2009 BFRL Project Description

Project Title: Validation of Bench-scale Smoke Toxicity Apparatus

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BFRL Program: Reduced Flammability of Materials

Objective: Establish the accuracy of generic bench-scale combustors operating under fire-simulation conditions in predicting the yields of toxic smoke components such as carbon monoxide and hydrogen cyanide in real fires.

Problem:

What is the problem? The toxic potency of smoke is a necessary input for assessing building tenability in the event of a fire, and the provisions for assuring safe egress from a building can add appreciably to the cost of construction and operation. Performance-based design requires construction materials and finished goods to be tested under realistic fire conditions to determine their yields of toxic compounds, but full-scale testing of all possible items is cost-prohibitive. If a valid bench-scale apparatus and operating conditions were established, test laboratories would be able to provide combustion product yield data of known accuracy, and fire safety professionals would be able to estimate the time available for escape from a burning facility with a known uncertainty. In addition, manufacturers would be able to design and test materials and finished goods for improved performance, i.e. reduced emission of toxic products in fires. According to the NRC[1], "our poor understanding of smoke and toxicity is a critical barrier to the further incorporation of polymers and their composites in building contents and structural applications".

ISO/TR 16312-2 (Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard risk assessment) identifies 12 bench-scale apparatus proposed or in use for determining the toxic yields from burning materials and specimens of finished goods. However, the ISO report notes that 10 of these apparatus do not replicate or have no published comparisons to full scale fires. Of the remaining two, one comes within a factor of 2 for overall toxicity and one has "reasonable correlation" but is appropriate for materials only, not specimens from (more complex) commercial products. The measurement science is lacking to predict the toxic hazard presented by smoke and therefore the available time to escape.

[1] "Making the Nation Safe from Fire: A Path Forward in Research", Committee to Identify Innovative Research Needs to Foster Improved Fire Safety in the United States, National Research Council (2003).

Why is it hard to solve? Full scale fire tests are expensive, time-consuming, and require a high-level of technical expertise, to the degree that there are not enough independent test labs or qualified personnel to test even a small fraction of the materials and finished goods introduced each year. Bench-scale tests are more feasible, but operate on scales that are several orders of magnitude smaller. No bench-scale test method for toxic potency has yet been shown to capture all the relevant phenomena observed at the full-scale. In order to determine the ability of a bench-scale method to reliably predict the toxicity of the full-scale fire effluents from materials or finished goods requires a concerted effort involving both full-scale and bench-scale tests. This has not been done for the large majority of the bench-scale apparatus, and therefore the accuracy of these tests in predicting toxic yields at the full scale is unknown.

How is it solved today, and by whom? The measurement science problem has not been solved. Currently, fire safety engineers assume that a) the only significant toxic product is carbon monoxide, and b) that all burning items produce carbon monoxide at the same yield (0.2 g/g). We have shown both these assumptions to be false.[2] ISO TC92 (Fire Safety) recognizes the need for validated test methods for predicting the toxicity of fire effluents, for the purpose of reliable fire safety engineering, and is developing standards for this purpose. However, ISO relies on participating members to provide the technical basis for standards development. Typically, the tests are provided or sponsored by companies with a commercial interest in the outcome. Relying on these data to provide the technical basis will result in inferior standards and put the U.S. at a competitive disadvantage.

Why NIST? Our participation in ISO TC92 is essential for laying a sound scientific basis for developing codes and standards in this area, and for representing U.S. interests in the international fire protection community. Determining the accuracy of test methods for the toxicity of effluents from burning materials and finished goods enhances the BFRL strategic priority of Measurement Science for Sustainable Infrastructure Materials. It lies at the intersection of BFRL core competencies of fire protection and fire spread within buildings and communities and the performance, durability and service life prediction of building materials.

Approach:

What is the new technical idea? NIST has generated room-scale gas yield data for various materials under both pre-flashover and post-flashover conditions,[2] from which the accuracy of bench-scale devices can be assessed. The current project is to assess the relationship between these data and data from bench-scale apparatus. We are examining four generic types of bench-scale apparatus for such a use: the radiant apparatus used in NFPA 269 / ASTM E 1678, the Smoke Density Chamber used in ISO 5659-2 and ASTM E 1995, the tube furnace that is now a British and IEC standard and an ISO Technical Specification ISO/TS 19700, and the cone calorimeter, ASTM E 1354 (and several equivalent ISO and NFPA tests). Experiments with samples from the *same* materials used in the full-scale tests (vinyl-veneered particleboard, polyurethane foam with fabric cover, and PVC-clad, nylon-jacketed power cable) will determine the extent to which, and the range of apparatus conditions over which, the bench-scale tests

[2] Gann, R.G., Averill, J.D., Nyden, M.R., Johnsson, E.L., and Peacock, R.D., "Smoke Component Yields from Room-scale Fire Tests," NIST Technical Note 1453, National Institute of Standards and Technology, Gaithersburg, MD, 159 pages (2003).

replicate the real-scale test results for the various fire-like conditions. The results will provide the U.S. and international standards committees with the basis for selecting apparatus and operating procedures for generating valid input data for fire hazard and risk analyses. These analyses can then be used to construct buildings that provide a desired safety without expensive overdesign.

Why can we succeed now? Through ISO TC92 SC3 (Fire Threat to People and the Environment, chaired by R.G. Gann), a foundation for the proper generation and use of smoke toxic potency data is being laid. This comprises a set of ISO Standards that proceed from philosophy, through experimental protocols, to integration with emerging standards for fire safety engineering. In addition, a joint effort with TC92 SC4, Fire Safety Engineering, is developing a protocol by which the information obtained using the SC3 Standards will be in a form ready for use by practitioners. The analyzed results of the NIST experiments are being presented to this and to domestic standards committees. Based on the results, drafts of new standards and amendments to existing standards will be prepared and submitted for consensus ballot.

What is the research plan? We will complete our portion of an international round robin to establish the repeatability and reproducibility of the ISO/TS 19700 tube furnace. We will then conduct test campaigns with the Smoke Density Chamber used in ISO 5659-2 and ASTM E 1995, and with the cone calorimeter, both adapted for the measurement of toxic compounds, using the same materials that were tested in the tube furnace, the radiant panel apparatus, and the full scale tests. As in the previous years, gas composition will be measured using a fixed-gas Non-Dispersive Infrared instrument as well as a Fourier Transform Infrared spectrometer.

For maximum impact of this project, there is urgency in our completing additional work in the next year. The International Maritime Organization (IMO) is in the process of revising its code for the selection of shipboard materials, including drafting a standard for toxicity utilizing the Smoke Density Chamber. The impact of our project will be enhanced by the timely completion of a test campaign with our own Smoke Density Chamber, so that we will have data to support our position (for or against) the IMO standard. At the same time ISO TC92 SC1 (Fire Initiation and Growth) is ready to draft a standard for the use of the cone calorimeter for toxicity testing. Therefore for our project to have the most impact in the ISO committee, we must also complete a substantial amount of testing with the cone calorimeter within the next fiscal year.

Recent Results:

- Output: Gann, RG; Averill, JD; Marsh, ND; Nyden, MR; "Assessing the Accuracy of a Physical Fire Model for Obtaining Smoke Toxic Potency Data" In *Proceedings of the 11th International Conference on Fire Science and Engineering*, London, England, Sept 2007; Interscience Communications: London, 2007; p 1021–1032.

- Output: Marsh, ND; Gann, RG; Averill, JD; Nyden, MR; "Sensitivity of a Smoke Toxicity Test Method to Test Conditions" In *Proceedings of the 9th International Symposium on Fire Safety Science*, Karlsruhe, Germany, Sept 2008; accepted for publication.

- The data set for the NFPA 269 radiant apparatus is now complete. It includes operation at the prescribed conditions, as well as variation of the oxygen concentration, variation of the

test specimen size and conformation, and modification of the test procedure to better separate the stages of combustion.

- The initial test campaign using the ISO/TS 19700 tube furnace is complete. It includes operation at two prescribed conditions corresponding to well-ventilated flaming and post-flashover, as well as variation of the air flow, and variation of the test specimen feed rate and conformation.

Standards and Codes: This project is driving the development of a comprehensive set of international standards. ISO 13571, Estimation of time available for escape, ISO/TR 16312-2, Assessing the validity of physical fire models for toxicity data, ISO/TS 19700, Controlled equivalence ratio method for hazardous components of fire effluents, and ISO 19706, Assessing the fire threat to people, were all published in 2007. Three documents are under review: ISO 19701:2005, Sampling and analysis of fire effluents, ISO 19702:2006, Toxicity testing of fire effluents using FTIR gas analysis, and ISO 19703:2005, Calculation of species yields, equivalence ratios and combustion efficiency in experimental fires. Four additional documents are in various stages of standards development: ISO/PRF 27368, Analysis of blood for asphyxiant toxicants — CO and HCN, ISO/WD 26367-1, Assessing the adverse environmental impact of fire effluents, ISO/PWI 29903, Comparison of toxic gas data between physical fire models, and ISO/PWI 29904, Aerosols generation and measurement in fire.

R. G. Gann, previously assigned to this project, is the chair of ISO TC92 SC3, Toxic Hazards in Fire. N. D. Marsh is an Assigned Expert.

Mapping of BFRL Programs and Strategic Priorities (FY 2009)

Strategic Priority	Programs
Measurement Science for Net Zero Energy, High-Performance Buildings	Healthy and Sustainable Buildings
	Cybernetic Building Systems
Measurement Science for Breakthrough Improvements in Construction Productivity	CONSIAT: Construction Integration and Automation Technologies
Measurement Science for Predicting Life Cycle Performance of Infrastructure Materials	SLP: Service Life Prediction of Nanostructured Polymeric Materials
	HYPERCON: Prediction and Optimization of Concrete Performance
	Reduced Flammability of Materials
Measurement Science for Disaster-Resilient Structures and Communities	Structural Performance Under Multi-Hazards
	NEHRP: National Earthquake Hazards Reduction Program
Measurement Science for Innovative Fire	Reduced Risk of Fire Spread in Buildings

Strategic Priority	Programs
Protection	
	Reduced Risk of Fire Spread in Wildland-Urban Interface Communities
	Advanced Fire Service Technologies

BFRL Core Competencies

- **Fire protection and fire spread within buildings and communities**
- **Performance, durability and service life prediction of building materials**
- **Information, communication and automation technologies for intelligent integration of building design, construction and operation**
- **Performance, reliability and resilience of structures and communities under extreme loads**
- **Measurement science for building energy technologies**