FIRE HAZARD MODEL DEVELOPMENTS AND RESEARCH EFFORTS AT NIST

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INTRODUCTION

Historically, fire safety decisions on the suitability of materials for specific applications have been based on the use of standard fire tests, each designed to represent a single fire scenario. These standard fire tests are generally used as pass/fail tests, thereby providing very little information about the performance of the material in a scenario different from that represented by the test. To assess the real fire safety benefits or fire hazards of different materials requires prediction of material performance under different fire scenarios. Versatile predictive fire models in combination with data from new bench scale material flammability measurement methods will someday meet the need.

Exposure conditions such as location, orientation, ventilation and proximity to other materials can influence the fire performance of the material, so these parameters must be addressed by the models and/or the flammability characteristics measurements. Before the combination of fire models and bench scale measurement methods become universally accepted as tools for assessing the fire safety suitability of materials for specific applications, the models must be shown to be valid, some of the shortcomings in the measurement methods need to be addressed and a usable data base needs to be assembled. The Building and Fire Research Laboratory at the National Institute of Standards and Technology is progressing in these areas, but broader participation in this mutual goal is needed.

MATERIAL FIRE CHARACTERISTICS

Material fire and thermal characteristics that can influence the development of fire hazard in a building include:

- heat release rate,
- flame spread rate,
- mass loss rate,
- ignition temperature,
- thermal conductivity,
- specific heat,
- density,

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- emissivity,
- optical properties of the smoke,
- toxicity of combustion products,
- response to suppressants, and
- fire endurance.

Many of the above characteristics depend on the conditions of exposure, particularly external radiation. Therefore, to be able to predict fire development, measurements are usually needed at more than one exposure condition.

Some input data for compartment fire models and submodels can be obtained from currently available measurement methods. A useful guide providing a compilation of material properties and other data needed as input to computer models will be published soon by ASTM. The "Draft ASTM Standard Guide on Data for Fire Models" will list the apparatus, procedures and in some cases reference texts to obtain necessary data. Although emphasis will be on zone models of compartment fires, much of the same input data is used in field models.

Two ASTM test methods provide much of the data for fire models. They are: the flame spread test using the LIFT apparatus (ASTM E 1321 (1)), and the heat and smoke release test using the Cone Calorimeter (ASTM E 1354 (2)). The LIFT apparatus, designed to measure lateral flame spread on materials, has been used to test aircraft panels and building materials but has yet to gain widespread acceptance. The Cone calorimeter, of which there are close to 100 in use around the world, measures time to ignition and release rates of mass, heat, smoke and gaseous products of combustion at various levels of external radiant flux. The use of the Cone is now an international standard, ISO (International Organization for Standards) 5660 (3). In Europe there is effort underway to use the Cone for building materials, plastics, electrical products, and building furnishings and contents. A recent report on fire safety and ASTM standards suggested that the Cone Calorimeter is likely to be the principal fire testing instrument of the future (4). Testing techniques and protocols have been suitably worked out for well-behaved materials. However, improvements may be needed in the apparatus or the procedures for materials that intumesce or melt and for laminated composites that display unusual degradation mechanisms. Each of the above tests requires a flux calibration using a calibrated heat flux gauge. An improved high flux calibration source is needed to improve the high end calibration of flux gauges.

The fire characteristics measured in these tests relate to fire development, however an important factor in assessing the fire safety of buildings is the extent to which fire can be contained within a compartment. The primary performance measure for fire endurance of walls and floors is the ASTM E 119 test (5). The weak link in containing fire in a compartment is often the door. The standard test for doors is ASTM E-152 (6). Both these endurance tests use the same standard time-temperature curve which duplicates only one fire scenario. Unfortunately, the door test until very recently used to be run with the pressure in the fire compartment lower than the pressure outside, a condition which will not frequently occur in real fires. Furthermore, the vertical temperature gradient in a burning room, which is likely to play a role in door warpage and leakage, is not simulated in the test. Ideally, a better understanding of failure mechanisms and material fire endurance and thermophysical characteristics should lead to predictive models of fire endurance under a range of fire scenarios.

STATUS OF MODELING

Although improvements in measurement methods will produce better data and thereby enhance the accuracy of computer model assessment of the influence of material fire properties on fire in buildings, the major advances in fire assessment will result from advances in models themselves. It is not possible here to present a complete review of fire models, but it is important to mention some of those that address the effects of material flammability on fire in compartments. An excellent review of room fire models is contained in a new publication on heat release in fires (7). A recent survey by Friedman (8) identified 62 operational computer programs relevant to fire protection. Of these models one, developed by Dietenberger (9), addresses fire spread on furniture, two submodels by Mitler (10) and Delichatsios (11) address flame spread on walls, and twelve address fire endurance (mostly columns and floor slabs).

NIST's development of the model HAZARD is continuing with the addition of single surface pyrolysis and fire suppression algorithms. A new generation input editor is being included. A first order carbon monoxide generation algorithm and ceiling flame spread algorithm are being developed for future inclusion.

A number of three dimensional computational fluid dynamics programs have become commercially available and have been applied to fire problems. One such program, FLOW 3D was applied to an investigation of a fire in King's Cross Underground station in London (12). The program was able to explain why flames spread so quickly up an escalator rather than impinge on the ceiling as might be expected.

As a further example of the usefulness of computational fluid dynamics in addressing fire problems, the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) has also used FLOW 3D to solve a problem of controlling a wind blown fire plume in a U.S. Navy fire fighter trainer (13). A number of potential solutions were tried on the computer before a specific fence design was chosen. The chosen design was installed and worked as predicted. Another three dimensional model, JASMINE, (14) has been used on a number of practical smoke movement problems. A more rigorous computational fluid mechanics program, developed at NIST, (15) has a much finer grid, and includes an algorithm accounting for combustion in each cell. All these codes are costly and require large computer capability.

When using computational fluid dynamics to answer questions concerning fire spread in a building it is important for the engineer to be sensitive to all the physical aspects of the fire such as the amount of air needed for combustion, structural failure and availability of fuel.

MODEL VALIDATION AND ACCEPTANCE

Although computer models are already starting to play a role in building material fire hazard assessment, the predictive capability of the models themselves, particularly the flame spread submodels, needs to be addressed. ASTM recently published a standard guide for evaluating the predictive capability of fire models and submodels (16). Besides calling for full documentation, the guide calls for a sensitivity analysis to identify the sensitive variables and their acceptable range. The listed methods of evaluation are: comparison with standard tests, comparison with large scale simulations, comparison with documented fire experience, comparison with previously published full scale test data, and comparison with proven benchmark models. Missing from the guide is the need for peer review to confirm that the correct physics has been used within the model.

In 1991 the International Council for Building Research (CIB) held a workshop on fire model verification, selection and acceptance, and Worcester Polytechnic Institute held a conference on fire safety design in the 21st. century. Both these meetings addressed actions needed for greater acceptance of fire models. Those needs included critical review and documentation of the usefulness, assumptions and limitations of each model by an independent and respected group of engineers, a detailed analysis of the physics used in each model by a group of experts, the publication of successful applications by independent users, and the availability of large scale test data.

Instrumentation currently used in large scale experiments to test zone fire models consists largely of thermocouples, pitot-tubes, bidirectional probes, heat flux gauges, gas sampling at a few points, optical smoke measurements and video recording. This is insufficient to test three dimensional computational fluid dynamics predictions of gas velocity and temperature at many locations within a compartment. High spatial resolution non-intrusive measurement techniques such as particle image velocimetry or laser doppler velocimetry need to be explored as ways to quantify the vector flow field in large-scale experiments. Thermal imaging techniques need to be applied to surface temperature measurements.

DATA BASE

Data on the fire performance of building materials and furnishings under controlled test conditions are a key ingredient of fire models for predicting their performance under different scenarios. The newer material flammability test methods produce data that give an extensive characterization of the material or product. These data are invariably generated as computer files. Unfortunately, the format used for storing information has varied among test laboratories thereby limiting the exchange of data and their use in models. A fire data management system (FDMS) (17) has been issued for Beta test and is under further development at BFRL. The system can store data from older types of tests such as fire endurance and flame spread tests, as well as the newer tests such as the Cone and LIFT.

BFRL DIRECTIONS

The four elements of the strategic direction of the Laboratory's fire program are: intimate understanding of the customer's needs for advances in fire safety and technology; basic research to improve understanding of the elemental phenomena of fire; research to develop or adapt technological tools and procedures to address critical issues of fire safety; and intensive collaborations with industry, the fire services, and fire and building regulatory officials. The program has three technical thrusts:

- Fire risk and hazard prediction
- Fire safety of products and materials, and
- Advanced technologies for fire risk sensing and control.

Many of the current projects, particularly those within the first two thrusts relate to material flammability or assessment of its importance. Those projects and their focus for this year are listed in Table 1.

INTERNATIONAL DEVELOPMENTS

In the field of building fire research and standards, new international attention has shifted to scientifically based models, measurement methods and data that are related to real fire conditions (18). The International Organization for Standardization (ISO) Technical Committee 92, Fire Tests on Building Materials Components and Structures, has formed a new subcommittee on fire safety engineering to develop a series of guidance documents for engineers to apply fire safety performance concepts to design objectives. Japan has developed a comprehensive alternate method for determining compliance with the fire provisions of their Building Standard Law. The number of approvals granted by this alternate method route in Japan is increasing exponentially. Australia is developing a performance based building code utilizing a fire risk assessment model of Vaughn Beck (19). In the United States a fire risk assessment method was released by the National Fire Protection Research Foundation (NFPRF) in 1990 (20). Although the method was tailored to quantify the fire risk associated with a specific class of products in a specified occupancy it can be used to assess general fire risk of a specified building design. The United Kingdom is developing a code of practice on the application of fire safety engineering principles to building design objectives. This work is forming the basis of the ISO effort. Many European nations are working together to plan the necessary research to develop modeling approaches to the design of fire safe buildings making use of bench-scale measurement methods.

The International Heat Release Association was formed a few years ago to sponsor conferences and workshops on measuring and using heat release data. Two conferences have been held in Europe, one in the US, and a fourth is planned for Japan in 1993. Many workshops focussing largely on heat release measurements in the Cone Calorimeter have been held.

These are but a few of the efforts underway around the world to develop systematic engineering approaches to building fire safety that provide an alternate if not a replacement for pass/fail fire tests for building materials.

SUMMARY AND CONCLUSIONS

Fire models can play a major role in reducing the number of large scale tests needed to assess the fire hazard of building materials and furnishings under the many fire scenarios that may be encountered, but they will not totally eliminate the need for large scale tests. Measurement methods are available to obtain most of the data to use the models.

Computational fluid dynamics has reached the stage of development where it can be useful in helping to understand fire development and the flow of smoke in buildings.

High spatial resolution non-intrusive measurement techniques such as particle image velocimetry, laser doppler velocimetry and thermal imaging techniques should be explored as ways to increase the data that can be obtained from large-scale fire experiments.

A computer stored data base should be further developed to collect and exchange the data on materials from both old and new test methods.

A substantial part of the Building and Fire Research Laboratory's fire program relates to material flammability or assessment of its importance.

International efforts are underway to bring engineering methods to building fire safety through the use of scientifically based models, measurement methods and data that are related to real fire conditions. Such methods will form the foundation of performance based fire codes and will provide an alternate if not a replacement for pass/fail fire tests for building materials.

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Table I

Current NIST Projects Relating to Material Flammability and Fire Hazard Assessment

PROJECT	CURRENT FOCUS
Furniture flammability	To predict the performance of fire barriers and the failure mechanisms at the seat cushion/side arm juncture
Fire data management system	To develop an improved export import format
Large scale smoke movement	To model smoke flow in shafts, atria, corridors and stairwells
HAZARD and FPETOOL	To make FPETOOL the front end to HAZARD
Fire risk assessment	To develop a fire risk calculation method that will be a foundation for a performance fire code
Burning rate of materials	To improve the understanding of physical and chemical gasification processes of thermoplastics and char forming polymers
HAZARD development	To complete a Beta test version of HAZARD 1.2 that will include flame spread on walls
Ceiling fires	To understand the effect of a ceiling on a wall fire and the spread of fire on the ceiling
Office buildings	To investigate the effect of materials and geometry on the fire performance of systems furniture
Carbon monoxide production	To understand the mechanisms of carbon monoxide production
Polymer flammability modeling	To complete theoretical and experimental investigations to elucidate the thermal degradation mechanisms of if vinyl and aramid polymers
Fire resistant aircraft materials	To perform flammability measurements on radiation grafted polymers
Radiative ignition and flame spread over cellulosic materials	To develop theoretical models of ignition and flame spread in microgravity