NIST Research On Less Flammable Materials

Richard G. Gann, Ph.D.
Building and Fire Research Laboratory,
National Institute of Standards and Technology (NIST), Gaithersburg, Maryland

ABSTRACT

A principal objective of the NIST Fire Research Program is supporting the development by U.S. manufacturers of a new generation of building and furnishing materials and products that contribute less to a fire, maintain their fire safety performance over the product life, and are environmentally friendly. This paper describes the NIST roles in fire safety science and engineering, as well as research projects currently underway on less fire-prone materials and products.

NIST ROLE IN FIRE SAFETY

The National Institute of Standards and Technology (NIST) is a non-regulatory science and technology agency that is part of the U.S. Department of Commerce. NIST and its predecessor, the National Bureau of Standards NBS) have been performing research to improve fire safety in the nation since 1904, three years after the founding of NBS. Over the following 70 years, the Federal Government assigned successive, specific fire responsibilities to NBS, and the resulting test methods, standardized data, and new technology have become mainstays of fire protection in the U.S.

In 1974, under the Federal Fire Prevention and Control Act of 1974, Public Law 93-498, which became part of the NBS Organic Act, NBS was directed to conduct a basic and applied fire research program that included, among other facets:

- the physics and chemistry of combustion processes;
- the dynamics of flame ignition, flame spread, and flame extinguishment;
- the composition and toxicity of combustion products developed by various sources and various environmental conditions;
- the early stages of fires in buildings and other structures, structural subsystems and structural components in all other types of fires, including, but not limited to, forest fires, brush fires, fires underground, oil blowout fires, and waterborne fires, with the aim of improving early detection capability;
- the behavior of fires involving all types of buildings and other structures and their contents (including mobile homes and high-rise buildings, construction materials, floor and wall coverings, coatings, furnishings, and other combustible materials), and all other types of fires, including forest fires, brush fires, fires underground, oil blowout fires, and waterborne fires;
- the unique fire hazards arising from the transportation and use, in industrial and professional practices, of combustible gases, fluids, and materials;

- design concepts for providing increased fire safety consistent with habitability, comfort, and human impact in buildings and other structures.

Over those years, the implementation of NBS research results on, e.g, fire resistance of compartment walls, flammability of transportation vehicle interiors, smoke detection, and furnishings flammability have led to improvements in public safety as manufacturers became able to market advanced, more fire-safe products.

In 1988, under the Omnibus Trade and Competitiveness Act, the Congress evolved NBS into NIST, with its primary goal to help U.S. industry to strengthen its international competitiveness. In 1991, the Center for Fire Research and the Center for Building Technology merged to form the Building and Fire Research Laboratory (BFRL) with a unified commitment to enhancing the competitiveness of U.S. industry and public safety through performance prediction and measurement technologies and technical advances that improve the life cycle quality of constructed facilities. The current BFRL Fire Research Program comprises a wide range of projects in materials flammability, advanced fire detection and suppression, smoke formation and evolution, fire modeling, and large fires.

RESEARCH IN THE NIST LABORATORIES

Of particular interest to the materials industry, BFRL has underway a research program with a vision of the marketing by U.S. manufacturers of a new generation of building and furnishing materials and products that contribute less to a fire, maintain their fire safety performance over the product life, and are environmentally friendly. Some intended products from this will be:

- New mechanisms of fire retardancy for commodity polymers;
- Technical basis for rational, economical, performance-based fire regulations relating to material products, including validated computer models of the phenomena and methods to obtain the appropriate material properties;
- Predictive model of the formation of combustion products in small fires, based on understanding the coupling between chemical processes, fluid mixing, and radiation transport above burning materials;
- Predictive capability for the smoke generated from post-flashover fires;
- Acceptance of performance-based standards by ASTM, NFPA, and codes bodies;
- Predictive capability for the key descriptors of burning materials and products: mass burning rate, toxic species yields, thermal radiation, smoke emission, and properties;
- Demonstrations of the value of advanced building materials and furnishing products;
- Accepted model for total cost of fire performance of building materials and furnishing products, as a means for stimulating life-cycle specifications and approvals, including an economic appraisal of the benefits to the nation of using such products;
- Tutorials for industry R & D staff on the science of less fire-prone materials; and
- Protocol for appraising *material*-specific concepts for improved fire performance using very small samples.

The following are examples of current projects:

New Advanced Fire Safe Materials

Objective — The long-range objective is to develop the technical basis for the design of a new generation of fire retardants and fire resistant materials. The 3-year target is an integrated model of thermal degradation and char formation in burning polymers.

Rationale — There is a strong correlation between char residue and fire resistance since char is always formed at the expense of volatile fuel. Furthermore, the presence of a surface char insulates the unburnt polymer in the interior from the heat generated in the gas phase combustion reactions and obstructs the outward flow of combustible gases. At present, there is little quantitative information about the relation between polymer structure, char properties, the effect of non-halogenated additives, and materials flammability.

Approach — In the theoretical component, both micro- and macroscopic phenomena will be addressed. The former is based on a molecular dynamics model of the thermal degradation of polymers which has been developed at BFRL. The dynamic trajectories of the polymers are calculated from Hamilton's equations of motion. Macromolecular systems, which are too costly or too complex to synthesize on a routine basis, can be modeled and systematically varied, all the while examining their tendency to form high molecular weight, crosslinked structures. The macroscopic component simulates the dynamics and fire retardant properties of swelling polymeric materials as the result of an ensemble of expanding and migrating bubbles. The motions of bubbles and the material surface obey the flow field obtained by summing the contributions from all bubbles. Material properties and bubble growth rate depend on local temperature and the chemistry of the gasification process.

The experimental component includes: 1) studying the effects of immiscible inorganic additives on polymer flammability, 2) investigating the flammability of blends of preceramic powders with commodity and engineering polymers, 3) studying the relationship between crosslinking and flammability properties, and 4) experimental validation of model calculations. The research makes use of the Cone Calorimeter to evaluate the heat release rates of candidate systems. Samples at intermediate stages of decomposition are generated under controlled conditions and a range of temperatures. Char yield, C/H ratio, aromatic/aliphatic ratio, crosslink density are then determined. The solid state decomposition chemistry is studied using CP/MAS ^{13}C and ^{29}Si NMR.

A NIST/Industry Fire Safe Materials Research Consortium on large-volume, commodity polymers is being formed to expand collaboration with industrial experts, accelerate this project, and effect efficient transfer of the results into industrial practice. The Consortium will focus on new flame retardant methodologies which work in the condensed phase to reduce heat release rate and increase ignition resistance by two methods: enhance formation of char and form an interference layer at the polymer surface during degradation. There will be coexclusive licensing rights to patents arising from the Consortium research.

Burning Rate of Realistic Materials

Objective — Develop global parameters which can represent the gasification characteristics of realistic, single- and multi-component materials that can be used to calculate their burning rate.

Rationale — Fire hazard models at present do not include predictive algorithms for the burning of contained combustibles.

Approach — The global parameters will be derived from the comparison of measured gasification rates of selected real materials and theoretically calculated weight loss rates. The gasification rates will be measured in a nitrogen atmosphere under several different radiant fluxes. One-dimensional heat conduction model with a global degradation reaction will be non-dimensionalized, and a minimal number of key parameters will be defined. The weight loss rates will be calculated at the external fluxes as a function of the derived parameters.

Furniture Flammability

Objective — Develop the technical basis, ultimately expressed in the form of guidelines for furniture manufacturers, to design upholstered furniture with (low) controlled rate of heat release.

Rationale — Soft furnishings are the most common initial combustible in fatal fires. Current furniture, particularly for residences, is capable of producing large, rapidly-growing fires that can lead to flashover. Most fire deaths occur after flashover. Limiting the peak rate of heat release can preclude large fires and prevent flashover. The peak value is nominally independent of the ignition source. Since other materials, such as carpeting and drapes can add to the heat release from burning furniture, our conceptual target is for the allowable peak rate from a single piece of furniture to be under 500 kW. This will be refined by further hazard analyses. The recent EC CBUF study demonstrated that most residential-type furniture undergoes very non-ideal behavior (e.g., a large geometry change or a floor pool fire occurs) before reaching its heat release peak. Thus, a fire model must go beyond a stable flat, unchanging cushion surface rendition. Neither the E.C. effort nor our own previous work have been successful in developing direct correlation with a single fire parameter, such as might be obtained using a Cone Calorimeter. One optimistic E.C. outcome was the development of a technique to relate the Cone Calorimeter behavior of a fabric/padding composite to the Cone behavior of the component materials.

Approach — The intent is to relate Cone Calorimeter and LIFT sample behavior to fullscale via an appropriate model. The models and supporting experiments will be developed in stages, beginning with single flat cushions (horizontal and vertical). The target for each orientation is an experimentally-validated, semiquantitative model that captures the important post-ignition rate of heat release behavior. This will then be extended to an interacting pair of cushions and then an elevated pair, allowing for the formation of a pool fire beneath. At each stage, the modeling process will identify the main parameters, even if the model is not quantitatively accurate. Finally, these key parameters will be correlates with the actual burning behavior of upholstered furniture. It is likely that the nature of the correlation will change with the gross character of the burning object.

High Performance Construction Materials and Systems Program

This NIST/BFRL program is in support of a 10-year, $2 billion national program for research, development and deployment of High-Performance CONstruction MATerials and Systems (CONMAT) established by the Civil Engineering Research Foundation in cooperation with ten sectors of the construction materials industry. The NIST research is aimed at providing U.S. industry with performance prediction and measurement technologies for high-performance construction materials and systems that greatly improve the life-cycle quality of constructed facilities, especially by:

- increasing their durability and flexibility;
- reducing project delivery time;
- reducing operations, maintenance, and energy costs; and
- improving the health and safety of construction workers and facility occupants.

The materials and systems currently under study include high-performance concrete, high-performance steel, polymer-matrix composites, and other structural systems emerging in Europe and Japan. The current plans include expanding the scope to include building service systems (including mechanical and HVAC systems) and fire suppression systems. Two major new products expected in the near term are integrated knowledge systems for high-performance construction materials and performance criteria for dwellings.

One of the projects within this Program is especially pertinent:

Flammability of Structural Composites:

Objective — Develop quantitative procedures for assessing the impact of fire on structural composites with the ultimate goal of materials guidelines which assure fire safety.

Rationale — Composites are highly attractive materials for a wide variety of structural uses, but their organic resin content renders them potentially flammable as well as subject to loss of strength in a fire. These two areas may be coupled since mechanical loading can yield delaminations which alter thermal properties.

Approach — The first concern is to ensure that fire growth over the surface of a chosen composite is minimal. To this end, the research now focuses on the potential value of intumescent coatings. These are being examined at small scale in the cone calorimeter and the LIFT apparatus for their ability to delay ignition, depress the rate of heat release, and limit lateral flame spread. In addition, the studies determine the attachment of the coating to the face of the composite during the severe heat stresses of fires.

RESEARCH UNDER THE ATP PROGRAM

Begun in 1990, The Advanced Technology Program at the National Institute of Standards and Technology invests directly in the nation's economic growth by working with industry to develop innovative technologies with strong commercial potential — technologies which, if successful, would enable novel or greatly improved products and services for the world market. The ATP accelerates promising, but high-risk enabling technologies that, because they are risky, are unlikely to be developed in time to compete in rapidly changing world markets without such a partnership of industry and government. It does not fund product development.

Industry conceives, partially funds and executes ATP projects. Proposals for ATP co-funding are reviewed by scientists and engineers expert in the subject area. Proposals that score well in this technical review go on to a further evaluation of potential economic impact, evidence of significant commitment to the project on the part of the proposer, and other business related factors affecting the likelihood that successful results will be commercialized.

ATP funds for-profit companies. Successful ATP proposals have been prepared by small, medium and large companies; by single companies and by joint ventures. Universities, Federal laboratories (other than NIST) and non-profit institutions may participate in ATP projects as subcontractors or as members of joint ventures.

At present, these are some of the several projects underway that relate to polymeric materials, with potential concerns about flammability:

Low-Cost Automotive Manufacturing with Injection Molded PET Composites

Performer — AlliedSignal Inc. and Research & Technology

Strategy — Replace the steel stamping facilities with a composites-forming process that combines recycled polyethylene terephthalate and discrete glass fibers into molded parts with sufficient mechanical and structural properties to safely serve the same automotive roles as did the steel parts.

Automotive Composite Structures: Development of High-Volume Manufacturing Technology

Performers — Chrysler Corporation, Ford Motor Company, and General Motors.

Strategy — Develop and demonstrate the full-scale process capability of Structural Reaction Injection Molding on a large, complex automotive composite structure that meets all the requirements; and to define parts and assemblies that can be manufactured in high volume and processed/manufactured economically and consistently.

Composite Production Risers

Performers — Brunswick Composites, Amoco Performance Products Inc., Hydril Company, Hercules Inc., Brown & Root USA Inc., Amoco Production Company, Shell Development Company, Conoco Inc., Stress Engineering Services Inc., and the University of Houston.

Strategy — Replace conventional steel components of offshore oil platforms with composite risers that would have a cascading weight-reducing effect on the entire facility, thereby significantly reducing the capital costs of pursuing oil in deep water tracts.

Low Cost Manufacturing and Design/Sensor Technologies for Seismic Upgrade of Bridge Columns

Performer — Composite Retrofit Corporation

Strategy — Develop a cost-effective procedure for getting polymeric resins to infiltrate in and among carbon and glass fibers to constitute the retrofit material, develop computer-based design tools that bridge engineers can use to optimize the cost and performance of the materials for each particular retrofit, and develop an array of sensors placed on or within the composite materials that will monitor the health and performance of the materials from the time they are being manufactured to the end of their service lifetime.

High-Performance Composites for Large Commercial Structures

Performers — DuPont, the Johns Hopkins University, the University of Delaware, Dow Chemical Company, Brunswick technologies Inc., and Hardcore Composites Inc.

Strategy — Remove a principal barrier to the use of structural fiber-reinforced resin composites by enabling the timely production of quality parts.

Thermoplastic Composites for Structural Applications

Performers — Dupont, Cambridge Industries Inc., Owens Corning, and the Herty Foundation

Strategy — Develop cost-effective method for manufacturing large volumes of composites, at costs less than for steel, with the proper balance of physical properties for structural applications in the automotive industry.

Synchronous In-Line CNC Machining of Pultruded Lineals

Performers — Ebert Composites Corporation, W.B. Goldsworthy & Associates, and the Naval Surface Warfare Center

Strategy — Develop a comprehensive process for creating large, complex composite structures without using bolts or adhesives, integrating in a continuous process the composite fabrication step, in which polymeric resins infiltrate and surround networks of reinforcing fibers, with downstream manufacturing steps.

Structural Composites Manufacturing Process

Performers — GenCorp Inc. and Ohio State University

Strategy — Develop a cost-effective manufacturing method for the automotive industry and demonstrate its utility by making 'suspension links' our of fiber-reinforced composite materials.

Innovative Manufacturing Techniques to Produce Large Phenolic Composite Shapes

Performer — Morrison Molded Fiber Glass Company

Strategy — Reduce the costs of bridge retrofitting by developing longer-lasting and more easily maintained fiber reinforced polymer composites to replace deteriorating steel and concrete materials, optimizing the mechanical properties of the composite through judicious choice of resins, reinforcing fibers, and their mutual arrangements, optimizing the shape and size of composite components, and establishing design standards and load capacities.

Spoolable Composite.Tubing Performer:

Performers — Hydril Company, Amoco corporation, Mobil Exploration and Producing Service, Shell Development Company, Phillips Petroleum Company, the Dow Chemical Company, Shell Chemical Company, Dobell Schlumberer Inc., Elf Atochem North America Inc., and the University of Houston

Strategy — Develop equipment and technology for the cost-effective manufacturing of composite tubes several miles long and produce composite materials whose combination of performance, predictability, and cost win acceptance as a material that can open more deep water tracts to development.

Development of Manufacturing Methodologies for Vehicle Composite Frames

Performer — The Budd Company

Strategy — Develop cost-effective methods for manufacturing the load-bearing frames of light trucks out of composite materials, creating and setting up the molds and the fiber preforms, injecting polymeric resin into the molds so that it fully infiltrates the preforms, and curing the preparation into reliable and acceptable parts that meet the stringent specification of the automotive industry.

Low-Cost Advanced Composite process for Light Transit Vehicle Manufacturing

Performers — U.S. Electrical, GE Plastics, and Miles Inc.

Strategy — Develop a manufacturing process that yields composites that are recyclable, require no environmentally troublesome finishing steps, and are cost effective enough for integration into the expected small manufacturing runs of electric vehicles.

Manufacturing Composite Structures for the Offshore Oil Industry

Performers — Westinghouse Electric Corporation Marine Division, ABB Vetco Gray Inc., DeepStar project (16 oil companies), Reading & Bates Development Co., Offshore Technology Research Center, and Hercules Inc.

Strategy — Make polymer composite tubular structures for connecting offshore platforms at the sea surface to well head components on the sea floor, focusing on manufacturing cost, design optimization, reduction of risk through accurate predictions of lifetime performance, and demonstration testing.

Polymer Matrix Composites for Surface Transportation Applications

Performers — Ciba Composites Industrial Business Group and Virginia Tech

Strategy — Develop an integrate design methodology that incorporates a cleansheet component design low-cost processing techniques, lifetime performance data, and materials innovations that reduce costs and improve performance.

In each case, the success of the project relies on the performance of the composite products. Flammability behavior, both loss of mechnical properties and combustibility, is a principal concern.

BIOGRAPHY

Dr. Richard G. Gann received a B.S. degree in chemistry from Trinity College (CT) and a Ph.D. in physical chemistry from the Massachusetts Institute of Technology. Following two years at the University of Pittsburgh Space Research Coordination Center and four years in the Combustion and Fuels Branch of the Naval Research Laboratory, Dr. Gann joined the National Bureau of Standards in 1976. Dr. Gann leads the Fire Science Division in developing the scientific and engineering understanding and metrology for fire research. The current foci are on the formation/evolution of smoke components in flames, less flammable materials and products, advanced fire sensing, and advanced fire suppression. He has over 40 personal publications, 250 supervised publications and 350 presentations to university, professional, industrial, and government audiences. In 1984, he was a Senior Executive Fellow at the John F. Kennedy School of Government, Harvard University. Dr. Gann is an active member of the Combustion Institute, the ASTM Committee on Fire Standards, and the National Fire Protection Association. He is currently on the Editorial Boards of *Combustion and Flame* and *Fire and Materials*.

This paper presented at the 41st International SAMPE Symposium/Exhibition, April 1996.