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

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 about 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 and Fire 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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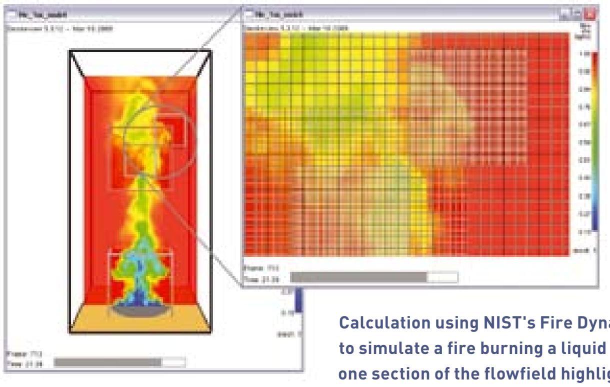

Calculation using NIST's Fire Dynamics Simulator (FDS) software to simulate a fire burning a liquid hydrocarbon fuel. A blow-up of one section of the flowfield highlights computational techniques being developed to enable more accurate calculations.

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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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

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).

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 damage 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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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

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.

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.

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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