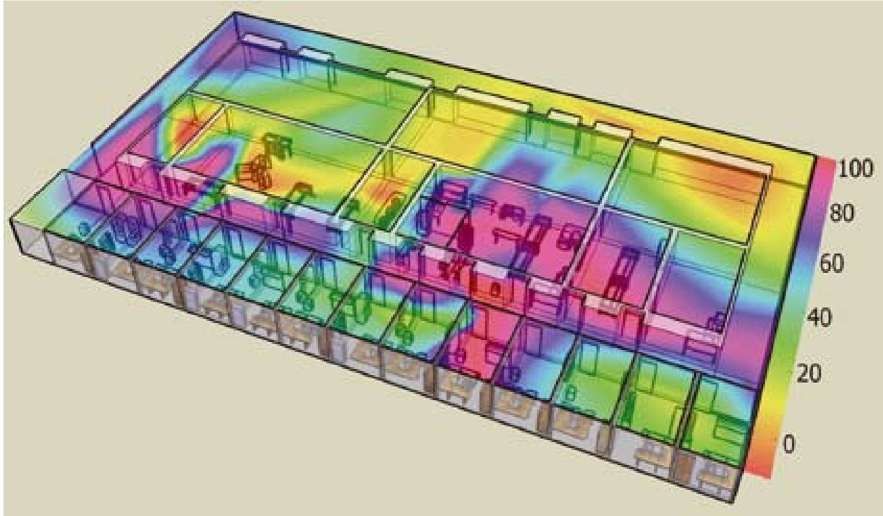
Wireless Sensor Networks for Monitoring and Control

Wireless sensor technology promises to reduce energy consumption in buildings while providing a more comfortable indoor environment by allowing the monitoring of a wide range of quantities in buildings. The increased amount of information could result in energy savings in a number of ways. For example, a greater number of sensed locations could allow for finer spatial control in a building, allowing a heating or cooling system to only be applied in regions of the building that need that service. Additional sensors could assist in diagnosing problems with the operation of the building systems, thereby identifying energy waste before an extended period of such waste occurs. Additional sensors could also allow for the monitoring of a greater range of constituents that affect occupant comfort other than simple temperature measurements that are in use today. Such quantities could include relative humidity, light levels, and air quality.

Wireless technology enables these additional sensing points by greatly reducing the cost of installation since wiring costs are a significant part of sensor deployment. The use of wireless sensors is also attractive to building operators because of the minimal inconvenience to occupants during installation and the flexibility that they can afford in terms of position and future modifications. Nevertheless, engineers and designers are sometimes reluctant to use these sensors because of concerns about reliability and battery life. To help overcome these barriers, NIST has embarked on an effort to develop metrics to quantify the reliability of wireless sensors in building applications. Data show that the presence of typical obstructions in buildings can have a marked effect on the distance over which a wireless signal can propagate. Likewise, interference sources such as other wireless communication devices or microwave ovens can significantly degrade the wireless sensor signal when placed in close proximity to the sensors.



Measured reliability of wireless sensor data transmission in office building.

This project is developing systematic methods to assess these issues in a simple manner so that potential users of wireless sensors in buildings can better estimate whether the sensors will reliably provide data in certain places within buildings and can position the sensors in a network to ensure reliable data communications. Future work will extend these test methods to give users estimates of the battery lifetime for wireless sensors in typical building applications.

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Embedded Intelligence in Buildings

A cybernetic building system integrates intelligent building automation and control systems for energy management, fire detection, security, and vertical transport. It also integrates the building systems with outside service providers and utilities. This research program aims to address building systems measurement needs in a holistic, integrated manner that considers complex system interactions and their impact on energy consumption, comfort, safety, and maintenance.

The research plan consists of eight key interrelated areas of measurement science needed to achieve successful development and implementation of cybernetic building systems with embedded intelligence. Collectively they provide a comprehensive approach that will result in a radical market transformation in building design and operation.

Expansion, certification, and demonstration of BACnet is the cornerstone upon which all other aspects of cybernetic building systems are built because it provides the basis for communication and information exchange. BACnet is a data communication protocol for building automation and control networks developed under the auspices of ASHRAE, to standardize communication between building automation devices and systems from different manufacturers. BFRL's past work has led to adoption of BACnet by more than 30 countries and most heating, ventilating, and air conditioning (HVAC) control system manufacturers. Conformance testing tools and processes have been developed and industry run certification programs are in place. It is one of the most widely used and successful standards in ASHRAE history, but that success has been primarily limited to HVAC applications. This research will remove a number of identified barriers to expanding BACnet beyond HVAC.

Another major contributor to the program is the Virtual Cybernetic Testbed (VCBT). The VCBT consists of a variety of simulation models combined with commercial and prototype BACnet controllers that create a hybrid software/hardware environment suitable for testing various integrated control system components for cybernetic buildings in ways that cannot be accomplished by testing in actual buildings. The current research focus is on expanding the capabilities of the VCBT to include additional building systems and a wider range of building types and emergency scenarios.

The NIST Virtual Cybernetic Testbed, a whole-building emulator used for a variety of integrated building system research activities.

Other aspects of the research program include fault detection metrics and tools for HVAC equipment, automated commissioning tools, autonomous, intelligent agents for optimizing system performance, integration of building systems with a future Smart Grid, and providing building system information to emergency responders.

Work being conducted under the Embedded Intelligence in Buildings program will result in the adoption of new and improved industry standards codes and regulations. It will advance industry practices and improve productivity, life cycle cost savings, energy efficiency, and occupant satisfaction. It will also increase U.S. market leadership through the commercial application of tested, integrated, and open cybernetic building systems and concepts.

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ACTIVITIES AND ACCOMPLISHMENTS

Expansion, Certification, and Demonstration of BACnet

For many years the building control industry has recognized the potential cost reductions and performance benefits of integrating products made by different manufacturers and from integrating historically stand-alone systems into a single building automation and control system. Significant progress has been made for heating, ventilating, and air-conditioning applications through a collaborative effort among BFRL and industry toward the development of the now widely used BACnet[1] communication protocol standard.

The BACnet standard has been adopted as a European standard, an International Organization for Standardization (ISO) world standard, and as a national standard by more than 30 countries. BACnet Interest Groups to promote the use of the technology have been formed in Australasia, Europe, Finland, the Middle East, Russia, Sweden, and North America. Industry testing and certification programs are in place, more than 350 companies make BACnet products, and they have been successfully deployed around the world.[2] In addition to integrating control products in individual buildings, BACnet has been used to integrate campuses of buildings, municipality wide networks of buildings, and even networks of buildings that span multiple states.

In spite of this success, significant barriers remain to the realization of fully integrated building systems. Recent BFRL research has focused on assisting industry to improve network security mechanisms to protect critical building systems and to extend the capability of BACnet for variety of building control applications. These include lighting control, access control, vertical transport, integration of building automation data with business management systems, and adapting to new technologies such as wireless sensors, and a future Smart Grid electrical distribution system. The outcome of this research can be seen in addenda to the standard that have been approved or are in public review. The long-term impact is expected to be a much broader range of integration capabilities in the marketplace.

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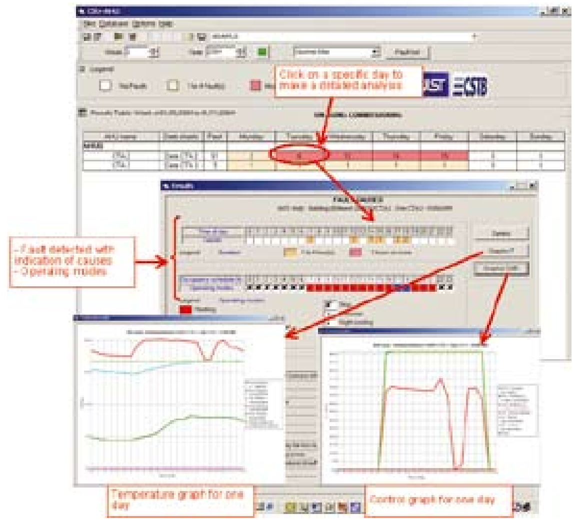
The ASHRAE BACnet standard has been adopted as an ISO standard and translated into Chinese, Korean, and Japanese.

[1] ANSI/ASHRAE Standard 135-2008, *BACnet–A Data Communication Protocol for Building Automation and Control Networks.*

[2] *www.BACnet.org*



A user interface screen from the CITE-AHU prototype automated commissioning tool for air-handling units.

Cost-Effective Commissioning

Commercial buildings in the U.S. represent 18 percent of the total national energy consumption[1] and significant improvements are needed to increase their operating efficiency. Mounting expectations, including a new national goal of achieving zero-energy buildings by 2030, are being placed on a mixture of diverse and often conflicting performance measures such as energy efficiency, indoor air quality, comfort, and reliability. Because these buildings are complex systems of interacting subsystems, cost-effective commissioning methods and tools are required to ensure that advanced components and systems reach their technical potential and operate energy-efficiently. The goal of NIST's commissioning research is to improve the operating efficiency of building systems by 10 percent to 30 percent by developing and demonstrating measurement science that enables more complete and effective system commissioning practices, transferring the proven technologies to the private sector by 2012.

Since 2001, BFRL has partnered with member countries under the International Energy Agency's (IEA) Energy Conservation in Buildings and Community Systems program. From 2001 to 2004, NIST led the U.S. team of the Annex 40 research project on Commissioning of Buildings and HVAC Systems for Improved Energy Performance.[2] Annex 40 commissioning tools have been successfully used in demonstration projects globally. The commissioning process detailed in the Annex 40 final report is increasingly recognized internationally as a best practice and is the basis for draft national standards in France, Finland, and Norway.

In 2004, a second commissioning-related annex, co-led by NIST, was established as a follow-on research project to address commissioning needs for non-conventional systems.[3] The Annex 47 project focuses on the application of engineering principles to the operation of buildings specifically to achieve energy savings, rather than as a possible side effect. A standard cost-benefit methodology documenting commissioning benefits was developed and applied to 54 international case studies.[4] The commissioning techniques developed through this research are helping to transition the industry from the intuitive approach that is currently employed in the operation of buildings to more systematic operation that focuses on achieving significant energy savings. The U.S. team for Annex 47, which will be completed in 2009, includes: Carnegie Mellon University, Texas A&M University, Johnson Controls, Inc., Lawrence Berkeley National Laboratory, NIST, Portland Energy Conservation, Inc., and Siemens Building Technologies.

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[1] *DOE 2007 Buildings Energy Data Book*, *http://buildingsdatabook.eren.doe.gov*

[2] Visier, J.C. et al. 2005. IEA Annex 40: Final report, *www.commissioning-hvac.org*

[3] Castro, N. (2006). Cost-Effective Commissioning for Existing and Low Energy Buildings–A New IEA ECBCS Research Project. *Proceedings of the National Conference on Building Commissioning*.

[4] N. Castro, H. Friedman, and M. Frank. 2007. "ECBCS Annex 47: Cost-Effective Commissioning Research" European Conference on Energy Performance and Indoor Climate in Buildings, Lyon, France.

Integrating Building Automation Systems with a Smart Utility Grid

The Energy Independence and Security Act (EISA) of 2007 charged NIST with "primary responsibility to co-ordinate development of a framework … to achieve interoperability of smart grid devices and systems." The Smart Grid is the concept of modernizing the electric grid, integrating the electrical and information technologies between generation and consumption. The Smart Grid is all about integrating distributed resources—such as rooftop photovoltaics (PV), and building electrical load reductions—into grid operations, developing a retail market for electricity so that automated load management can flourish, and smart sensors on the grid to make the system more efficient.

The BFRL project objective is to develop a technical basis for industry standards that will enable interconnection of building automation and control systems with a future "smart" utility grid and support industry efforts to develop the needed standards. The first task is development of a national roadmap for interoperability standards. The second task is addressing information modeling for the smart grid: pricing, demand response, and BACnet protocol extensions to allow for load control, metering, and distributed generation communications, implementing the roadmap. The final project element is to model and simulate facility and microgrid control system energy management to support efficient management of consumer resources in the smart grid.

In the past year, NIST has authored a draft Smart Grid Standards Roadmap, sponsoring three workshops to build consensus for that roadmap. Details of the Smart Grid program can be found at *www.nist.gov/smartgrid*. BFRL leads the Building-to-Grid (B2G) Domain Expert Working Group in addressing the requirements of the buildings industry in Smart Grid development. The B2G working group has been instrumental in addressing information modeling and architecture for the smart grid; a standard pricing model across the Smart Grid has been identified as the highest priority item for standards work. In addition, B2G has supported the development of Open Automated Demand Response (OpenADR) and the selection of it as the leading candidate for a demand response signaling standard. BFRL currently co-chairs an Organization for the Advancement of Structured Information Standards (OASIS) committee focused on moving OpenADR from a California-focused protocol to a national smart grid standard.

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Advanced Building Energy Technologies

The path to achieving net-zero energy residential and commercial buildings is projected to be realized from a combination of resources. Full utilization of technologies that are available today provides the means to reduce the building energy consumption on the order of 40 to 50 percent at no or minimum life cycle cost. Consequently, the remaining 50 to 60 percent of energy savings must be realized through on-site deployment of renewable energy generation and by novel energy efficient solutions. The goal of this program is to develop the measurement science needed to deploy renewable and new, energy efficient technologies that will help bridge the 50 to 60 percent energy savings gap that remains after employing current energy conserving technologies.

The program's topical focus is on three technology thrusts: Space Conditioning, Renewable and Distributed Energy Technologies, and Cleaning and Control Technologies for Indoor Air Quality. This last focus area is important and so included because the impact of net-zero energy technologies on the indoor environment must be assessed to ensure that indoor air quality is not compromised but preferably enhanced. The technical ideas pursued within these thrusts can be placed in the following four categories:

Cost-neutral energy savings

- Apply advances in material science—nanolubricants—to improve the energy efficiency of chillers used to cool commercial buildings.
- Apply particle image velocimetry measurements, computational fluid dynamic modeling, and evolutionary computation methods for optimization of space-conditioning heat exchangers.

Since the concept of the net-zero energy building includes cost effectiveness on a life-time basis, advanced cost-neutral solutions are of particular interest.

Testing and rating methodologies

- Reduce the measurement uncertainty associated with rating of photovoltaic modules.
- Develop testing and rating procedures for micro-cogeneration systems.
- Develop test methods for high-efficiency particle filtration devices.

Indoor air quality

- Enhance NIST's multizone modeling tools for indoor environmental analysis to incorporate more complete particle transport.
- Apply multizone building analysis to relate air cleaner performance as measured in the laboratory to contaminant exposure reduction in actual occupied environments.

Exploratory research

- Identify measurement science barriers that impede market implementation of alternative, emerging cooling technologies.

Collectively, the projects within this program will bring innovation and promote competitiveness in the building sector by enabling the introduction and widespread use of next-generation building energy technologies that are needed to achieve net-zero energy, high-performance buildings.

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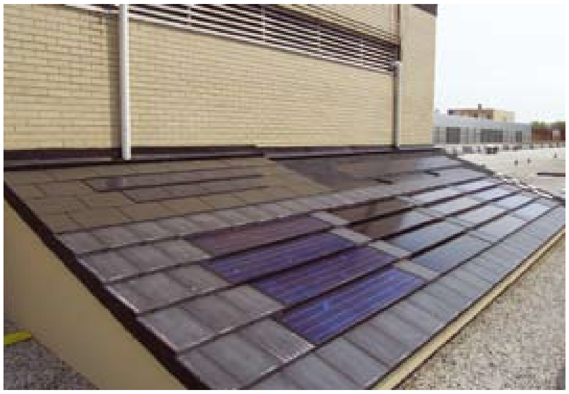
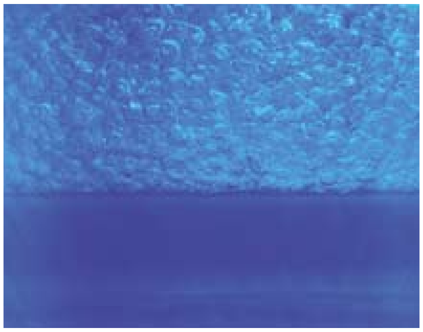


Six photovoltaic (PV) roofing products are currently being monitored to provide the data needed to develop, improve, and validate computer simulation programs that model the response of PV systems for a wide range of environmental conditions.



Optical microscopy image (10 mm across) of boiling refrigerant/nanolubricant mixture.

ACTIVITIES AND ACCOMPLISHMENTS

Nanofluids Heat Transfer Measurements

BFRL's Nanofluids Heat Transfer Measurements Project is investigating the effect of nanolubricants on refrigerant boiling. One nanolubricant—a lubricant for chillers with dispersed nano-sized particles—has resulted in as much as a 275 percent improvement in the boiling heat flux as compared to refrigerant/lubricant boiling without nanoparticles. This shows great potential for energy savings in chillers that keep the occupants of large buildings cool.

However, adding an insufficient amount or the wrong type of particles might lead to degradation in performance. So far, nanoparticles made of copper oxide are found to provide significant improvement if a critical mass of nanoparticles is present. Diamond nanoparticles can also significantly benefit refrigerant/lubricant boiling heat transfer but may not be viable for chillers because their surface chemistry makes it difficult to create a stable diamond nanolubricant.

New knowledge and understanding gained from this research is important because buildings consume 73 percent of the nation's electricity, 13 percent of which is required for air-conditioning.

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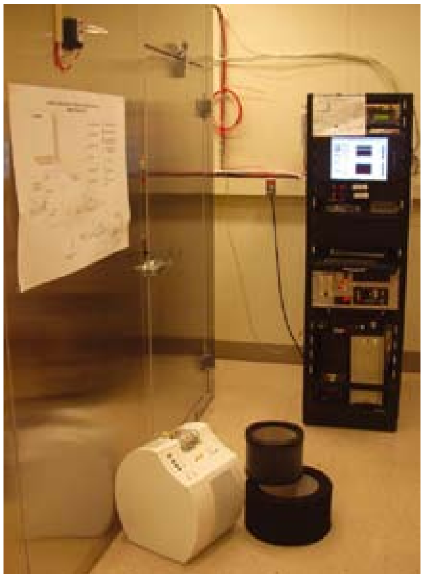
Air Cleaner Performance Measurement and Prediction

Poor indoor air quality (IAQ) affects nearly everyone around the world and results in significant costs due to healthcare expenses, sick leave and lost productivity. It has been estimated that IAQ improvements could reduce U.S. healthcare costs by $17 to $48 billion. EPA has cited the need for standards to evaluate the capability and reliability of air cleaning technologies; however rating standards currently do not exist to evaluate gaseous contaminant removal or the filtration efficiency of high performance particle filters entering the market. Gaseous air cleaner testing is very difficult due to the wide range of chemical contaminants, the variation in removal rates of different chemicals for the same piece of air cleaning equipment, and the need to measure very low contaminant concentrations. It is also difficult to maintain stable environmental conditions at the high airflow rates over the lengthy test durations required to test these devices.

Through a series of tests in the highly controlled environmental chamber at NIST, the required test conditions and factors influencing the results are being identified, along with the achievable levels of experimental uncertainty. Working with manufacturers to understand their performance concerns and using BFRL's established technical experience with air cleaner testing, BFRL is developing practical test procedures for evaluating gaseous air cleaners. Given recent concerns arising from the Hurricane Katrina experience, these efforts are also addressing the control of formaldehyde in particular. Building IAQ modeling is being employed in order to provide an understanding of the impact of these devices



Full-scale test chamber (32 m^3) and the environmental and tracer gas control and monitoring systems used for testing of gaseous air cleaners, high-efficiency particle air cleaners and method development. A portable gaseous air cleaner with filters is shown in front.

on occupant exposure to demonstrate the value and validity of the performance metrics and to relate air cleaner performance as measured in the laboratory to contaminant exposure reductions with devices installed in actual occupied environments.

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Novel Methods for Optimization of Finned-Tube Heat Exchangers

Recent studies have shown that one of the most important factors governing the performance of finned-tube heat exchangers is the pairing of air and refrigerant thermodynamic parameters and flow rates on a tube-by-tube basis. By properly designing the refrigerant circuitry, which defines the refrigerant's path through the heat exchanger, the performance penalty typically associated with non-uniform air distribution can be avoided. However, the tools currently available to industry neither include a reliable means to determine the air flow distribution, nor do they provide a method for optimizing the refrigerant circuitry for it.

BFRL is studying the distribution of air flowing through finned-tube heat exchangers by using particle image velocimetry measurements and detailed computational fluid dynamics simulations. These studies have consistently shown that the air flow is rarely uniform and that manufacturers can realize considerable efficiency gains over current practice by optimizing the refrigerant circuitry for the in-situ air flow distribution. To address this issue, BFRL collaborated with George Mason University to develop an evolutionary computation software module called ISHED (Intelligent System for Heat Exchanger Design), which optimizes the refrigerant circuitry in finned-tube air-to-refrigerant heat exchangers using a genetic algorithm-based approach.

In 2009, ISHED will be released as an integral component of EVAP-COND, a software package that simulates the performance of finned-tube heat exchangers. The group developed the original version of EVAP-COND six years ago and made it available on the BFRL Web site. Since its inception, EVAP-COND has been downloaded close to 4,000 times. The new version of EVAP-COND with ISHED will provide optimization capabilities that are not available elsewhere. Other project outputs include two peer-reviewed journal publications which were translated into foreign languages.

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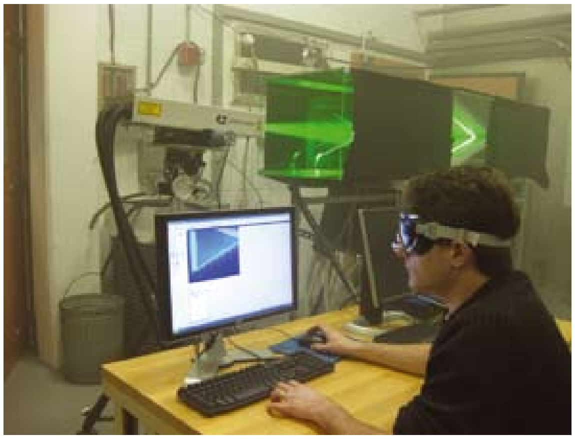

BFRL researchers are using Particle Image Velocimetry to measure the air flow distribution through heat exchangers used in residential air conditioners. The data gathered from these measurements is used to validate CFD air distribution predictive models. Detailed knowledge of the air flow distribution is critical for the development of high-efficiency heat exchangers.

MEASUREMENT SCIENCE FOR

Advancing Infrastructure Delivery

What is the problem?

The U.S. physical infrastructure is enormous and aging poorly. How the nation renews and expands the infrastructure will help determine the quality of life for future generations, our competitiveness in the global economy, and our capability to reduce dependency on foreign oil.[1] The U.S. government and public recognize the critical importance and benefits of renewing and expanding the nation's physical infrastructure.

The nation and the construction industry face a projected $2.2 trillion cost-burden for renewal of existing, critical physical infrastructure.[2] More than a quarter of the nation's 600,000 bridges are either structurally deficient or functionally obsolete. Replacement of America's aging drinking water systems has an annual shortfall of at least $11 billion. Projected power generation and distribution investment needs could be $1.5 trillion by 2030. Initiating infrastructure renewal and expansion by continuing to use the same processes, practices, technologies and materials that were developed in the 20th century will likely yield the same results: increasing instances of cost overruns, delays, service disruptions, higher operating and repair costs, and the possibility of cascading failures.[1]

As part of advancing infrastructure delivery, engineering, construction, manufacturing, and research, organizations must address the eroding productivity demonstrated on many construction projects. During the past 40 years, studies have illustrated how construction productivity at the industry level has declined at an average annual rate of 0.6 percent.[3] This trend is in stark contrast to all other non-farm industries (e.g., manufacturing), which have improved labor productivity at an average rate of 1.8 percent per year. Industry studies have identified inefficiencies ranging from 25 percent to 50 percent in coordinating labor and managing, moving, and installing construction materials.[4]

Other industries have realized their productivity advances largely due to new or improved work processes and the integration of information, communication, automation, and sensing technologies. Leading construction industry groups, such

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[1] *NRC Report*,"Sustainable Critical Infrastructure Systems – A Framework for Meeting 21st Century Imperatives". Available at *http://www.nap.edu/catalog.php?record_id=12638*

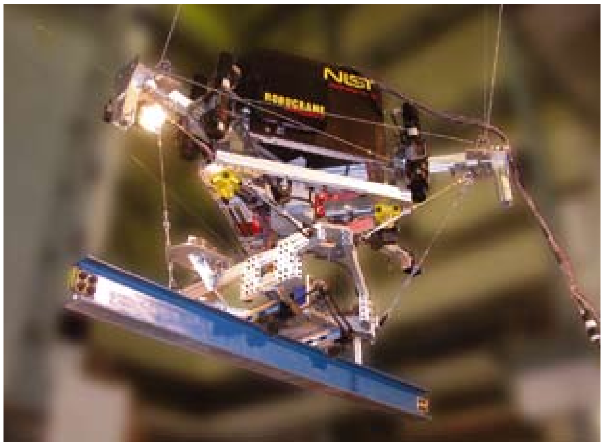
[2] ASCE 2009 Report Card for America's Infrastructure. Available at *http://www.asce.org/reportcard2009*

[3] Teicholz, P., "Labor Productivity Declines in the Construction Industry: Causes and Remedies," *AECbytes Viewpoint*, Issue 4, April 14, 2004.

[4] Chapman, R. E., Butry, D.T., "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities," *NIST White Paper*, May 2008.

as the American Institute of Architects (AIA), Associated General Contractors of America (AGC), Construction Industry Institute (CII), Construction Users Roundtable (CURT), Electric Power Research Institute (EPRI), and FIATECH have identified the critical need for fully integrated and automated project delivery processes. The application of these advanced methods and technologies could enable breakthrough improvements in the delivery, quality, and reliability of the nation's infrastructure.

There is a lack of measurement science for: 1) enabling automated access to and integration of diverse information systems; 2) enabling real-time monitoring and control of construction processes; 3) determining productivity of industry work processes, discrete tasks and aggregate tasks levels; and 4) evaluating the performance of promising automation and integration technologies in construction. Creating and validating the needed measurement science requires a neutral, representative, and accurately monitored environment in which the application of new technologies and processes can be evaluated.



BFRL researchers successfully equipped a unique cable-suspended six degree of freedom robotic crane—the RoboCrane™—with real-time laser tracking and demonstrated an autonomous steel assembly process. This capability is one of many that BFRL is developing as part of the Intelligent and Automated Construction Job Site Testbed.

Why is it hard to solve?

These measurement problems are hard because of the complexity and variability of design and construction (both the work process and the built product), the unstructured environment of a construction site, and the inefficient processes in place for coordinating labor and movement of components. Large infrastructure projects involve the design, selection, and installation of millions of individual products. Some are manufactured off site, some are manufactured on site, and some are assembled on site from manufactured components. Designing, constructing, and commissioning a complex infrastructure project involves hundreds to thousands of contractors, each with unique roles and relationships to the others. Each contractor uses unique processes, software tools and technologies to execute their portion of the work. Variability comes from the fact that each project is one-of-a-kind, each project is a unique combination of participating organizations, and construction site conditions change continuously. This distinguishes construction from manufacturing, which is characterized by an environment that is carefully designed and controlled to efficiently and precisely repeat operations that produce multiple copies of the same product.

Innovation in construction project delivery is currently being addressed by a patchwork of industry associations, government/private research organizations and consortia. Progress is hampered by the reluctance of the construction industry and most owners of constructed facilities to adopt innovative technologies that will initially add risk and cost. Advancements in measurement sciences and quality assurance techniques are needed to enable firms to evaluate and deploy potential improvements and cost savings of integration and automation technologies over traditional approaches.

Why BFRL?

The Building and Fire Research Laboratory (BFRL) is uniquely positioned to:

- analyze the construction industry's measurement science needs;
- identify and generalize major barriers and opportunities to improving infrastructure delivery;
- synthesize and apply relevant advancements from other research and industries; and
- develop and validate the missing measurement science needed for achieving improvements in the renewal of the nation's physical infrastructure.

This strategic goal leverages the BFRL core competency in information, communication and automation technologies for intelligent integration of building design, construction and operation and the BFRL network of industry and research partnerships. The development of the needed measurement science and the use of testbeds provide tools and catalysts for a broad range of improvements in infrastructure delivery.

Now is the time for BFRL to succeed in delivering the needed measurement science because the enabling technologies are sufficiently mature to be applied to design and construction processes, the cost of computing is no longer a barrier, and the industry and the public are demanding new capabilities for assessing and improving infrastructure project delivery and construction productivity. Industry organizations have confirmed the importance of this goal and are committed to working with BFRL to achieve success. Leaders in the construction industry know the benefits that have accrued from the investments in measuring and monitoring construction safety and see similar potential for improving infrastructure delivery and construction productivity.

By working with industry and the research community, BFRL will enable industry to achieve integrated and automated collaboration and work processes, measure construction productivity at discrete and aggregate levels, incorporate automated access to and integration of diverse information systems, and leverage real-time control systems to fully integrate and automate construction processes, resulting in:

- reduction of infrastructure project delivery times and construction costs;
- increased capabilities to identify and implement productivity-improving practices and technologies;
- reduced uncertainty, unpredictability and risk in construction processes; and
- new construction processes and capabilities.

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Automated and Integrated Infrastructure Construction Processes

This program was initiated with the investigation of the challenges and evolving technologies applicable to construction integration and automation. The program strategy is to develop, in parallel, metrics for multifactor construction productivity, real-time sensing and control, data model characterization and validation, and interoperability testing. These new metrics are being applied to priority work processes and technologies identified in collaboration with industry. Those processes and technologies serve as test cases for evaluating the application of the measurement science in the Intelligent and Automated Construction Research Testbed (described later) and in collaborative projects with industry partners.

BFRL is developing and using baseline measures and data on project cost, schedule, and field work and rework to identify tasks and processes (e.g., automated assembly, real-time control, materials tracking) for targeting improvements in infrastructure project delivery. BFRL is partnering with the Construction Industry Institute (CII) to measure how combinations of industry best practices and automation and integration technologies impact task and project productivity. In collaboration with the Bureau of Labor Statistics (BLS), BFRL is using a multifactor productivity approach to produce industry-level metrics for selected construction industry sectors (e.g., steel erection). Multifactor productivity metrics enable separable estimates of the contribution of labor, capital, and technology.

The U.S. manufacturing industry has successfully developed integration and automation technologies to gain real-time control of its processes, resulting in increased productivity, decreased time-to-market of new products, and greater customer satisfaction. The U.S. construction industry has tried to employ many of these same technologies but with only limited success. A key contributor to this failure is the lack of an overall conceptual framework and supporting reference model architecture for the end-to-end monitoring and control of the construction process. NIST is adapting its open and scalable reference model architecture for real-time control systems (RCS) to support the construction domain's loosely coupled, distributed system components and arbitrary mixes of automated and manual task work. To achieve this level of monitoring and control, BFRL is developing the enabling measurement science and performance metrics for evaluating individual sensors (e.g., 3-D imaging, calibrated camera networks, RFID, ultra-wideband tracking), construction object recognition and tracking algorithms, and combined real-time sensing and control systems for maintaining robust situational awareness of cluttered and dynamic construction sites.

BFRL is developing methods and metrics for combining 3D imaging and building information modeling (BIM) to improve construction productivity and enable automated construction control. This image shows the combination of technologies as applied to the NIST Large Fire Research Facility.

One of the features of the construction industry's complexity and variability is the extraordinarily large number of highly diverse information systems that are used over the lifecycle of the built product. BFRL is developing and evaluating data model characterization techniques and measurement science to determine commonalities, differences and alignment mechanisms for enabling interoperability and integration. BFRL is also developing measurement science to enable validation of data models and data exchange protocols, conformance assessment of construction information systems and interoperability testing. The ultimate goal is enabling automated access to and integration of those systems.

BFRL is developing an Intelligent and Automated Construction Job Site Testbed to demonstrate and transfer the resulting productivity metrics and tools to industry. In addition, industry, academia, and other research organizations are partnering with BFRL to use the testbed for measuring the productivity impacts of new construction technologies and processes, and for testing new construction standards and protocols. The capabilities of the testbed under development include: world-class sensing for monitoring real-time status of construction processes; control of construction equipment and processes (real, scaled, and simulated); advanced communication and information exchange; and modeling, simulation and visualization. The Intelligent and Automated Construction Job Site Testbed will enable the transfer of construction productivity measurement science to the field, which will enable industry to develop best practices, protocols, and standards to achieve breakthrough improvements in construction productivity and the delivery of physical infrastructure.

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ACTIVITIES AND ACCOMPLISHMENTS

NIST Processes to Help Build Next-Generation Nuclear Power Plants

Information exchange processes developed by BFRL will be at the center of the effort to design and build the next generation of modern, highly efficient nuclear power plants.

New nuclear power plants will be designed, procured and constructed using advanced software applications for three-dimensional modeling and exchange of engineering information. Construction information gleaned from multiple databases and electronic documentation sources also will be used. The power industry and regulators recognize that an automated, integrated and interoperable configuration management capability must be established to maintain consistency between the design requirements and facility configuration documentation to ensure the ability to document and maintain compliance with a plant's Nuclear Regulatory Commission license.

The Electric Power Research Institute (EPRI) is leading the effort to develop this needed capability for new nuclear plant projects. EPRI assessed the results of the NIST-led Automating Equipment Information Exchange (AEX) project and adopted the AEX methodologies and specifications as foundational technology for achieving this new level of integrated and interoperable configuration management for critical equipment in new nuclear power plants.

AEX provides a common mechanism for designers and manufacturers using varied software applications to exchange data required to engineer, manufacture and install equipment such as fans, pumps, valves, heat exchangers and pressure vessels. The AEX XML (XML is a computer language designed to transport and store data.) specifications are used to automate information exchange among various software systems that support capital facility equipment engineering, procurement, construction, and operations and maintenance work processes.

These XML specifications standardize the names of equipment types and their attributes, such as those found on common industry equipment data sheets. Automated data interfaces between software systems enable significant reductions in manual transcription costs and errors. The economic benefits of these XML specifications are estimated to be substantial.

Additionally, EPRI adopted the "NIST Capital Facilities Information Handover Guidelines" (NIST Internal Reports 7259 and 7417) to develop a new nuclear plant information handover guide providing a full plant life cycle information strategy establishing the methodology for defining the information requirements and for developing and implementing an information handover plan. The information handover plan is used to achieve comprehensive information management and integration of work processes across all organizations participating in the design, review and construction of the power plant.

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Product Data Standards for Structural Steel Construction

The CIMsteel Integration Standards (CIS/2) and Industry Foundation Classes (IFC) are the two product data standards that are used to exchange project and product information related to structural steel construction. CIS/2 is the product data exchange standard that has been endorsed by the American Institute of Steel Construction (AISC) to create a means for collaboration and data sharing among the various parties involved in steel construction. Over 25 steel design, analysis, and detailing software packages have adopted CIS/2 as the primary structural steel product data standard for interoperability and have demonstrated significant cost savings and productivity improvements for the delivery of structural steel projects by their users.

BFRL researchers have developed SteelVis, also known as the CIS/2 to VRML and IFC Translator. VRML (Virtual Reality Modeling Language) is a standard method to view and navigate 3D models in a web browser. With SteelVis, steel design, analysis and fabrication software developers are able to debug their CIS/2 import and export capabilities, and end-users can visually verify their CIS/2 models and check model coordination and bills of materials. There have been over 3000 downloads of SteelVis, and thousands of files have been translated through the web services version of SteelVis.

Mapping examples and IFC test files generated by SteelVis from CIS/2 files have identified several deficiencies in the IFC schema for modeling structural steel and for general structural analysis models. The ability to translate structural steel from CIS/2 to IFC also provides that capability to do model coordination with other parts of a building such as wall, floors, HVAC, MEP, and cladding systems that have been modeled in other CAD software.

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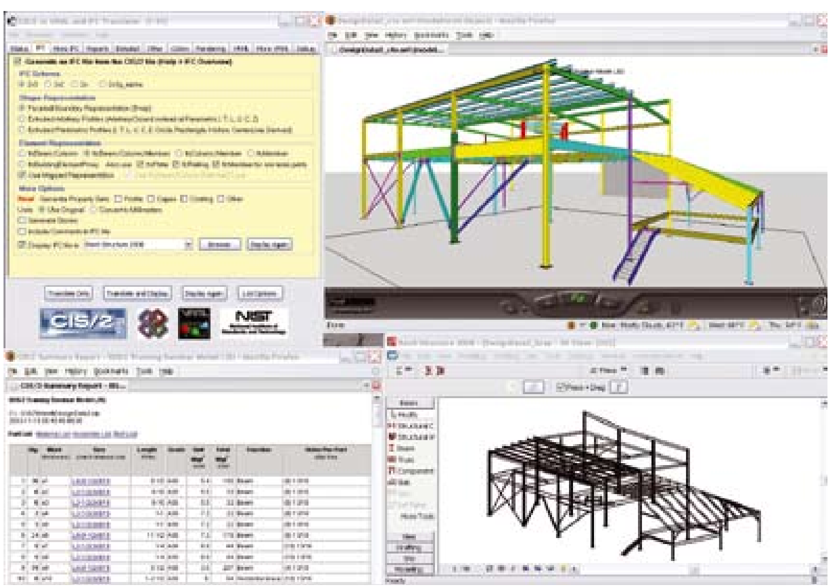
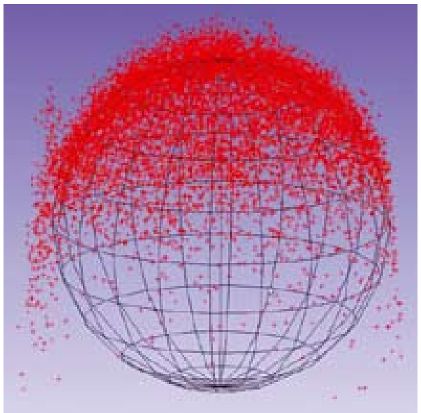


The SteelVis CIS/2 to VRML and IFC Translator translates a CIS/2 file of a steel structure into a 3D interactive model in the form of a VRML file and an IFC model.

BFRL Indoor Artifact Facility



Point cloud of a sphere

The Performance and Use of 3-D Imaging Systems for Construction Applications

A 3-D imaging system is a non-contact measurement instrument used to produce a 3-D representation of an object or a site. A common example of such a representation is a point cloud. Use of these systems in widely varying fields such as manufacturing, forensics, autonomous vehicle navigation, and archeology grew significantly during the past decade. The most growth though was in the use of 3-D imaging systems in the construction sector, where these new measurement technologies enable improved construction productivity through reduced errors and rework, schedule reduction, improved responsiveness to project changes, increased worker safety, and better quality control.

The expanded use of 3-D imaging systems revealed the quite significant lack of commonly accepted methods to both characterize and report the performance of these systems and to develop confidence limits for the data and their end products. Industry, and in particular the construction sector, needs open, consensus-based standards regarding the performance and use of 3-D imaging systems for construction applications. To support this need, BFRL is developing measurement science to facilitate the creation of standards for 3-D imaging systems.

As BFRL worked directly with industry, one of the first and most important outcomes was the establishment of ASTM E57 3-D Imaging Systems in 2006. This committee is dedicated to the creation of a suite of performance-based standards as reflected in the structure of its four subcommittees: Terminology, Test Methods, Best Practices, and Data Interoperability. The standards produced by ASTM E57 will accelerate the adoption of 3-D imaging in construction work processes by establishing a common vocabulary, allowing for fair comparisons of instruments, removing barriers to data exchange, and providing methods for verifying and certifying the uncertainty associated with 3-D image data.

To support this research, BFRL developed an Indoor Artifact Facility and an Outdoor Long-Range Benchmark Facility for the neutral evaluation of 3-D imaging system performance and evaluating new test protocols. Prototype reference measurement artifacts and new algorithms to process 3-D image data have also been developed when required to support performance evaluation.

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Metrics and Tools for Construction Productivity

Although the construction industry is a major sector of the U.S. economy, it has experienced a prolonged period of decline in productivity. Due to the lack of critical measurement methods, however, the magnitude of the productivity problem in the construction industry is largely unknown. To address these deficiencies, efforts are underway to measure construction productivity at three levels: task, project, and industry. Tasks refer to specific construction activities such as concrete placement or structural steel erection. Projects are the collection of tasks required for the construction of a new facility, e.g., the construction of a new commercial office building, or renovation, e.g., additions, alterations, and major replacements of an existing constructed facility. Industry measures are based on building types published by the Census Bureau and represent the total portfolio of projects. Producing measures of construction productivity at each level involves the development of both metrics and tools. Once produced, these metrics and tools will help construction industry stakeholders make more cost-effective investments in productivity enhancing technologies and improved life-cycle construction processes. They will also provide stakeholders with new measurement and evaluation capabilities.

In 2008, BFRL produced a white paper, "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities," discussing how productivity measures could be developed for the construction industry; how they are related to the use of information and automation technologies and construction processes; and how to build on several ongoing collaborative efforts aimed at improving the efficiency, competitiveness, and innovation of the construction industry. The paper provided the framework for a National Academies workshop, "Advancing the Productivity and Competitiveness of the U.S. Construction Industry," held in Washington, D.C. on Nov. 19-20, 2008. Industry leaders and experts from academia and the government assembled to: (1) identify the key opportunities for achieving breakthrough improvements in the productivity and competitiveness of the capital facilities sector of the U.S. construction industry and (2) identify and prioritize technologies, processes, and deployment activities with the greatest potential to achieve breakthrough improvements. Ten productivity-enhancing priorities areas were identified: 3-D Building Information Models (BIM), test beds, role of Construction Industry Institute (CII) and Construction Users Roundtable (CURT), craft training, benchmarking, prefabrication, metrics, jobsite information, training for engineers and professionals, and training for field management.

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MEASUREMENT SCIENCE FOR

Sustainable Infrastructure Materials

What is the problem?

National and international economic growth cannot continue into the next century unless industries, especially high volume trades like the construction industry, dramatically reduce the amounts of natural resources and energy they consume and the waste that they produce. To remain globally competitive while embracing sustainability, the U.S. construction industry needs to reexamine and redefine its practices: chemicals, materials, manufacturing methods, products, and waste disposal. Currently, construction materials, mainly concrete, steel, and polymeric materials, are being consumed at an annual rate of approximately $500 billion per year in new construction, and an additional $2.2 trillion in materials and construction products are required for renewal of the existing deteriorating U.S. physical infrastructure, according to the 2009 American Society of Civil Engineers Infrastructure Report Card.

Sustainability drivers include energy costs, global climate change, environmental regulations, disposal costs, resource scarcities, and population increases. Examples of environmental concerns include the need to reduce environmental impact through the inclusion of increased fractions of supplementary cementitious materials, like fly ash (one of the residues generated in the combustion of coal) and slag (a byproduct of metal smelting), into concrete as well as reduce environmental, health, and safety concerns related to the potential release of nanoparticles from nanocomposite materials that are rapidly being introduced into the marketplace.

Sustainability decision analysis tools are currently being developed by industry, government agencies, and standards organizations. The efficacy of these decision tools, however, is greatly hampered by the lack of reliable sustainability input data, especially service life data for materials, components and systems, and the absence of measurement science for gauging this critical input. Without technically sound, thoroughly evaluated measurement science, the input available for making sustainability decisions is too crude and unreliable. This deficiency was highlighted at a recent meeting hosted by the U.S. Department of Commerce where industry expressed the "need for the establishment of internationally comparable metrics to measure the cost-effectiveness of sustainable manufacturing practices."

Why is it hard to solve?

The most fundamental quality in full-life cycle assessment is a reliable estimate of the expected service life of a material, component, or system. Current durability tests were designed early in the 20th century to make qualitative performance assessments (i.e., at best, they can provide assessments as to whether product A is better than product B or vice versa under a specified set of exposure conditions) and these tests are fraught with scientific uncertainties. Extensive research efforts are being made to put service life estimation on a scientific basis. The measurement science needed to generate quantitative and accurate predictions of service life, however, is at a nascent level.

The measurement science for predicting the service life of construction materials involves measurements of the degradation, flammability, and nanoparticle release from these materials. These processes are inherently complex. They involve numerous component interactions and multifunctional (chemical, physical, and mechanical) responses that operate over extremely wide length and time scale ranges. Nanoscale materials also possess unique properties (high surface area, high surface reactivity, large interparticle forces) that will affect degradation, flammability, and the release rate of nanoparticles in unknown ways. Science-based models for predicting these complex phenomena are just beginning to be developed, but such modeling is known to involve multiscale, multifunctional interactions in which damage accumulates over time. A multiplicity of linked models will be necessary to span these length and time scales, which in turn require advanced, high resolution measurement tools for characterizing the constituent properties of nano-infrastructural materials (NIMs).

Why BFRL?

The Building and Fire Research Laboratory (BFRL) is the primary federal laboratory serving the building and fire safety industries. This strategic goal leverages the BFRL core competency in performance, durability, and service life prediction of building materials. BFRL's research in sustainability decision analysis tools and in high performance construction and building materials has been ongoing for several decades, and is internationally recognized. Industrial customers continue to recognize BFRL's world class expertise in advancing the measurement science of infrastructure materials. This recognition is evidenced by their willingness over the last two decades to establish and support ongoing NIST/industry consortia, which have as their objectives creating and validating the measurement science necessary to effect reliable sustainability decisions for infrastructure materials.

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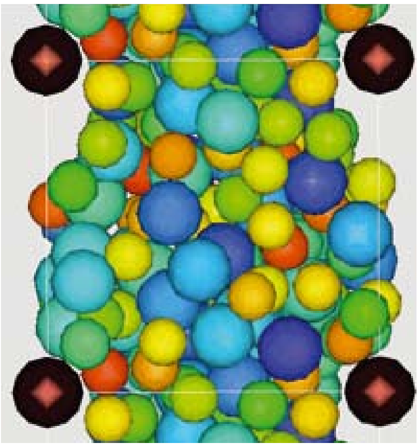
Service Life Prediction of Concrete Building and Infrastructure Materials

This program will develop and implement the enabling measurement science that will give the concrete industry and state and federal government agencies the predictive capability upon which they can base the use of performance-based standards and specifications in key technical areas.

The overarching problem for the U.S. cement and concrete industry is that



A computer model for predicting the flow properties of high performance concrete (HPC) aimed at designing HPC mixtures with optimum performance, both in the fresh and hardened states.

either relevant performance-based standards do not exist or that the performance-based standards that do exist are not built upon measurements that reliably predict real performance. This problem becomes evident in the technical problems plaguing the cement and concrete industry and concrete construction users and owners. The main problem is concrete durability, which needs predictive tests for the many new materials being produced, and assured longer service life. Some of these new materials include nanoadditives, whether to the liquid part of concrete (water-filled pore space), or the solid part (a complex composite of cement, hydration products, sand, and gravel), or the interface between the two, which is very large in concrete and crucially affects properties like shrinkage and ionic transport.

But concrete durability is just a part of the larger problem of concrete sustainability—trying to make and use concrete that has less of an environmental impact, uses less energy and produces less carbon dioxide, yet at the same time continues to meet or exceed expectations as the main construction material used in a rapidly-growing world. A large part of sustainability efforts in the cement and concrete industry is focused on increasing the use of fly ash and other waste-stream materials as substitutes for cement. This will reduce the need for cement and safely recycle coal combustion products, yet at the same time will improve the properties of concrete, including durability, to rebuild the nation's physical infrastructure with more sustainable materials.

Building performance prediction capabilities for cement-based materials is a challenging task due to the complexity of these materials. It is known that the materials industry in general needs performance prediction capability, which for complex modern materials (among which concrete is arguably the most complex) can only be supplied by computational materials science/engineering models or what is called an Integrated Computational Materials Engineering (ICME).[1] Therefore, the technical idea that underlies this research program is to use a combination of experimental and computational materials science/engineering, in an ICME approach, to develop performance prediction capability for selected major problems encountered by the U.S. concrete industry and in major national problems involving sustainable transportation infrastructure rebuilding and sustainable nuclear waste containment structures and new nuclear facilities.

The impact of success in improving the sustainability of concrete will include: satisfying the construction needs of a growing U.S. and world economy while minimizing increase in CO_2 emissions; close to 100 % recycling of fly ash, minimizing land-fill disposal; improving the performance and durability of concrete used in the infrastructure; and minimizing the CO_2/ton of cementitious material used in concrete.

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[1] ICME, Integrated Computational Materials Engineering: A Transformational Discipline for Improved Competitiveness and National Security, National Research Council, *National Academies Press*, 2008

ACTIVITIES AND ACCOMPLISHMENTS

Quantitative Characterization of Concrete-Making Materials for Performance Prediction and Increased Fly Ash Utilization in Concrete

Advancing the materials science of construction materials requires the ability to quantitatively characterize the micro- and macrostructures. BFRL researchers have been developing a protocol to characterize microstructure of concrete-making materials and hardened concrete; cements, aggregates, and mineral admixtures, which can be used to determine the effects of materials, processing, and environmental variables on performance.

One of the many constituents concrete may contain is fly ash, a powdered by-product of coal-fired power generation. While sustainability initiatives have intensified the desire for greater use of fly ash in concrete, making a distinction between ashes is problematic and has led to difficulties in predicting undesirable effects on concrete rheology, setting times, strength development, and durability. This in part stems from the tenuous classification scheme traditionally used for fly ash, where distinction between the two classes, F and C, are essentially based upon quantitative measures of the calcium oxide (CaO) content. While knowledge of the bulk chemistry is useful, the crystalline and glassy phases are the actual constituents of interest, and they may be either reactive or inert.

Using analytical methods developed for characterizing the NIST SRM clinkers and cements, BFRL is examining fly ash mineral and glass characteristics and measuring mass fractions and surface areas to provide both a more accurate and more complete characterization of these materials. Developing a standardized measurement scheme will yield an improved understanding of the types and distribution of phases, their relative reactivity, and provide the basis for an improved classification scheme for fly ash. These data will also be invaluable for interpreting fly ash and its interactions with cement and chemical admixtures, which will lead to a better understanding of the problems and successes in high-volume fly ash utilization on concrete production.

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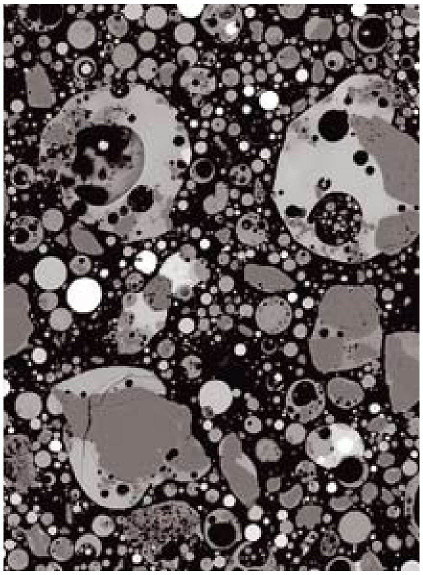
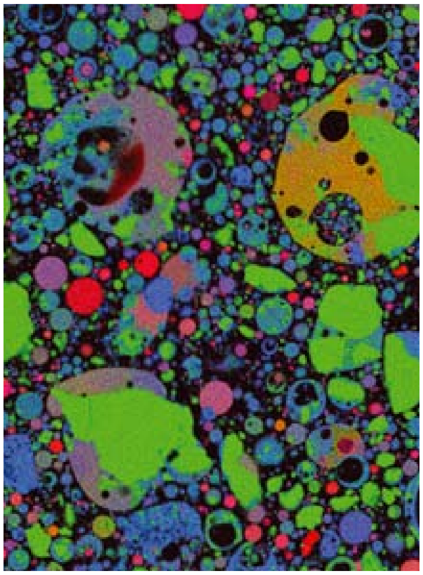


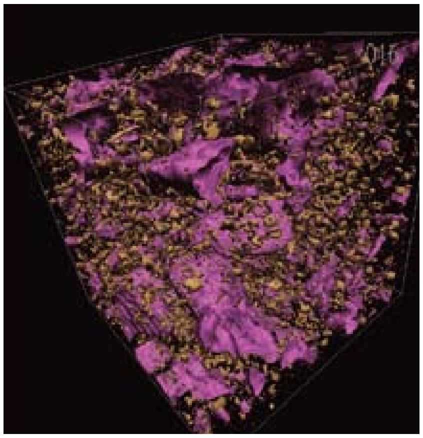
SEM backscattered electron image of a fly ash material.



SEM X-Ray image combining calcium, silicon, and aluminum spatial data are useful in delineating mineral and glassy phases.

Modeling Hydration of Concrete Binders

To maximize sustainability and optimize short-term performance of concrete, mineral additions, waste stream materials, and organic admixtures all are being used in the binder at higher concentrations, but the concrete industry lacks the measurement science capability, specifically a modeling framework, to understand and predict the chemical and structural changes that can occur for a given binder formulation. Without this capability, material optimization for a given application has become increasingly difficult because potential incompatibilities among the binder components are difficult to detect in advance and can cause major service life problems in the field. In response, BFRL researchers are developing computer modeling tools both to simulate the chemical and 3-D microstructural changes to concrete binders and to predict critical performance indicators such as setting time, heat release, and strength development. One of these modeling tools, called HydratiCA, includes a full chemical kinetic description of the coupled reactions that occur in fresh concrete and is targeted at predicting the nature and rates of the complex changes that occur within the first day of mixing the material. A second model, called THAMES, is based on general principles of equilibrium thermodynamics and is being developed to address the longer-term performance of concrete binders, including their hydration and resistance to groundwater leaching, sulfate attack, and alkali-silica reactions. Together, these models span the entire service life of concrete, from mixing to demolition.



Computer simulation of a sample of a cementitious mineral microstructure that has undergone dissolution, diffusion, and precipitation according to exact chemical and physical equations with real kinetics.

Key outcomes from this project include new insights into the detailed kinetic mechanisms of cement hydration at early ages, published in major international journals. Completion and preliminary verification of the THAMES model for portland cement binder microstructures will help provide the Department of Energy, under the Cement Barriers Partnership, with a comprehensive model for predicting concrete service life in important long-term use in the U.S. nuclear infrastructure. A second major outcome of this project has been the identification of HydratiCA as a central organizing principle in a proposed research roadmap for characterizing and modeling cementitious materials, as detailed in a recent invited paper (H. M. Jennings et al, *J. Adv. Concrete Tech.* 6 [1] 1-25 (2008)). Such a roadmap will help the concrete industry by providing a guide on critical needs for improving measurement science for concrete materials assessment.

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Doubling the Service Life of Concrete

Concrete has been around since the Romans, and it has been an engineered material since the beginning of the 20th century, yet the expected service life of concrete has remained relatively unchanged for the past 40 years.

The vast majority of the damage in concrete, which controls service life, originates from ions, such as chlorides from road salts and sulfates from groundwater that enter the concrete through its water-filled pores. Past attempts to reduce diffusion rates have focused on producing denser, less porous concretes, but unfortunately these formulations have a greater tendency to crack. This project, VERDiCT, has taken a novel approach. Rather than change the size and density of the pores in concrete, change the viscosity of the pore solution in the concrete to reduce the rate at which chlorides and sulfates penetrate the concrete. Doubling the *viscosity* experienced by the transported ions can reduce the rate of ion transport to half, thereby doubling the expected service life.

The technical challenge is to identify chemicals composed of molecules that are small enough to slow down diffusion of relatively small ionic species of interest, large enough so that only a moderate concentration of the chemical is needed to double the viscosity, and essentially inert with respect to influencing the cement hydration reactions.

To date, the project has successfully demonstrated the VERDiCT concept in mortars submerged in a chloride solution for up to one year. Even better performance is achieved when the VERDiCT admixture is incorporated into porous, lightweight sand (LWA) that is used in the mortar. The photo below reveals the extent of chloride ingress into mortar cylinders split along the central axis. Appearing from left to right in the photo are cross sections of mortars without VERDiCT or LWA, with VERDiCT added to the mix water, and with LWA saturated with VERDiCT. Although the effect of VERDiCT in the mix water is measurable, the effect of VERDiCT saturated LWA is striking in reducing chloride penetration from the outside.

A non-provisional patent application was filed in September 2008, and the technology is now available for licensing from the U.S. government. The NIST Office of Technology Partnerships may be contacted for further details. Future work will consist of demonstrating VERDiCT technology in concrete and improving our understanding of the chemical and physical mechanisms that influence the effectiveness of VERDiCT admixtures.

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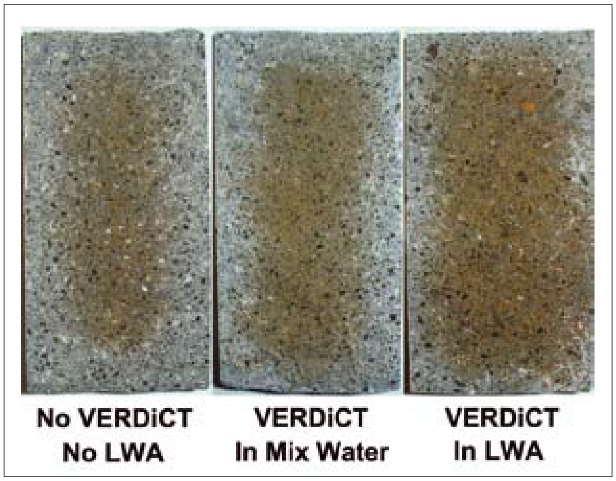
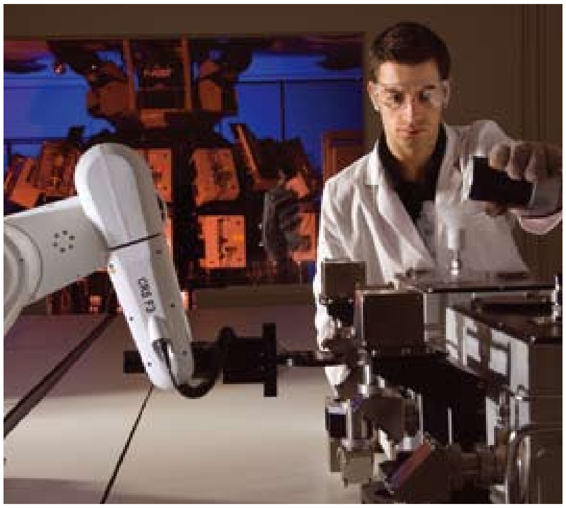


Chloride penetration in mortar cross sections after one year submersion in chloride solution. The presence of chlorides are shown in grey, and the absence of chlorides in brown.

Service Life Prediction of High Performance Polymers and Composites



The goal of BFRL's Automated Analytical Laboratory (AAL) is to automate and accelerate analytical measurements on polymeric specimens following exposure to various exposure environments.

Polymeric materials are used in the construction and building industries in a myriad of applications including protective coatings, siding, roofing, windows, doors, pipes, and geotextiles. They can be combined with fibers to form composites that have enhanced properties, enabling them to be used as structural and load-bearing members. Polymers offer many advantages over conventional materials including lightness, corrosion resistance, and ease of processing and installation. There is currently no established, scientifically-based methodology for accurately and quantitatively predicting life cycle performance of polymeric construction materials in their end-use environment. The addition of nanoparticles to polymeric matrices further increases the difficulty of predicting life cycle performance. Degradation and nanoparticle release phenomena in nanostructured materials are inherently complex and involve numerous component interactions and multifunctional (chemical, physical, and mechanical) responses that operate over extremely large length and time scales. Nanoscale materials also possess unique properties (high surface area, high surface reactivity, and large interparticle forces) that affect many initial and long-term properties. Thus, new metrologies and methodologies that are radically different from the approaches currently used are required to obtain the necessary data for accurately modeling lifetimes and particle release behavior in new nanostructured materials.

In 2006, BFRL became the first research team to successfully and quantitatively link field and laboratory exposure results for an unfilled, model epoxy coating using a reliability-based methodology. Success in applying this methodology in predicting the service life of the epoxy coating has provided BFRL with an opportunity to move into the study of nanostructured systems, which includes polymers filled with nanoscale materials. Measurement science is being developed by BFRL researchers over a wide range of length and time scales to enable quantitative prediction of the life cycle performance [1] of nanostructured polymeric materials.

The linkage between field and laboratory exposures is studied using a reliability-based methodology for the three major classes of polymers: thermoset, thermoplastic, and elastomers. High resolution microscopy, spectroscopy and nanomechanical testing devices are being used to elucidate the effects that nanofillers have on the chemical

[1] Life cycle is defined as material performance from manufacturing to decommissioning/disposal.

and physical properties of nanomaterials, and as well as on the service lives of filled polymer systems. Temperature, relative humidity, and spectral UV are the primary environmental factors of interest. BFRL is focusing on metal oxide particles and carbon nanotubes, which are nano-scale fillers of interest in many structural applications.

Release of nanoparticles occurs in-service via environmental degradation and incineration through thermal, chemical, mechanical, and photolytic decomposition of nanostructured polymeric materials. The release rates and properties of these nanoparticles could have environmental, health and safety impacts. BFRL is quantitatively measuring release rates, chemical compositions, morphologies, and size distributions of aerosolized nanoparticles, using a number of advanced methods. Total mass loss and depletion of nanostructured materials during environmental exposure is being characterized with high resolution nano-gravimetry and infrared spectroscopy. Such models will be instrumental in designing improved nanocomposite materials.

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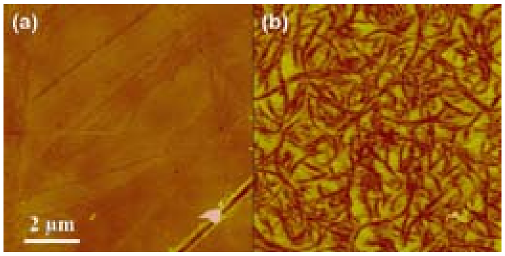
ACTIVITIES AND ACCOMPLISHMENTS

Reliability Approach for Relating Outdoor and Accelerated Laboratory Aging for Nanostructured Polymeric Systems

Nanostructured polymeric materials (NPMs), i.e., polymeric materials containing nanoparticles, have tremendous technical potential and provide competitive advantages to U.S. industry. However, due to the extremely small size of the nanoparticles and their extensive interfacial area, the incorporation of nanoparticles into traditional polymeric materials presents many technological and scientific challenges. No methodology exists currently for generating accurate, precise, and timely long-term performance estimates for NPMs exposed in their intended in-service environment.

BFRL was the first to successfully link field and laboratory exposure results for a neat, model epoxy coating using a reliability-based methodology. This success has laid a solid foundation to expand the reliability approach to link outdoor and accelerated laboratory aging for NPMs. This project consists of four major thrusts: (1) characterization of the multiscale chemical and physical properties of the aged and unaged, nano-filled and

BFRL researchers are exposing NPM specimens on the NIST Simulated Photodegradation via High Energy Radiant Exposure (SPHERE).



Surface and sub-surface imaging of a single wall carbon nanotube (SWCNT)-filled nanocomposite. (a) Atomic force microscope height image shows the surface morphology of the film, and (b) Non-contact electric force microscope phase image reveals the dispersion of SWCNTs in the polymer matrix beneath the surface.

unfilled polymers, (2) laboratory accelerated exposures on the NIST Sphere, (3) outdoor exposures in Gaithersburg, Md., and (4) linking laboratory and field exposure results via appropriate scientifically based mathematical models.

In 2008, significant progress was made in this project. A protocol was established for characterizing the major chemical and physical properties at multiple length and time scales for NPMs before and after UV exposure, which included the development of *electric force microscopy*—a technique based on atomic force microscopy—for quantitative detection of buried nanoparticles in NPMs. The research also clearly demonstrated that atmospheric relative humidity plays an important role on the failure mechanisms and service life of NPMs during laboratory accelerated aging. In 2009, the same model NPM was subjected to outdoor exposure and this data set will be used along with the laboratory data in the reliability-based methodology. Future research includes studying the effect of nanoparticle-polymer interfacial interactions on nanoparticle dispersion and the long-term performance of the NPMs and developing models for service life prediction of NPMs.

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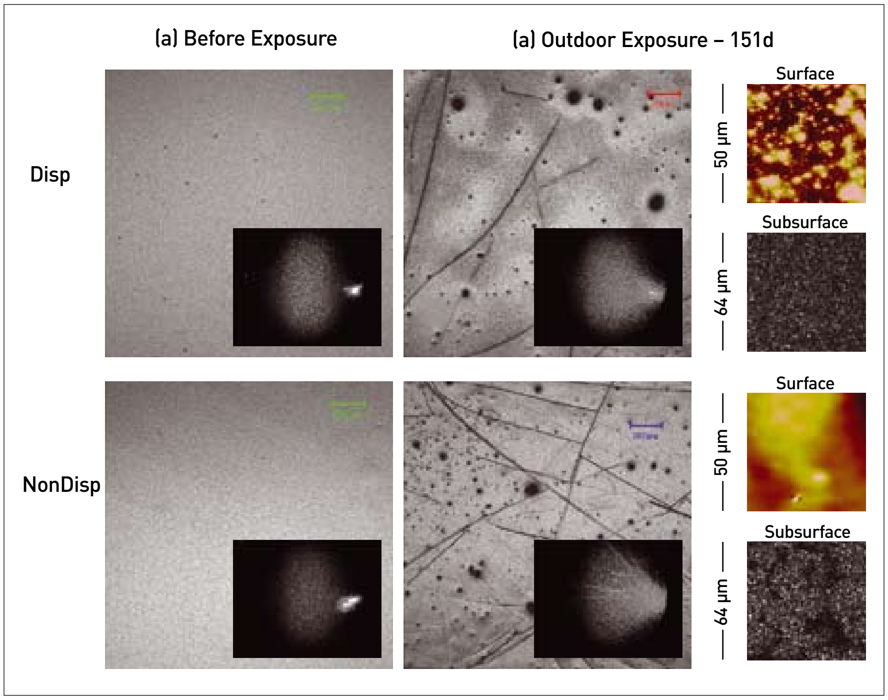
Metrologies for Characterizing Filler Dispersion, Multi-scale Structure, and Optical Properties of Polymeric Materials

In recent years, the increased use of nanoparticle fillers in polymeric systems has driven the need for techniques to measure the degree of dispersion and orientation of the nanofiller in the polymeric matrix. Both nanofiller dispersion and orientation have been documented to contribute to short and long-term performance of the filled polymeric system, and both dispersion and orientation can be characterized with a suite of advanced, non-destructive techniques based on optical scattering. The primary goals of this project are to (1) characterize nanofiller dispersion in liquid (uncured) and in solid (cured) polymeric matrices over multiple length scales and (2) relate nanofiller dispersion and physical properties to the weathering service life of



Surface morphology (LSCM) and optical scattering for coatings of two different dispersion states before and after outdoor exposure.

polymeric materials. Current research efforts have focused on metal oxide nanoparticulate systems because of their importance to the polymeric composites and coatings industries, but the techniques developed here will be applicable to a wide range of nanofillers.

Recent major outcomes include a new measurement capability, Scanning Wavelength Illumination system, for color and multi-wavelength scattering; protocols for measuring high diffused composite suspensions using back scattering photocorrection spectroscopy; and a method for correlating the surface morphological results to physical measurements on a series of TiO_2 pigmented coatings exposed to ultraviolet (UV) radiation. Future efforts will focus on developing optical methods for characterizing materials containing nanofillers with degrees of dispersion resulting from differences in polymer/filler interaction. Methods are also being developed to more accurately quantify optical properties in terms of angular-resolved optical reflectance and color as a function of filler dispersion and multi-scale material structure.

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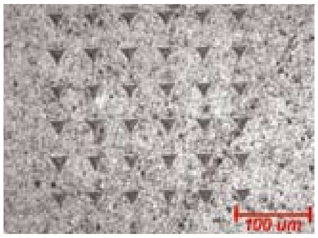
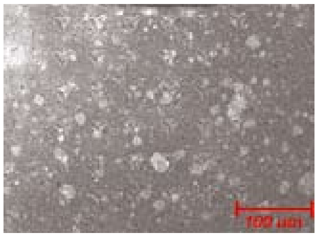
Multi-scale Mechanical Properties of Nanostructured Materials

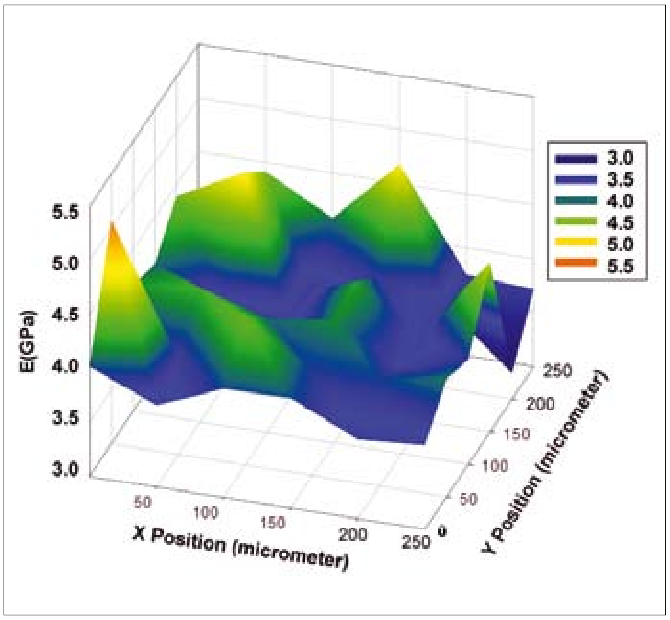
Nanocomposites are gaining acceptance in the building and construction industry for use in structural components, architectural components and adhesives. These novel materials contain nano-sized fillers that provide a variety of benefits such as extended service life, reduced weight, and increased strength or toughness. The incorporation of nanofillers into the polymer matrix affects performance across multiple length scales ranging from the nanometer scale (particularly near the nanofiller-matrix interface) to the millimeter scale.



at surface



1m below surface



(Top) Confocal images at and below surface of a nano-sized titanium dioxide-epoxy composite.
(Bottom) Elastic modulus across the surface of the image on the left. Colors indicate modulus.

In order to develop the next generation of high performance materials, it is critical to understand the impact of multi-scale structure and interfacial properties for nanocomposites over their lifetime. This research develops and refines indentation methodologies to quantify the elastic, plastic and time-dependent properties of microscale volumes of nanostructured materials. Measurement science tools are being developed to elucidate the relationship between materials response at the nanometer/micrometer level to that at the millimeter level, which is the benchmark used industry quality control. These measurement tools would be applicable to both new and aged materials. Ultimately, these tools will help to develop novel materials and determine lifecycle costs for replacement technologies.

Laser-scanning confocal microscopy and depth-sensing indentation are currently utilized to develop a three-dimensional map of local mechanical properties and morphology across the surface and within the interior of a nanocomposite material. The mechanical properties are spatially tracked with filler characteristics as a function of indentation depth, tip geometry, and indentation rate. The advantage of this current methodology is that a uniform dispersion of particle sizes is not required to understand small-scale material behavior. This database of near-surface properties is combined with data on bulk properties and analytical models to obtain an understanding of mechanical properties at different length scales. BFRL successfully used this approach to understand the impact of filler agglomerate size on indentation measurements.

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Reduced Flammability of Materials

The phenomena associated with fire are inherently stochastic, complex and dynamic. To successfully address these challenges, BFRL is providing industry with measurement tools capable of accurately predicting the flammability behavior of materials over a multiplicity of time and length scales. Furthermore, developing the measurement science tools to enable industry to accurately evaluate the sustainability of fire safe products, especially those based on nano-materials, is primarily impeded by the lack of data available on their sustainability, i.e., their environmental, health and safety performance, manufacturability, aging and recyclability.

BFRL works with the U.S. mattress industry to develop the technical underpinnings for a mattress/foundation standard that would serve as the basis for limiting the consequences of residential bed fires.

The challenge of coupling the difficult fire problem to the equally complex sustainability analysis is considerable.

This program is focused on three specific thrusts: 1) development of validated bench scale flammability measurement methods, 2) evaluation of new methods and materials for fire safe products and 3) a critical assessment of the sustainability of new fire safe approaches. The program will provide a competitive advantage in international markets where the new bench scale measurement methods and sustainable flame retardant approaches will enable U.S. companies to develop sustainable, cost effective, fire safe products.

Recent results of this program have led to two important impacts:
1) the promulgation of a National Mattress Flammability Standard, and
2) the development, by the polymer industry, of the first new non-halogen flame retardant system in decades based on nanoadditives.

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ACTIVITIES AND ACCOMPLISHMENTS

Validation of Bench-scale Smoke Toxicity Apparatus

The majority of people who die in fires die from smoke inhalation due to exposure to the toxic gases that are produced when common building materials, contents, and furnishings are burned in an enclosure, such as a residence. There is currently no established way to determine the likelihood that any particular item will produce these toxic gases other than to burn it in a full scale experiment, which is prohibitively expensive and difficult to reproduce.

BFRL has proposed four candidate bench-scale apparatus (the NBS Smoke Box, the NFPA 269 "Radiant Panel", the Cone Calorimeter, and the ISO/TS 19700 Tube Furnace) that might be used to determine the yields of toxic gases from burning items ranging from upholstered furniture to bookcases to electrical cables. In each case, a specimen is exposed to a thermal flux typical of a fire environment and burns, producing smoke and potentially toxic gases. These gases are measured by several gas analyzing instruments, including a Fourier Transform Infrared Spectrometer, so that their composition and yields (in grams of gas per gram of specimen burned) can be determined for each specimen type in each apparatus.

A researcher prepares to load a test specimen into one of the four candidate apparatus, the ISO/TS 19700 Tube Furnace.

Ultimately, these data will be compared to gas yields measured in full-scale experiments that were performed in a previous project. If one or more of these apparatus is found to produce reliable gas yields that are consistent with those measured at full-scale, then this research will have provided a way for fire safety engineers to gather needed input data, e.g. how much carbon monoxide a chair will produce in a fire, for fire models where the exposure of people is significant.

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No flame penetration through barrier fabric after 6 min, whereas foam is significantly contributing without the barrier fabric after only 90 seconds.

High Performance Barrier Materials

When they are the first item ignited, mattresses and upholstered furniture account for 5 percent of the residential fires in the U.S. every year, yet they account for 33 percent of the civilian deaths, 18 percent of the civilian injuries, and 11 percent of the property losses.[1] New and proposed mattress and upholstered furniture flammability regulations, such as Consumer Product Safety Commission 16 CFR 1633 (Standard for the Flammability (Open Flame) of Mattress Sets) and 16 CFR 1634 (Standard for the Flammability of Residential Upholstered Furniture (Proposed Rule)), are expected to reduce these fire losses with the primary compliance route likely being a fire-blocking barrier fabric that encapsulates the foam. The objective of this project is to prioritize and address the measurement science needs to enable the development and/or utilization of barrier fabrics for these industries.

In March 2009, NIST and the American Fiber Manufacturer's Association co-sponsored a two-day workshop called "Progress in Technologies and Fire Performance Testing of Barrier Fabrics Intended for Mattress and Upholstered Furniture Industries." Fifty industry stakeholders participated in the workshop, which focused on discussing the materials, technology, and measurement science deficiencies and obstacles preventing the advancement of innovative barrier fabric materials, and the utilization of barrier fabrics for the mattress and upholstered furniture industries. This workshop and the subject matter is important to the fire service community as reflected by the 10,800 hits to the workshop Web site (*http://www.bfrl.nist.gov/866/barrierfabric*) and 9,480 presentation downloads in four months. A meeting report is being prepared and expected to be available by the end of 2009.

This research focuses on developing performance metrics and standard testing protocols for assessing the fire-blocking performance of barrier fabrics. The critical measurement science needs are to develop a testing tool and the associated methodology for using this tool to predict how barrier fabrics will perform in full-scale tests and to define

[1] Ahrens, M; "Home Fires that Began with Upholstered Furniture," *NFPA One-Stop Data Shop Report*, May 2008.

the performance metrics critical to the success of a barrier fabric. In an attempt to address these measurement science needs, BFRL has built a prototype bench-scale tool (Barrier Fabric Testing device) that simulates a stationary or moving flame consistent with burning cover fabrics or bedclothes. The tool allows for adjusting the tension to simulate the tension of barrier fabrics in a mattress and upholstered furniture.

Current activities include conducting full-scale open flame upholstered furniture experiments (sponsored by the Consumer Product Safety Commission), completing the assembly and the methods development of the Barrier Fabric Testing device, and evaluating commercially available barrier fabrics using this BFRL designed tool.

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Flammability Reduction of Flexible Polyurethane Foams via Carbon Nanofiber Network Formation

Foams are used in upholstered furniture, mattresses, seating in trains and automobiles, and in building insulation. Reducing the flammability of these products significantly enhances public safety and provides a competitive advantage for U.S. companies in international markets.

Untreated polyurethane flexible foams (PUFs) are prone to rapid fire growth due to their low density and low thermal conductivity. Furthermore, the low viscosity of the decomposition products generates severe dripping that increases the fire hazard related to the combustion of PUFs. In fact, this downward flow of flaming liquid often results in a pool-fire that promotes flame propagation and boosts the heat release rate (HRR) due to a significant increase in the burning area and to feedback between the flame on the pool-fire and the residual foam. In this work, the effect of nanoparticles, i.e. clays and carbon nanofibers (CNFs), on the HRR was investigated with special attention given to melt dripping. A modified cone calorimeter test has been developed for this purpose. It is shown that CNFs form an entangled fiber network that eliminates melt dripping and decreases HRR by 30 percent.

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Pool-fire
(Standard FR PU Foam)

No Pool-fire
(PU Foam+ Carbon Nanofibers)

Polyurethane foam with 4 percent CNF and 2 percent organobromine/phosphate flame retardant has a 30 percent lower HRR than the control PU foam (with 6 percent flame retardant) primarily because of the char formation and elimination of dripping during burning.

MEASUREMENT SCIENCE FOR

Innovative Fire Protection

What is the problem?

The cost of fire in the U.S. is growing. In 2007, direct property loss due to fire was $14.6 billion and the total burden of fire on the U.S. economy is estimated to be around $320 billion/year. In 2006, the annual losses attributable to fire included 3,430 civilian lives and 17,675 serious injuries. Fire service losses included 103 lives and about 83,000 injuries. Fire losses from systemic causes are preventable.

Significant damage from wildland-urban interface (WUI) fires is on the rise in the U.S. There have been three major WUI fire loss events in the last six years: The 2003 Cedar fire in California cost $2 billion in insured losses and destroyed 3,600 homes, the October 2007 southern California fires which displaced residents of over 300,000 homes, and the 2009 Station fire. Overall, the trends suggest that the severity of the U.S. fire problem is growing.

There is an incomplete understanding of fire behavior, which hinders the development of innovative fire protection. Current prescriptive fire standards and codes stifle innovation in fire safety systems, technologies, and building design. To ensure fire safety in a cost-effective manner and to reduce fire losses, it is essential that adequate science-based tools are developed to enable the implementation of the next generation of standards, codes, and technologies that address the U.S. fire problem. Measurement science is lacking to reduce the risk of fire spread in buildings, to reduce fire spread in WUI communities, to ensure effective and safe use of emerging fire service technologies, and to derive lessons from fire investigations.

Addressing these measurement science needs is essential if fire losses are to be reduced and the resilience of buildings and communities (people and property) are to be increased.

Why is it hard to solve?

Fire is a complex set of dynamic interacting processes that are inadequately understood. Unwanted fires occur in unconfined geometries with heterogeneous mixes of fuel, uncontrolled air supply and uncertain ignition events. Fires are characterized by a multiplicity of time and length scales, and the complexity of the phenomena that control fire dynamics renders computer predictions approximate, at best. While soot is a dominant factor in the radiative heat transfer that controls the rate of fire spread and the formation of deadly smoke, key mechanisms that dictate the amount of soot are not yet tractable. Quantitative measurements at full-scale can be dangerous, limited by environmental constraints, technically challenging, and expensive. Solutions to reducing losses extend beyond fire dynamics to include structural dynamics and human behavior within a fire environment. Manufacturers of new fire technologies lack the measurement science to evaluate the performance of products due to complexities of fire dynamics and man-machine interactions in a fire environment.

Why BFRL?

NIST has sole statutory responsibility under the Fire Prevention and Control Act of 1974 to support fire safety research for constructed facilities. Research on this strategic goal is supported by the core competency of the Building Fire and Research Laboratory (BFRL) in fire protection and fire spread within buildings and communities. BFRL has strong links with industry, the fire services, the construction communities, and codes and standards organizations, which enable rapid dissemination of new knowledge, tools and measurement science results from laboratory to practice. BFRL staff has leadership positions on key U.S. and international standards committees that will make use of the research results. This strategic goal supports recommendations from nationally recognized reports, studies and investigations.

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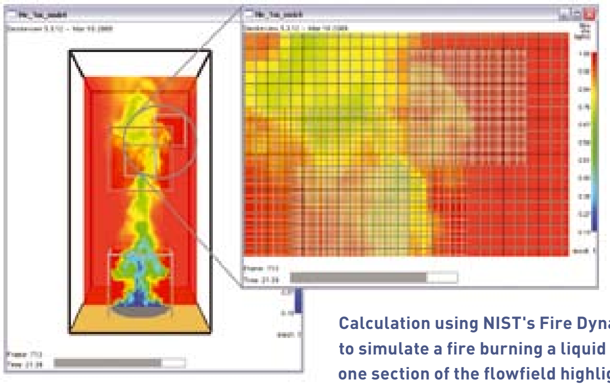

Calculation using NIST's Fire Dynamics Simulator (FDS) software to simulate a fire burning a liquid hydrocarbon fuel. A blow-up of one section of the flowfield highlights computational techniques being developed to enable more accurate calculations.

Reduced Risk of Fire Hazard in Buildings

The lack of measurement science (including knowledge, standard test methods, methodologies to interpret the test results, and validated predictive methods) form a substantial technical barrier to the development and introduction of innovative fire protection involving materials, building design, and technology. The current gaps in understanding (including modeling capability, appropriate test methods, and methodologies) preclude the ability to demonstrate that proposed innovations are technically feasible, safe, and economically viable. Lack of a quantitative understanding of uncertainty and system performance hinders the development of rational safety factors in fire protection engineering analysis and design.

The objective of this program is to reduce the risk of fire spread in buildings through the development and implementation of measurement science. BFRL is developing and quantifying the accuracy of performance-based design tools and analysis, and creating the scientific basis for the next generation of standards, codes, and fire measurement techniques.

Performance-based design of buildings requires validated tools to justify equivalent safety when compared to prescriptive code requirements. Without the necessary tools to develop and quantify the cost of possible design options, architects and engineers are constrained from realizing effective solutions. A performance-based option has been included in the National Fire Protection Association's Life Safety Code, and the Society of Fire Protection Engineers has published engineering design guides to facilitate implementation and best practices in the use of performance-based fire protection techniques.

The program includes several major measurement science research thrusts, each with corresponding new technical ideas. The emphasis of the work is to ensure that scientific knowledge can be effectively disseminated to facilitate standards and code development and to enhance the capabilities and the scope of the predictive models, which are associated with all four thrust areas. The new technical ideas are described below for each of the major thrust areas.

Predictive Fire Model Development: Three areas are emphasized: algorithm development, verification and validation, and user support. The new idea is to improve and expand the predictive capability of current fire models using sub-models that better simulate critical physical and chemical processes in fires. New data generated on solid and gas-phase phenomena is guiding sub-model development and validation of material burning and soot emission. A Configuration Management Plan is being established that automates maintenance with full revision tracking documentation and coordinates software development within an established set of guidelines.

Advanced Fire Measurements: The new idea is to develop new measurement techniques that are well-characterized and accurate, that improve our understanding of fire physics, and facilitate innovation in fire protection. The area is also providing critical data to guide the development and enable validation of predictive models. Research is focused on development of innovative measurement techniques (e.g., real-time extractive soot measurements), improvement of traditional measurement techniques (including heat release rate and bi-directional velocity probe), and using these techniques to improve our understanding of the structure of compartment fires. These results are being used to guide and validate the NIST Fire Dynamics Simulator (FDS) software, a predictive fire model.

Fire Protection in Buildings: New theory is being developed and new data is being acquired to characterize performance in critical areas of fire protection in building systems. The research includes the development of a decision support software tool for communities interested in cost-effective investment in water sprinklers, an egress model based on data taken during fire drill evacuations from select building types, and full-scale experiments that examine the effects of detector type, placement, and fuel source on the performance of smoke detectors.

Hydrogen Fire Safety: Research is being conducted to develop emerging technologies in detection and predictive methods to hydrogen safety. Experiments are being used to assess the effectiveness of the Fire Dynamics Simulator (FDS) software for predicting the dispersion behavior of a buoyant gas and to identify necessary modifications to the model. Hydrogen gas sensor performance is being tested in the BFRL Hydrogen Detector Environment Evaluator facility.

BFRL continues to work with industry, fire testing laboratories, national and international organizations that determine fire standards and codes, university researchers, other government agencies, and international fire researchers to reduce fire losses. This program is providing the knowledge and tools to reduce systemic fire losses as the recognized source of accurate measurement and prediction methods used in practice.

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ACTIVITIES AND ACCOMPLISHMENTS

Predictive Model Development

Fire protection engineers, regulatory authorities, fire service personnel, and fire researchers all rely on fire models for design and analysis of fire safety features in a building and for post-fire reconstruction and forensic applications. Performance-based design of buildings requires validated fire modeling tools to justify equivalent safety when compared to prescriptive code requirements. For example, performance-based standards such as NFPA 805, *Fire Protection for Light-Water Reactor Electric Generating Plants*, require that fire models be *verified* and *validated* according to guidelines set forth in standard guides such as ASTM E 1355, *Evaluating the Predictive Capability of Deterministic Fire Models.*

BFRL currently maintains two fire models: Consolidated Fire and Smoke Transport (CFAST), a two-zone compartment fire model; and Fire Dynamics Simulator (FDS), a computational fluid dynamics model. CFAST, as its name implies, requires only a few minutes of computer time to perform a calculation, but it is limited in terms of its fire physics. FDS has more detailed physics, but requires hours or days of computer time to complete a simulation. Both models undergo continual maintenance, including verification and validation, but most of the development work is focused on FDS.

The development of FDS is proceeding along two major fronts—the gas phase and the solid phase. For the gas phase, the goal is to make FDS run in parallel on hundreds of individual processors to resolve, for example, fire spread in the wildland-urban interface over areas that are roughly 100 km^2 or fire spread in buildings whose volumes are comparable to 10 floors of the World Trade Center. The increased resolution in the gas phase will lead to more accurate prediction of the heat flux to solid surfaces. This makes possible a more detailed treatment of residential materials such as upholstery, carpet, wall linings, and industrial materials such as electrical cabinets and cables.

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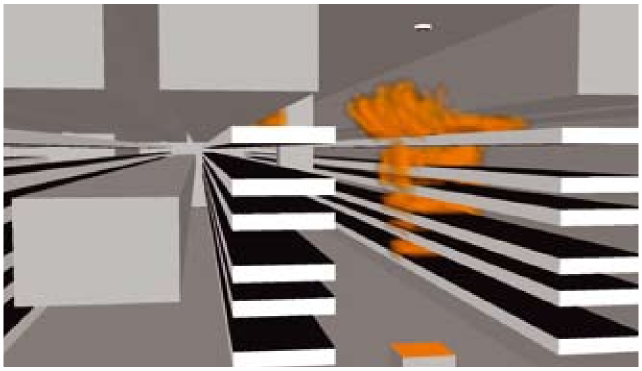

(Top) Smokeview rendering of a fire in a cable spreading room of a nuclear power plant. (Bottom) Cable burning experiment conducted in the NIST Large Fire Laboratory and sponsored by the U.S. Nuclear Regulatory Commission.


Reduced-scale garage constructed of poly(methyl methacrylate) to study the release and dispersion of helium (used as a hydrogen surrogate).

Hydrogen Flammability, Detection, and Fire Safety

The safe utilization of hydrogen as an energy carrier and the timely realization of the envisioned hydrogen economy require many technical, non-technical, and societal barriers to be overcome. While many safety aspects of hydrogen are well documented, knowledge gaps still exist in various applications. One of the many technical challenges and research needs is to understand and characterize the dispersion of hydrogen in a confined space with natural infiltration and/or mechanical ventilation. In particular, research is needed to define the potential fire/explosion hazard due to an accidental release of hydrogen from a source (e.g., a hydrogen fuel-cell vehicle parked inside a residential garage or a stationary power-generation fuel cell in a room). The lack of high quality scientific and technical data and validated computer fire models hinders the development of hydrogen fire safety codes and standards in these applications. Sensors that detect hydrogen gas in spaces where gas accumulation is possible allow for hazard mitigation through automatic and human means but lack standard test protocols for proper characterization in real-life applications.

This project focuses on the development of measurement science tools (data, predictive methods, and test protocols) to characterize, detect, prevent, and mitigate fire hazards associated with an accidental hydrogen release from a hydrogen source using laboratory-scale and real-scale settings and to provide a technical basis for standards and codes development to enable safe, efficient use of hydrogen in confined structures.

Recent accomplishments include forming research partnership with Department of Energy national laboratories (Sandia National Laboratories and National Renewable Energy Laboratory) and NASA; the adaptation of the recent research findings in the revised SAE hydrogen vehicle fire safety standard on hydrogen leaks; the interaction with international community (International Energy Agency); the participation in the drafting of NFPA-2, *Hydrogen Technologies*; the development of a hydrogen sensor evaluator able to assess the effect of ambient temperature and humidity and nuisance vapors and aerosols on sensor performance; the completion of a series of release and dispersion experiments in a reduced-scale and a full-scale garage using helium as a hydrogen surrogate; the verification and validation of the NIST Fire Dynamics Simulator for hydrogen dispersion applications; and the dissemination of research results in archival journals and international conference proceedings.

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Economic Performance of Residential Fire Sprinklers

In 2007, 300,500 residential structure fires produced 2,350 civilian deaths, 9,650 civilian injuries, and $6.2 billion in direct property damages. These numbers have been constant over the past decade. Back in 1975, in an effort to limit fire-related fatalities, injuries, and economic damages, the National Fire Protection Association (NFPA) produced NFPA standard 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*, to ensure fire sprinklers installed in residences would limit flashover and allow for occupant egress and rescue while maintaining system affordability. Since then residential fire sprinklers have proven themselves as life-safety technologies to the fire service community, but homeowner adoption has been remarkably slow. Although residential sprinkler systems protect lives and property from fire, earlier research suggested that sprinkler systems were not economical. The purpose of this research is to determine whether recent advancements in fire sprinkler technology, resulting in lower cost and improved performance, might be significant enough to improve the economic performance of these systems. In addition, a Web-based software application is being produced to enable communities to assess the benefits and costs of requiring fire sprinklers for new construction.

Several accomplishments have been made. The current costs of residential fire sprinklers for three prototypical house designs, incorporating several different sprinkler designs and technologies, have been quantified. The benefits of residential sprinkler adoption—including reductions in occupant and fire service fatalities and injuries, as well as reductions in property losses—have been estimated and compared to sprinkler installation and maintenance costs. Benefit-cost analysis demonstrated those residential sprinkler systems consistent with NFPA 13D to be economical. Further, results showed that sprinklers provide a level of life-safety performance in addition to that produced by smoke alarm use (i.e., using both technologies provides the greatest level of protection); this level of performance compares favorably to other life-safety technologies, such as automotive air bags.

Evidence used in support of an International Code Council (ICC) code modification (IRC RB64), requiring all new one- and two-family dwellings to be so equipped with residential sprinklers, was based on current NIST research. The code modification passed and will take effect in 2011. A Web-based decision support tool is in development to aid state and local benefit-cost analysis. This project will provide communities and local governments with nationally representative, and current, sprinkler-based benefits and costs data and tools enabling informed decision making on community adoption of NFPA 13D.

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A close-up of an activated fire sprinkler.

People Movement During Building Evacuation Drills

BFRL researchers have studied people movement speeds during three full-building fire evacuations drills and compared the data to already published results—including those from NIST's investigation of the World Trade Center disaster on Sept. 11, 2001—to try to identify the factors that could hamper rapid evacuation using stairways. Research to date provides limited insight into how people react and behave during evacuations though, for the most part, variances in speed cannot be explained by the evacuation models currently used in building design and emergency planning.

Building engineers typically use five factors to describe occupant descent down stairwells during building evacuations: pre-evacuation delay, distance traveled during evacuation (movement from higher floors versus lower), counterflow situations (such as firefighters moving up a stairwell while occupants are moving down), stairwell geometry and density of persons in the stairwell. Models make use of such variables to predict the performance of egress systems and the expected speed for a complete evacuation.

However, the BFRL researchers found that these engineering parameters could only explain about 13 percent of the differences they observed in evacuation speeds for the three fire drills. Since these speeds were similar to ones reported by previous studies, the researchers suggest that psychological and behavioral factors may be more important in determining how fast occupants can actually exit a building. They also note that inaccurate evacuation data based on simplifications about behavior could lead to unsafe building designs and procedures.

NIST research on stairwell evacuation included the study of simultaneous use of stairwells by occupants and firefighters.

As a start toward improving understanding, BFRL has posted a Web page, *http://www.fire.nist.gov/CDPUBS/bldg_occupant*, with links to all four building occupant research studies completed in 2008, including the stairwell evacuation report, *Stairwell Evacuation from Buildings: What We Know We Don't Know.*

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Use of Elevators in Fire Emergencies

Aggressive building designs, changing occupant demographics, and consumer demand for more efficient systems have forced egress designs beyond the traditional stairwell-based approaches, with little technical foundation for performance and economic trade-offs.

BFRL research, conducted as part of a cooperative effort supported in part by the General Service Administration (GSA), has formed the technical basis for significant revisions to model building code provisions that consider the impact of all aspects of building design including the use of elevators by occupants and first responders.

BFRL studies of smoke protection for elevator hoistways; the need for enclosed elevator lobbies; use of elevators for evacuation of disabled occupants; structural, sprinkler, and elevator control designs; and egress procedures have provided the technical basis for new requirements for elevator use.

Working with the American Society of Mechanical Engineers (ASME), ICC, the NFPA, and others, BFRL and GSA, through this research, led a revolution in code provisions for the use of elevators by occupants and first responders during fire emergencies. The 2009 edition of the NFPA Life Safety Code and NFPA

Building Construction and Safety Code includes adoptable (though not required) provisions for elevators for occupant evacuation prior to Phase I recall and for firefighter emergency operations. The 2009 edition of the ICC International Building Code also includes similar requirements on elevator use for fire fighter access and occupant egress.

Extensive details of the multi-year BFRL research program can be found in the report *Summary of NIST/GSA Cooperative Research on the Use of Elevators During Fire Emergencies.*

This smokeproof elevator is installed at an Italian residential facility for mobility impaired people to provide access and egress. The glass hoistway enclosure permits the fire service to determine if the elevator is in use. *(Photo courtesy of the Italian National Research Council)*

The report can be found on the Web site *http://www.fire.nist.gov/CDPUBS/bldg_occupant.*

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Modeling Human Behavior from Building Fires

Evacuation models, including engineering hand calculations and computational tools, are used to evaluate the level of safety provided by buildings during evacuation. Building designs and occupant procedures are based on the results produced from these models, including evacuation time results (i.e., how long building occupants will take to evacuate a building). However, most evacuation models focus primarily on calculating and predicting evacuation movement (i.e., how long will it take an occupant to move from his/her initial position to safety), almost ignoring the prediction of behaviors that occupants perform before and during evacuation movement that can delay their safety (e.g., searching for information, fighting the fire, and helping others). Instead of modeling and predicting behavior of simulated occupants, evacuation models and users often make assumptions and simplifications about occupant behavior (i.e., what people do during evacuations) that can be unrealistic and are likely to produce inaccurate results.

A solution to this problem is to generate a robust, comprehensive, and validated theory on human behavior during evacuation from building fires. The social scientific literature can be gleaned to develop these theories, which can then be incorporated into the current evacuation models to accurately simulate occupant behavior during fire evacuations. These models can then achieve more realistic results, which will lead to safer, more efficient building design.

BFRL researchers are reevaluating current egress modeling techniques, advocating for the inclusion of a comprehensive conceptual model of occupant behavior during building fires. The paper, *Modeling Human Behavior during Building Fires*, begins this evaluation by describing the current state of evacuation modeling of human behavior in fire, identifying gaps in current behavioral techniques, and outlining a general process model for occupant response to physical and social cues in a building fire event. The paper can be found on the Web site *http://www.fire.nist.gov/CDPUBS/bldg_occupant.*

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Conceptual drawing of the planned expansion of the LFL in 2011 to include the National Structural Fire Resistance Laboratory.

The Large Fire Laboratory (LFL)

The ability to conduct safe, repeatable and accurate intermediate and large-scale fire experiments is essential to understanding fire behavior. BRFL's Large Fire Laboratory is used to provide researchers with well-quantified large fire measurements to support fire model validation studies, enable advances in fire standards and codes, and enable fire investigations. Many of the studies in the LFL rely on the heat release rate (HRR) measurement, which is the most fundamental characterization of a fire. The ability to quantify the uncertainty of dynamic (non-steady) HRR measurements is needed for realistic fire configurations. If the next generation fire models are to ever be used to predict flame spread in buildings with real furnishings, then a quantitative understanding of HRR uncertainty will be needed for model development and validation.

A major renovation of the large fire calorimeters was completed in 2008, improving exhaust flow measurements and reducing uncertainty of the HRR measurement by 50 percent for 3 megawatt (MW) to 10 MW fires. BFRL collaborated with the Consortium of North American Fire Testing Laboratories (NAFTL) to develop proficiency programs for standardized fire tests including ASTM E119 1354, and 16 CFR 1633.

Construction of a new facility is being planned for 2011 that will help quantify the fire resistance performance of different real-scale structural system components and connections. Expansion of the LFL to include a new National Structural Fire Resistant Lab will lead to improvements in performance, reliability and resilience of structures under extreme loads and fire. The current plan is to expand the LFL by 1,700 m^2 to include a strong floor and strong walls where experiments on structural connections and assemblies can be conducted with precise control on temperature and loading in three dimensions and where 9 meter high building frames can be subjected to full-scale fires as large as 20 MW.

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Underventilated Compartment Fire Measurements to Support FDS Development

Understanding the behavior of underventilated compartment fires, including dynamics and effluent production, is important for predicting toxicity and evacuation timing throughout a structure. Current fire models are challenged to accurately predict dangerous fire products, such as carbon monoxide (CO) and soot, in real-scale underventilated compartment environments. Additionally, there are limited data to validate an attempt to model this type of environment in a detailed way. The project is developing a more detailed understanding of the internal dynamics of an underventilated compartment fire and producing a database of underventilated compartment conditions, including temperature, gas species, heat flux, and soot, to facilitate the development and validation of fire models such as the Fire Dynamics Simulator (FDS).

Many accomplishments have been made in this project including new measurements in an underventilated environment that have never been possible before. A simple and intuitive description of how underventilated a compartment may be is now possible due to the more complete accounting of all carbon in the system that makes possible an accurate mixture fraction calculation for each fire. This has been facilitated by the development of new test methods to resist the harsh environment inside an underventilated compartment. These innovative techniques have lead to an extensive and growing database of published underventilated compartment measurements that are already being used by the fire model development community. Validation studies utilizing these data have been presented both at the NIST fire conference and internationally. Currently, these data are being utilized to help improve the prediction of CO and soot in FDS.

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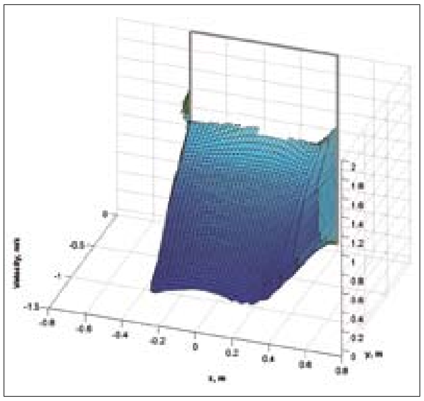
Image of a underventilated compartment fire with flames and smoke billowing out the doorway. This is typical of these types of fires and produces an environment in which it is quite difficult to make good measurements.

Gas Velocity Measurements in Full-Scale Structural Fires

There exists a limited amount of spatially resolved experimental data on the fluid dynamics of fires occurring in real structures. Prior research has focused on simple configurations such as open-fire plumes or wall-bounded plumes. Understanding the coupling of fluid dynamics, combustion, radiation, and scalar transport is important for a complete appreciation of the processes occurring in structural fires. The same interactions are present in the simple fire configurations, but their effects are muted. Quantitative flow measurements are difficult in structural fires due to the complexity and spatial extent of the flows as well as the extreme conditions caused by the fire. The flows are buoyancy dominated and therefore are easily influenced by the structural geometry and other conditions of the environment. The result is a collection of complex flow patterns that vary significantly over space and time.

The bi-directional probe has been the exclusive flow measurement technique in the fire research and fire testing community because of its ruggedness and affordability. However, the measurement uncertainty of this device has not been well characterized and current uncertainty estimates are large for the application. Stereoscopic Particle Image Velocimetry (SPIV) is a state-of-the-art flow



Time-averaged SPIV measurements of the velocity field for the lower half of the doorway of the ISO 9705 room. The fire inside the room induces a flow of air through the doorway and into the room providing oxygen to the fire.

measurement technique routinely used in fluids research. It is an independent comparison technique to the bi-directional probe and new approach to characterizing the fluid dynamics of enclosure fires. Along with bi-directional probe measurements, SPIV has been applied to provide a large-scale planar interrogation of the flow induced by fire at the doorway of a standard fire test enclosure: the ISO 9705 room. Time-averaged velocity fields across the doorway were computed from the SPIV measurements. The measurements provide the first ever comparison of the bi-directional probe with a totally independent velocity measurement technique in a full-scale fire-induced flow. The SPIV results have a lower uncertainty and have therefore created a new benchmark for gas velocity measurements in fire-induced vent flows. The spatial extent and spatial resolution of the SPIV results are comparable to the output of the most utilized Computational Fluid Dynamics (CFD) models. Developers of CFD models now have access to a new source of high-quality experimental velocity data to increase the strength of fire model validation efforts.

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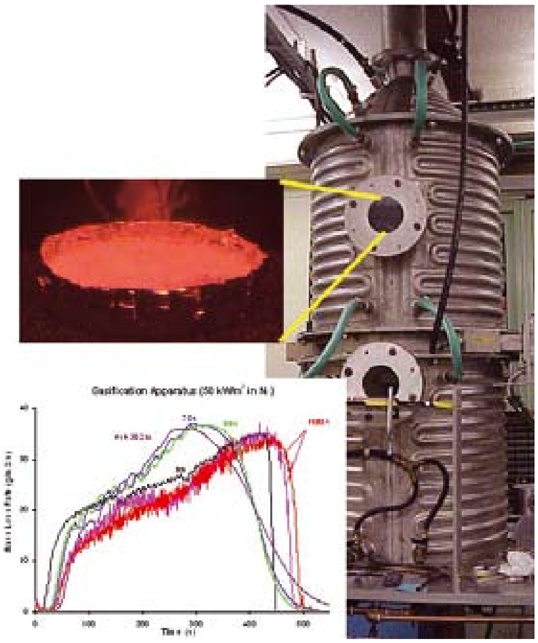

NIST Gasification Device, with insets of a decomposing sample and plot of experimental mass-loss curves and modeling predictions (which include finite rate decomposition kinetics, heat and mass transport, and radiation heat transfer in the polymer).

Predicting Material Decomposition in Fires

The most important parameter controlling the growth and spread of fires in buildings is the heat release rate from the burning materials. This is a positive feedback system: the fire provides heat to the burning material, which then decomposes, and provides fuel for the fire, making the fire larger, providing more heat feedback, etc. Today, determining the heat release from a burning material (or from a final product) is done with small- or intermediate-scale empirical tests in a calorimeter. If means could be developed to predict the fire performance of materials from first principles, they could replace the empirical tests, and manufacturers could use the calculations both to assess the performance of their products, and as a design tool to develop the most fire-safe materials and products. This is particularly important now since many of the most commonly used fire retardants for polymers are being banned due to environmental and health concerns, and the search for alternative fire retardants is intensifying. In addition, the ability to predict the burning rate of real materials exposed to a fire would strengthen existing computer models of the behavior of fires in buildings. Such capability will aid the fire protection community in their efforts to implement performance-based design.

Predicting material decomposition in fires is a two-step process: simplifying and then describing mathematically the physical phenomena that occur, and then measuring the physical parameters that are required in the model. Several numerical models of the decomposition of solid materials in fires are available, including that within the NIST Fire Dynamics Simulator and an FAA-developed code (Thermakin). In order to test the model prediction of the decomposition process, BFRL employs a unique apparatus: the NIST gasification device, which exposes a sample to a specified radiant flux in a controlled atmosphere. Since there is no flame, the uncertainty in the heat flux and chemical environment due to the flame is removed, and the behavior of the solid phase itself is more clearly examined.

Recent progress includes quantification of the importance of each of the physical parameters to the decomposition rate for a typical polymer; the successful prediction of the mass loss rate for the common thermoplastics poly(methylmethacrylate), high-impact polystyrene, and high-density polyethylene; and measurement of the absorption rates of incident radiant energy by twelve of the most common polymers (necessary for input into the calculations).

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Reduced Risk of Fire Spread in Wildland-Urban Interface Communities

Wildland-urban interface (WUI) fires occur when wildland fires cannot be controlled, often due to extreme wind and fuel conditions, and spread into communities. These fires occur worldwide. In the last ten years, significant damage from WUI fires has occurred in the U.S., Australia, and the Mediterranean region. Even with the increased level of risk reduction effort through wildland-fuel treatments, California has suffered three major WUI fire loss events in the last six years. Since little experimental or post-WUI fire analysis has been conducted to evaluate existing risk mitigation approaches for a representative range of WUI environments, their effectiveness is generally unproven (from both a risk reduction and an economic point of view).

Destructive WUI fires often occur over large scales and in extreme environmental conditions that are difficult to reproduce experimentally or measure with field deployable instrumentation. This presents significant challenges to effective modeling, experimental, and field based research.

The overall objective of this program is to evaluate and improve the tools used by communities, homeowners, and fire officials to effectively and economically reduce damages and improve safety in WUI fires. BFRL is developing improved tools via advances in measurement science through collaborative and synergistic projects involving laboratory and field measurement, post-fire analysis, physics-based fire behavior modeling, economic cost analysis models, and workshops with stakeholders.

This program will lead to reduction of costs due to WUI fires by providing the measurement science to develop and evaluate new standard test methods, building codes, and structure retrofitting techniques. Similarly, the adoption of improved and tested WUI community-scale risk assessment and mitigation methodologies will lead to reduced damages and improved emergency responder safety. Stakeholders include homeowners, homeowner associations, city fire departments, federal and state fire officials, building material manufacturers, homebuilders, standards organizations, and fire researchers.

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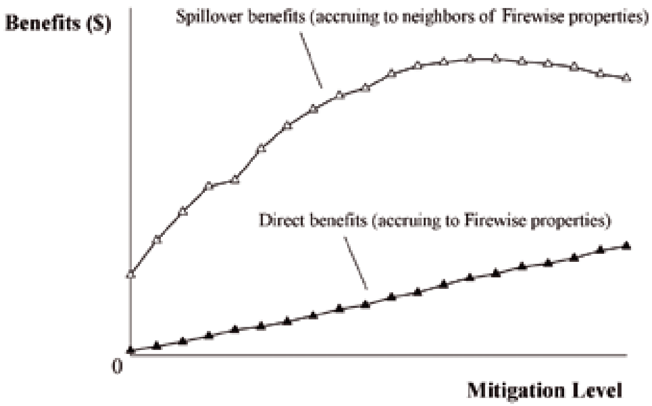
ACTIVITIES AND ACCOMPLISHMENTS

Economics of Wildland-Urban Interface Fires: Understanding the Role of Community-Based Protection and Risk Mitigation

Single wildland-urban interface (WUI) fire events can produce numerous homeowner and fire service fatalities and injuries, cause economic damages in the billions of dollars, and threaten ecosystem health and function. Nationwide, tens of thousands of wildland fires threaten tens of millions of acres of forests and WUI communities each year. Advancements in measurement science are needed to assist these communities in (1) evaluating wildfire risks and vulnerabilities, (2) determining cost-effective strategies to mitigate economic losses, and (3) understanding incentives to encourage community-optimal levels of mitigation investments. More and more people from more urbanized, low

BFRL conducts experiments of burning trees in order to validate predictions of heat fluxes and heat release from simulated trees using the Wildland-Urban Interface Fire Dynamics Simulator (WFDS). WFDS is a physics based numerical modeling approach which includes all modes of heat transfer (convection, conduction, and radiation).



Example of how homeowner wildland-urban interface fire mitigation affects the homeowner (direct benefits) and the community (spillover benefits), with the community benefits being much larger.

wildfire risk areas are moving into WUI communities. It is not surprising, then, that many of these new residents are unaware of either the elevated risks that come with living in or near forested areas or how their actions affect those risks. Because the actions taken by homeowners can influence the fire risk to those around them, barriers, e.g., imperfect information and externalities, exist that expose homeowners to unacceptably high levels of risk. Increasingly, programs, such as Firewise (*www.firewise.org*), are providing information to homeowners on fire dangers and ways to reduce them. Although these programs provide an important first step in ensuring community resilience to wildland fire hazards, they place little, if any, emphasis on their cost-effectiveness. Economic studies suggest that self-sustaining levels of mitigation will occur if homeowners understand and financially incur the actual benefits and costs associated with their investment decisions. The focus of this research is to quantify community costs and losses resulting from major WUI fire events and to develop a decision support tool to evaluate the economics of community-based WUI fire mitigation.

Several accomplishments have been made. In collaboration with the U.S. Forest Service, NIST has developed a theoretical economic model of community-based mitigation. The first of its kind, this research demonstrated that interdependent fire risk significantly affects economic solutions and developing community-based solutions is essential to minimizing fire-related losses. In addition, this research has quantified the losses associated with WUI fires, estimated the effectiveness that wildfire prevention education activities have had on unintentional ignition starts, and developed models capable of forecasting the timing and location of future intentional fires in the wildland, WUI, and in urban settings. NIST expects that standards organizations will implement the use of these economic tools as a standard method for community risk assessment and disaster planning.

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Experimental Investigation of Structure Ignition in Wildland-Urban Interface (WUI) Fires

The rapid growth of the Wildland-Urban Interface (WUI) in the United States has put an increasing number of communities at risk to fires originating from wildland fuels. As vegetation and structures burn in WUI fires, pieces of burning material, known as firebrands, are generated. These firebrands are carried aloft by the wind and bombard structures during WUI fires. Anecdotal evidence and post-fire damage assessment studies suggest that wind-driven firebrand attack is responsible for the majority of structure ignitions in WUI fires. Building codes and standards are needed to guide construction of new structures in areas known to be prone to WUI fires in order to reduce structural ignition in the event of a firebrand attack, and retrofit strategies are required for existing homes. For these standards to be relevant, a thorough scientific methodology must be developed to understand the types of materials that can be ignited by firebrands, as well as vulnerable points on a structure where firebrands may easily enter.

Because wind plays a critical role in the spread of WUI fires, NIST and the Building Research Institute (BRI) in Japan have built a unique experimental apparatus capable of generating a controlled and repeatable firebrand attack called the NIST Firebrand Generator (NIST Dragon). BRI also maintains

NIST Dragon unleashing a firebrand attack on a structure installed at BRI's FRWTF in Japan.

the Fire Research Wind Tunnel Facility (FWRTF), one of the only full-scale wind tunnel facilities in the world designed specifically for fire experimentation. In tandem with the NIST Dragon testing at BRI, unique field deployable instrumentation has been developed that can be used to quantify the ignition of structures and determine the firebrand exposure of WUI structures in actual fires. Such measurements will enable the NIST Dragon to be tuned to replicate firebrand attack observed in real WUI fires. Standards organizations are using the test results to guide and develop reduced-scale test methods in order to develop new standards that should make structures more resistant to firebrand attack. These measurements are being used to create an experimental database to support the development of computer models, such as NIST's Wildland Fire Dynamics Simulator (WFDS), for application to structure ignition in WUI fires. This project is funded in part by the Department of Homeland Security (DHS).

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Wildland Urban Interface Fire Behavior—Post Fire Analysis

Since 2000, more than 1,000 structures per year on average have been lost to Wildland Urban Interface (WUI) fires in California alone. Despite this significant WUI fire problem, there is little information on fire behavior at the WUI. An improved understanding of WUI fire dynamics is critical to assessing and improving current methods of reducing structure ignitions. There are currently a number of approaches for reducing the risk of structure ignition. These include recommended actions for homeowners to take on both their structures and residential vegetation. To date, the effectiveness of these methods has not been thoroughly assessed via post-fire study. Such a study requires comprehensive data collection methods, which includes information on the design and materials of residential structures, characteristics of the residential and wildland vegetative fuels, knowledge of the type and times of human activity during the fire, and information on the wildland fire.

The collection, management, and analysis of this information are challenging tasks. Sources of the data include homeowners, first responders, satellite imagery, LiDAR data, and photographic data. New field measurement methods are also needed in order to obtain critical information in a timely manner immediately after the fire, as well as weeks later.

NIST has initiated a Post-Fire Analysis effort aimed at characterizing fire behavior at the WUI. The first study focused on *The Trails* subdivision at Rancho Bernardo that was burned over by the Guejito and Witch Fires on Oct. 22, 2007. This community of approximately 270 homes was almost entirely within the fire perimeter. Seventy-four homes were completely destroyed and 16 were damaged. The study focused on the

Data collection after the 2007 Guejito and Witch Fires in California.

development of a timeline for the evolution of fire and structure ignitions throughout the community. The first study also identified actions taken by first responders and homeowners to protect properties during the fires.

Using the lessons learned during the Witch and Guejito fires data collection, a methodology is being developed to collect, store, and analyze pre- and post-WUI fire data. The joint effort of NIST, the California Department of Forestry and Fire Protection (CALFIRE), and the City of San Diego is aimed at standardizing data collection to ensure data compatibility and that critical data are not lost due to recovery efforts. Different hardware, software and field methodologies are assessed with the aim of creating a California state-wide data collection infrastructure. The data collected at *The Trails* will be put in the database and analyzed to determine how structure construction and landscaping attributes affected structure behavior during the Witch Fire. This database will also be used by the NIST developed Wildland Urban Interface Fire Dynamics Simulator (WFDS) fire model to develop case studies and recreate parts of the Witch Fire.

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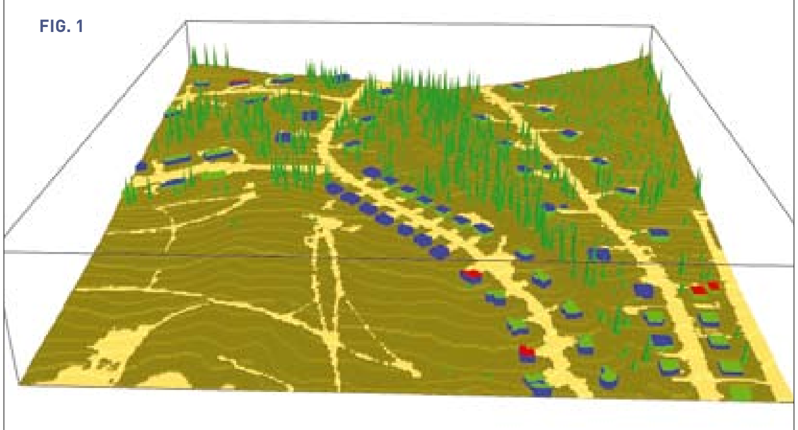
Fires in the Wildland-Urban Interface—Development of an Outdoor-Scale Fire Model

Fires in the wildland-urban interface (WUI) are an international problem with significant ongoing costs. Current firespread models capable of operating over WUI community scales (thousands of meters) are limited to vegetative fuels and rely heavily on empirical relations. Physics-based models are needed that adequately capture firespread through WUI fuels (vegetation and structures) over neighborhood (hundreds of meters) to community scales. Such models can be used to improve our understanding of fire behavior in WUI communities and evaluate and advance risk assessment and mitigation methods. Existing methods of risk assessment and mitigation are rule-based and do not take into account the range of conditions that represent realistic WUI communities, e.g., the range of housing densities, construction types, degree of housing maintenance, vegetation characteristics, terrain, and weather conditions.

Physical processes in WUI fires exist across a large range of scales: from the ignition event (sub-meter) to smoke transport through communities and interactions with larger-scale atmosphere dynamics. This presents a significant challenge to numerical modeling because computer resources, i.e. memory capacity and processor speeds, cannot support models of equal physical fidelity across all the relevant spatial and time scales. The input data requirements of a WUI

FIG. 1



WFDS model representation of a 500m by 500m portion of Worley, Idaho. Vegetative fuels include trees and surface fuels. House roofs and sides are colored according to a fire risk rating system.

fire model will vary depending on the physical fidelity of the modeling approach. A range of models, which vary in their physical fidelity, are under development.

The model with the highest physical fidelity is called WFDS (Wildland-urban interface Fire Dynamics Simulator), which is an extension of NIST's structural fire model FDS. An example of the type of input used in WFDS is given in FIG. 1. The spatial distribution of surface fuels (grass) and raised fuels (trees) is required at resolutions that resolve the distribution of fuels in a tree crown. Similarly, the location and shape of structural fuels is needed. Terrain is another significant factor in fire behavior. The fuel and terrain information in FIG. 1 was obtained via LiDAR (Light Detecting and Ranging) in collaboration with the Coeur d'Alene Indian Tribe GIS Group. Validation of WFDS firespread predictions through surface and raised vegetation is ongoing. Once the capabilities of WFDS are suitably validated, firespread predictions through the complex fuel and terrain environment (such as seen in FIG. 1) can be performed to support an improved understanding of WUI fire behavior and the conditions leading to structure ignition.

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Advanced Fire Service Technologies

At an increasing rate, the fire service is learning to put to use existing technologies such as thermal imaging and positive pressure ventilation techniques, and is anticipating the integration of new innovative technologies, such as tactical decision aids, training simulators, and improved protective clothing. For existing technologies, it is critical that performance be measured and evaluated in a scientifically sound manner and that the technology be successfully transferred to the fire service through training programs and fire fighting simulators. For emerging technology, industry needs science-based performance metrics to evaluate and improve their products and develop new technology, and an understanding of the requirements of the fire service. For both existing and emerging technologies, it is critical that the technology be successfully transferred to the fire service through computer model simulations, virtual training programs and science-based training materials.

BFRL is taking a leadership role that is recognized nationally and internationally for the transfer of science, metrics, and technology, into the hands of fire fighters, incident commanders, and other first responders. Approximately half of the measurement science effort is focused on providing the science that supports the development of performance metrics, standards, and testing protocols for existing equipment and technology. About forty percent of the measurement science effort is applied to emerging innovative technologies that allow the fire service to quickly take advantage of the technology and/or the information rich environment. The remaining ten percent of the measurement science effort is directed at fire fighting simulators and training programs to insure that the above science and technology can be successfully transferred in a usable form to the fire service.

BFRL fire protection engineers use an abandoned New York City brick high-rise as a seven-story fire laboratory to better understand the fast-moving spread of wind-driven flames, smoke and toxic gases through corridors and stairways of burning buildings.

Through this program, fire fighting technology developers, manufacturers, and users will have a proven set of performance metrics, standards, and testing protocols for evaluating existing technology and developing new technology. The results of the program will provide uniform, unbiased, and science-based standards that will encourage improving current fire service equipment and enable the creation of next generation fire service technologies.

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ACTIVITIES AND ACCOMPLISHMENTS

Thermal Imaging Technology and IR Camera Image Quality Standards for Emergency Responders

Firefighter views the opening to a furnished room with a thermal imager as the compartment flashes over

Infrared (IR) technology for firefighting applications has matured to the point that most first responder organizations in the U.S. either have purchased or are considering the purchase of thermal imaging cameras. Thermal imagers can provide first responders with critical information to size up a fire incident, track fire growth, and locate victims, other first responders, and egress routes. While these devices represent a significant investment, typically on the order of $10,000 per camera, first responders have little guidance on instrument performance beyond manufacturer literature and recommendations from other users. These issues are further complicated because the demands placed on thermal imagers are application dependent. The end users may have very different ideas about which imaging properties are most important: sharp image contrast may be sufficient for some firefighting applications, such as finding the source of a fire, but high thermal sensitivity may be required to locate a person or structural component when flames and water are in the imager's field of view.

Over the past several years, BFRL has been developing a suite of performance metrics and test methods for inclusion in a national consensus-based standard on thermal imaging cameras used by first responders. The performance metrics are related directly to the environment in which the imagers are used and tasks typically performed by first responders. Laboratory test methods to measure image contrast, effective temperature range, spatial resolution, image uniformity, and thermal sensitivity are currently included in the draft standard. While these objective laboratory test methods were being developed, a parallel effort was made to investigate the appropriate pass/fail criteria to apply to them. Work was performed in collaboration with the U.S. Army's Night Vision and Electronic Sensors Directorate in which the quality of thermal images common to firefighting applications was related to the ability of firefighters to perform a task. In this way, human perception was used to determine the quality of the image while the imagers are tested using objective test methods. This work has provided a technology-independent basis upon which test methods for image quality were developed for NFPA 1801, *Standard on Thermal Imagers*, currently scheduled for release to the public in early 2010.

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Evaluating Positive Pressure Ventilation in Large Structures

Positive pressure ventilation (PPV) uses portable fans to pressurize or blow air into structures. When used properly, PPV provides cooler and safer conditions for building occupants to evacuate and better conditions for firefighters to extinguish the fire. PPV can improve the effectiveness of firefighting tactics and reduce the number of fatalities and injuries on the ground. Because there are many variables that impact PPV fan effectiveness and many different types of structures where they can be used, the fire service needs guidance on how to adapt their tactics to provide a successful outcome based on the variables presented. The fire service as a whole is not receptive to new tactics and tools unless they have a lot of supporting evidence and data. In the past, the fire service has resorted to trial and error on emergency scenes, which is extremely dangerous to both the fire service and the public. The challenge for BFRL researchers was to develop the science necessary to understand the impact of ventilation, both positive pressure and natural wind, on building fires. Researchers needed to combine computer fire-modeling simulations with small- and full-scale test burns that provided data under realistic conditions. Science-based methodology was developed and used to evaluate the effectiveness of the positive pressure ventilation. Using this methodology during a series of full-scale experiments in collaboration with first responders and PPV fan manufacturers, researchers have collected extensive data on the performance of PPV in a range of structures including one-, three-, seven-, 16-, and 30-story structures in five different states. Researchers used this performance data to develop a set of tactical guidelines and test methods that directly relate to the operating environment and tasks performed by first responders.

Major fire departments across the United States and Canada have incorporated the research results into firefighting tactics and are implementing them on a daily basis. The science and understanding of the impact of positive pressure ventilation and wind driven fires will be incorporated into fire service training and will enable implementation of effective tactics in each of the 35,000 fire departments across the United States. This research will assist in reducing the number of firefighter fatalities and injuries, as well as reduce the total costs of fire in the United States.

The computer model simulations, small- and field-scale experiments were documented in a series of six reports, 24 hours of videos, and a slide presentation; all are available on a set of two dual-layer DVDs entitled *Positive Pressure Ventilation Research: Video & Reports.*

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Positive Pressure Ventilation Fire Experiments conducted in 16-story residential structure with Chicago Fire Department.

Raw phase change granular material, instrumented vest with embedded reactive cooling system, and full-scale fire exposure test.

Reactive Cooling Systems For Firefighter Protective Clothing

First responders operate in scenarios where they may experience thermal exposures that can lead to heat exhaustion, heat stroke, and burns. Firefighters are often exposed to short duration, but intense, thermal conditions causing burn injuries. Law enforcement officers exposed to less intense heat for longer periods may cause heat stroke. A reactive cooling system would use a chemical reaction or physical phase change to absorb heat energy to provide additional protection. Reactive cooling technology can absorb heat before a fire fighter is burned by thermal flux or hot gases. The focus of implementing this technology for first responders is to reduce the thermal exposure and prevent injuries, not to extend the working period under hazardous conditions. A reactive cooling system would be designed to activate when the thermal exposure exceeds preset values and provide cooling as the first responder exits or escapes additional thermal exposure. Without science-based performance standards and testing protocols, industry cannot evaluate the performance of existing or emerging reactive cooling systems.

This research, in collaboration with the U.S. Department of Homeland Security, is being directed at developing performance metrics and standard testing protocols for reactive protective clothing for firefighters. Reactive cooling systems include gas-based systems such as air, nitrogen, argon, carbon dioxide; endothermic reactions such as barium hydroxide and ammonium salts; and phase change materials that are typically proprietary mixtures. Research includes using existing facilities to measure the heat rise inside existing clothing and modeling the amount of heat that must be removed to prevent burn injury in a high heat load environment. An established burn injury model is used to determine when the reactive systems activate, how long they must operate, and how much heat must be removed to avoid fire injury and dissipate stored energy. Using existing equipment (radiant panel heater, instrumented fire fighter protective suits, and the Large Fire Laboratory) researchers are making simultaneous measurements on identical protective suits, with and without reactive systems. It will be necessary to identify the best mechanism for reactive cooling, including criteria of: speed of activation, rate of heat removal, compactness, cost and manufacturability. Laboratory- and full-scale experiments are being conducted to characterize the reactive cooling systems embedded within several different firefighter protective suits. Activation sensors, such as thermocouples, vs. a "panic button" manual activation are also being examined. When developed, performance metrics and testing protocols will be transferred to standards developing organizations such as National Fire Protection Association NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting, and ASTM E-54 Committee.

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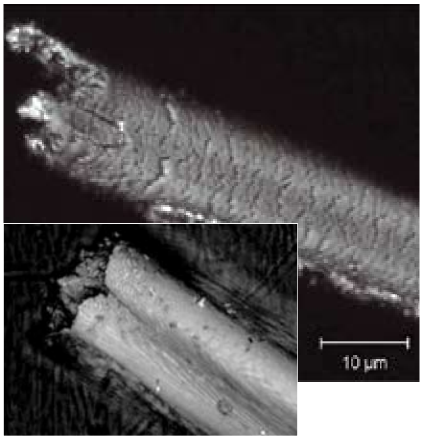
Fire Fighter Protective Clothing Standards

Fire fighters' protective clothing (pants and jacket) is a three-component ensemble intended to protect the fire fighter from radiant and thermal exposure, unexpected flashover conditions, and puncture and abrasion hazards while still maintaining an adequate level of dexterity and comfort. The performance requirements for the individual components (moisture barrier, thermal liner, and outer shell) and the ensemble are described in NFPA 1971 whereas the scan, care, and maintenance of the "turnout gear" is described in NFPA 1985. Considerable research has been devoted to the development and testing of turnout gear. However, little information is available as to how environmental stresses on the turnout gear during routine activities and storage deteriorate its performance and service life.

This research focuses on developing performance metrics and standard testing protocols for assessing the aging performance of fire fighter protective gear. Understanding the aging performance of in-service turnout gear gives the fire service community measurement protocols to use as a basis for defining a minimum performance regulation to provide fire fighters with adequate protection to perform their duty and for defining a performance regulation for retiring turnout gear from service. In addition to developing performance-based regulations, understanding the failure mechanisms allows the development of new and/or utilization of existing technologies that will improve and extend the performance life of turnout gear.

Recent BFRL activities have focused on assessing the mechanical and chemical degradation of the outer shell resulting from ultraviolet (UV) light exposure. These accelerated UV exposures studies were conducted using the NIST SPHERE *(http://www.bfrl.nist.gov/861/sphere.htm)*, which is typically used to conduct accelerated UV aging studies of coatings, sealants, and body armor. After UV exposure the turnout gear specimens are tested and analyzed using infrared spectroscopy (chemical composition), dynamical mechanical thermal analysis (DMTA) (tensile properties), and Instron (tear resistance).



SEM Images of fractured fibers from as-received (top) and UV exposed (bottom) outer shell.

After 13 days on the SPHERE (approximately equivalent to 96 real world UV exposure days) at 50 °C and 50 percent relative humidity, several outer shells experienced significant polymer decomposition, and an 85 percent decrease in tear resistance and tensile strength, both of which are NFPA 1971 performance requirements. Scanning electron microscopy images of the fractured fibers taken from the DMTA tested as-received ("new") and 13 days exposed ("exposed") outer shells visually support that the outer shell mechanical performance has significantly deteriorated after 13 days of accelerated UV exposure. Specifically, the new fiber experienced ductile failure (necking at fracture end), has a regular "rough" pattern indicating a sudden breaking at long fiber elongation, and still maintains its cylindrical shape. The exposed fiber experienced brittle failure (sharp cleavage), has significant surface pitting (polymer decomposition), and has been compressed to an oval shape during elongation.

Current activities include evaluating new technologies to increase UV resistance of the outer shell, assessing thermal performance of the as-received and UV resistant outer shells, and assessing the impact of other environmental stresses.

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Fire Fighter Tactics Under Wind Driven Conditions

Wind blowing into the broken window of a room on fire can turn a "routine room and contents fire" into a floor-to-ceiling firestorm. Historically, this has led to a significant number of firefighter fatalities and injuries, particularly in high-rise buildings where the fire must be fought from the interior of the structure.

BFRL, together with the Fire Department of New York City (FDNY), and the Polytechnic Institute of New York University and with the support of the Department of Homeland Security Federal Emergency Management Agency Assistance to Firefighters Research and Development Grant Program and the United States Fire Administration, conducted a series of wind-driven fire experiments in a seven-story building on Governors Island, New York, in February 2008.

The objective of these experiments was to improve the safety of firefighters and building occupants by developing a better understanding of wind-driven fires and wind-driven firefighting tactics, including structural ventilation and suppression. The experiments evaluated the ability of positive pressure ventilation fans (PPV), wind control devices (WCD), and exterior water application via high rise nozzles (HRN), operated from the floor below to mitigate the hazards of a wind-driven fire in a structure.

The building was instrumented to measure temperature, differential pressure, and gas velocity to examine the impact of the PPV fans, WCDs and HRNs. Each of the experiments was documented with video and thermal imaging cameras. These experiments captured video of specific fire phenomena that are not typically observable on the fire ground.

These experiments demonstrated the "extreme" thermal conditions that can be generated by a "simple room and contents" fire and how these conditions were extended along a flow path within a real structure when wind and an open vent are present. The thermal conditions generated along the flow path were untenable, even for firefighters in protective gear. Deployed from the floor above the fire, a WCD was shown to be effective in reducing the thermal hazard in the corridor and stairwell. Deployed from the floor below the fire, external water application with a HRN was demonstrated to be effective in reducing the thermal hazard in the corridor and stairwell. FDNY has implemented the use of these tools and tactics throughout the department.

Wind-driven fire experiment on Governors Island in New York Harbor.

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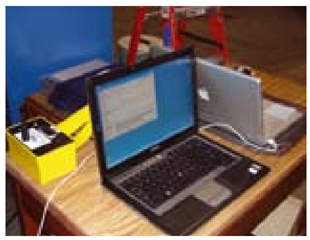
RFID Standards for Rough Duty Exposure



RFID tags following a large-scale fire test, tag reading equipment, and photo of a large-scale fire test.

Numerous firefighters have lost their lives after becoming lost in a burning structure, and there are a number of cases where firefighters have entered structures to rescue lost firefighters only to become lost and perish themselves. One of these cases was the cold storage warehouse fire in Worcester, Mass., where six firefighters lost their lives on Dec. 3, 1999. Although electronics technology has been applied in an attempt to solve this critical issue, to date it has not been able to provide a complete solution for the tracking of emergency responders. The ability to accurately track the activities of emergency responders during operations is critical to the safety of the responders and to maintaining effective command and control over the operations. Global Positioning System (GPS) satellites and lightweight GPS receivers have made it possible for emergency responders to accurately identify their locations when outdoors, but the ability to track the individual is lost when an emergency responder enters a building because building structures not only weaken radio signals, but also channel and reflect them, which makes it difficult to pinpoint firefighter location. Radio Frequency Identification (RFID) tag technology using point-of-location identification has the potential for extending tracking to the interior of buildings and other structural enclosures that would have the system built in. However, these RFID tag systems must be able to work in rough duty environments where firefighting conditions, such as temperature and water, are likely to challenge the technology.

This project, in collaboration with the U.S. Department of Homeland Security, will facilitate consensus standards to ensure that RFID tag systems will adequately perform in rough duty environments. The effort provides measurement data on RFID tag systems for thermal performance and for wet conditions. BFRL is developing metrics relevant for the development of best-practices, test methods, and performance standards for rough-duty applications. Findings are being disseminated through reports and publications as well as direct interaction with standards committees such as the ASTM Committee F23 on Protective Clothing and Equipment, the National Fire Protection Association Committees on Electronic Safety Equipment (FAE-ELS), NFPA 1982, *Standard on Personal Alert Safety Systems (PASS),* and Public Emergency Service Communication NFPA 1221, *Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems.*

The ultimate result of this work will be the deployment of network-integrated IEEE 1451.7 compliant RFID systems. Linking RFID systems and sensor networks will enable increased flexibility in deployment and reconfiguration of first respondent applications and thus improve performance and safety while reducing costs.

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MEASUREMENT SCIENCE FOR

Disaster-Resilient Structures and Communities

What is the problem?

Natural and technological disasters cause an estimated $55 billion in average annual costs (and growing), with single catastrophes like Hurricane Katrina and future "Kobe" earthquakes causing mega-losses exceeding $100 billion. Existing extreme load-related prescriptive requirements of building codes, standards, and practices stifle design and construction innovation and increase construction costs. The risk in large disaster-prone regions of the Nation is substantially greater now than ever before due to the combined effects of development and population growth. As noted by the National Science and Technology Council, "...a primary focus on response and recovery is an impractical and inefficient strategy for dealing with [natural disasters]. Instead, communities must break the cycle of destruction and recovery by enhancing disaster resilience." [1]

The link between basic research and building codes, standards, and practices is weak. Further, the measurement science is lacking to: 1) predict structural performance to failure under extreme loading conditions: 2) predict disaster resilience at the community scale; 3) assess and evaluate the ability of existing structures to withstand extreme loads; 4) design new buildings and retrofit existing buildings using cost-effective, performance-based methods; and 5) derive lessons learned from disasters and failures involving structures.

Why is it hard to solve?

The natural processes that produce risks in the built environment and the information relative to those risks for use by design professionals, standards developers, and emergency planners are not well understood. Cost-effective mitigation strategies that improve the performance of structural systems are complex, often lying outside the breadth of the prescriptive procedures that dominate building codes, standards, and practices. Methods for transferring basic research results into practice are limited. The engineering community lacks standard methods of predicting, evaluating, and assessing the disaster resilience of structures as they respond to extreme loads. Communities lack standard methods of assessing disaster resilience at the community scale for use in making disaster preparedness and mitigation decisions.

[1] National Science and Technology Council, Grand Challenges for Disaster Reduction—A Report of the Subcommittee on Disaster Reduction, June 2005.

The disaster resilience of structures and communities is determined by building codes, standards, and practices used when structures were built—most older structures have only minimal resilience. Most codes, standards, and practices are highly prescriptive, simplified, and inconsistent with respect to risk—stifling innovation and increasing cost. There is a lack of validated tools and metrics to evaluate structural and community performance, as well as the risks to which they are exposed—the lack of accurate models increases conservatism and decreases cost-effectiveness. Codes and standards are developed by private sector organizations that often lack the resources needed to develop the technical bases to improve them in a timely manner. Practices, codes, and standards used in design, construction, and retrofit are based largely on research performed or supported by the government.

Why BFRL?

Measurement Science for Disaster-Resilient Structures and Communities supports the Building and Fire Research Laboratory (BFRL) mission of promoting U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of the U.S. building and fire safety industries in ways that enhance economic security and improve the quality of life. This program fulfills a national knowledge transfer role that is not well-supported by a fragmented U.S. construction industry. The program supports the BFRL core competency in performance, reliability, and resilience of structures and communities under extreme loads. Finally, NIST has specific statutory responsibilities including: the Fire Prevention and Control Act (1974); the National Earthquake Hazards Reduction Program Reauthorization Act (1977, amended 2004); the National Windstorm Impact Reduction Act (2004); and the National Construction Safety Team Act (2002).

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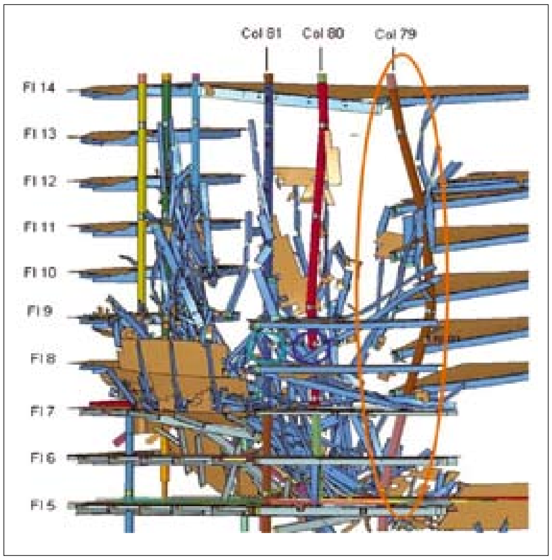
Investigation of the World Trade Center Disaster

On August 21, 2002, NIST announced its building and fire safety investigation of the World Trade Center (WTC) disaster. The WTC Investigation was conducted under the authority of the National Construction Safety Team (NCST) Act, which was signed into law on October 1, 2002.

The specific objectives of the investigation were to: 1) determine why and how the towers, WTC 1 and WTC 2, collapsed following the initial impacts of the aircraft and why and how the WTC 7 building collapsed; 2) determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response; 3) determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and 4) identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.



Graphic showing the buckling of WTC 7 Column 79 (circled area), the local failure identified as the initiating event in the building's progressive collapse.

NIST completed the study of the World Trade Center towers and released the final report in October 2005. The final report entitled, "Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report of the National Construction Safety Team on the Collapses of the World Trade Center Towers" (NCSTAR 1) and the 42 companion reports are available on the NIST WTC web site: *http://wtc.nist.gov/reports_october05.htm*.

The results of this extensive research led to the conclusion that the tragic consequences of the September 11, 2001, attacks were directly attributable to the combination of initial structural damage and the resulting multi-floor fires resulting from the impact of large, jet-fuel laden commercial airliners into the WTC towers. Buildings for use by the general population are not designed to withstand attacks of such severity; building regulations do not require building designs to consider aircraft impact. In U.S. cities, there has been no other experience with a disaster of such magnitude, nor has there been any in which the total collapse of a high-rise building occurred so rapidly and with little warning.

NIST also completed the investigation of WTC 7, the third building that collapsed on September 11, 2001. The study found that the fires in WTC 7, which were uncontrolled but otherwise similar to fires experienced in other tall buildings, caused an extraordinary event. Heating of floor beams and girders caused a critical support column to fail, initiating a fire-induced progressive collapse that brought the building down. A key factor leading to the eventual collapse of WTC 7 was thermal expansion of long-span floor systems at temperatures hundreds of degrees below those typically considered in current practice for fire resistance ratings. WTC 7 used a structural system design in widespread use.

As a result of its investigation of the WTC towers, NIST compiled a list of 30 recommendations to improve the safety of tall buildings, occupants, and emergency responders based on its investigation of the procedures and practices that were used for the WTC towers. The recommendations call for action by specific entities regarding standards, codes and regulations, their adoption and enforcement, professional practices, education, and training; and research and development. Additionally, as a result of the investigation of WTC 7, NIST has issued one additional recommendation and reiterated 12 of the recommendations from the WTC towers investigation.

Responding to the recommendations, the International Code Council (ICC) has adopted 23 code changes that were incorporated in the 2009 edition of the International Building Code and the International Fire Code. In addition, the National Fire Protection Association (NFPA) approved fifteen changes that were incorporated into the 2009 editions of the NFPA 5000 Building Code, the NFPA 1 Fire Code, and the NFPA 101 Life Safety Code. These far-reaching building and fire code changes will lead to future buildings—especially tall structures—that are increasingly resistant to fire, more easily evacuated in emergencies, and safer overall for occupants and emergency responders. NIST is continuing to work with the codes and standards bodies and the technical community toward implementing additional changes to codes and standards based on the recommendations of the WTC investigation.

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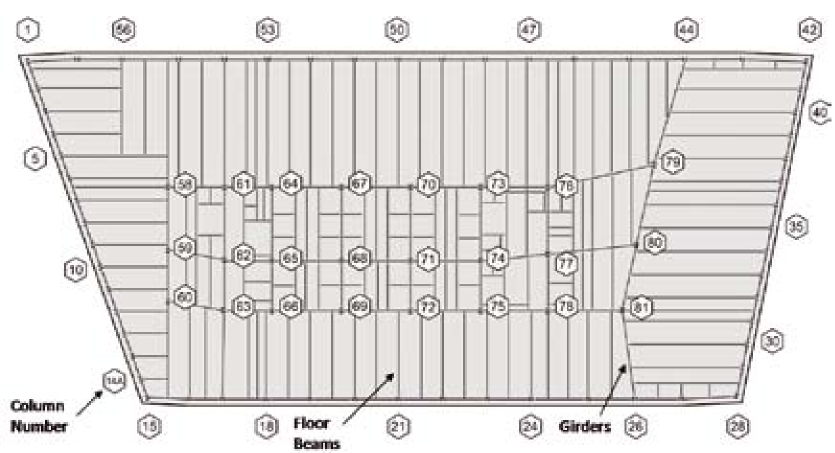
ACTIVITIES AND ACCOMPLISHMENTS

Collapse of World Trade Center Building 7

In November 2008, NIST released its final report on the Sept. 11, 2001, collapse of the 47-story World Trade Center building 7 (WTC 7) in New York City. The extensive three-year scientific and technical building and fire safety study found that the fires on multiple floors in WTC 7, which were uncontrolled but otherwise similar to fires experienced in other tall buildings, caused an extraordinary event. Heating of floor beams and girders caused a critical support column to fail, initiating a fire-induced progressive collapse that brought the building down.

Determining the probable collapse sequence for WTC 7, NIST found that the impact of debris from the collapse of WTC 1 ignited fires on at least 10 floors of WTC 7, and the fires burned out of control on six lower floors. The heat from these uncontrolled fires caused thermal expansion of the steel beams on the lower floors of the east side of WTC 7, damaging the floor framing on multiple floors. Eventually, a girder on Floor 13 lost its connection to a critical interior column that provided support for the long floor spans on the east side of the building. The displaced girder and other local fire-induced damage caused Floor 13 to collapse, beginning a cascade of floor failures down to the fifth floor. Many of these floors had already been at least partially weakened by the fires in the vicinity of the critical column. This collapse of floors left the critical column unsupported over nine stories.

NIST complemented its in-house expertise with private-sector technical experts; accumulated an extensive collection of documents, photographs and videos related to the WTC events of 9/11; conducted first-person interviews of WTC 7 occupants and emergency responders; analyzed the evacuation and emergency response operations in and around WTC 7; and performed the



Column and floor framing on a typical floor in WTC 7 most complex computer simulations ever conducted to model a building's response behavior and determine its collapse sequence due to a combination of debris impact damage, fires and a progression of structural failures from local fire-induced damage to collapse initiation, and, ultimately, to global collapse.

NIST issued one new recommendation as a part of the report on the collapse of WTC 7; the other 12 are reiterated from the previously completed investigation of the World Trade Center towers, WTC 1 and 2. While the partial or total collapse of a tall building due to fires is a rare event, NIST recommended that building owners, operators and designers evaluate buildings to ensure the adequate fire performance of the structural system. Of particular concern are the effects of thermal expansion in buildings with one or more of the following features: long-span floor systems, connections not designed for thermal effects, asymmetric floor framing, and/or composite floor systems.

With the release of the final WTC 7 report, NIST has completed its federal building and fire safety investigation of the WTC disaster that began in August 2002. A three-year study of the collapses of the WTC towers (WTC 1 and 2) was completed in October 2005 when NIST released its final report on the towers.

All NIST reports and other supporting information on the WTC Investigation are available at *http://wtc.nist.gov.*

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Implementation of the World Trade Center Recommendations

The International Code Council (ICC) adopted 23 changes into the 2009 edition of the ICC's I-Codes (specifically the International Building Code, or IBC, and the International Fire Code, or IFC). These changes responded directly to the recommendations made by NIST as a part of its final report on the collapses of the WTC Towers. The I-Codes are a state-of-the-art model code used as the basis for building and fire regulations promulgated and enforced by U.S. state and local jurisdictions.

The new codes address areas such as increasing structural resistance to building collapse from fire and other incidents; requiring a third exit stairway for tall buildings; increasing the width of all stairways by 50 percent in new high-rises; strengthening criteria for the bonding, proper installation and inspection of sprayed fire-resistive materials commonly known as "fireproofing"; improving the reliability of active fire protection systems such as automatic sprinklers; requiring a new class of robust elevators for access by emergency responders as well as similar elevators for occupant evacuation in lieu of the additional stairway; making exit path markings more prevalent and more visible; and ensuring effective coverage throughout a building for emergency responder radio communications.

In addition to the code changes adopted by the International Code Council, the National Fire Protection Association (NFPA) has adopted 15 changes to the NFPA 1 Fire Code, NFPA 101 Life Safety Code, and NFPA 5000 Building Code. A detailed list of proposals to the ICC and NFPA appear in the chart tracking the progress of implementation of the recommendations at *http://wtc.nist.gov.*

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Structural Performance Under Multi-Hazards

The fundamental new idea guiding this program is that disaster resilience can be enhanced significantly by developing a robust capability to predict the effects of hazards on the performance of complex structural systems and on community-wide response.

The scope of the BFRL's measurement science research includes extreme wind engineering and structural fire resistance with progressive collapse and multi-hazard failure analysis being cross-cutting research topics. Development of cost-effectiveness tools for evaluating multi-hazard risks at the community scale is a significant part of the research plan.

The program consists of five research thrusts: 1) develop validated tools that predict structural performance to failure under extreme loading conditions; 2) develop community-scale loss estimation tools to predict consequences of disasters, leading in turn to increased resilience; 3) develop validated tools to assess and evaluate the capabilities of existing structures to withstand extreme loads; 4) develop performance-based guidelines for cost-effective design of new buildings and, where warranted, rehabilitation of existing buildings; and 5) derive lessons learned from disasters and failures involving structures.

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The US-90 Biloxi-Ocean Springs bridge (looking west toward Biloxi from the east shore). Simply supported superstructure spans were displaced and dropped north off their piers due to storm surge and wave actions during Hurricane Katrina in 2005.

ACTIVITIES AND ACCOMPLISHMENTS

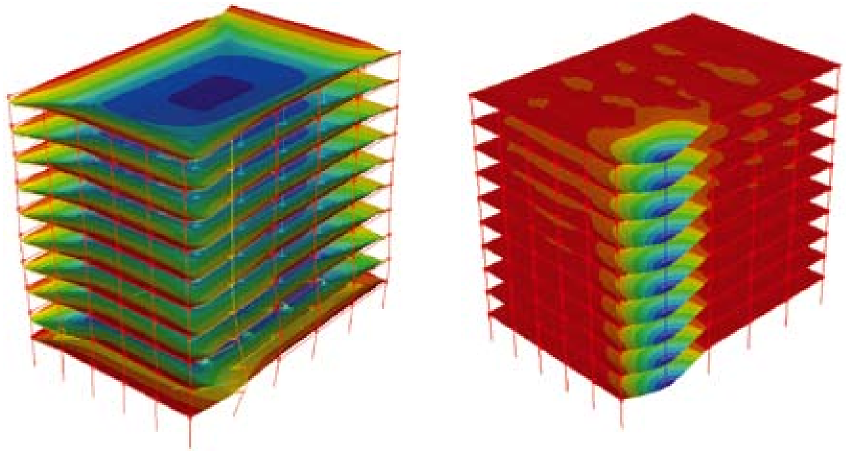
Prevention of Disproportionate Structural Collapse

Many U.S. buildings are vulnerable to extreme loads that may cause partial or total collapse. Modern structures have a limited reserve capacity to accommodate abnormal loads such as accidental explosions, extreme fires and deliberate terrorist acts. There is no accepted science-base or design practice to maintain overall structural robustness that considers both design loads and abnormal loads in a multi-hazard context. The building industry needs methodologies and computational tools for assessment of overall structural robustness. This project is providing the measurement science for the development of performance-based provisions in U.S. codes and standards for disproportionate collapse resistance that will ensure improved robustness of building structures.

Robustness is a key structural property that is related to disproportionate collapse resistance. Both structural redundancy and integrity are key factors that influence the robustness of the structure. These factors must be quantified to express the robustness in a meaningful and measurable manner. The assessment of the degree of structural redundancy for redistribution of loads and structural integrity for system continuity requires simulation of structural behavior under various local failure scenarios. Realistic and efficient simulations require the development and use of advanced and experimentally validated modeling tools to examine the structural system performance.

BFRL is examining collapse limit states of structural systems to quantify the reserve capacity of various structural systems. It is also developing design and retrofit methodologies that take explicit advantage of the synergies associated with mitigating progressive collapse under multiple hazards to enhance overall efficiency and cost-effectiveness.

BFRL has published a "Best Practices Guide" for the design of new buildings and rehabilitation of existing buildings *(http://www.bfrl.nist.gov/861/861pubs/collapse/NISTIR_7396.pdf)*. This document has been incorporated into the commentary of the ASCE 7 standard on "Minimum Design Loads for Buildings and Other Structures." BFRL, in partnership with other federal agencies and industry, conducted full-scale experiments of steel beam-column assemblies to study the behavior of beams and connections under progressive collapse scenarios and validate detailed and reduced computational models of steel frames. Similar work is underway for reinforced concrete buildings. The validated component and connection models have been used to develop comprehensive three-dimensional models of typical steel and concrete buildings to assess their reserve capacity, develop robustness metrics, and assess potential for disproportionate collapse. A series of push-down and push-over analyses have been conducted to compare the relative robustness of a number of steel and concrete structural systems. Furthermore, NIST, in partnership with industry, is currently developing guides for assessing progressive collapse vulnerability of new and existing buildings, including both rapid and comprehensive evaluation tools.



3-D model of a 10-story steel-framed building under push-down and local failure analysis.

Full-scale testing of a steel beam-column assembly undergoing large displacement.

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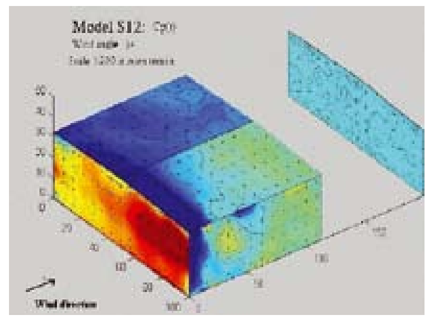
Image of the Graphical User Interface of NIST's SLOSH MapXtract program. SLOSH MapXtract is a map-based program used to extract wind speed and storm surge data and compute their joint probability for specific locations along the U.S. coastal regions.

Wind Engineering and Multi-hazard Failure Analysis

The objective of the project is to develop the measurement science methods and tools that will enable performance-based standards for designing structures to resist wind and storm surge in a multi-hazard context. The project is motivated by the finding that current design practices can result in (1) the under- or overestimation of wind effects by up to 40 percent for tall buildings and 80 percent for low-rise buildings; (2) the significant underestimation of the storm surge hazard for design of coastal structures; and (3) the underestimation by up to 100 percent of the probability of exceedance of design limit states in multi-hazard environments. These findings have serious implications from a safety point of view—average losses due to hurricanes alone exceed $10 billion per year—as well as from the points of view of economy and wasteful consumption of embodied energy.

BFRL has concentrated on the analysis of test and design methods and the development of tools that can contribute substantially to (1) improving standard provisions for the design of structures for wind and multiple hazards, (2) developing methodologies to better characterize hurricane hazards, and (3) establishing risk-consistent design criteria for coastal structures under combined effects of hurricane winds, storm surge, and waves. Specifically, BFRL is developing:

- Realistic wind maps to replace the current, statistically incorrect, ASCE 7 Standard maps, via
  - the mining and use of wind data from the National Oceanic and Atmospheric Administration (NOAA) Automated Surface Observing System (ASOS), and
  - innovative multi-hazard modeling of wind speed extremes in mixed wind climates, e.g., climates with thunderstorm and synoptic winds, or tropical and extratropical storms.
- Science-based methodologies for aerodynamic simulation and measurements to eliminate the gross errors revealed by international comparisons of wind tunnel estimates. Probabilistic concepts applied to extreme wind and seismic effects, structural optimization under multi-hazard constraints, and nonlinear structural analysis tools will be employed to develop a coherent basis for multi-hazard engineering.



Fluctuating wind pressure model for 100ft x 200ft x 32ft building in suburban terrain. (Red = Pressures, Blue = Suctions)

- An integrative methodology that (1) utilizes a probabilistic approach for calculation of site-dependent mean recurrence intervals (MRIs) of any joint wind speed/surge height events; (2) enables incorporation of the wave model (SWAN, **S**imulating **WA**ves **N**earshore) into the SLOSH model (**S**ea, **L**ake, and **O**verland **S**urges from **H**urricanes) to account for wave action in addition to total inundation; (3) allows for comparison of competing hydrodynamic simulation models; and (4) provides data/validation for use as in-design criteria for structures in coastal regions.

A methodology for incorporating wave estimates using the SWAN model into hydrodynamic simulation using the SLOSH model was recently developed. This work was a collaboration between NIST, NOAA, and the University of Florida that was jointly funded by NIST and NOAA's National Hurricane Center (NHC). Work to expand this methodology for application to larger U.S. coastal basins is ongoing.

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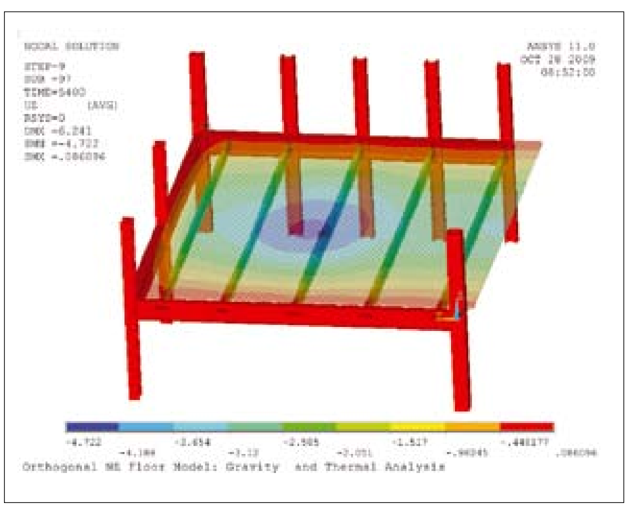
Fire Safety Design and Retrofit of Structures

Current building design practice does not consider fire as a design condition to predict and evaluate structural performance in fire. Instead, fire resistance ratings of building members, derived from a standard fire endurance test, e.g., ASTM E-119, are specified in building codes.

The project follows recommendations from a national industry workshop held in 2002, which provided a national R&D roadmap for performance based fire resistance design and rehabilitation of structures. Additionally, Recommendation 9 from the NIST World Trade Center investigation recommends the development of: (1) performance-based standards and code provisions, as an alternative to current prescriptive design methods, to enable the design and retrofit of structures to resist real building fire conditions, including the ability to achieve the performance objective of burnout without structural or local floor collapse and (2) the tools, guidelines, and test methods necessary to evaluate the fire performance of the structure as a whole system. The project is developing measurement science-based simulation models and tools to predict structural fire performance, combining expertise in fire dynamics, heat transfer, and structural modeling.

The technical approach includes the development of a unified performance-based methodology to evaluate the fire behavior of concrete and steel structures by incorporating current knowledge concerning fire development, growth and spread, material property degradation, and overall structural response to thermal loads and material weakening. The proposed approach predicts the performance of structural components, including connections and members, in a real fire environment. It also develops a risk and reliability-based approach to predict and specify the fire hazard, structural fire loads, the thermally induced reduction of structural resistance, and to calculate the structural response.

Sensitivity studies on composite floor models are being conducted by including features identified in the WTC Building 7 Investigation that contributed to the fire-induced floor failure (e.g., long span floors, composite sections, asymmetrical framing, and shear connections not designed to accommodate thermal effects) to identify critical design factors.



A composite floor model for sensitivity studies of features identified in WTC Building 7 Investigation that contributed to the fire-induced floor failure, e.g., long span floors, composite sections, asymmetrical framing, and shear connections not designed to accommodate thermal effects.

Efforts are ongoing to develop tools for evaluating the performance of building structures when subjected to fire effects. Recently, development of an Immersive Visualization Environment (IVE) was initiated to aid in interpreting the complex interaction among fire, heat transfer, and structural deformation from a typical room fire by displaying simultaneously results from fire, thermal, and structural analyses. A draft "Best Practices Guidance" document for Structural Fire Resistance Design of Concrete and Steel Buildings was recently released for public comment.

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Fire Resistive Materials for Structural Steel

The objective of the Fire Resistive Materials for Structural Steel project is to provide the measurement science infrastructure for the performance assessment and optimization of fire resistive materials (FRMs). Commonly employed FRMs include low density gypsum or cement-based materials containing fibers or lightweight fillers and intumescent coatings that may expand up to 40 times in thickness during a fire exposure. The two major performance objectives of an FRM are that it provides thermal protection (insulation) for the steel that it is protecting and that it remains in place prior to and during a fire exposure. With these objectives in mind, research has focused on measurement of thermal and adhesion properties of these materials. The relevance of this research to the industry has been tangibly demonstrated via the successful completion of a three-year consortium entitled "Performance Assessment and Optimization of Fire Resistive Materials," with industrial participation from the American Iron and Steel Institute, Anter Corporation, Barrier Dynamics LLC, Isolatek International, Lightconcrete LLC, PPG, and W. R. Grace & Co.

A major accomplishment of the FRM project has been the development and approval of a new ASTM test method (E2584) for measuring the thermal conductivity of these materials at elevated temperatures using a slug calorimeter methodology. This technology has been commercialized by a manufacturer of thermal testing equipment and adopted by several independent testing laboratories worldwide. Other significant accomplishments in the thermal performance research have included the development of a quantitative methodology for characterizing FRMs with respect to inputs for thermal performance models, the demonstration of X-ray microtomography as a powerful technique for characterizing the three-dimensional microstructure of FRMs, and the fire testing of a bare steel column at a national testing laboratory to establish the appropriate viewing factor to use for radiative transfer in computational thermal models.

Specimen of a commercial intumescent coating prior to and after testing in the slug calorimeter high temperature experimental setup.

Adhesion research has focused on the development of new testing methods for both laboratory and field use. In the former area, a new test method has been submitted to the ASTM E06.21 subcommittee, while in the latter, a prototype for a test method to replace the so-called "mayonnaise cap" test has been successfully demonstrated. Reports summarizing the research conducted during the course of this project can be found at: *http://concrete.nist.gov/monograph* under Part II - Fire Resistive Materials.

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National Earthquake Hazards Reduction Program (NEHRP)

Although damaging earthquakes occur infrequently in the U.S., they strike with little or no warning, with potentially catastrophic consequences. A 2003 report by the Earthquake Engineering Research Institute (EERI)[1] states that a single large earthquake in an urban area could easily result in direct and indirect economic losses between $100 billion and $200 billion. While seismic provisions for new buildings in U.S. model building codes have gradually been improved, their focus on life safety for their occupants has led to costly prescriptive design procedures. The existing building stock is much more vulnerable to earthquake damage than newly designed buildings and is likely to be in use for many decades. Cost-effective seismic evaluation and rehabilitation methodologies are not widely available or applied.

Four Federal agencies—FEMA, NIST, NSF, and the US Geological Survey (USGS)—comprise the NEHRP partnership and perform research and implementation activities related to earthquake hazard mitigation in the U.S. under directions provided by NEHRP authorization legislation. The most recent NEHRP reauthorization occurred in 2004. That reauthorization directed that NIST be established as the NEHRP lead agency, with responsibility for program coordination and planning for the four NEHRP partner agencies. The same authorizing legislation makes NIST responsible for performing applied earthquake engineering research under the auspices of NEHRP.

BFRL is targeting six general areas of measurement science research to support near- and long-term improvements to building and community disaster resilience with respect to the earthquake threat:

- technical support for building code development;
- performance-based seismic engineering;
- national design guidelines;
- evaluated technology dissemination;
- enhanced design productivity and interoperability; and,
- improved evaluation and strengthening for existing buildings.

NEHRP research and implementation efforts will result in reduced societal risk, cost, and operational impacts from earthquakes on individuals, businesses, and government. The program will also foster a transformation from prescriptive to performance-based design codes and standards, enabling innovation in materials, technologies, and system designs and fostering cost-effectiveness.

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1 Earthquake Engineering Research Institute, Securing Society Against Catastrophic Earthquake Losses: A Research and Outreach Plan in Earthquake Engineering, June 2003.

Earthquake damage to the Olive View Hospital in San Fernando, CA, from the 1971 earthquake.

Photo Credit: Earthquake Engineering Research Institute (EERI), James L. Stratta

ACTIVITIES AND ACCOMPLISHMENTS

Risk Mitigation Standards, Guidelines, and Tools—Code Development Technical Support

In its report ATC 57, *The Missing Piece: Improving Seismic Design and Construction Practices*, the Applied Technology Council (ATC) outlined a five element approach for NIST to fulfill its research and knowledge transfer role within the National Earthquake Hazard Reduction Program (NEHRP). The first of these elements is to provide support for the seismic practice and code development process.

Within the four agency NEHRP partnership, the Federal Emergency Management Agency (FEMA) works with the Building Seismic Safety Council (BSSC), the American Society of Civil Engineers (ASCE), and the International Code Council (ICC) to support the development of new prescriptive earthquake-resistant design provisions for the nation's model building code. FEMA and BSSC periodically develop the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*. The "Recommended Provisions" are based on the consensus inputs of leading earthquake engineering practitioners and researchers. ASCE cites the "Recommended Provisions" as the basis for its updates of the earthquake engineering portions of ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*. The ICC in turn largely adopts by reference the earthquake engineering provisions of ASCE/SEI 7 in the *International Building Code*.

Commencing in FY 2007, NIST began partnering with FEMA to support this code development process. FEMA had undertaken a project (ATC 63) with ATC to develop a methodology for more rationally and rigorously determining the structural performance factors that are used in ASCE/SEI 7 to characterize the expected behavior of classes of structural, or lateral force-resisting, systems in earthquake. These factors are used in the simplified linear design analysis procedures that are prescribed for conventional building design in ASCE/SEI 7. The project produced FEMA P695, *Quantification of Building Seismic Performance Factors*, in June 2009. While FEMA P695 presents a new, technically rigorous procedure, there was a need for "beta testing," or validating, it prior to its wide-spread adoption. BFRL is supporting an ongoing validation study of six representative lateral force-resisting systems: reinforced masonry shear wall systems (ordinary and special), reinforced concrete shear wall systems (ordinary and special), special steel moment-resisting frames, and special steel concentrically-braced frames. The validation study involves using the FEMA P695 procedure of archetypical structural design and rigorous nonlinear analysis with the six systems. The results of the study will be used to refine the FEMA P695 procedure. The final report for the project is slated for publication in early 2010.

Paralleling the validation project, BFRL is commencing a new study with ATC in 2009 that focuses on bringing more performance-based seismic engineering (PBSE) principles into the prescriptive building codes by extending the current building seismic performance factors, which only consider general classes of lateral force-resisting systems, to address key building characteristics such as building height and geotechnical conditions at the building site. The basic methodology of FEMA P695 will serve as the basis for starting this planned multi-year effort.

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Performance-Based Seismic Design Workshop

The objective of this workshop, which was managed by the Building Seismic Safety Council (BSSC), was to develop a prioritized list of research needs to support full implementation of Performance-Based Seismic Design (PBSD). BSSC conducted a national workshop of 30 leading seismic engineering practitioners and researchers in May 2008 and produced a report with this list in April 2009.

Most buildings in the U.S. have been designed to comply with prescriptive building code requirements; in the earthquake engineering area, the primary objective of these codes is to assure life safety. These prescriptive requirements target general classes of buildings and are largely based on experience in past earthquakes. PBSD is intended to provide a means of designing and constructing individual buildings that satisfy owners' and tenants' functional needs more effectively than the prescriptive provisions of the building codes. Designing directly for desired performance, rather than following specific prescriptive requirements, improves cost-effectiveness and facilitates international competitiveness.

NIST GCR 09-917-02, Workshop Report, *Research Required to Support Full Implementation of Performance-Based Seismic Design.*

Beginning with national efforts supported by the Federal Emergency Management Agency (FEMA) which developed FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, in 1997, the national earthquake engineering community became more interested in and supportive of PBSD, in which designers can work with building owners to tailor building designs to meet specified performance objectives that consider, in addition to life safety, post-earthquake functionality and economic loss limitation. The new concept of PBSD requires significantly more detailed information about building performance – both structural systems and associated architectural and installed equipment systems – than has been typically been referenced in developing prescriptive building code provisions.

FEMA has engaged the practitioner and research communities since the advent of FEMA 273 in increasingly developing PBSD approaches, but has not had a wealth of research data on which to build. The result has been a series of procedures and guidelines largely based on expert "engineering judgment." This workshop formulated a prioritized list of experimental and analytical research needs to carry PBSD into a technically more rigorous form than is currently available. Both basic and applied research requirements are provided. It is expected that this report will shape research supported by both NIST and the National Science Foundation (NSF).

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Seismic Design and Construction Techbriefs

In its 2003 report, *The Missing Piece: Improving Seismic Design and Construction Practices*, the Applied Technology Council (ATC) recommended a roadmap for NIST to follow in fulfilling its research and development role within the National Earthquake Hazard Reduction Program (NEHRP). The roadmap included five "program elements," or areas of research focus, for NIST. One of the five was to "make evaluated technology available to practicing professionals in the design and construction communities." Specifically, ATC recommended that NIST work with earthquake professionals in the research and practitioner communities to produce ***techbriefs***, which are topical, tightly written, and well-illustrated discussions of solutions to practical problems.

When NIST awarded a multi-year task order research contract to the NEHRP Consultants Joint Venture (NCJV) in 2007, one of the first initiatives undertaken was to begin producing the recommended techbriefs, to address topical areas that are suggested by researchers and practitioners around the U.S.

NCJV has now produced for NIST the first two of these new documents. The first, NIST GCR 8-917-1, *Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers*, was published in August 2008. The document was co-authored by nationally prominent reinforced concrete researchers and practitioners. It addresses design principles, design and analysis guidance, and detailing and constructability guidance for reinforced concrete moment frames that are sited in areas of high seismic activity (hence the term "special"). The second, NIST GCR 8-917-3, *Seismic Design of Steel Special Moment Frames: A Guide for Practicing Engineers*, was published in June 2009. This document provides the same information for steel moment frames sited in areas of high seismicity as that found in the reinforced concrete document. The guidance that is provided in both is in complete compliance with current national model building code provisions but also provides information and innovations not included in the codes.

NIST GCR 8-917-01, NEHRP Seismic Design Techical Brief No.1, *Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers.*

The first two techbriefs have been received very well by both practicing engineers and by university professors who intend to use them in graduate level structural engineering classes.

NIST is continuing its efforts to produce new techbriefs. In 2009, it initiated projects on design and analysis of reinforced concrete diaphragm (roof and floor) systems and on nonlinear structural analysis techniques.

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Standards and Technical Committees

BFRL staff are actively engaged with technical committees and standards developing organizations (SDOs) that are key to implementing technologies that are aligned with the Laboratory's five strategic goals. Staff members serve on about 130 committees and working groups, many in leadership positions. For example, the output of BFRL research is a source of technical information for ASTM International (ASTM), the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), the National Fire Protection Association (NFPA), Underwriters Laboratories, Inc. (UL), the Society of Fire Protection Engineers (SFPE), the International Organization for Standardization (ISO), the International Council for Research and Innovation in Building and Construction (CIB), the International Code Council (ICC), the Construction Industry Institute, and others as mentioned below.

Net-Zero Energy, High-Performance Buildings

Standards activities that support this goal are focused on indoor air quality, building heating and cooling, alternative building energy systems, and building controls and communications.

Dr. Shyam Sunder serves on the ***Board of Directors of the Sustainable Building (SB) Alliance***, a non-profit, non-partisan international network of universities, research centers and technical assessment organizations that is intended to accelerate the international adoption of SB practices through the promotion of shared methods of building performance assessment and rating. The SB Alliance initiative is supported by the UNESCO Chair for sustainable buildings, the UNEP sustainable building and construction initiative (UNEP-SBCI), and the World Federation of Technical Assessment Organizations (WFTAO).

Dr. Andrew Persily is the Vice President of ***ASHRAE***. He will chair the ***ASHRAE Technology Council***, which is responsible for standards development, research and related technical activities.

Indoor Air Quality

Dr. Andrew Persily is Vice Chair of the ***ASTM Subcommittee on Indoor Air Quality (D22.05)*** and **Dr. Cynthia Reed** is this Subcommittee's Secretary. D22.05 has approved and is currently developing a suite of standards related to indoor contaminant measurement, analysis and interpretation. Several of these standards are based directly on research and methods developed by BFRL. In addition, Dr. Persily and Dr. Reed have led two ASTM indoor materials emissions workshops involving industry and various federal agencies, which have helped reshape the direction of D22.05's indoor emissions standards.

Dr. Persily is a member and former Chair of the ***ASTM Subcommittee on Infiltration and Ventilation Performance (E06.41)***. Under his leadership, more than 15 standards for evaluating building air-tightness, ventilation performance and other aspects of air leakage and airflow in buildings were developed. He also was a member of the ***ASHRAE Committee on Ventilation for Acceptable Indoor Air Quality (SPCC 62.1)*** from 1992 through 2003, serving as Chair for the last four years of his tenure. He now serves the committee as a consultant.

Mr. Steven Emmerich serves as Chair of the ***ASHRAE Standards Committee on Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings (ASHRAE SSPC 62.2)***. This standard was first published in 2003. Mr. Emmerich is also Chair of the subcommittee that is developing a companion guideline and overseeing development of a users' manual.

Mr. Steven Bushby is Vice Chair of the ***U.S. Technical Advisory Group (TAG) to ISO/TC 205, Building Environment Design***. This committee is developing a wide range of standards related to design criteria for the indoor environment of buildings. The U.S. TAG is responsible for developing the U.S. input and official positions on all standards developed in the committee.

Building Heating and Cooling

Dr. Mark Kedzierski serves on the ***ASHRAE Committee on the Method for Measurement of Proportion of Lubricant in Liquid Refrigerant (ASHRAE SSPC 41.4)***, which is responsible for revising the measurement standard for determining the mass concentration of miscible lubricant-and-liquid-refrigerant mixtures and, in limited cases, immiscible mixtures. The goal of this revision is to assure that the standard is applicable to new refrigerants and lubricants. **Dr. Kedzierski** is the Secretary of ***ASHRAE SSPC 41, Methods for Measurement Standards***.

Dr. W. Vance Payne serves on the ***ASHRAE Committee on Method of Testing Capacity of Four Way Refrigerant Reversing Valves (ASHRAE SSPC 153P)***. This committee is developing a new standard for determining the flow capacity and pressure drop characteristics of four-way refrigerant flow reversing valves commonly used in vapor compression heat pump systems. Producers normally supply customers with reversing valves based on refrigerating capacity ratings in kW (tons) of refrigeration at a specified suction vapor line pressure drop. This standard seeks to provide a common method for capacity rating of these valves thus reducing valve rating variability.

Dr. Payne is also a member of the ***Standard Project Committee*** formed to update ***ASHRAE 16 Method of Test for Rating Room Air Conditioners and Packaged Terminal Air Conditioners***. The standard prescribes a method of testing for obtaining cooling capacity and airflow quantity for rating room air conditioners/heat pumps and packaged terminal air conditioners/heat pumps. The committee is combining two standards into one complete standard for cooling and heating ratings. The last update of this standard was in 1983.

Mr. Brian Dougherty is a voting member on the ***Standards Project Committee*** working to update ***ASHRAE Standard 116 Methods of Testing for Rating Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps***. The standard, last revised in 1995, is being updated to be compatible with current industry practices, equipment technologies, and recently revised ASHRAE standards and the DOE test procedure. The revised standard was released for public review in September 2007.

Dr. William Healy is a voting member of ***ASHRAE Standard 118.2 Method of Testing and Rating Residential Water Heaters***. This standard governs the evaluation of the energy factor, which rates the thermal efficiency of residential water heaters, and the first-hour rating, which provides a metric for the amount of hot water provided by a tank. The committee is currently considering changes in this test procedure to correct errors in calculations and to make the procedure more consistent. Work has been undertaken to determine the differences between the ASHRAE procedure and the Department of Energy's procedure in an effort to align the two methods of test.

Dr. David Yashar is an expert to the ***International Electrotechnical Commission (IEC) TC59 WG12 Testing and Rating of Household Refrigeration Appliances***. This group, comprised of diverse experts representing the interests of 10 countries on four continents, is working to develop a globally acceptable method for rating the energy consumption of household refrigerating appliances. The ultimate goal of this working group is to develop an international standard that can be adopted by all nations requiring performance ratings.

The International Organization for Standardization's (ISO) Technical Committee 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. **Mr. Brian Dougherty** participates as a member of the U.S. Technical Advisory Group (TAG). The TAG monitors and formulates the U.S. position on all TC 86-sponsored standards activities. Mr. Dougherty serves as a member of Panel 6, which makes recommendations to the full TAG on ISO standards activities dealing with factory made air conditioning and heat pump units. **Mr. Dougherty** is also a member of the ***U.S. delegation on ISO Working Group 1 within Subcommittee 6***. WG1 recently revised two testing and rating standards that apply to unitary air-conditioners and heat pumps while developing a third testing and rating standard for multi-split air conditioners and heat pumps. This same committee was recently tasked with adding sections to all three forthcoming ISO standards that address seasonal performance and guidance on evaluating the uncertainties associated with the reported performance parameters.

Alternative Building Energy Systems

Mr. Mark Davis is the standards subcommittee Chair of ***ASHRAE Technical Committee 1.10 Cogeneration Systems***. This subcommittee is beginning to develop a method of test to determine the performance for micro-cogeneration systems. This new standard will ultimately provide test data that can be manipulated by a separate rating standard to communicate to consumers the potential costs and benefits of installing a micro-cogeneration device.

Dr. A. Hunter Fanney is an active member of ***ASME***. He is an ASME Fellow and past Chairman of the ***ASME Solar Energy Division***. This Division is responsible for coordinating all solar energy activities within ASME including the *Journal of Solar Energy Engineering*, annual conferences, student activities, and awards. He has served as an **Associate Editor of ASME's *Journal of Solar Energy Engineering*** and is currently serving as Senior Advisor to the Division as well as Chairman of the *Frank Kreith Energy Award*.

Dr. Fanney is a member of subcommittee ***ASTM E44.09 Photovoltaic Electric Power Conversion***. E44.09 deals with numerous issues concerning the testing and evaluation of photovoltaics. Current areas of interest include developing rating methodologies for photovoltaics that use short-term data to predict long-term performance, and improved indoor and outdoor test procedures.

Building Controls and Communications

Mr. Steven Bushby has served on the ***ASHRAE Standards Committee*** since 2005 in a variety of roles. He is currently Vice-Chair of the committee and Chair of the ***Technical Committee Liaison Subcommittee***. The Standards Committee is responsible for overseeing the development and maintenance of all ASHRAE standards, guidelines, and code language documents.

Mr. Bushby is the convener of ***ISO/TC 205 WG 3 Building Control System Design***. This working group is developing a multi-part international standard that addresses several issues related to building control systems including control system functionality, communication protocols, system specifications, and project management. ***ANSI/ASHRAE standards 135 and 135.1 (BACnet and its companion testing standard)*** have been adopted as ISO standards through this committee. **Mr. Bushby** chairs ***ISO TC 205, Maintenance Agency for EN ISO 16484-5 and EN ISO 16484-6, Building Environment Design*** for the purpose of streamlining the process for updating and maintaining the standards. These standards are the international versions of the ASHRAE BACnet standard and its companion testing standard. The purpose of this activity is to keep these European and ISO standards synchronized with the underlying ASHRAE standards upon which they are based.

Dr. David Holmberg serves on ***ASHRAE Standing Standards Project Committee 135 (SSPC 135)***. SSPC 135 is responsible for maintaining the ***BACnet communication protocol standard (ANSI/ASHRAE Standard 135)*** and a companion standard ***ANSI/ASHRAE 135.1 Method of Test for Conformance to BACnet***. These standards have been adopted by CEN, ISO, and more than 30 countries around the world. The BACnet standard provides a way to integrate building automation and control products made by different manufacturers for applications such as heating, ventilation, and air-conditioning control, lighting control, access control, and fire alarm systems. **Dr. Holmberg** also leads the ***Utilities Integration Working Group of SSPC 135*** and served as a voting member between July 2004 and June 2008.

Dr. Stephen Treado serves on ***ASHRAE Standing Standards Project Committee 135 (SSPC 135)*** and ***ANSI/ASHRAE 135.1 Method of Test for Conformance to BACnet***. He serves on the ***Life Safety and Security Working Group*** and the ***Lighting Applications Working Group*** and began a four-year term as a voting member of the committee in July 2008. **Dr. Treado** represents BFRL on the ***CIB Working Commission on Climate Change and the Built Environment (W 108)*** and the ***CIB Task Group on Energy and the Built Environment (TG66)***.

Mr. Michael Galler is the Secretary of the ***ASHRAE Guideline Project Committee 20, XML Definitions for HVAC&R***, which is tasked with establishing a common data exchange format for the description of commodity data and HVAC&R information via the standard XML (extensible Markup Language) formatting language. Guideline 20 will define a process for development of XML schemas applicable to the HVAC&R field, and **Mr. Mark Palmer** serves the committee as a consultant.

Advancing Infrastructure Delivery

Dr. Shyam Sunder serves on the ***Board of Advisors of the Construction Industry Institute***, a consortium of the top 100 U.S. owners, engineering and construction contractors, and suppliers with a mission to improve the life-cycle cost effectiveness of the engineering and construction process by providing guidance on best practices discovered through research—in partnership with more than 30 leading U.S. universities—and by collaborating on important industry issues.

Dr. Sunder serves on the ***Board of Directors of the International Council for Research and Innovation in Building and Construction (CIB)***. CIB was established as an association whose objectives are to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research.

Dr. Sunder is the Co-Chair of the ***Buildings Technology R&D Subcommittee of the White House National Science and Technology Council's Committee on Technology***. The Subcommittee—composed of 16 Federal Executive Branch Agencies plus the Architect of the Capitol, the Smithsonian Institution, and the U.S. Postal Service—(1) provides R&D guidance aimed at supporting advances in buildings technology and related infrastructure, with a particular focus on enabling the energy efficient, automated operation of buildings and building systems; (2) provides R&D guidance to enable sustainable renewal of the nation's physical infrastructure, improve construction productivity, enhance disaster resilience of buildings, and benefit human health and productivity; and (3) identifies R&D priorities and opportunities, develops long-range interagency R&D plans, coordinates with other NSTC subcommittees, and coordinates R&D implementation plans.

Mr. Robert Lipman participates in the ***American Institute of Steel Construction (AISC) Information Technology Committee***. One of the responsibilities of the committee is to oversee the CIMsteel Integration Standards (CIS/2), a product model for interoperability between various parties involved in steel construction. Mr. Lipman has contributed to the future directions for CIS/2 and has developed a widely used visualization tool for CIS/2 files and a translator to Industry Foundation Classes files, a product model used in the building industry.

Mr. Mark Palmer is a special advisor to the ***ASHRAE Building Information Modeling and Interoperability Steering Committee (BIM&I SC)***. The committee is developing recommendations for how ASHRAE can best help the HVAC&R industry achieve Integrated Building Design with the use of Building Information Modeling (BIM) and interoperability among software applications. The BIM&I SC is examining how to transform the format and structure of ASHRAE standards and guidelines for use as "smart documents" and for delivering engineering knowledge in the digital age.

Dr. Harold E. Marshall has been the Chairman of ***ASTM's Building Economics Subcommittee, E06.81***, since its inception in 1979. He has played major authorship, educational, and leadership roles in writing and shepherding successfully 23 standards, two software products, and two adjuncts through the ASTM standardization process. One standard that merits particular attention is an elemental building classification called UNIFORMAT II. This standard is helping owners, project managers, designers, builders, and facility managers construct and manage their buildings more cost effectively.

Dr. Robert E. Chapman is the Secretary and Techniques Task Group Chairperson of ***ASTM's Building Economics Subcommittee***. In addition to his strong leadership role in the subcommittee, he has provided the technical content and write-ups for revising two standard economic methods to provide case illustrations of economic decision making in support of improved, cost-effective protection against natural and man-made hazards affecting the nation's infrastructure. Dr. Chapman also drafted a standard guide for developing a cost-effective risk mitigation plan for protecting infrastructure. In addition, **Dr. Chapman** represents BFRL on ***CIB W055, the Working Commission on Building Economics***.

Mr. Mark Palmer participates in the ***Hydraulic Institute (HI) Electronic Data Exchange (EDE) Committee***. The Hydraulic Institute, the association of pump manufacturers and related equipment and software suppliers, agreed to work with the ***FIATECH AEX Project*** and established an ***Electronic Data Exchange Work Group***. In FY2007, HI approved the development of an HI standard that will use AEX as the data exchange specification.

Mr. Christopher Currens represents BFRL on the ***CIB Task Group on Research and Innovation Transfer (TC 71)***.

Mr. Alan Lytle serves as the Chair of ***ASTM E57 3D Imaging Systems*** committee which was founded to provide 3D imaging system specification and performance evaluation for applications including construction and maintenance, surveying, and mapping and terrain characterization. **Mr. Lytle** also serves on the ***Breakthrough Strategies Committee of the Construction Industry Institute***.

Ms. Gerry Cheok serves as the Chair and **Dr. Kamel Saidi** serves as Vice Chair of ***ASTM E57.01 Terminology for 3D Imaging Systems*** and serves on the committee's executive board. Ms. Cheok and Dr. Saidi were principally responsible for successful development and balloting of the committee's terminology standard in 2007. **Dr. Saidi** also serves on the ***Breakthrough Strategies Committee of the Construction Industry Institute.***

Dr. Robert E. Chapman serves on the ***Benchmarking and Metrics Committee of the Construction Industry Institute (CII)***. The Benchmarking and Metrics Committee develops policy and procedures, provides oversight, and recommends a strategic approach to CII's collection, analysis, and dissemination of industry data. The committee develops key definitions to guide the effort and identifies critical measurements needed for identification of best practices and management of a continuous improvement program.

Mr. Mark Palmer serves on the ***Research Committee of the Construction Industry Institute (CII)***. The Research Committee develops policy to guide CII's research function. Annually, the committee develops a list of recommended research topics for review and authorization by CII's Board of Advisors, requests proposals from the academic community, and selects those proposals that best meet the intent of the research topic.

Sustainable Infrastructure Materials

Participation in standards organizations that support BFRL's strategic goal of sustainable infrastructure materials is focused on cementitious materials, polymeric materials, and metrics for sustainability.

Cementitious Materials

Mr. Paul Stutzman is active in multiple ASTM task groups and subcommittees of the ***ASTM Committee on Concrete (C90)***. He serves on the ***Subcommittee on Particle Size Analysis*** and on the ***C09.65 Petrography*** and the task group on scanning electron microscopy, ***C09.61 Resistance to the Environment***, and ***C09.66 Concrete's Resistance to Fluid Penetration Subcommittees***. Mr. Stutzman chairs the ***ASTM C01.23 Compositional Analysis Subcommittee*** as well as the task groups on ***X-Ray Diffraction Analysis and Microscopy***, and also is a member of the ***Executive, Administrative Coordination, Coordination of Standards, and Sulfate Content Subcommittees***. He participated in the development and writing of the *X-ray Powder Diffraction Test Method*, and also developed and coordinated the XRD Interlab study that led to the standard. Mr. Stutzman is currently involved in developing the *X-ray Flourescence Standard Test Method* and is analyzing interlaboratory data to evaluate precision and bias. These interlab studies are being used to establish performance criteria for qualification of laboratories.

The test methods are principal in estimating cement composition, which is used in cement specifications. Mr. Stutzman is also a member of the **Editorial Board for the *Journal of ASTM International***.

Mr. Ken Snyder is a member of ***ASTM Subcommittee C09.65 Petrography, Task Group on ASTM C 457 Air Void Analysis in Concrete***, which is currently working to revise the standard method to allow for automated systems and to include meaningful uncertainty statements. The *ASTM C 457* standard method is a standard procedure for characterizing the freeze-thaw durability of a concrete and is a time-consuming (4-6 hours constant attention) test.

Dr. Chiara Ferraris is the Secretary of the ***ASTM C01.29 Subcommittee on Sulfate Resistance***. She is helping the committee approve the NIST-developed test on accelerated testing of cement for sulfate resistance. This test would allow more widespread usage of supplementary cementitious materials in cement to improve durability. **Dr. Ferraris** is the Chair of ***ASTM C01.22 Subcommittee on Workability***, which is sponsoring new tests to measure the workability of cement paste in order to predict performance of concrete from its composition. Some of the technologies developed at NIST for cement paste measurements are now being considered to become an ASTM test method.

Dr. Ferraris chairs the ***ACI Committee 238, Workability of Fresh Concrete***. As Chair, she leads the international comparison of concrete rheometers, which identified the need for a granular reference material for calibration. NIST is working on developing such material from cement paste to concrete. Other fresh concrete properties are linked to material science that will allow prediction of concrete performance from composition and better measurement techniques. **Dr. Ferraris** is currently serving on the ***ACI Technical Activities Committee (TAC)***. This is the highest technical committee in ACI and helps NIST become aware of new technical challenges facing the concrete construction industry. She also is serving as an **Associate Editor for the *Journal of Materials in Civil Engineering***.

Mr. Dale Bentz is an active participant in ***ASTM Subcommittee C01.31 Volume Change***, where he led the adoption of *ASTM E1608-05 Test Method for Chemical Shrinkage of Hydraulic Cement Paste* and coordinated a completed interlaboratory study that established a multi-laboratory precision statement for the standard test method. **Mr. Bentz** is also a voting member of subcommittees ***C01.10 Hydraulic Cements for General Concrete Construction*** and ***C01.26 Heat of Hydration***. **Mr. Bentz** represents BFRL on ***ASTM Subcommittee C09.68***, where he is participating in a task group to develop a standard test method for "Autogenous Strain of Cement Paste and Mortar." He is also a voting member of ***ASTM Subcommittee C09.48***, where he is serving on a task group to develop a standard practice for "Measuring Hydration Kinetics of Hydraulic Cementitious Mixtures Using Semi-Adiabatic Calorimetry."

Polymeric Materials

Dr. Christopher White is an active participant on the ***ASTM C24 Building Seals and Sealants Committee***. He is a voting member in C24 and is leading the effort to develop a new test method within ***C24.20 General Test Methods***, specifically ***ASTM WK20492, New Test Method for Viscoelastic Characterization of Sealant Using Stress Relaxation***. This is the first of several test methods as part of the research efforts of the service life prediction for sealants industrial consortium. These standards will be critical to the adoption of performance based standards for materials used in building envelope design.

Metrics for Sustainability

Dr. Christopher White is an active participant in the ***ASTM E6.21 Serviceability of Performance of Buildings*** subcommittee. He has led the effort to create several standards relating to the measurement of the adhesion of spray applied fire resistive materials. Currently, the first standard is out to ballot on a new test method to measure the adhesive energy of SFRM on structural steel. These standards activities result from BFRL research with an industrial consortium at NIST. **Dr. White** is also a member of ***ESIS, European Structural Integrity Society, Technical Committee 4 (ESIS-TC4) on Polymers and Composites***. He recently presented updates on both the work on SFRM adhesion and service life prediction of sealants at the Committee's meeting in Switzerland. The proposed methods in ASTM are under consideration for adoption within ESIS-TC4 once they clear the ASTM process.

Ms. Barbara Lippiatt represents BFRL on ***CIB TG 70, the Task Group on Sustainable Design of Tall Buildings***. **Dr. Jonathan Martin** represents BFRL on the ***Working Commission dealing with Prediction of Service Life of Building Materials and Components (CIB W 080)***.

Innovative Fire Protection

BFRL staff are active in sharing the results of their research in national and international fire safety standards and codes organizations. Their activities parallel the program elements that support measurement science for innovative fire protection: advanced fire service technologies, fire spread within buildings and structures, and fire spread through communities including at the wildland/urban interface (WUI).

Mr. Richard Bukowski is a member of the ***NFPA Safety to Life Technical Correlating Committee***. The TCC provides oversight to the technical committees developing requirements for individual topics and assures that the requirements are consistent and correlated throughout the document. **Mr. Bukowski** also participates in several other NFPA committees including: ***Signaling Systems for the Protection of Life and Property Technical Correlating Committee, Technical Committee on Hazard and Risk of Contents and Furnishings***, and ***High Rise Building Safety Advisory Committee***.

Mr. Bukowski is a member of the ***ICC Code Technology Committee*** created by the ICC Board of Directors to develop positions and code change proposals on broad technical issues not amenable to the normal, incremental code development process. The CTC uses study groups to develop technical positions and holds public hearings before advancing positions in the code writing process. **Mr. Bukowski** is also the U.S. representative to ***ISO TAG8***, a technical advisory group to the ***Technical Management Board (TMB) of the International Organization for Standardization (ISO)***, which develops ISO standards. A current activity is the development of an ISO policy on performance standards.

Mr. Daniel Madrzykowski has been the Chair of the ***NFPA Research Section*** for the past four years. In this role he has been effective in transferring NIST fire research technology, by assisting with the development of the research program for the NFPA's World Safety Conferences.

Dr. Anthony Hamins represents BFRL on the ***CIB Working Commission on Fire, W014***. He also serves on the ***Research Advisory Committee for the Fire Protection Research Foundation (FPRF)***. The FPRF responds to the needs of the NFPA for technical information that supports standards development.

Dr. William Grosshandler chairs the ***International Forum of Fire Research Directors (FORUM)***, which aims to reduce the burden of fire (including the loss of life and property, and effects of fire on the environment and heritage) through international cooperation on fire measurements, standards, and related research activities.

In his capacity as a member of the ***Science Advisory Committee of the National Association of State Fire Marshals (NASFM)***, **Dr. Grosshandler** provides a link between the measurement science and standard test methods being developed at NIST and the Executive Committee of NASFM, an organization that represents the nation's top fire safety officials at the state level.

Dr. Grosshandler serves on the ***Underwriters Laboratories, Inc., (UL) Fire Council***, which advises UL on safety requirements for fire suppression equipment, fire resistant building designs, flame and smoke characteristics of building materials and other products related to fire safety. Fire Council Members may be involved in the UL Standards development process, reviewing proposals for new and revised Standards and new product reports.

Dr. Matthew Bundy represents BFRL as an associate member of the ***North American Fire Testing Laboratory (NAFTL) Consortium***. The purpose of the NAFTL Consortium is to provide a forum for the exchange of technical information, conduct studies, and develop industry consensus positions relating to the full range of standard fire tests, e.g., reaction to fire, fire suppression, fire resistance and fire detection.

Advanced Fire Service Technologies

Dr. Francine Amon is a member of and active participant in ***NFPA Technical Committee FAE-ELS on Electronic Safety Equipment***, for which she has provided performance metrics and test methods for measuring image quality of thermal imagers for *NFPA 1801 Standard on Thermal Imagers for the Fire Service*. She has also contributed to *NFPA 1800 Standard on Electronic Safety Equipment for Emergency Services* and *NFPA 1982 Standard on Personal Alert Safety Systems (PASS)*.

Dr. Amon is a member of the ***ASTM Subcommittee E07.10, Emerging NDT Methods***. This subcommittee is developing a test to evaluate the performance of infrared temperature measurement devices. This test method (ASTM E1543) gives an objective measure of the temperature sensitivity of a thermal imaging system (relative to a standard reference filter) exclusive of a monitor, with emphasis on the detector(s) and preamplifier. **Dr. Amon** is also a member of the ***ASTM Subcommittee E20.02, Radiation Thermometry***.

Mr. Nelson Bryner is a member of ***NFPA Technical Committee on Electronic Safety Equipment***. He has been working with this committee on the development of new performance metrics for thermal imagers, which have been incorporated into *NFPA 1801 Standard on Thermal Imagers for the Fire Service*. He has also worked with this committee on a new umbrella standard for all electronic safety equipment used by the fire service and on the existing *NFPA 1982, Standard on Personal Alert Safety Systems (PASS)*.

Mr. Bryner is a member of the ***ASTM Subcommittee E54.08, Operational Equipment***. This subcommittee is developing methods to evaluate the performance of radio communication links used in Urban Search and Rescue Robots, WK 14437. **Mr. Bryner** is also a member of ***ASTM Subcommittee E54.04, Personal Protective Equipment***. This subcommittee is working on standards for fire fighter respirators, protective clothing using reactive cooling, and fire fighter locator technologies including radio frequency identification.

Mr. James R. Lawson is an active participant on the ***ASTM F23 Main Committee on Protective Clothing and Equipment***. His activities on this committee include participation on the ***F23.8 Subcommittee on Heat and Thermal Tests*** for protective clothing and equipment and ***Subcommittee F23.6 on Human Factors*** related to the testing of protective clothing and equipment systems. Recently, Mr. Lawson has contributed to the development of new test methods, measurement techniques, and the maintenance of existing safety standards.

Mr. Lawson is an active member of ***NFPA Technical Committee on Structural and Proximity Fire Fighting Protective Clothing and Equipment***. The primary standards published by this committee were renewed in 2007. Several TIA's (Tentative Interim Amendments) were recently addressed that provided technical interpretation of the standard and corrected some difficulties associated with equipment performance testing.

Mr. Daniel Madrzykowski is the Chair of the ***International Association of Arson Investigators (IAAI) Engineering Committee***. The committee provides input and technical review for the IAAI Journal and the IAAI web-based training site, *www.CFITrainer.net*. Mr. Madrzykowski has assisted with the development of several CFI Trainer programs. He is also a member of the ***NFPA Technical Committee on Fire Investigations***. He works with the committee to utilize NIST measurement science results for the advancement of fire investigation technology and methodology.

In 2008, **Mr. Madrzykowski** joined the ***NFPA Technical Committee on Fire Service Training***. Live fire training is an essential part of developing a fire fighting team. The focus of NIST's effort is to assist the committee on improving the effectiveness and safety of live fire training, using results from real scale fire experiments and NIST-developed computer-based fire models.

Fire Spread within Structures

Mr. Jason Averill and **Mr. Richard Peacock** serve on the ***NFPA Technical Committee on Means of Egress***. The committee is responsible for the egress provisions in the *NPFA Life Safety Code, NFPA 101*, and the *NFPA Building Construction and Safety Code, NFPA 5000*. These standards are the primary conduits for activities related to results of the NIST Investigation of the World Trade Center collapse on September 11, 2001.

Mr. Richard Bukowski and **Mr. Averill** are members of a task group formed within the ***ASME/ANSI A17.1-2007***. The objective of the task group is to perform a hazard analysis outlining the requirements for use of elevators during emergencies (including fires) by occupants for evacuation and by emergency responders for firefighting and rescue operations. Mr. Bukowski has led analyses covering the minimum number of required elevators and elevator size requirements. Mr. Averill has led analyses covering the design of elevator controllers for emergency operation and requirements for elevator lobby enclosures.

Mr. Averill is a voting member of the ***ICC International Building Code Means of Egress Committee***, which considers code change proposals primarily to Chapters 10 and 11 of the International Building Code, which relate to egress and access provisions for new construction. Work is underway to ensure that code change proposals reflect the most advanced research findings in egress and occupant safety.

Mr. James R. Lawson is an active participant on the ***ASTM E5 Main Committee on Fire Standards***. He recently completed a six year period as Chairman of ***Subcommittee E5.15 on Furnishings and Contents***, where he managed the development of new fire test standards and guided the revision of numerous other standards. In addition, Mr. Lawson provided significant input to the development and revision of *ASTM E 2335-08 Standard Guide for Laboratory Monitors*, and he was the primary writer of *ASTM E 2653-08 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Fire Test Method with Fewer Than Six Participating Laboratories*. **Mr. Lawson** is also an active member of ***Subcommittee E5.22 on Surface Flammability and Subcommittee E5.23 on Combustibility***, where he has participated in the development and maintenance of more than a dozen fire standards. Additionally, he has worked with ***Subcommittee E5.11 on the ASTM E119*** test method for building construction relative to improvements in the standard associated with findings from the World Trade Center investigation.

Mr. Lawson is an active participant on the ***NFPA Fire Test Committee***, where he has worked on the evaluation, modification, and maintenance of existing NFPA fire test standards for building construction, building materials, furnishings, and contents. Much of the work this year was related to standards revisions. Developing and maintaining these standards is the cornerstone to effective control of the fire contribution of products in the United States.

Dr. Richard G. Gann is an active member of ***ASTM E5.15 on Furnishings and Contents*** and ***E5.21 on Smoke and Combustion Products***. The NIST role is guiding the development of standards that lead to reduced ignitions and uniform characterization of the mass and nature of combustion products from fires. **Dr. Gann** chairs ***Task Group E5.15.09 on Cigarette Ignition Propensity***, where he is the principal author of *ASTM E 2187 Standard Test Method for Measuring the Ignition Strength of Cigarettes*. Thirty-seven states, Canada, Australia, and Finland have adopted regulations based on this standard, with the European Union underway. Preliminary data from New York State indicate a significant reduction in fire deaths due to this Standard. **Dr. Gann** also chairs ***E5.21.50***, where he is the principal author of *ASTM E1678, Standard Test Method for Measuring Smoke Toxic Potency for Use in Fire Hazard Analysis*. This and the companion document, *NFPA 269*, are the only U.S. standards that provide a basis for including the effects of fire effluent in engineered fire safety.

Dr. Gann chairs the ***NFPA Toxicity Technical Advisory Committee (TTAC)***, which provides authoritative advice to the NFPA Standards Council on toxicity-related issues arising from code committee deliberations. The TTAC thus promotes consistency in the way provisions in the various NFPA fire and building codes address human tenability in fires, providing a uniform basis for specification and acceptance of construction and furnishing products.

Dr. Gann sees U.S. participation in the ***ISO TC92 Committee on Fire Safety*** as the key to minimizing the potential for U.S. manufacturers to face unsound and prohibitive fire standards in international markets. TC92 is also the forum where the relatively few experts in the broad reach of fire science and technology pool their expertise to develop standards for reducing ignitions, keeping fires small, and reducing the harmful effects of heat and smoke. **Dr. Gann** chairs and has revitalized ***TC92 SC3, Fire Threat to People and the Environment***. During the eight years of his leadership, the subcommittee has increased the number of published standards from one to nine, with eight more under development. Combined, these documents provide the technical basis for incorporating human tenability in fire safety engineering. **Dr. Gann** is also active in ***SC4, Fire Safety Engineering***, and in ***SC1, Fire Initiation and Growth***. He is an Assigned U.S. Expert to ***SC4 Working Groups on general principles for fire safety engineering***, ***input data for fire safety engineering, and fire risk***. He also chairs the U.S. Technical Advisory Group to SC4, the group that develops the U.S. positions on ballots from this subcommittee. Dr. Gann is a Project Leader in SC1, leading development of ISO Standards that mirror the U.S. standards for less fire-prone cigarettes and low heat release mattresses. Broadening the realm of these methodologies will enhance the likelihood that the increased fire safety of U.S. products will be reinforced by imported products and increase the openness of markets for U.S. products. **Dr. Gann** also sits on the ***Technical Program Management Board of ISO TC92***.

Dr. Jeffrey W. Gilman and **Dr. Rick Davis** are members of ***ASTM E5.15 on Furnishings and Contents***. The NIST role is guiding the development of standards that lead to reduced ignitions and uniform characterization of the mass and nature of combustion products from fires.

Dr. Nathan D. Marsh is an active participant in ***ISO 92/SC3 and SC4***. His focus is on the several documents involving the generation and measurement of chemical species that affect human tenability in fires and the environmental effects of fires.

Dr. Jiann C. Yang is a principal voting member of the ***NFPA-2 Technical Committee on Hydrogen Technologies***. He currently serves on the ***Committee Task Group 10 on Explosion***. The Group is tasked to review the draft of Explosion Protection Provisions in NFPA-2. **Dr. Yang** is also a principal voting member of the ***NFPA-2001 Technical Committee on Gaseous Fire Extinguishing Systems***. **Dr. Greg Linteris** is technical advisor to this committee.

Mr. Thomas Cleary is a member of ***UL 1994 STP Luminous Egress Path Marking Systems*** and has been reviewing proposals for revisions to the 3rd edition of the standard. **Mr. Cleary** is also assisting ***UL 217/268 on Smoke Detectors and Alarms*** as a technical expert. He is a member of a task group working on nuisance alarms which formulated a report urging nuisance alarm testing of residential smoke alarms to be used near cooking appliances.

Mr. Cleary, as a member of ***NFPA 72 National Fire Alarm Code 11 SIG HOU***, led a task group focused on combination photo/ion smoke alarm sensitivity and performance. He is also a member of ***NFPA 76 Standard for the Fire Protection of Telecommunications Facilities***.

Mr. Richard Peacock serves as a member of ***ASTM E05.33 on Fire Safety Engineering***. This subcommittee is responsible for development of standards for the evaluation and documentation of predictive fire models. BFRL has been key in the development of *ASTM E 1355, Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*.

Dr. Paul Fuss participates as a member of ***ASTM E05*** and participates in ***Subcommittee ASTM E.05.33, Fire Safety Engineering***, which is developing standards related to obtaining data and determining predictive capability for fire models. He is also a member of ***Subcommittees E.05.13, Large Scale Fire Tests,*** and ***E.05.32 on Research***.

Dr. Kevin McGrattan is a member of two SFPE Technical Working Groups, the ***SFPE Standards Making Committee on Predicting the Thermal Performance of Fire Resistive Assemblies*** and the ***SFPE Task Group on Substantiating a Computer Model as being Appropriate for a Given Application***. The former is drafting a standard on the thermal resistance of structures, and the latter is drafting a guide on the appropriate uses of fire models. Both are expected to be completed by the end of 2009.

Mr. Richard Peacock represents NIST on ***NFPA 130*** and ***ASTM E05.17*** developing standards for fire safety in passenger rail vehicles. Mr. Peacock is working with the Federal Transit Administration and the National Association of State Fire Marshals to update the FTA *Recommended Fire Safety Practices for Rail Transit Materials Selection Manual*. These recommendations represent an upgrade of guidelines, including *Urban Mass Transportation Administration, Recommended Fire Safety Practices for Rail Transit Materials Selection* published in the Federal Register in 1984.

Fire Spread through Communities

Dr. Samuel L. Manzello is a voting member of ***ASTM E05.14 Subcommittee on External Fire Exposures***. New standards are being developed, aimed at mitigating firebrand penetration into building vents. Dr. Manzello is leading the development of a testing protocol for vents standards through full scale testing.

Dr. William Mell and **Mr. Alex Maranghides** are members of ***NFPA Technical Committee on Forest and Rural Fire Protection***. This committee has primary responsibility for documents on fire protection for rural, suburban, forest, grass, brush, and tundra areas. A recent result is *NFPA 1144, Standard for Reducing Structure Ignition Hazards from Wildland Fire, 2008 Edition*.

Disaster-Resilient Structures and Communities

BFRL's strategic goal for disaster-resilient structures and communities requires active participation in a wide range of standards organizations, dealing with seismic design, structural loads, and structural fire resistance.

Dr. Shyam Sunder serves on the ***Board of Directors of the Building Seismic Safety Council***, established in 1979 by the National Institute of Building Sciences (NIBS)—a Congressionally chartered institution, to develop and promote building earthquake risk mitigation regulatory provisions for the nation by dealing with the complex regulatory, technical, social, and economic issues.

Seismic Design

Dr. John Harris participates in the ***AISC Committee on Manuals and Textbooks***. The committee is responsible for the continual development, review, and maintenance of technical guidance related to the design of structural steel, including the *Manual of Steel Construction, Design Guide* series, and *Seismic Design Manual*. **Dr. Harris** is a member of ***AISC Task Committee 9 (TC 9) – Seismic Design***. The committee is responsible for development of the *Seismic Provisions for Structural Steel Buildings*. He is also active within the American Society of Civil Engineers (ASCE) where he serves on the Seismic Subcommittee (SSC) for ***ASCE 7 – Minimum Design Loads for Buildings and Other Structures (TC2 – General Provisions)***. This committee is responsible for development of the seismic provisions of ASCE 7, and is currently focused on the Risk Targeted Earthquake to replace the Maximum Considered Earthquake, in an effort to make risk the common denominator in design, instead of hazard.

Structural Loads

Dr. Emil Simiu is distinguished member of the ***ASCE 7 Committee on Minimum Loads on Buildings and Other Structures*** and a member of its ***Subcommittee on Wind Loads***. He led efforts that resulted in the incorporation in the ASCE 7 standard of a provision allowing the application of database-assisted design within the framework of the wind tunnel method. ASCE 7 has also recently included methods for estimating wind speeds based on the logarithmic law, long advocated by NIST. Proposals based on BFRL research submitted recently have been approved by the ***ASCE 7-10 Wind Load Subcommittee*** on the relation between Saffir-Simpson hurricane scale and design wind speeds; database-assisted design; and wind directionality effects (per the World Trade Center (WTC) investigation report recommendation). Dr. Simiu also authored, and is monitoring the response to, a NIST appeal concerning the draft ASCE standard on wind tunnel testing, with a view to implementing WTC Investigation recommendations on wind effects on tall buildings. BFRL work was incorporated into the NRC Regulatory Guide 1.76, *Design-basis tornado and tornado missiles for nuclear power plants* (2006). Dr. Simiu is currently developing, in conjunction with NRC, criteria on hurricane-borne missile speeds. **Dr. Simiu** is also a member of the ***ASCE Committee on Temporary Structures***.

Dr. Therese McAllister serves as a voting member on the ***ASCE 7 Standard Main Committee*** and participates on the ***General Requirements and Load Combinations Subcommittees***. ASCE 7 prescribes the minimum design loads for buildings and other structures and is referenced by the current model building codes.

Dr. Christopher White is an active member of ***ASTM E54.08 Operational Equipment for Homeland Security***. He led the creation of a new standard ***ASTM WK11343 – New Test Method for Blast Resistance of Trash Receptacles***. This standard, the first of three, will be adopted by the Department of Homeland Security. Two additional standards on a specification for the use of blast resistance of trash receptacles are under development. These standards are being developed in response to the expressed needs of both the Department of Homeland Security and the major transit agencies.

Dr. Fahim Sadek represents BFRL on ***CIB Task Group on Disasters and the Built Environment (TG 63)***.

Dr. H. S. Lew serves on ACI Committee 318, which is responsible for developing ***ACI Standard 318 – Building Code Requirements for Structural Concrete***. Dr. Lew introduced new provisions for adoption by ACI 318. Dr. Lew serves on Subcommittee C for safety, serviceability and analysis. Dr. Lew also serves on the ***SEI/ASCE Executive Committee on Codes and Standards*** that oversees the development of 27 standards including A-7 Standard on Minimum Design Loads for Buildings and Other Structures. He works closely with committees that develop standards for seismic evaluation and rehabilitation of buildings, and structural condition assessment and rehabilitation. He also participates in the ***SEI/ASCE Committee on Blast Protection of Buildings***. The committee develops standards for blast resistance design and construction of new and existing structures.

Dr. John L. Gross serves on the ***American Institute of Steel Construction (AISC) Committee on Specifications***. The committee is responsible for developing requirements for the design, fabrication and erection of steel buildings and publishes the Specification for Structural Steel Buildings. Dr. Gross serves on Technical Subcommittee 3 (TC3) – Loads, Analysis and Systems, and TC8 – Design for Fire.

Structural Fire Resistance

Dr. Long Phan is an active voting member and former Chairman of ***ACI TC 216 Fire Protection of Concrete & Masonry Structures***. While serving as Chairman of the committee, he led the effort to revise ACI standard on fire protection of concrete and masonry structures by incorporating recent knowledge on fire performance of high strength concrete (HSC), obtained from research at NIST and elsewhere, into the standard. Prior to this effort, the standard was only applicable to normal strength concrete. This effort culminated in the publication of *ACI 216.1-07 Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies* in July 2007.

Dr. Phan is an active voting member of ***ASCE Standard Committee 29 Standard Calculation for Structural Fire Protection***. He contributed to the revision and publication of *ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection* in 2005. He was recently selected by ASCE to serve as Chairman of the ***ASCE Fire Protection Committee***. **Dr. Phan** is also a Senior Member of the ***International Union of Research and Testing Laboratories for Materials and Structures (RILEM) High Temperature Concrete Committee***. This committee issues a series of recommendations on testing of concrete at elevated temperature for possible adoption by international code organizations.

Mr. Dale Bentz is an active participant in ***ASTM Subcommittee E37.05***, where he led the adoption of *ASTM E2584-07 Standard Practice for Thermal Conductivity of Materials Using a Thermal Capacitance (Slug) Calorimeter*. This practice has been commercialized and also adopted by several private testing laboratories nationwide. Currently, Mr. Bentz is coordinating an interlaboratory study to develop a multi-laboratory precision statement for the standard practice. The specific application for which this test method was developed was sprayed fire resistance materials (SFRM) for structural steel.

Dr. John L. Gross has been appointed to represent the United States (through ANSI) to serve as expert on ***International Standards Organization ISO/TC 92/SC 4/WG12 – Structures in Fire***. ISO TC92 Fire Safety produces internationally accepted standards and documents on fire testing, measurements of fire parameters, fire safety engineering and other related topics. Subcommittee SC4 provides fire safety engineering documents for supporting performance-based design for fire.

Staff Highlights and Awards

Gold Medal

The Gold Medal Award is the highest honor award conferred upon an employee by the Department of Commerce. It is bestowed for "distinguished performance characterized by extraordinary, notable, or prestigious contributions that impact the mission of the Department of Commerce and/or one operating unit and which reflect favorably on the Department."

2008

Stephen Kerber and Daniel Madrzykowski

Mr. Kerber and Mr. Madrzykowski were recognized for advancing the science and understanding of positive pressure ventilation (PPV) and wind-driven fires and transferring this knowledge to the fire service, arson investigators, and codes officials. This research combined both experimental and modeling components to understand and document how wind impacts fires in structures and how positive pressure ventilation can improve the safety and effectiveness of fire fighters. The research has led to implementation of better fire fighting tactics and will lead to decreased injuries for fire fighters and building occupants.

Stephen Kerber and Daniel Madrzykowski, recipients of a 2008 Department of Commerce Gold Medal.

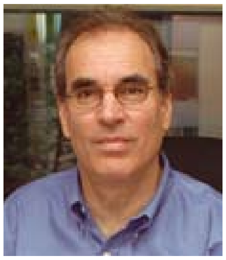
Silver Medal

The Silver Medal is the second highest honor awarded by the Department for "exceptional performance characterized by noteworthy or superlative contributions that have a direct and lasting impact".

2008

Andrew Persily

Dr. Persily was recognized for contributions to the increased protection of building occupants against airborne chemical and biological releases through the development and application of measurement science and predictive tools related to building airflow and contaminant transport. His technical accomplishments have lead to new technologies and practices. Both the public and private sectors have benefited from this effort through safer and more secure buildings including iconic structures such as the U.S. Capitol and the Pentagon.



Andrew Persily, recipient of a 2008 Department of Commerce Silver Medal and elected Vice President, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

2007

Stephen Cauffman, Dat Duthinh, Long Phan, and Fahim Sadek

The group was recognized for conducting the reconnaissance of the performance of structures during Hurricanes Katrina and Rita. The team collected perishable data during field reconnaissance, analyzed data on wind, storm surge and flooding. The comprehensive report included recommendations to improve the safety of buildings, infrastructure, and residential structures in the future. Actions consistent with NIST's recommendations are being taken by federal, state, and local agencies to improve safety in hurricane prone regions of the country.

Stephen A. Cauffman, Dat Duthinh, Long T. Phan, and Fahim Sadek, recipients of a 2007 Department of Commerce Silver Medal.

Bronze Medal

The Bronze Medal Award is the highest honorary recognition available for Institute presentation. The award, approved by the Director, recognizes work that has resulted in more effective and efficient management systems as well as the demonstration of unusual initiative or creative ability in the development and improvement of methods and procedures. It also is given for significant contributions affecting major programs, scientific accomplishment within the Institute, and superior performance of assigned tasks for at least five consecutive years.

2008

William Davis, Michelle Donnelly, James Lawson, and Michael Selepak

The group was recognized for their careful and original measurements of the performance of electronic safety equipment used by emergency responders. They developed four Thermal Exposure Classes for fire fighter exposure conditions and characterized the performance of gas monitors and personal alert safety system (PASS) devices that are used by over 1.25 million fire fighters across the country.

Michael Selepak, Michelle Donnelly, James Lawson, and William Davis, recipients of a 2008 NIST Bronze Medal.

Nelson Bryner, Andrew Lock, and Francine Amon, recipients of a 2008 NIST Bronze Medal.

Francine Amon, Nelson Bryner, and Andrew Lock

The group was recognized for the comprehensive development of performance measurements for thermal imaging technology utilized by fire fighters and first responders. The team provided the scientific basis necessary to develop test methods that assess the performance of thermal imaging technology, allowing for better development and evaluation, and allowing fire fighters to use improved technology to reduce fatalities and injuries to both civilians and fire fighters.

2007

Paul Stutzman

Mr. Stutzman was recognized for his excellent measurement science and technical leadership resulting in the writing and adoption of ASTM C1365-06 Standard Test Method for Determination of the Proportion of Phases in Portland Cement and Portland-Cement Clinker Using X-Ray Powder Diffraction Analysis. This is the world's first X-ray powder diffraction method for cement and the first ASTM standards based on the Rietveld method for powder diffraction analysis. As a result of his research, uncertainties for all cement phases are now in the few percent range, down from 100% uncertainty for the crucial minor phases.

Paul Stutzman, recipient of a 2007 NIST Bronze Medal and an ASTM International P. H. Bates Memorial Award.

Robert Vettori, Jay McElroy, Michael Selepak , Nelson Bryner, David Stroup, Stephen Kerber, Roy McLane, and Daniel Madrzykowski, recipients of a 2007 NIST Bronze Medal.

Nelson Bryner, Stephen Kerber, Daniel Madrzykowski, Jay McElroy, Roy McLane, Michael Selepak, David Stroup, Robert Vettori, and Anthony Kos

The group was recognized for completing a complex series of live fire tests in a 16-story Chicago apartment building to characterize the performance of two fire fighting technologies: positive pressure ventilation (PPV) systems, and radio frequency identification (RFID) tracking systems. PPV provides better conditions for building occupant evacuation and fire fighter operations. RFID tags allow fire fighters to update their locations while working inside complex structures. The data collected and the standards that will evolve from the data will allow both of these critical technologies to be safely and effectively utilized by the fire service to reduce property loses and minimize injuries to fire fighters and civilians throughout the United States.

A. Hunter Fanney

Dr. Fanney was part of a group recognized for contributions to the first-ever assessment of the U.S. measurement system's ability to sustain innovation at a world-leading pace. The detailed results are

Hunter Fanney, recipient of a 2007 NIST Bronze Medal.

presented in the report, "An Assessment of the U.S. Measurement System: Addressing Measurement Barriers to Accelerate Innovation," Dr. Dennis A. Swyt, National Institute of Standards and Technology, NIST Special Publication 1048, February 2007. The results of this project have been recognized by Administration and Congressional policy makers, and the report is helping guide priority setting by NIST and private and public sector organizations as they identify and overcome measurement barriers to innovation.

2008 Allen V. Astin Measurement Science Award

Robert Zarr, recipient of a 2008 NIST Allen V. Astin Measurement Science Award.

Robert Zarr

The Allen V. Astin Measurement Science Award is given annually to recognize outstanding achievement in the advancement of measurement science. Mr. Zarr was recognized for being solely responsible for the NIST 1-meter guarded hot plate facility, which serves as the nation's standard in the measurement of thermal conductivity of building insulation. He has recently completed a new facility that is capable of measuring the thermal conductivity of insulation from 90K to 900K. To promulgate measurements conducted at NIST, he developed a Web-based Standard Reference Database for over 2,000 thermal conductivity measurements. He also developed five Standard Reference Materials, participated in six inter-laboratory comparisons, and provided over 100 thermal conductivity measurements to industry, academia, and other government laboratories.

2008 Equal Employment Opportunity/Diversity Award

Kathryn Butler and Chiara Ferraris

Dr. Butler and Dr. Ferraris have been active during their entire tenure at NIST, working individually and as a team to bring students and young women to NIST to expose them to the exciting challenges and opportunities associated with their research and that of others throughout NIST. They have enhanced the NIST work environment for all staff through their considerable investment of time and effort to ensure the success of Girl Scout Day, Take your Sons and Daughters to Work Day, the Summer Undergraduate Research Fellowship (SURF) Program, the NIST Committee for Women, and the Administrative and Support Professional Day.

Kathryn Butler and Chiara Ferraris, recipients of a 2008 Equal Employment Opportunity/Diversity Award.

2008 Department of Commerce Special Act Awards

Terri McAllister, Richard Gann, John Gross, Kevin McGrattan, Bill Pitts, Kuldeep Prasad, Jason Averill, Richard Bukowski, Steve Cauffman, Fahim Sadek, Kathy Butler, Randy Lawson, Val Junker and Harold Nelson

Each recipient was recognized for distinguished contributions to the investigation of the World Trade Center Building 7 collapse.

Gail Crum

Ms. Crum was recognized for exceptional and sustained support to the Building and Fire Research Laboratory.

Gail Crum, recognized for exceptional and sustained support to the Building and Fire Research Laboratory.

2007 BFRL Communicator Award

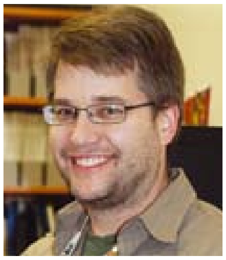
Richard Bukowski

Mr. Bukowski was recognized for his contributions to the collection, organization and dissemination of information on elevator use by occupants and fire fighters during fire emergencies from 2001-2007.

2007 BFRL Communication Award

Steven Emmerich

Mr. Emmerich was recognized for the paper "Simulation of the Impact of Commercial Building Envelope Airtightness on Building Energy Utilization," Emmerich, S. J.; McDowell, T.; and W. Anis, *ASHRAE Transactions*, July, 2007.



Steven Emmerich, recipient of a 2007 BFRL Communication Award and a 2008 BFRL Certificate of Appreciation for distinguished contributions to the NIST Washington Editorial Review Board.

2006 BFRL Communication Awards

William Healy

Dr. Healy was recognized for the paper "In-situ Measurement of the Moisture Content of Building Materials Using Ultra-Wideband Radio Waves," Healy, W. M., *Proceedings of the 3rd International Building Physics Conference*, International Building Physics Conference, Montreal, Canada, August 2006.

Mark Kedzierski

Dr. Kedzierski was recognized for the paper, "A Comparison of R245fa Pool Boiling Measurements to R123, and R245fa/Isopentane on a Passively Enhanced Horizontal Surface," Kedzierski, M. A., *International Journal of Transport Phenomena*, April 3, 2006.

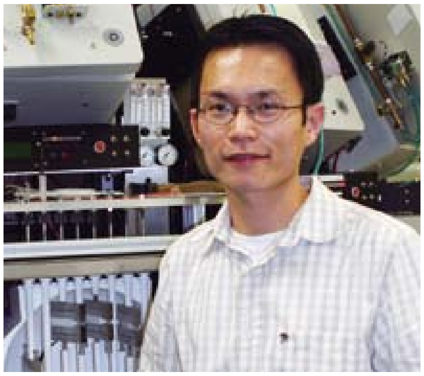
Mark Kedzierski, recipient of a 2006 BFRL Communication Award.

2008 Distinguished Associate Awards

Liangzhu (Leon) Wang

Mr. Wang was recognized for the development of methods for measuring and simulating carbon monoxide exposure in homes resulting from portable generators operating in attached garages and outdoors.

Liangzhu (Leon) Wang, recipient of a 2008 BFRL Distinguished Associate Award.



Kar Tean Tan, recipient of an Adhesion Society Outstanding Young Adhesion Technologist Award and a 2008 BFRL Distinguished Associate Award.

Kar Tean Tan

Mr. Tan was recognized for his prodigious and inspiring contributions to adhesion, fracture mechanics, rheology, and standards development associated with these technical areas.

Mauro Zammarano

Mr. Zammarano was recognized for pioneering research leading to improved understanding of the flammability of materials.

2007 BFRL Distinguished Associate Awards

Xiaohong Gu

Dr. Gu was recognized for distinguished contributions to the development of nanoscale characterization techniques for predicting the service life and durability of polymeric material systems.

Harold Nelson

Dr. Nelson was recognized for distinguished contributions in conducting the Federal Building and Fire Safety Investigation of the World Trade Center Disaster.

Harold Nelson, recipient of a 2007 BFRL Distinguished Associate Award and a 2008 Department of Commerce Special Act Award.

Daniel Flynn

Mr. Flynn was recognized for distinguished contributions to the design and fabrication of the NIST 500mm Guarded Hot-Plate Apparatus.

2008 BFRL Safety Awards

Stephanie Watson

Dr. Watson was recognized for her conscientious and proactive approach to safety within the Materials and Construction Research Division.

John Wamsley, Nicholas Scott, Nathan Marsh and Kamel Saidi

The group was recognized for a conscientious and proactive approach to safety as members of the High Voltage Hazard Tiger Team.

2007 BFRL Safety Award

Luis Luyo

Mr. Luyo was recognized for his conscientious and proactive approach to safety within the Building Environment Division.

2008 BFRL Support Staff Awards

Jennifer Horning

Ms. Horning was recognized for her outstanding administrative support to the Materials and Construction Research Division.

Jennifer Horning, recipient of a 2008 BFRL Support Staff Award.

John Winpigler

Mr. Winpigler was recognized for his outstanding property management support to the Building and Fire Research Laboratory.

2007 BFRL Support Staff Awards

Paula Svincek

Ms. Svincek was recognized for her outstanding administrative support to the Building and Fire Research Laboratory.

Regina Burgess

Ms. Burgess was recognized for her outstanding support to the Building and Fire Research Information Services.

2008 Certificates of Appreciation

H.S. Lew and Kellie Beall

Dr. Lew and Ms. Beall were recognized for exceptional support to the investigation of the World Trade Center 7 collapse.

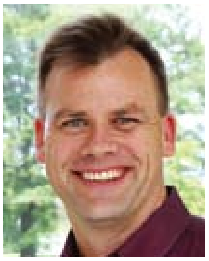
Gerry Cheok, Paul Reneke and Steve Emmerich

The group was recognized for distinguished contributions as the BFRL Representative to the Washington Editorial Review Board.

ASTM International Robert J. Painter Memorial Award

Alan Lytle

Mr. Lytle was recognized for his standards work for 3D imaging systems. This award is presented to the individual contributing the most outstanding service in a given year in the field of standards. The presentation was held at the 57th SES Annual Conference in San Diego, California, on Aug. 18, 2008.



Alan Lytle, recipient of an ASTM International Robert J. Painter Memorial Award, a SPAR 2007 Distinguished Achievement Award, and a FIATECH Celebrates Engineering and Technology Innovations (CETI) Outstanding Early Career Researcher Honorable Mention.

2007 International FORUM of Fire Research Directors Sjolin Award

Richard Gann

Dr. Gann was recognized for outstanding contributions of extraordinary significance to fire safety engineering by quantifying the propensity of cigarettes to ignite soft furnishings, and providing the scientific foundation for selecting fire suppressants for aircraft applications. The award was presented at the 2008 meeting of the International Association of Fire Safety Science.

Richard Gann, recipient of a 2008 Department of Commerce Special Act Award and an International FORUM of Fire Research Directors Sjolin Award.

ASTM International P. H. Bates Memorial Award

Paul Stutzman

Mr. Stutzman was recognized for the paper "Phase Analysis of Hydraulic Cements by X-ray Powder Diffraction: Precision, Bias, and Qualification" Stutzman, P. E., *Journal of ASTM International*, February, 2007, and its presentation relating to the subject of the manufacture, handling, testing, usage, or any other aspect of hydraulic cement that comes within the scope of Committee C01 on Cement.

Delmar L. Bloem Distinguished Service Award, from ACI (the American Concrete Institute)

Clarissa Ferraris

Dr. Ferraris was recognized for her outstanding leadership of Committees 236, Material Science of Concrete, and 238, Workability of Fresh Concrete.

Superior Civilian Service Award from the U.S. Department of the Army

William Davis

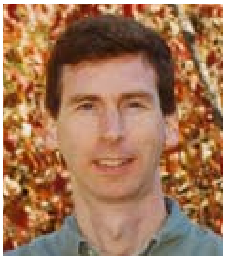
Dr. Davis was recognized for of his contribution to the Stem-to-Stern Safety Review of the Boston Central Artery/Tunnel project. Working with the Office of the Inspector General of the Department of Transportation, Davis was instrumental in reviewing fire protection systems, and in specifying a more severe "worst-case" design fire for the safety review.

William Davis, recipient of a Superior Civilian Service Award from the U.S. Department of the Army.

2007 Interflam Trophy

Kevin McGrattan

Awarded at the 11th International Fire Science and Engineering Conference (Interflam) held in London, England, Sept. 1-3, 2007, this award is given out once every three years to someone who has just completed a key contribution to fire science, or to someone who has had a sustained leadership in a particular area. Dr. McGrattan represents excellence in both categories for his key contribution to the development of the NIST FDS (Fire Dynamic Simulator), and to his sustained leadership in the application of computational fluid dynamic models in fire protection engineering practice.



Kevin McGrattan, recipient of a 2007 Interflam Trophy.

Top Seismic Program of the Twentieth Century

NEHRP

The National Earthquake Hazards Reduction Program (NEHRP) received an award for being the "Top Seismic Program of the Twentieth Century" at a national awards dinner that was hosted by the Applied Technology Council (ATC) and *Engineering News-Record* magazine. The NEHRP team is composed of the

Federal Emergency Management Agency (FEMA), NIST, the National Science Foundation, and the U.S. Geological Survey. NIST serves as the NEHRP lead agency and houses the NEHRP Secretariat, directed by Jack Hayes, within BFRL.

Elected Vice President, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

Andy Persily

In June 2008, Dr. Persily was elected for a one-year term as a Vice-President of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). He will chair the ASHRAE Technology Council, which is responsible for standards development, research and related technical activities.

American Society for Testing and Materials (ASTM) International William Cullen Award

Walter Rossiter

Dr. Rossiter was recognized for his distinguished contributions and personal commitment to ASTM Committee D08 and to the field of roofing and waterproofing through his extensive research, prolific publication, and exemplary leadership. This is the Committee's highest award and is named in honor of Bill Cullen, who worked for more than 30 years in Building Materials at NBS/NIST. The award was presented to Rossiter at the meetings in Denver, Colorado, on June 23, 2008.

SPAR 2007 Distinguished Achievement Award

Alan Lytle

Mr. Lytle was recognized for valuable service advancing engineering and construction technology and work processes. Awarded March 26, 2007, in Houston Texas.

Elected President, Commission B1, Thermodynamics and Transfer Processes, International Institute of Refrigeration (IIR) Science and Technology Council

Piotr Domanski

The International Institute of Refrigeration (IIR) has elected Dr. Domanski to serve as the 2007-2011 President of Commission B1, Thermodynamics and Transfer Processes. This election also places Dr. Domanski on the IIR Science and Technology Council. The mission of the IIR is to promote expansion of knowledge and dissemination of information on all refrigeration technologies and their applications to address today's major issues, including food safety and protection of the environment (mitigation of global warming, prevention of ozone depletion), and the development of the least developed countries (food, health).

Piotr Domanski, elected President, Commission B1, Thermodynamics and Transfer Processes, International Institute of Refrigeration (IIR) Science and Technology Council, and recipient of a ASHRAE Distinguished Service Award.

Honorary "Diploma" from BACnet Interest Group-Russia

Steven Bushby

Mr. Bushby was presented with a "diploma" conveying honorary membership in the BACnet Interest Group-Russia (BIG-RU), by Andrey Golovin, executive director of BIG-RU, at the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) conference in New York City, New York. BACnet is an international standard communication protocol for building automation and control systems developed collaboratively by NIST and industry partners under the auspices of ASHRAE. BIG-RU promotes the use of BACnet technology in Russia through educational activities, professional training, and business services for companies seeking to do business in the building automation market in the Russian Federation. The honorees were recognized for the role they played in helping to establish and support BIG-RU by giving keynote addresses at an international conference in Moscow and other activities related to the successful launch of the new organization.

FIATECH (Fully Integrated and Automated Technology) 2006 STAR Award for Technical Leadership

Mark Palmer

FIATECH is a research, development, and deployment consortium that joins together facility owners, operators, contractors, government agencies, and academic organizations to work together to develop and use high-value technologies. Mr. Palmer received this award in recognition of his significant contributions to many of the FIATECH initiatives and his leadership of the AEX (Automating Equipment Information Exchange) Project.

Mark Palmer, recipient of the FIATECH 2006 STAR Award for Technical Leadership.

Expanded Shale, Clay, and Slate Institute Frank G. Erskine Award

Dale Bentz

Mr. Bentz was selected in 2007 as the recipient of the Frank G. Erskine award by the Expanded Shale, Clay, and Slate Institute for his research on internal curing using lightweight aggregates.

Dale Bentz, recipient of both the Frank G. Erskine Award and an ACI Wason Medal for Materials Research, and named Associate Editor of *Cement and Concrete Composites*.

Adhesion Society Outstanding Young Adhesion Technologist Award

Kar Tean Tan

Mr. Tan was recognized for conducting outstanding work in the innovative application and/or use of an adhesive or sealant.

Samuel Manzello, recipient of an invitational fellowship from the Japan Society for the Promotion of Science.

Fellowship from Japan Society for the Promotion of Science (JSPS)

Samuel Manzello

Dr. Manzello received a fellowship from JSPS Invitation Fellowship Programs for Research in Japan. This prestigious fellowship is one of only 16 fellowships granted in engineering sciences in 2008. Dr. Manzello's host institute was the Building Research Institute (BRI) in Tsukuba, Japan. As a JSPS fellow, Dr. Manzello's research focused on using the Fire Research Wind Tunnel Facility at BRI to conduct wildland-urban interface fire research.

Elected American Concrete Institute (ACI) Fellow

Edward Garboczi

Dr. Garboczi was recognized for outstanding contributions to the American Concrete Institute and to concrete technology. The position of ACI Fellow was established by ACI in 1973 stating that "A Fellow shall be a person who has made outstanding contributions to the production or use of concrete materials, products, and structures in the areas of education, research, development, design, construction, or management."

Edward Garboczi, elected ACI Fellow.

Elected American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Fellow

Steven Bushby

This award recognizes distinction in the arts and sciences of heating, ventilation, air conditioning, and refrigeration technology. Bushby was recognized for his research on integrated and "intelligent" building control systems that have led to national and international standards and a new generation of commercial building control products used in over 80 countries.

Elected American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Fellow

Piotr Domanski

This award, which recognizes distinction in the arts and sciences of environmental technology, is based on Dr. Domanski's contributions benefiting the refrigeration and air-conditioning industry. Dr. Domanski was cited for his research on stratospheric ozone-safe refrigerants, modeling work on vapor-compression systems, and development of rating procedures used by industry.

American Concrete Institute's (ACI) Wason Medal for Materials Research

Dale Bentz

Mr. Bentz was recognized for the paper "Mixture Proportioning for Internal Curing," Bentz, D. P., Lura, P., Roberts, J. W., *Concrete International*, 27 (2), pp. 35-40, February 2005. The paper was co-authored by Pietro Lura of the European Patent Office and John Roberts of Northeast Solite Corp. The award was presented at the opening session and awards program during ACI's convention in Atlanta, Georgia, April 22, 2007. The Wason Medal for Materials Research was established by ACI in 1917 for "original research work on concrete materials and their use, or a discovery that advances the state of knowledge of materials used in the construction industry."

Roon Foundation Award for Best Technical Paper

Jonathan Martin and Tinh Nguyen

Dr. Martin and Dr. Nguyen were recognized for the paper "A Novel Method to Covalently Functionalized Carbon Nanotubes with Isocyanate for Polyurethane Nanocomposite Coatings," Nguyen, T., Granier, A., Steffens, K., Lee, H. J., Sharpiro, A., and Martin, J., *Proceedings of the International Coatings Exhibition and Conference*, Toronto, Canada, October, 2007. The award was presented by the Federation of Societies for Coatings Technology and Coatings Industry Education Fund on October 5, 2007, in Toronto, Canada.

Tinh Nguyen and Jonathan Martin, recipients of a Roon Foundation Award for Best Technical Paper.

The Japanese Association for Wind Engineering (JAWE) Prize for Outstanding Publication

Emil Simiu

Awarded to Dr. Simiu and to Dr. Toshio Miyata, Emeritus Professor of Yokohama National University in Japan, in recognition of an outstanding publication for their book, *Design of Buildings and Bridges for Wind Loads* (Hoboken: Wiley, 2006). The book provides structural engineers with the practical knowledge and tools required for the proficient design of buildings and bridges for wind loads and it addresses both ordinary and special structures. The prize was presented at the annual JAWE meeting on May 31, 2007, in Mitakyushu City, Japan.

Emil Simiu, recipient of The Japanese Association for Wind Engineering (JAWE) Prize for Outstanding Publication.

Asia Pacific Coatings Best Paper Award

Tinh Nguyen

Reaffirming longstanding and ongoing collaborative research efforts on nano-composites with the Chinese Academy of Sciences in Beijing, China, and with the Xiamen University Key State Laboratory in Xiamen, China, Dr. Nguyen was recognized for the paper "A Novel Method to Covalently Functionalize Carbon Nanotubes with Isocyanate for Polyurethane Nanocomposite Coatings," Nguyen, T., Granier, A., Steffens, K., Lee, H. J., Sharpiro, A., and Martin, J., *Proceedings of the Asia Pacific Coatings Conference*, Bangkok, Thailand, June, 2007.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Technical/ Symposium Paper Award

Gregory Linteris

Dr. Linteris was recognized for his paper, "Burning Velocity of 1, 1-Diflurorethane (R-152a)," Linteris, G. T., *ASHRAE Transactions*, 112 (2), 448-458, 2006, which discusses the importance of flame stretch in burning velocities measurements for refrigerants/air mixtures. The measurements are important as the refrigeration industry moves towards the use of flammable working fluids to overcome constraints associated with the global warming and ozone depletion potential of formerly used working fluids.

Associate Editor, *Cement and Concrete Composites*

Dale Bentz

Mr. Bentz was invited in January 2009 to be the associate editor of the international journal *Cement and Concrete Composites*, in recognition of his research productivity (over 200 papers), his many awards, and his contributions to the journal via writing and reviewing.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Distinguished Service Award

Piotr Domanski

Dr. Domanski was recognized for exceptional service to the society through his leadership on several standards and technical committees, numerous technical presentations and publications, and organization of various technical sessions and seminars. Presentation of the award took take place on June 23, 2007, during the opening plenary session of the society's annual meeting in Long Beach, California.

ASTM International E. George Stern Award of Excellence

Harold Marshall

Dr. Marshall was presented the ASTM International 2007 E. George Stern Award of Excellence for his "continuous and outstanding contributions to the work of Committee E06 on Performance of Buildings." Marshall initiated in 1979 the ASTM E06.81 Subcommittee in Building Economics, and has been the chief architect, recruiter, and inspiration of the subcommittee in producing 26 standards and adjuncts used worldwide in building evaluations. The Stern Award was established in 2000 to honor E. George Stern, an active and esteemed ASTM E06 member since 1955. It is granted to individuals who have provided continuous and outstanding contributions in Committee E06 to standards development.

ASTM International Award of Appreciation

Gerry Cheok and Kamel Saidi

Mr. Cheok and Dr. Saidi were recognized for their exceptional service to the Society as founding members of ASTM E57 3D Imaging Systems, and as Chair and Sub-Chair of E57.01 Subcommittee on 3D Imaging System Terminology. In particular this award recognizes their leadership and efforts which resulted in the delivery of Committee E57's inaugural standard, ASTM E2544 "Standard Terminology for Three-Dimensional (3D) Imaging Systems."

FIATECH Celebrates Engineering and Technology Innovations (CETI) Outstanding Early Career Researcher Honorable Mention

Alan Lytle

Mr. Lytle was recognized for having a profound impact on shaping the vision for the future Intelligent and Automated Construction Job Site, demonstrating and assessing the performance of enabling technologies, and leading the effort to define standards for the necessary site metrology systems to support that vision.

Patent Awarded for Moisture Detection System

The United States Patent and Trade Office awarded a patent to NIST for a technique to detect moisture problems within walls. Patent #7,236,120, entitled "Ultra-Wideband Detector Systems for Detecting Moisture in Building Walls," resulted from a joint effort between BFRL (William Healy) and Intelligent Automation, Inc., of Rockville, Maryland (Eric Van Doorn). This invention describes a nondestructive method for locating moisture problems within walls

William Healy, recipient of a 2006 BFRL Communication Award.

that utilizes the fact that wet building materials reflect radio waves more significantly than dry materials. The use of a wide frequency range allows for detection of water even when the wet layer is hidden from view, and careful measurement of the time of flight of the reflected waves provides the location of the moisture in the wall. Synthetic aperture imaging software was developed to provide a visual display of the excess moisture present in the wall, and a handheld array of antennae was constructed to capture the data necessary to generate such images.

Patent Filed for Increasing the Service Life of Concrete

At the end of 2008, NIST filed a patent application on the research done by Dale Bentz and Kenneth Snyder on a new concept in reducing the chloride diffusivity of concrete and thus increasing the service life, without causing an increased probability of early-age cracking.

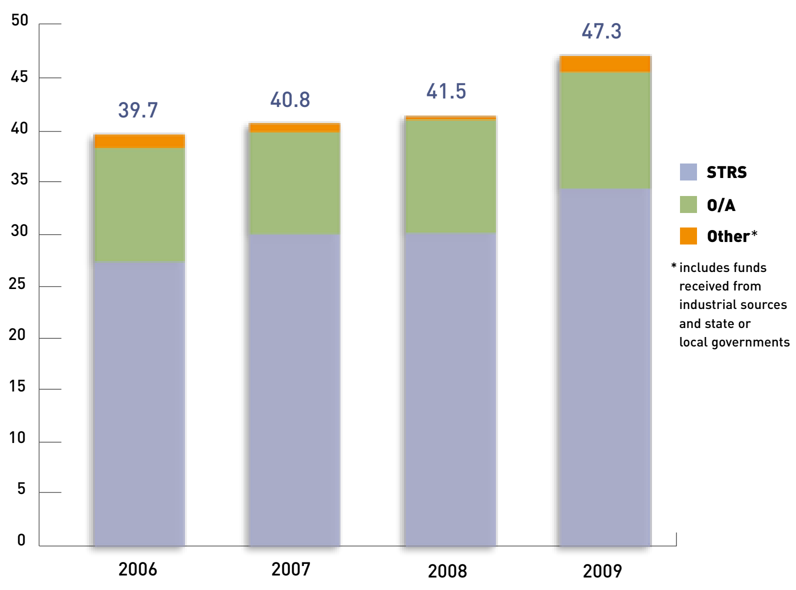
Finances, Organization and Resources

BFRL Budget and Finances

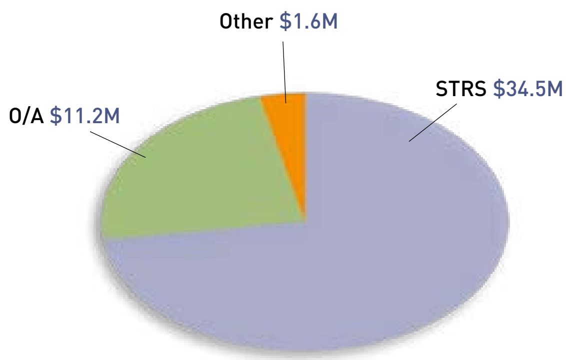
BFRL saw a 23 percent growth in congressionally appropriated budgets between 2006 and 2009, due primarily to expanded programs in disaster-resilient structures and communities (NEHRP and WUI) and hydrogen fire safety that were funded through the America Competes Act. These in-house funds for Scientific and Technical Research and Services (STRS) made up just under three-fourths of BFRL's total financial resources. Other federal agency (O/A) funds totaling about $11 million were the primary source of the remaining resources. During this period, BFRL awarded about $2 million to $3 million in grants each year to universities and other scientific and engineering organizations.

BFRL RESOURCES 2006-2009

($ MILLIONS)



FY 2009



Organizations Funding BFRL's Research

Federal agencies, industry groups, and consortia support about one-fourth of BFRL's overall research.

FEDERAL AGENCIES

Consumer Product Safety Commission
Department of Agriculture
Department of the Army
Department of Defense Agencies
Department of Energy
Department of Health and Human Services
Department of Homeland Security
Department of Housing and Urban Development
Department of Interior
Department of Justice
Department of Labor
Department of the Navy
Department of State
Department of Transportation
Department of Treasury
Environmental Protection Agency
Federal Emergency Management Agency
Federal Highway Administration
General Services Administration
National Aeronautics and Space Administration
National Institutes of Health
National Science Foundation
Nuclear Regulatory Commission
Smithsonian Institution
U.S. Air Force
U.S. Army Corp of Engineers
U.S. Fire Administration
U.S. Forest Service

PRIVATE SECTOR AND NON-FEDERAL GOVERNMENT

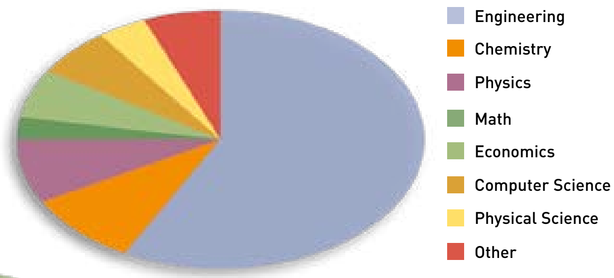
Adhesive and Sealant Council, Inc.
Advanced Fire Alarm System Consortium
Air Conditioning and Refrigerating Technology Institute
Air Products
Akzo Nobel
Albemarle
American Association of State Highway and Transportation Officials
American Fire Sprinkler Association
American Iron and Steel Institute
Anter Corporation
Arkema
Association Technique l'Industrie des Liant Hydrauliques (ATILH)
ASTM International
Atlas Material Testing Technology, LLC
Atofina Chemicals
Barrier Dynamics
BASF
BYK USA
California Energy Commission (CEC)
Cemex
CSM Instruments
DAP
DeGussa
Dow Chemical Company
Dow Corning Corporation
Dupont Company
Dyckerhoff
Eastman Chemical Company
FM Global
Holcim
IAC Group North America
International Center for Aggregate Research (ICAR)
Iowa State University
Kaneka
Kerr-McGee Corporation
MAPEI Corporation
Master Builders Technology
Millennium Chemicals
MTS
Nanophase Products
National Association of Fire Testing Laboratories
National Electrical Manufacturers Association
National Fire Sprinkler Association, Inc.
National Institute of Building Sciences
National Ready-Mixed Concrete Association
New York State
Northwestern University
NYACOL Nano Technologies
Poly One
Portland Cement Association
PPG Industries
Rohm Hans
Sasol
Samsung Cheil
Sherwin Williams
Sika Technology AG
Sleep Product Safety Council
Solvay
Tremco
Underwriters Laboratories
Verein Deutscher Zementwerke (VDZ)
Visteon
Wacker Silicones Corporation
W.R. Grace

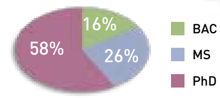
CONSORTIA

Building Joint Sealants Consortium
Fire Resistive Materials Consortium
Interphase/Interface Consortium
Polymer Interface Consortium
Virtual Cement and Concrete Testing Laboratory Consortium

BFRL Staff and Resources

BFRL embodies a science culture, developed from a large and well-equipped research staff that enthusiastically blends programs that address the near term, medium term, and long term measurement science needs of U.S. industry in areas of critical national interest. BFRL consists of 151 full-time equivalent employees and over 100 associates with measurement science expertise in materials and system performance; sensing, information, automation, and control technologies; mathematical and complex systems modeling and simulation; non-destructive testing; and diagnostics.





BFRL Staff Scientific Disciplines

BFRL has many specialized research facilities including:

Building Integrated Photovoltaic Testbed

The long-term performance of building integrated photovoltaic panels is measured "in-situ" using the Building Integrated Photovoltaic Testbed. The facility provides comparison between different building integrated photovoltaic panels when exposed to identical meteorological conditions. Up to nine panels can be evaluated simultaneously.

Cone Calorimeter

Originally developed by NIST in 1982, the Cone Calorimeter is used to study the fire behavior of small samples of various materials in condensed phase. It gathers data regarding the ignition time, mass loss, combustion products, heat release rate and other parameters associated with its burning properties.

Fire Emulator/Detector Evaluator

The Fire Emulator/Detector Evaluator (FE/DE) is a computer-controlled flow tunnel used to re-create the environments surrounding detectors in the early stages of fire and background environments that give rise to false alarms.

Guarded Hot-Plate Facilities

The 1-meter and 0.5 meter guarded hot-plate facilities provide steady state thermal transmission properties of building and industrial insulations near room temperature and up to 900 K, respectively. These facilities provide the measurement and building communities with thermal insulation reference materials for calibration and verification of their thermal conductivity equipment.

Indoor Air Quality (IAQ) Test Chamber

This 32 m^3 chamber is instrumented for the measurement of contaminant concentrations, environmental parameters and ventilation rates, and has a custom air conditioning system to supply clean air to the space with precisely controlled temperature and humidity levels. This unique facility is used to characterize contaminant emissions from building materials and furnishing as well as to test air cleaning and other IAQ technologies under well-controlled test conditions.

Integrating Sphere UV Exposure Chamber

For testing the weathering of materials, The NIST SPHERE (Simulated Photodegradation via High Energy Radiant Emission) can generate controlled temperatures, humidity, and UV exposure for more than 500 samples at a time. Materials exposed to the SPHERE's UV light for one day receive the equivalent dose of 50 days of sunlight. The ability to independently vary spectral irradiance, mechanical loads, temperature and humidity provides researchers with a high level of flexibility in designing artificial weathering experiments.

Laser Detection and Ranging (LADAR) Performance Evaluation Facility

A LADAR is an optical device that typically yields voluminous 3D "point clouds" by scanning scenes. The LADAR Performance Evaluation Facility is a 5m × 5m × 14m indoor artifact-based test facility for evaluating 3D imaging systems.

Large Fire Laboratory

As the federal government's principal fire research laboratory, more than 400 fire experiments are performed each year in the specially equipped, 27m (90 ft) x 37m (120 ft), Large Fire Laboratory. The facility has a variety of instrumentation for measuring temperature, mass, pressure, thermal radiation, real-time gas concentrations for oxygen, carbon dioxide, carbon monoxide, nitrogen oxides and hydrocarbons, and smoke concentration. Several computerized data acquisition systems are available in the facility for recording the inputs from the instrumentation.

Large Structures Testing Laboratory

The Large-Scale Structures Testing Facility consists of a universal testing machine (UTM), and a 13.7m-high reaction buttress equipped with a horizontal hydraulic ram. A combination of 4.5 MN horizontal force and 53 MN compressive vertical force may be applied to large-scale specimens.

Mobile Solar Tracker Facility

The Mobile Solar Tracking Facility is used to characterize the electrical performance of photovoltaic panels. It incorporates meteorological instruments, a solar spectroradiometer, a data acquisition system, and a single-channel photovoltaic curve tracer.

Residential Fuel Cell Testing Laboratory

A test facility for residential fuel cell systems to determine the performance of these systems on a seasonal basis, the Residential Fuel Cell Testing Laboratory encompasses three rooms: an environmental chamber to simulate outdoor ambient conditions, an environmental chamber to simulate indoor ambient conditions, and a control room that houses the data acquisition and control system.

Residential Photovoltaic Roof Test Facility

Six residential (sloped roof) and three commercial (flat roof) photovoltaic roofing products are currently being monitored to quantify performance of photovoltaic systems and provide data to develop/validate performance models. The electrical output of each photovoltaic product is measured every 5 seconds, with average values for these quantities being saved at five minute intervals. In addition, measurements are made of the coincident ambient temperature, wind speed, and solar radiation incident upon the samples.

Virtual Cement and Concrete Test Laboratory (VCCTL)

A computer-based virtual laboratory for evaluating and optimizing cementitious materials, the core of the VCCTL is a computer model for the simulating the hydration and microstructure development of cement-based materials that is based on 15 years of research at NIST.

Virtual Cybernetic Building Test Bed (VCBT)

A real-time, distributed cybernetic building emulator, the VCBT consists of a variety of simulation models combined with commercial and prototype BACnet controllers that create a hybrid software/hardware environment suitable for testing various integrated control system components for cybernetic buildings. The VCBT provides a way to simulate fault conditions, fires, and other hazardous events. It can be used to reproducibly test commissioning tools, fault detection and diagnostics (FDD) technology, emergency decision support tools, new building integration and control strategies, and building information models.

BFRL Organization and Contact Information

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BFRL's technical Divisions and Offices each contribute to multiple strategic measurement science goals. Contact information for the Goal Leaders and Program Managers are listed below. *(Contributing Divisions or Offices leading their respective efforts are shown in bold.)*

STRATEGIC GOALS	PROGRAMS	CONTRIBUTING DIVISIONS
Measurement Science for Net-Zero Energy, High-Performance Buildings Dr. Hunter Fanney, 301-975-5864, *hunter.fanney@nist.gov* Mr. Steven Bushby, 301-975-5873, *steven.bushby@nist.gov*	**Improved Building Energy Performance Program** Dr. William M. Healy, 301-975-4922, *william.healy@nist.gov* **Embedded Intelligence in Buildings Program** Mr. Steven Bushby, 301-975-5873, *steven.bushby@nist.gov* **Advanced Building Engergy Technologies Program** Dr. Piotr A. Domanski, 301-975-5877, *piotr.domanski@nist.gov*	**Building Environment Division** **Office of Applied Economics** Fire Research Division
Measurement Science for Advancing Infrastructure Delivery Mr. Mark Palmer, 301-975-5858, *mark.palmer@nist.gov* Mr. Alan Lytle, 301-975-6048, *alan.lytle@nist.gov*	**Automated and Integrated Infrastructure Construction Processes Program** Mr. Mark Palmer, 301-975-5858, *mark.palmer@nist.gov*	**Building Environment Division** **Materials and Construction Research Division** Office of Applied Economics
Measurement Science for Sustainable Infrastructure Materials Dr. Jonathan Martin, 301-975-6717, *jonathan.martin@nist.gov* Dr. Jeffrey Gilman, 301-975-6573, *jeffrey.gilman@nist.gov*	**Service Life Prediction of Concrete Building and Infrastructure Materials Program** Dr. Edward Garboczi, 301-975-6708, *edward.garboczi@nist.gov* **Service Life Prediction of High Performance Polymers and Composites Program** Dr. Joannie Chin, 301-975-6815, *joannie.chin@nist.gov* **Reduced Flammability of Materials Program** Dr. Jeffrey Gilman, 301-975-6573, *jeffrey.gilman@nist.gov*	**Materials and Construction Research Division** **Fire Research Division** Office of Applied Economics
Measurement Science for Innovative Fire Protection Dr. Anthony Hamins, 301-975-6598, *anthony.hamins@nist.gov* Mr. Nelson Bryner, 301-975-6868, *nelson.bryner@nist.gov*	**Reduced Risk of Fire Hazard in Buildings Program** Dr. Anthony Hamins, 301-975-6598, *anthony.hamins@nist.gov* **Reduced Risk of Fire Spread in Wildland-Urban Interface Communities Program** Dr. William Mell, 301-975-4797, *william.mell@nist.gov* **Advanced Fire Service Technologies Program** Mr. Nelson Bryner, 301-975-6868, *nelson.bryner@nist.gov*	**Fire Research Division** Materials and Construction Research Division Office of Applied Economics
Measurement Science for Disaster-Resilient Structures and Communities Mr. Stephen Cauffman, 301-975-6051, *stephen.cauffman@nist.gov* Dr. John Hayes, 301-975-5640, *john.hayes@nist.gov*	**Investigation of the World Trade Center Disaster Program** Dr. S. Shyam Sunder, 301-975-5900, *sunder@nist.gov* **Structural Performance Under Multi-Hazards Program** Mr. Stephen Cauffman, 301-975-6051, *stephen.cauffman@nist.gov* **National Earthquake Hazards Reduction Program** Dr. John R. Hayes, 301-975-5640, *john.hayes@nist.gov*	**Materials and Construction Research Division** **National Earthquake Hazard Reduction Program Office** Fire Research Division Office of Applied Economics

Find Out More About BFRL

Building and Fire Research Laboratory Website

http://www.bfrl.nist.gov

Inquiries

If you have general questions about BFRL programs, contact us at ***bfrl@nist.gov*** or call 301-975-5900.

The mailing address for BFRL is:

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National Institute of
Standards and Technology
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Gaithersburg, MD 20899-8600

Publications and Research Results

Access to BFRL's published research results, which now come in many forms including printed publications, Web sites, CDs and DVDs, can be found online at BFRL Research Information Services ***(http://www.bfrl.nist.gov/bfrlris)***.

This includes access to BFRL publications, where many full texts of publications from 1994 to the present are available. To request copies of these free publications or inquire about BFRL's research reports, contact BFRL Research Information Services, 301-975-6696, ***bfrl@nist.gov***.

Visit the Laboratory

Potential collaborators are encouraged to visit BFRL when in the Washington, D.C., area. To schedule a visit, contact us at ***bfrl@nist.gov*** or call 301-975-5900.

BFRL Careers

The strength of any organization is in its human capital resources. BFRL's ability to accomplish its unique mission ultimately depends on attracting and retaining talented technical staff. For more details about our current recruitment efforts, please visit the BFRL Career Website ***(http://www.bfrl.nist.gov/careers)*** or contact ***bfrlcareers@nist.gov***.

The National Institute of Standards and Technology (NIST)

Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

NIST carries out its mission in four cooperative programs:

- the **NIST Laboratories**, conducting research that advances the nation's technology infrastructure and is needed by U.S. industry to continually improve products and services;
- the **Baldrige National Quality Program**, which promotes performance excellence among U.S. manufacturers, service companies, educational institutions, health care providers, and non-profit organizations; conducts outreach programs and manages the annual Malcolm Baldrige National Quality Award, which recognizes performance excellence and quality achievement;
- the **Hollings Manufacturing Extension Partnership**, a nationwide network of local centers offering technical and business assistance to smaller manufacturers; and
- the **Technology Innovation Program**, which provides cost-shared awards to industry, universities and consortia for research on potentially revolutionary technologies that address critical national and societal needs. (Note: This is a newly created program that has been authorized by Congress.)

The agency operates in two locations: Gaithersburg, Md., (headquarters—234-hectare/578-acre campus) and Boulder, Colo., (84-hectare/208-acre campus). NIST employs about 2,900 scientists, engineers, technicians, and support and administrative personnel. Also, NIST hosts about 2,600 associates and facility users from academia, industry, and other government agencies. In addition, NIST partners with 1,600 manufacturing specialists and staff at about 400 MEP service locations around the country.

Editors:

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Information Specialist
Building and Fire Research Laboratory
National Institute of Standards and Technology

William L. Grosshandler
Deputy Director
Building and Fire Research Laboratory
National Institute of Standards and Technology

S. Shyam Sunder
Director
Building and Fire Research Laboratory
National Institute of Standards and Technology

U.S. Department of Commerce
Gary Locke, Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Director

NIST SP 838-20
January 2010

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