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The Role of Fire Testing in Building Design

By Vytenis Babrauskas, Ph.D.

In order to allow adequate time for the escape of occupants and for the needed activities of the fire service, building designers must ensure that (1) structural components do not collapse rapidly and fire is kept out for a sufficient period of time from spaces not initially fire-involved, and that (2) combustion of the building materials themselves does not significantly increase the fire hazard, especially along escape routes. Requirement #1 is termed fire endurance or fire resistance, and test methods for this purpose had already been known in the late 19th century.[1] Internationally, testing is done in a large-size furnace according to ISO 834.[2] In the U.S., the building codes specify ASTM E 119,[3] which is similar in principle but incompatible in details with ISO 834. The ISO standard is currently being expanded into a series of tests, based on recent European work. These test methods subject a room-size wall, floor/ceiling assembly, beam, column, etc., to testing under conditions simulating a post-flashover fire. Testing these single elements, while it is "large-scale" testing, lacks a certain realism since Bresler[4] showed nearly 30 years ago that building structural frames can behave in a fire in ways that are not anticipated on the basis of these furnace tests. Thus, it is perhaps more realistic to provide fire endurance calculationally rather than by testing, that is, by performing a thermostructural design. This approach has become rather popular in Europe, but is still rare in the U.S. In view of the concerns raised by the collapse of the World Trade Center, however, U.S. designers may also start to provide fire endurance by performing whole-frame thermostructural calculations.

Historically, the need to limit combustion of building materials was accomplished by use of noncombustibility tests, such as ISO 1182[5] or ASTM E 136[6] (which are again similar in principle but incompatible in detail). With the wide range of building materials that are available, this "all-or-nothing" concept is too simplistic, and it is more useful to quantify the building materials' contribution to fire. The contribution to fire is most appropriately quantified[7] as the heat release rate (HRR), and this is what is done in the international standard on this issue, ISO 9705.[8] This is a mod-

ern test method that uses a test room where the walls and ceiling are lined with the materials to be tested and the HRR is measured; building code criteria can then be set based on the HRR. The U.S., however, still uses for this purpose the Steiner Tunnel, ASTM E 84,[9] which was developed during the 1930s and finalized in the mid-1940s.

The ISO 9705 test is rather large, and for most purposes, it is sufficient to test materials in small scale. Thus, for example, Japan adopted the ISO 9705 test, but based the provisions of their building code primarily on small-scale HRR testing with the ISO 5660[10] Cone Calorimeter on the basis that there is sufficient agreement between the two sets of results. The European Union also adopted the ISO 9705 test as the reference standard but devised an entirely new "working" standard, the Single-Burning-Item (SBI) test.[11] This test requires an apparatus roughly the same size and cost as the ISO 9705 room/corner test but, unlike ISO 9705 or ISO 5660, gives results that do not have a fundamental engineering significance. It also has the dubious distinction of being the only fire test method designed by regulatory officials rather than research scientists.[12]

Fire endurance and combustion properties of building materials (noncombustibility or HRR) are sufficient for the design of buildings according to prescriptive codes. Buildings are now more frequently designed on a performance basis, and fire growth also needs to be quantified in this type of design. The role of testing is not yet clear here. In principle, fully furnished rooms of the occupancy in question would need to be tested, but this has rarely been done. Usually, fire growth is presumed to evolve with HRR being proportional to time squared, using one of the schematic fire growth rates (slow, medium, fast, ultra-fast). The justification for choosing one of these growth rates, however, is often nebulous.[13] In case of special fuel loads, ad hoc HRR testing is sometimes also done. The basic guidance for such testing is usually derived from ISO 9705 or ASTM E 2067,[14] which is a guide of practice for conducting HRR tests.

Finally, there is a specialized area of fire testing that is important for certain sprinkler-protected facilities, and that is the testing of commodities to determine that a proposed sprinkler type will actually control a fire in that commodity. In the U.S., most of this test-

ing has been done by Factory Mutual using their in-house test procedures. Their results are often eventually incorporated into the requirements of NFPA 13,[15] but the system is opaque from the point of view of the design engineer, since the actual test reports are not made publicly available and details cannot be learned.

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Fire Prevention Week 2002

QUINCY, MA – The National Fire Protection Association annual Fire Prevention Week is recognized nationally this year from October 6-12, 2002. For early promotion, the NFPA launched a Web site (www.firepreventionweek.org) last month about the prevention week. The NFPA aims to make firefighters across North America familiar with this year's Fire Prevention Week theme, "Team Up for Fire Safety™." This year, educational materials and information are available online months in advance to assist firefighters with their planning efforts in the communities they protect. Included on the site are the latest fire statistics, advice on how to look for home hazards and eliminate them, how to install and test smoke alarms, and how to conduct a fire drill at home. Community members and educators may also find the Web site materials helpful for tips on fire safety and how to create a home fire-escape plan.

This year's Fire Prevention Week campaign promotes three simple ideas: install/test smoke alarms, practice home-escape plans and hunt for home hazards. Not only will this effort reach the community

through various activities and events, this year's campaign also marks the first time that so many of NFPA's Fire Prevention Week materials have been available online.

The NFPA has documented 74 lives saved in the past five years as a result of the public's participation in Fire Prevention Week.

Visit the official Fire Prevention Week Web site at www.firepreventionweek.org.

NFPA announces consulting role for former Association president

QUINCY, MA, May 31, 2002 – The non-profit NFPA (National Fire Protection Association) announced today that former NFPA President George D. Miller will continue to serve the organization in a part-time consulting role. Miller, who has retired from NFPA after 10 years as president, will be involved in outreach to state and local code enforcers and key organizations central to NFPA's mission and goals. Miller will begin his new role immediately, at the direction of NFPA President James M. Shannon.

During Miller's tenure, NFPA's regional and international operations were strengthened with targeted strategic plans designed to expand the adoption and use of NFPA codes, standards and programs.

National Awareness on CO Poisoning

MEBANE, NC – March 17-23, 2002, was National Poison Prevention Week. This year's theme was "Children Act Fast... So Do Poisons!"

According to the *Journal of the American Medical Association*, "unintentional CO poisoning causes approximately 2,100 deaths in the U.S. each year." In addition to these fatalities, more than 10,000 injuries occur annually.

Sam Solomon, vice president of marketing for Kidde PLC's Residential and Commercial Division, took the week of awareness as an opportunity to discuss CO detection. "Carbon monoxide is an invisible, odorless, and potentially fatal gas that I don't think a lot of expecting, new, and experienced parents think about when childproofing their homes," he said. "CO is the same weight as air, so mounting height is not important; but it is important to have the detectors positioned so they are out of drafts and not behind curtains and furniture. A dual smoke/CO alarm can be a good solution as long as people know the difference between the two alarm sounds."

For more information about Kidde detectors, visit www.kidde.com.

Sales Offices

FIRE PROTECTION Engineering

TESTING FOR
ENGINEERED FIRE PROTECTION
IN PERFORMANCE-BASED DESIGN

By James R. Quiter, P.E, FSFPE, and Richard L.P. Custer, FSFPE

Fire testing has been around for decades. The NFPA *Fire Protection Handbook*[1] states that fire tests of metal and masonry for building construction were conducted in Germany as early as the mid-1880s. The first large-scale tests for structural integrity in this country are reported to have been performed in 1890 in Denver, Colo., on masonry arches.

After the Baltimore conflagration of 1905, the American Society for Testing and Materials (ASTM) established a committee to standardize a test method for fire resistance. A test method for floor construction was proposed in 1906, and a method for testing wall and partition constructions was proposed in 1908.

In 1916, a joint committee was developed from several engineering societies to update the test standard for fire-resistive construction. NFPA, ASTM, and ANSI adopted a standard time-temperature curve in 1918. This is the same standard time-temperature curve used today, although a high challenge curve has been adopted for exposure to hydrocarbon fires.[2]

Besides the standard tests for fire-resistive construction, tests of interior finish have also been developed. In the 1930s, the Steiner Tunnel Test was developed at UL. The Steiner Tunnel became a test method in the 1950s and has been used as the primary fire test for classifying flame spread for interior finish since that time. It is still referenced by all the model codes in the U.S., and the rating determined by the test is used as basis for flame-spread classification used in the codes to control the use of materials in various occupancy settings.

The increasing knowledge of fire science makes it clear that these tests do not provide the information needed to predict the expected fire effects of alternative materials and designs. When materials and/or systems were considered independently, a pass/fail criterion was adequate to determine whether a material met the prescriptive requirements of the code. However, with the advent of performance-based design, data are needed regarding how materials or sys-

tems behave in specific fire scenarios. This is not something that a traditional test procedure can provide for engineered fire protection.

ENGINEERED FIRE PROTECTION

As the knowledge of fire science and engineering methods grows, so does the need for data. Performance-based codes create entirely new opportunities for engineered fire protection design. Instead of prescriptive approaches, the performance-based code will allow the stakeholders to determine the levels of performance needed and how the acceptable levels will be achieved. However, to do that, a knowledge base and the supporting data to predict performance of materials and systems are needed.

As an example, the prescriptive code says that travel distance shall not exceed a maximum distance (for example, 75 meters [250 feet]) in certain buildings. The reason for a maximum travel distance limitation is that the code intends that occupants of the building must be able to reach an exit before they are impacted by fire or smoke. The 75 meters (250 feet), or whatever distance a particular code states, is a number that was deemed to be reasonably safe for the typical building. However, that may be too long a travel distance for some design situations and may be unnecessarily restrictive for others depending upon many factors including the expected fire scenarios, the building geometry, the occupant characteristics, and the alternative fire protection design approaches. Most of the prescriptive code provisions have similar rationale behind them. However, each prescriptive requirement stands alone and does not necessarily take into account the other provisions of the code or the fire protection features of the building.

A performance-based approach would require that people get out of the building or into a protected area before they are impacted by fire or smoke. Travel distance would be one of the items to be considered. However, travel distance would be considered with respect to building geometry, fire growth rate, smoke development, fire spread, avenues of smoke spread, fire detection, suppression and smoke management strategies, ease of movement, exit routes, and the condition of the occupants.

What Is Performance?

Using prescriptive distance requirements will not necessarily predict a success or failure with regard to life safety performance. The performance would be that the people have exited before being impacted by smoke or fire. However, in developing a performance approach, several questions need to be answered. What is the reliability of the system? What are the sensitivities? What is the safety factor or level of certainty? What are acceptable tenability/damage thresholds (performance criteria)? In other words – how safe is safe? These are things that do not need to be considered in prescriptive code application because it is implied that those who wrote the code have already developed the answers. Whether this is true is beyond the scope of this article.

So the performance code or performance-design process may establish goals, objectives, and performance criteria, but there must be engineering analysis to determine whether or not they are met. Much of the input for engineering analysis comes from tests – fire tests as discussed in this article, human behavior studies, and analysis of real events. From that information, expected performance can be evaluated.

What Is Expected?

In discussing what is expected from an engineered fire protection system or from a performance-based design, it is most logical to work backwards, from the stresses imposed by the design fires expected to the appropriate design solutions. In other words, the design process should attempt to evaluate how well the building can respond to various events throughout the life of the structure.

Structural and mechanical engineers design not only for day-to-day conditions, but for major credible events. Fire protection engineers need to do the same. The trick for performance-based fire protection design is in appropriately defining the credible events, or bounding fires. At this point, the fire tests called out in the building codes don't help do that.

Since this article is about how tests are used and not specifically about performance-based design, the specifics of a credible event will not be defined, and the reader is referred to *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design.*[3] Everything else, from analysis through construction and commissioning, is intended to result in a building that can meet these goals.

With that in mind, the engineered fire protection analysis should include development of goals and objectives, and the evaluation of credible events. Engineered fire protection designs need to incorporate materials and systems that can adequately protect against these events and meet the goals and objectives. The specification process, then, defines the materials to be used and the functions they must fulfill. Specifications very often define materials well in terms of physical properties or dimensions, but not necessarily their performance in a particular application. They may reference a test such as flame spread, but not the level of performance such as ignition time or heat release rate. With performance-based design and with new tests, it is important to understand the test and the available information, not just provide a reference to the test or standard.

The approval process with performance-based design is much more rigorous and often requires detailed review of the analytical approach and the input data upon which the design is based. Commissioning, then, is simply making sure that what was promised actually works and that the performance can be met.

THE ROLE OF TESTING

So why is testing so important? It is so important because it serves as source of input data for the analysis.

Going back to the travel distance example, the objective is to get people out safely. There are several questions that need to be answered:

1. What is the initial fire? Information is needed about materials involved and their properties. How easily do they ignite? How fast will the fire grow, and what is the heat release rate over time? What is the smoke production rate, and how toxic are the products of combustion? Will the fire be controlled, or will it self-extinguish before tenability limits

are exceeded?

2. Where might the fire go? Does the fire spread from the materials first ignited to adjacent materials, or to adjacent compartments?
3. Where will the smoke spread, and how will the fire impact the fire-resistive elements of the building?

Evaluation of the above questions in the abstract can provide some general insight (some might argue how much) into how buildings react, but cannot assess the role of properties of the materials themselves. Working with the tested fire resistance of specific design will not necessarily represent performance in the actual end-use situation for a range of scenarios, much less how the performance is related to the specific materials of construction. In addition, since the fire-resistance test subjects the system to only one fire source and growth rate, how it might react to a different heat release rate curve from the "standard" is not known.

TYPES OF TESTING

Fire tests can be divided into two categories: prescriptive testing and testing for engineered fire protection.

Prescriptive Testing

Traditionally, testing has been prescribed by the building or fire code. Generally, this has been prescriptive testing, which results in a pass or fail, or a classification, such as flame-spread classification or fire endurance rating. The building codes have, for many years, contained references to such fire tests. By meeting the requirements of these prescriptive tests, materials and assemblies are "deemed to satisfy" the objectives of the codes. Although these tests may result in a "performance" number, such as a flame spread index or fire resistance rating expressed in hours, the data developed are specific to each given test method and cannot be easily used to extrapolate to other conditions for the purposes of engineering analysis or design to meet specific objectives. For example, the language in one of these "deemed to satisfy" test methods contains the following wording:

"This standard should be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions and should not be used to describe or appraise the fire hazard of fire risk of materials, products, or assemblies under actual fire conditions; however, the results of the test may be used as elements of a fire hazard assessment or a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end-use."[4]

The two primary types of fire tests called out in the codes are tests for fire resistance of construction, typically exposed to a standard time-temperature curve, and tests for interior finish, which describe flame spread and smoke development.

Interior Finish Tests. Since it was first identified as a standard in 1950, the Steiner Tunnel Test, also known as ASTM E84, UL 723, or NFPA 255, has served as the most common test for evaluating interior finishes. For many types of materials, it has served as a good screen to weed out poorly performing products. It provides flame spread results as well as indices of smoke development and fuel contributed. The building codes make significant use of the flame spread results, some use of the smoke development, and no use of the fuel contributed data. Even in the prescriptive arena, this test has some drawbacks.

The Tunnel tests evaluate the specimen in the horizontal position. There are some materials that react quite differently in a vertical configuration. This includes foam plastics, which, as they are preheated, drip to the floor of the tunnel rather than allowing continued flame propagation. In a vertical configuration, the upper surface is preheated, and flame may progress quite rapidly. Therefore, the Tunnel tends to underpredict the fire hazard from certain foam plastics. The Tunnel has had similar problems predicting flame spread on textile or napped surfaces. This has led to a series of new tests, including room corner tests, of various sizes and configurations, and radiant panel tests that are more representative of end-use conditions but that do not necessarily provide performance data for design purposes.

In addition to the problems described for prescriptive application, the Tunnel test provides little assistance for performance-based applications. The results of the test are reported as a relative flame spread or smoke development, with the benchmarks of asbestos cement board at a flame spread of 0 and red oak with a flame spread of 100. Smoke development characteristics of asbestos cement board and/or red oak are also assigned 0 and 100. All other flame spread or smoke development factors are related to these two benchmarks. Therefore, while the result may indicate whether certain material performs poorly or well under fire exposure, there are no means to quantify or predict numerically the results.

Fire Resistance Testing. The ASTM E119 test relies on the standard time-temperature test developed in the early 1900s. In order to determine fire resistance of a system or product, the system or product is installed in a furnace, and gas flow into the furnace is modulated so the temperature follows the standard curve. Acceptance criteria vary but may include the following:

1. Failure to support the load.
2. Temperature increase on the unexposed surface.
3. Passage of heat or flame sufficient to ignite cotton waste.
4. Excess temperature on steel members.
5. Failure under application of a hose stream.

When dealing with prescriptive requirements, these test methods tell the user what they need to know – the material or system either did or did not pass the criteria for a given amount of time.

When dealing with performance, the published results of these tests provide very little information. For instance:

1. If the test assembly failed, why specifically did it fail (e.g., was it the material or the manner of assembly)?
2. At what point in time did the material or system fail?
3. What was the temperature of the material that failed vs. the furnace temperature?
4. How would the assembly or material perform if exposed to a different set of fire conditions?

Besides these limitations or questions, there is current concern and discussion about the realistic basis of the furnace

tests themselves. Tests in Cardington, England, have recently been performed on frames with composite metal deck floor systems and steel beams that indicate that the overall fire resistance of a system of beams and floors may be greater than that determined by furnace tests. In the tests, the beams were unprotected, and the columns were protected to the connection. Although there were large deflections, failure by collapse did not occur. It has been suggested that the apparent increase in load-bearing capacity may arise from load redistribution from the heated elements to cooled parts of the structure and from membrane action in the floor slab.[5, 6] Of course, there is also the issue of an assumed fire resistance based upon a time-temperature curve, when the rest of the performance-based design may be based on a different time-temperature curve that is dependent upon on the actual material that is burning.

Testing for Engineered Fire Protection

In carrying out engineered fire protection design, a set of objectives is developed for the design. These objectives are characterized in engineering terms such as temperatures not to exceed a specified threshold or smoke layer not to descend below a desired height above the floor. Detection and suppression systems might have a performance objective of responding before the fire reaches a specified size or before limiting conditions are reached at specified locations. The fire protection engineer has been provided with a number of methods that can be used to predict the effects of fire in buildings and the response of fire protection equipment. These methods include computer fire models and correlations that require the engineer to supply input data relative to the characteristics of the fire, as well as building geometry, ventilation, and other variables.

Heat Release Rate and Species Production. Heat release rate (HRR) has been described as the single most important variable in fire hazard.[7] Since HRR is not generated directly from first principles by the models and correlations, it must be input by the fire protection engineer for specific fire scenarios based upon data generated by tests of materials and assemblies/products.

HRR is generally determined by measuring the oxygen consumed by the burning materials as they are being tested[8] and is expressed as kilowatts. HRR can be expressed as a constant for a given material or assembly based on unit surface area burning (kW/m²) or as a curve describing a material burning over time. Figures 1 through 3 illustrate sample HRR curves.[9]

In addition to HRR, information regarding the rate of production of smoke and toxic species is also required. The rate of production of smoke and toxic species is generally expressed in terms of the mass of material produced per mass of material burned. These values are input to computer models in order to predict visibility through smoke and species concentrations for a given design analysis.

A number of test methods are available to generate the needed input data for engineered fire protection. The test methods range from small, or "bench-scale," tests of materials burning at a few kilowatts to large-scale apparatus and room size tests in excess of a megawatt.
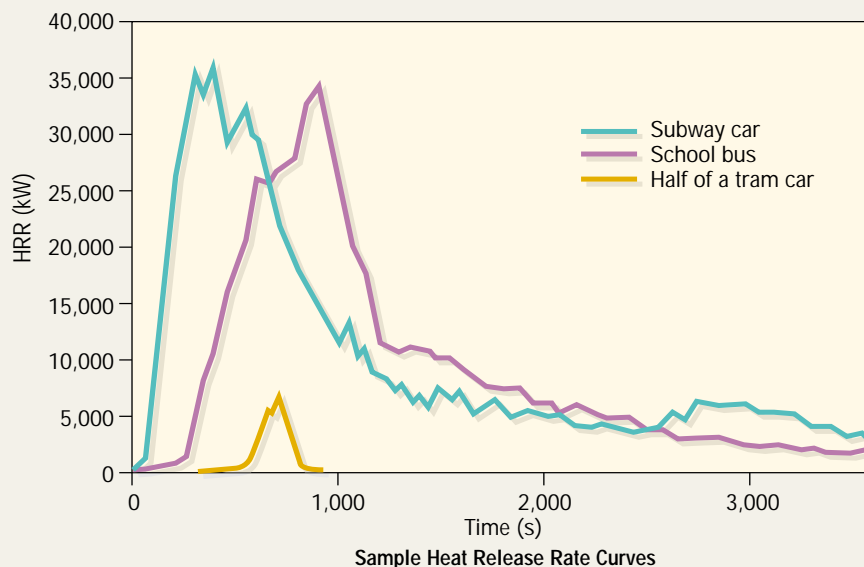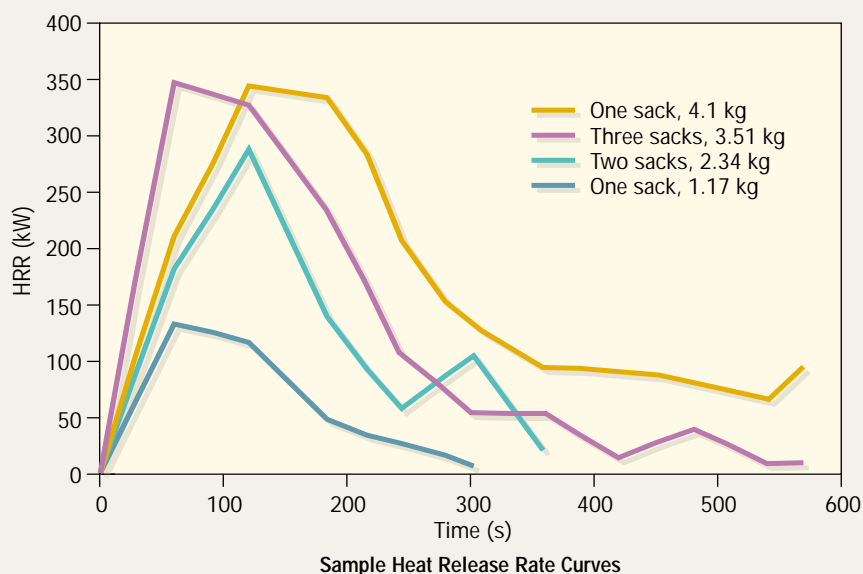

Sample Heat Release Rate Curves

Figure 1

Sample Heat Release Rate Curves

Figure 2

Figure 3

Sample Heat Release Rate Curves

Legend:
- Single chair
- 4 chairs in 1 stack
- 8 chairs in 1 stack
- 8 chairs in 1 stack in corner
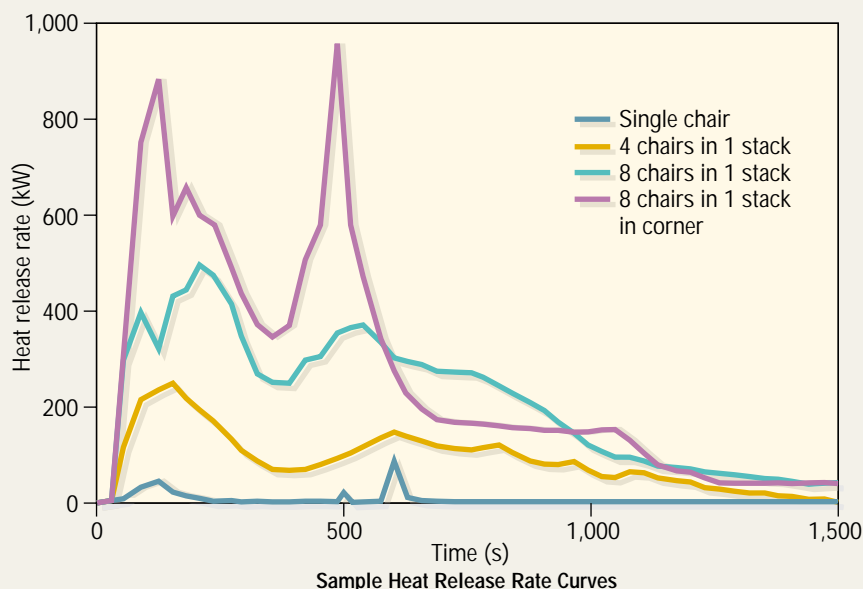
Small-scale tests, while less expensive and easier to conduct, might not characterize fully the material or product, particularly if the geometry and materials of construction of the product affect its burning rate (such as with furniture, other consumer products, or wall-lining materials).

Cone Calorimeter. The most widely used test method for determining HRR is ASTM 1354, commonly known as the cone calorimeter. This test method determines the average heat release rate in kW/m^2 of a material using a small sample. The sample can be exposed to external radiation up to about 100 kW/m^2 to assess its burning characteristics under conditions where it might be exposed in a room fire or to an adjacent burning item. The sample can be ignited by a small electric spark device or allowed to autoignite under radiant exposure. The time to ignition is recorded. The test method also permits collection of smoke and toxic species data and mass loss data.

An intermediate-scale calorimeter (ICAL) has been developed to accommodate larger specimens (ASTM E1623).

Furniture Calorimeter. For large items such as furniture, ASTM E114-74, the furniture calorimeter, can be used. The furniture calorimeter consists of a large hood to collect the products generated during the burning of an item of furniture. As with the cone calorimeter,

HRR is determined by oxygen depletion. Smoke, species, and mass loss rate data are also obtained. The samples are tested "in the open" where the effects of radiation and oxygen reduction in a room fire do not affect the HRR. The HRR history from ignition to burnout is produced as an HRR curve. Either the peak burning rate or the entire HRR history can be used as input to fire models.

Room Calorimeter. A number of test methods are available using room-sized compartments. These methods are generally used for prescriptive, or "deemed to satisfy," purposes for wall linings. Typically these tests are conducted to demonstrate that flashover does not occur under exposure to specified fire conditions. Wall linings are exposed to a fire in one corner. NFPA 265 is an example of such a test. Although NFPA 265 is a prescriptive test, HRR and species data can be obtained by collecting products emanating from the compartment for use in hazard analysis or engineered fire protection.

Nonstandard Tests. In some instances, it may become necessary to obtain burning rate information for very large objects or unusual configurations. Oxygen depletion calorimetry can be applied to nearly any situation, provided that all the products generated are collected for analysis and the materials themselves are not oxidizers.

Documentation

When performance test data are used for engineered fire protection design or analysis, it is important that the source of the information and the methods used to generate it be fully documented. It is important to make sure that the data used are appropriate for the design calculations. For example, some correlations are based upon the total HRR, while other correlations require the convective HRR. For values obtained from the literature, complete references need to be provided. Where the data are generated from nonstandard tests, documentation should be in the form of a report providing the details of the test method, instrumentation, and the resulting data.

The above discussion of test methods is intended as an introduction, and it is suggested that the readers consult the *SFPE Handbook of Fire Protection Engineering* (third edition) for more detailed information. The Handbook provides detailed descriptions of test methods and their limitations, as well as sample HRR for real products, smoke and toxic species data, and extensive references to the literature.[9, 10, 11, 12]

SPECIFICATIONS

As designers use more performance-based design-related tests, the methods of specifying will also need to change. Specifications are very often "boilerplate," with a series of tests or standards that materials must meet called out in the introductory portion of the specifications. Since most of the tests are pass/fail, the specifier merely calls out the standard or test and gives no further discussion to its application.

With performance-based design, the specific fire-performance characteristics must be specified, and they will likely differ from project to project. For instance, in an atrium project, one performance-based design may be based on a maximum fuel package output of 5 megawatts, while another may be based on 2 megawatts per unit. Either could be supported, as long as the materials at the base of the atrium are properly controlled. This will require carefully specifying the materials, their fire characteristics, and their locations. In developing the specifications, the designer may

need to call out the HRR or time to ignition of materials, the maximum time to temperature transmission for certain fire-resistive materials, the toxicity level of certain materials, or many other items that have not previously been a part of specifications. Similarly, for active systems, the specifier may need to more clearly describe system characteristics.

COMMISSIONING

As with preparing specifications, use of performance-based design and new fire tests will greatly change commissioning. For instance, with adjustable-sensitivity smoke detectors, the person commissioning the system may need to look at the specific sensitivity setting rather than simply blowing smoke into the detector. If the performance-based design has been reliant upon particularly sensitive detectors, the application of this sensitivity factor may be important. Similarly, the detector may use alarm verification technology. If a performance-based design relies upon detector activation within a certain amount of time, the timing of the alarm verification is critical and should be verified.

Similarly, for suppression, many performance-based designs rely upon time to activation of sprinklers to initiate smoke control and evacuation. Sprinkler response time has an impact upon the size of the fire and the amount of smoke that will be generated. Therefore, commissioning will need to include verification that the response time index of the automatic sprinkler is the same as the response time index used in the calculations.

Smoke control testing has become a significant feature of opening new buildings in recent years. Commissioning smoke control systems is a time-consuming process and can reveal many of the problems associated with complicated systems. Beyond the problems of commissioning a system designed to meet current codes, a performance-based design may include requirements for smoke control features beginning at a certain time after detection of the fire. While the codes very often describe maximum times for smoke control functions to begin, the performance-based approach may rely on different times than are traditionally found within the codes. Therefore, quicker response or quicker pressurization or exhaust may be necessary to meet the performance-based design criteria.

Lastly, commissioning may require physical verification of locations and types of materials forming fuel packages. This type of information is necessary for the design description, but is often overlooked during commissioning. Because the results of the fire test are an important part of the performance-based design, the actual application of the materials in the same way as described in the test and/or the design is very important to the process. It will also require clearly describing to the owner and the authority having jurisdiction limitations on flexibility in

future uses of the space or building. It is important that the nature of the fuel (amount, configuration, and burning properties) not change such that the design fires used in the analyses are exceeded. In addition, changes to the building geometry such as increasing compartment sizes or ceiling heights can also negatively affect the performance of engineered fire protection. This places an onus on the owners or occupants to maintain the initial conditions or consult with fire protection engineers before making changes. Continued verification of the commissioned conditions may be the role of the fire prevention officer or insurance inspector. ▲

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Validating FIRE RESEARCH and TEST PROTOCOLS
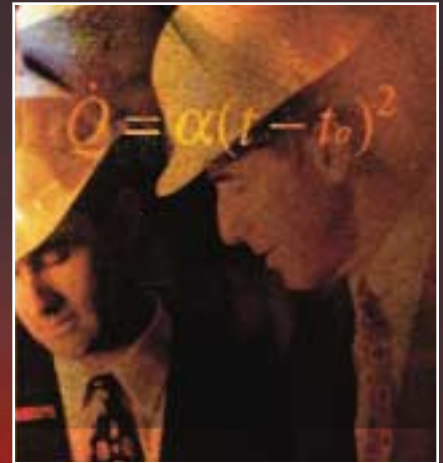
By George Smith

History warns that, when it comes to evaluating flammability and fire resistance of materials, problems could arise if engineering design practices do not have a sound, scientific basis. Past use of invalidated test methods and models has resulted in misapplication of products, which increased the fire risk in building environments. Fortunately, many countries are moving rapidly toward performance-based codes which will promote the development of well-documented, scientifically validated practices.

By widely accepted definition, a validated fire test method must:

- Evaluate the product, material, or device in its anticipated end-use.
- Have a solid, scientific basis.
- Include detailed test protocols, like sample conditioning and ignition parameters, to enable laboratories to conduct experiments properly.
- Provide results that can be reproduced by others using the protocols.
- Disclose limitations of the method to practitioners before test results are used in the real world.

In the 1970s, two building insulation foam polymers – polyurethane and polystyrene – came on the market for wall and ceiling installations. But manufacturers, designers, and accepting authorities did not fully understand their flammability properties in as-installed conditions. They usually relied on nationally recognized, small-scale, bench-top test methods that did not reflect real-world usage. These tests inaccurately showed a limited fire hazard for the tested materials. Advertisements based on results frequently labeled these products as "noncombustible" or "self-extinguishing."

Three procedures, established more than 50 years ago, were the basis of most of these flammability evaluations. Adopted by the American Society for Testing and Materials (ASTM), the tests were:

- ASTM Method D635, *Flammability of Rigid Plastics over 0.05 in (1.27 mm) in Thickness*
- ASTM Method D1692, *Flammability of Plastics, Foams, and Sheeting*
- ASTM Method E84, *Tunnel Test*

ASTM D635 and ASTM D1692 involved exposing a small specimen to a Bunsen burner for a specified time. The

specimen was classified as "self-extinguishing" or "burning," depending upon how long it took to ignite and how far the flame progressed. Even though these screening tests were not designed to represent real-world performance, products were promoted using results to indicate flammability. Because of this, Factory Mutual Research, in 1962, launched a small-scale testing program to investigate their limitations. By following ASTM 635 and ASTM D1692 test procedures, Factory Mutual Research evaluated samples of ponderosa pine, Douglas fir, spruce, balsa, and red oak. Both procedures compared the relative flammability of plastic products.

Plastics, in general, are combustible, much like wood, paper, and textiles. Testing the wood samples showed that both ASTM methods could classify these obviously combustible materials as self-extinguishing.

Similar results were obtained for foam polymers, even though common sense dictated against classifying any material comparable to wood as self-extinguishing. Factory Mutual Research was concerned that the ASTM ratings would lead users to wrongly assume that foam plastics wouldn't burn. But eventually their flammability became well known because of severe fires. The ASTM standards were withdrawn and manufacturers began to label their products with appropriate flammability ratings.

The ASTM E84 Tunnel Test, developed in 1941 to evaluate the flame spread across the surface of interior finish on ceilings and walls, is still in wide use today to meet building code requirements. The sample is placed inside a rectangular tunnel with gas burners at one end and an exhaust flue at the other. At the burner end, the sample is exposed to the gas flame. Flame spread ratings are assigned depending on how far and fast the fire propagates horizontally from one end to the other. When this test was developed, most ceiling and wall materials were made of cellulosic or mineral-fiber-based materials. When synthetic (noncellulosic) materials came on the market, some organizations used the ASTM E84 Tunnel Test to evaluate these materials, even though the burning and physical
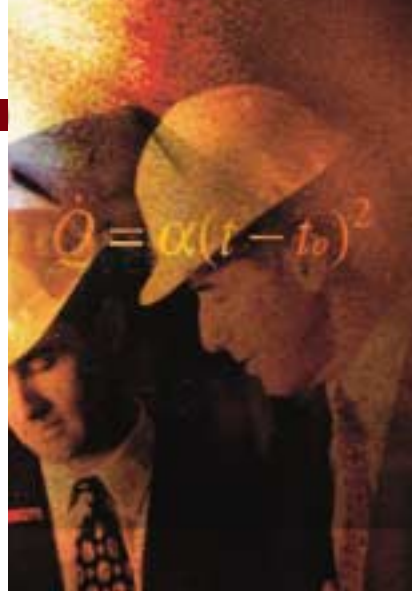
response of synthetics differed from cellulosics. Full-scale correlation testing comparing the flame spread rating to real-world conditions was not done. Unfortunately, national and local building codes and other regulations referenced the flame spread ratings for interior flammability.

But in time, the National Bureau of Standards (NBS) investigated the validity of this test for rating noncellulosics. They measured the heat flux from the ignition source down the 25 ft. (7.6m) length of the tunnel and found that half of the original heat flux exhausted out the other end.

In addition, ASTM E84 evaluates only one surface, the sample under the ceiling of the tunnel, and cannot evaluate radiation effects from one surface to another. Heat radiating from both ceiling and wall surfaces is an essential part of any valid fire test involving plastics installed in horizontal and vertical surfaces together, like walls and ceilings.

Many foam and rigid plastics typically melt during a fire and drop from the ceiling; however, during a test, flame often stops once the material has melted away from the burner. Favorable flame spread ratings were often assigned to materials even without valid correlation between the materials' true flammability and the test results.

To better predict the fire performance of finish materials in actual use conditions, Factory Mutual Research scientists, working independently and with other laboratories, designed several advanced fire testing methods between 1950 and the early 1980s, including:
- The White House Test
- The Construction Materials Calorimeter Test
- The Factory Mutual Research Building Corner Test
- Various tests using the Fire Propagation Apparatus

The White House Test, a full-scale procedure developed between 1955 and 1957, was originally designed to replicate a disastrous fire at an automobile transmission plant in Livonia, Mich. The fire started at the floor level. The heat from the fire rose to the underside of the roof, heating the steel deck. The roofing materials began releasing combustible vapors that flowed under the roof covering, entering the building through the seams in the metal deck. These vapors ignited and, within half an hour, began propagating an intense fire under the roof deck and inside the building, totally destroying the building and its contents. The fire remains one of the most severe in U.S. history.

Engineers designed the test to determine why the fire progressed so quickly below the roof on an assembly that had a noncombustible surface. In the end, the test answered their questions and revealed more facts about how fires grow and propagate. The test setup is a 100 ft. (30.5m) long by 20 ft. (6.1m) wide structure. Original testing evaluated similar, if not identical, materials to the Livonia building. Investigators sealed the edges of the roof tightly to prevent roofing vapors from venting prematurely. This made it possible to replicate a real-world fire exposure for most large, commercial, and industrial buildings.

As testing progressed, engineers developed data on many significant fire parameters, such as total heat flux, offgassing of combustible materials, and rate of heat release of building materials during fires. The method was so successful that other laboratories have been using it for testing certain types of roofing material and decks.

Within the last decade or so, some researchers began departing from the original protocol. One recent departure involved the testing of polystyrene roofing insulation applied directly to the top surface of the steel deck without the use of a thermal barrier.

The edges of the sample were not completely sealed. This allowed combustible vapors accumulating under the insulation to vent out of the struc-

ture prematurely. The 18 in. (457mm) draft curtain at the end of the test structure also was eliminated, allowing more rapid loss of heat to occur. The original White House Test protocol, which duplicated the results of the Livonia fire, prevented the premature release of combustibles. And the published White House Test protocol requires sealing of the eaves along the entire 100 ft (30.5 m) length of the structure. Finally, no validation tests were conducted to compare the results to the original White House Test series to those conducted on the polystyrene assemblies.

This revised method allowed installers to apply polystyrene roofing insulation directly to the roof deck without installing thermal insulation barriers, like gypsum board, between the polystyrene insulation board and the steel deck as required by FM Global.

While thermal barriers do not prevent polystyrene from decomposing, they do delay decomposition of polystyrene (EPS/XPS) and reduce the likelihood of it causing a self-propagating fire on the underside of a steel deck assembly.

Factory Mutual Research's Approved EPS/XPS assemblies are always identified with a minimum thickness thermal barrier. Minimum thickness is needed to be sure the decomposition is delayed long enough to assure that sprinklers or manual firefighting can be effective.

Successful full-scale tests were conducted for direct-to-deck application of polyurethane/polyisocyanurate assemblies using the Factory Mutual Research Full-Scale Corner Test procedure. These thermosetting plastics are able to meet Factory Mutual Research requirements without a thermal barrier because of their charring ability. The char helps to protect combustible materials below or above them. Thermoplastics, like polystyrene, burn differently – generally dripping and burning as a pool fire without forming a char.

The Construction Materials Calorimeter Test, developed in the 1950s, is an intermediate-scale method correlating directly with the White House Test results. The test identifies alternate roofing materials (insulations, vapor barriers, adhesives) that will not propagate fire when installed in a roof assembly.

When designing this test, Factory Mutual Research scientists wanted the method to measure the maximum rate of heat release (RHR) of an assembly of materials. This concept was fairly new and unexplored at the time.

The results of this work have been evident for 30 years. Buildings constructed with materials that do not exceed the FM Global requirement for maximum RHR have not experienced self-propagating fires involving insulated steel deck roofs.

The Building Corner Test was developed by Factory Mutual Research in the 1970s to evaluate the combustibility of foamed polymers like foamed polystyrene, polyurethane, and polyisocyanurate. Building codes recognized this test as a direct way to evaluate the flammability of foamed plastics.

This test was designed to replicate the use of foam plastic insulation materials on walls and/or ceilings and the underside of roofs in structures like metal buildings and warehouses and in specialty areas like anechoic chambers.

Today, the Building Corner Test is a more realistic way to deal with flammability of construction materials. Geometry and fire exposure development are simulated as close as possible to the real exposure. The Building Corner Test structure and exposure is a better predictor of a material's tendency to melt, run, drip, burn as a pool fire, vent through the assembly, and collapse than any of the tests available at the time it was developed.

The Fire Propagation Apparatus, developed in the mid-1970s, is the forerunner of all current fire calorimetry. In the early 1980s, it was used to measure the total heat flux from fires.

By measuring the total heat generated by various fires, Factory Mutual Research and Approvals has used the data to develop test protocols leading to designs of improved fire protection systems and system hardware.

For many years, Factory Mutual Research has been able to use sophisticated calorimetry to determine engineering information on such issues as water supply adequacy and suppression requirements for certain fuel packages. By using its current family of calorimeters, Factory Mutual Research has assisted industry to develop new and safer products and fire protection equipment. ▲

George Smith is with Factory Mutual Research.

Mission Effectiveness and Failure Rates
Drive Inspection, Testing, and Maintenance of
Fire Detection, Alarm, and Signaling Systems

When a fire alarm system fails, it impacts mission effectiveness. The degree of impact depends on the role or mission of the alarm system in the overall fire safety mission.

The first type of potential failure is when a system that has been designed and installed to meet specific objectives fails to meet those objectives. The failure may be the result of an operational failure or fault, or it may result from changes in the environment or hazards that affect the system's ability to meet its objectives. The second failure mechanism is when the objectives of the fire alarm system have not been properly matched and integrated with the overall fire safety mission. A third type of failure is when a system "fails positive" due to false or nuisance alarms. Fire protection engineers can have a measurable impact on each of these potential failure mechanisms. Next to mission definition and integration, a program of system inspection, testing, and maintenance (ITM) has the greatest potential to assure system success or failure. In addition, an ITM program can identify when a system has not been properly integrated into the overall fire safety mission.

In a survey of the operational status of 46,339 fire alarm systems conducted by the California State Board of Fire Services,[1] 73% of the respondents cited lack of maintenance for the cause of system failures. Another survey[2] showed that actual equipment problems with smoke detectors, smoke alarms, and control panels were comparable for new systems (less than one year) and

existing/old systems (one year or more). The numbers showed a trend towards higher numbers of failures in older systems for conditions such as "in alarm" or "in trouble" that would be discoverable during routine ITM. A false/nuisance alarm survey showed that 72% of all unwanted alarms could be prevented in the design and installation stages of systems.[3]

Components and assemblies tend to follow the typical "bathtub" failure rate curve as shown in Figure 1. Following the infant mortality phase, the statistical or "intrinsic" failure period is relatively flat, constant, and long until the wear-out or end-of-life phase is reached.

Some manufacturers use 100% burn-in programs to eliminate infant mortality for certain products. In other situations, Quality Control (QC) or Quality Assurance (QA) programs use statistical sampling and analysis to reduce infant mortality by reducing manufacturing defects and by assuring the quality and reliability of the components used to make the product. At the other end of the curve, system changes, upgrades, building renovations, and other factors tend to result in "retirement"[4] of systems and components before the end-of-life or wear-out phase is reached. Thus, the infant mortality phase can be reduced or nearly eliminated and the end-of-life phase cut off, resulting in a relatively flat failure rate over the life of the product. From a component and system product standpoint, today's fire alarm systems are very reliable. In the case of smoke detectors, the statistical failure rate is less than 3.5 or 4.0 failures per million hours (of operation), depending on how the number is determined.[5]

Other fire detection devices, fire alarm appliances, and more complex systems such as control units, which often include customizable software and modular components, do not require computation of failure rates by the listing laboratories as do
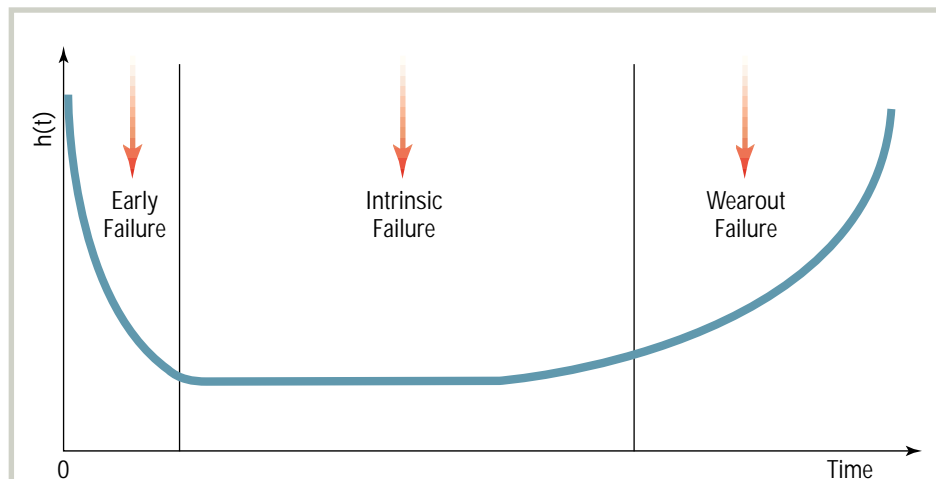
Figure 1. Bathtub Curve[6]

smoke detectors and smoke alarms. In addition, while individual devices, appliances, and subsystems (modules) use manufacturing controls, QA, and QC programs to reduce or eliminate infant mortality, the installation process and assembly of a complete system introduces new failure modes that effectively reintroduce the infant mortality section of the bathtub curve for the overall system.

When systems undergo ITM at frequent intervals, the failures are discovered. If the faults are fixed, time out of service is minimized. The time out of service is equivalent to the time it takes to discover a fault and the time needed to repair or correct the fault.

In a paper addressing the need for functional testing of smoke detectors and smoke alarms,[7] Hjalmar N. Nelson, Jr., showed statistically that component reliability has less of an impact than inspection and test frequency on the mean time out of service, or unprotected time. For example, a smoke alarm in service for ten years and having a failure rate of 4.0 failures per million hours would have an estimated time out of service of 33.5 weeks over the ten-year period if the unit were tested only once per year and replaced within two weeks if found defective. Halving its failure rate to 2.0 failures per million hours would result in an estimated time out of service of 30.6 weeks over ten years of service life – a reduction of 20 unprotected days.

However, increasing the test interval to twice per year instead of once per year lowers the unprotected time from 33.5 to 17.9 weeks – a reduction of 109 days of unprotected time. These examples assume a "quiet failure", i.e., unsupervised, no-trouble signal. They also assume a nonrepairable failure resulting in a new unit being in place within two weeks of the failure being found by testing or inspection. Nevertheless, these calculations show the tremendous importance of ITM.

It is clearly more cost-effective for overall mission reliability to implement a well-designed program of ITM. Entire industries and professional organizations specialize in how to determine the necessary intervals for ITM. For an excellent discussion of performance-based reliability, mission effectiveness, and ITM frequencies related to fire detection and alarm systems, see the *NFPA Fire Protection Handbook*.[8]

Looking at the big picture, failure rates and, hence, calculated ITM frequencies are not available for complete system installations. The frequencies specified in *NFPA 72, the National Fire Alarm Code*,[9] do not have a known failure-rate basis that can be used in performance modeling – at least none that has been quantified or documented. However, new data[10, 11] suggest that design, installation, and the installed environment of a complete system have a large impact on the failure rate and mission effectiveness. Knowing the failure rates of individual components is not sufficient to predict failure rates for completed systems. Manufacturing and production methods may reduce infant mortality of components, but design and installation introduce new, cumulative failure modes that can be uncovered and corrected only through thorough ITM programs.

How do ITM programs affect failure rates, the probability of success, and overall mission effectiveness?

INSPECTION

The first evaluation of a physical system – as opposed to a design or plan – is performed by conducting an inspection. During system installation and following its completion, inspections are performed to determine if the installation conforms to the intent of the design. During the rough-in stage, it is easy for the engineer to check wire sizes, circuit loading, and terminations as well as the quantity and location of fire-detection devices and alarm appliances. At the same time, the designer has the opportunity to see the physical environment of the system and to evaluate conditions that may not have been apparent during the design stage. For instance, the shape of complex ceiling geometries combined with air supply and return registers may warrant changes to detector layouts in order to enhance actual fire detection or to reduce maintenance costs and prevent nuisance alarms.

After installation, periodic inspections are necessary to identify changes in the environment that might also affect system performance. For example, the construction of a wall to subdivide a room may leave a space without adequate smoke detection or sprinkler coverage. Similarly, noise-generating equipment may affect occupant notification or the intelligibility of voice communications.

TESTING

Manufacturers can do 100% testing of production and 100% burn-in to nearly eliminate infant mortality, but faults will

still be introduced by the system design and installation. Therefore, codes require a 100% acceptance test of the installed system and reacceptance testing when a system is altered.

While the codes require complete testing of all devices and appliances, is it possible to test all possible failure modes and to calculate all success probabilities? Just consider a system requiring two detectors in alarm before an extinguishing system is discharged. The number of combinations of n things, taken r at a time, where order is not important, is:

$$C = (n, r) = \frac{n!}{r!(n-r)!}$$

For a system of four smoke detectors (n=4) taken two at a time (r=2), the number of tests required is six. For 10 detectors, 45 tests are required, and for 30 detectors, 435 tests are required. In addition, each detector must be tested by itself to verify that it works and alarms the panel as required, but does not activate the discharge circuit. It may be possible to use program analysis, sampling, and scenario testing to reduce the required number of tests. This would require more advanced statistical modeling.

Periodic testing over the life of a system is performed to discover faults that do not generate trouble signals and to possibly identify increased failure rates, which may signal the approach of end-of-life failure modes.

In addition to acceptance and periodic testing, fire alarm systems use electronic testing methods to identify faults that might affect mission effectiveness. Monitoring the integrity of installation conductors and power supplies is one form of automatic, internal testing as is automatic sensitivity testing of smoke detectors. However, this does not eliminate the need for functional tests, as there are silent modes of failure in all systems.

MAINTENANCE

There are two forms of maintenance required for fire alarm systems. The first is preventative maintenance intended to keep a system operational. This includes

the cleaning smoke detectors and the lenses of flame and spark detectors. The second form of maintenance involves the repair or replacement of devices, appliances, or components that have been identified as having failed or degraded. The combination of testing, integrity monitoring, and repair results in reduction, control, or even elimination of end-of-life failure rate increases.

CONCLUSIONS

The mean time to failure (MTTF) of fire alarm system components can be used by engineers and code committees to calculate ITM frequencies. However, considerable work is needed to model the contribution of design, installation, and environment on total system MTTF. Only then can statistical methods be used to model the reliability of fire detection, alarm, and signaling systems. Nevertheless, ITM programs are used to reduce infant mortality and to intervene before end-of-life failures become dominant, thus reducing the failure rate to a relatively constant, though unknown, rate.

Failure rate data are needed for all fire alarm system components, not just smoke detectors. This does not need to be manufacturer-specific since it has been shown that failure rate is less important than testing frequency on the out-of-service time. The data can be in the form of a range or a limit as we have for smoke detectors and smoke alarms.

At the same time, we need more data on installed systems. Combined with the component data, it is then possible to identify the root causes of failures (system design, integration, component design, performance, installation, maintenance, etc.) and their relative contribution to mission effectiveness. Then, engineers and code committees can better design and target ITM programs to maximize the probability of success. ▲

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Editor's Note – About This Article

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THE AGE OF PERFORMANCE-BASED CODES AND STANDARDS

By Paul Fitzgerald, P.E.

INTRODUCTION

The loss of life, property, and productivity from fire is a worldwide concern. Public protection dollars are becoming increasingly scarce. Friction-costs* are higher than ever. Many of these increased costs reflect the dramatic change in the design, material, and construction technologies used in today's building sciences. Whereas most building sciences have evolved new methods and/or assumptions regarding data, models, and design techniques, a large percentage of product fire-safety evaluations rely on laboratory test procedures developed for very different generations of construction and finishing materials.

Over the past fifty years, much has been learned about the fundamental nature of fire and has been introduced into engineering practice. The accelerated development of other building science disciplines has produced a significant push to reduce all costs associated with new construction. Further, the buyer's concept of an acceptable project completion time, from drawing board to occupancy, has dramatically reduced.

Performance-based building codes and a family of supportive design and product standards are often cited as the way to cope with these trends. In mature engineering disciplines, engineering data and practices are assumed to be time-tested, and so reliance on performance-based designs are accelerating. The enforcement community[†] appears to be willing to accept performance-based designs in these disciplines because of greater familiarity with the underlying support assumptions.

Unfortunately, performance-based fire safety designs are comparatively new and have a limited experimental and real-world application database behind them. This limited fire-safety database and the associated scientific protocols used to develop it will drive a substantial part of the future fire research agenda.

A RESEARCH DILEMMA – EMPIRICAL OR FUNDAMENTAL RESEARCH

The historic dilemma facing the development of a performance-based, fire-safe engineering practice is that the resources available for fire research have been a small fraction of that expended in other areas. This is particularly true of fundamental fire research. A high percentage of scarce research dollars was diverted into projects directed at solving immediate problems rather than investing in the future through fundamental fire research. With few exceptions, neither the fire protection engineering nor the fire research communities built a sustainable business-driven model justifying expenditures in fundamental fire research. For performance-based fire safety designs to advance reasonably apace to that in other engineering disciplines, building such a model is necessary. Not to do so will result in waste and in the delayed advancement of cost-effective technologies. Scarce fire research resources will continue to be primarily directed toward addressing the most recent crisis. Worst of all, the danger exists that the engineering practice and associated building codes and standards that develop will not produce an optimal level of safety to both the occupants and the arriving emergency personnel.

The term "fire research" is often used to describe any investigation into the combustion of a material or the suppression of some form of test fire. Many past and present fire research programs consisted of an individual or groups of tests designed to provide data on a single or very limited number of variables. Table 1 summarizes the different types of today's research and test programs and their characteristics as they relate to the development of performance-based codes.

Empirical test programs tend to be very costly to conduct. They often require a large number of individual large-scale tests. On occasion, key tests have to be repeated in order to assure the accuracy of the findings of a previous test or to tweak one variable. Different dimensional and ventilation characteristics of test facilities hinder experimenters from different laboratories replicating the work of other investigators. Because certain key variables are fixed while one or two others are investigated, they have been and will continue to be limited in developing scientifically based performance criteria.

On the other hand, empirical test programs have the unquestionable advantage of timeliness in meeting immediate needs. Past test records are replete with success stories where an occupancy or building hazard has been reduced or innovative new products have been brought to market in a timely fashion through a series of empirical tests that addressed a limited set of conditions. The value of empirical testing is not the issue; instead, it is the competition that empirical testing produces for the disproportionate share of scarce fire research dollars that is important. The "here-and-now" pressures for immediate answers to some problem or some opportunity to market a new product will always be considered to be a greater priority than building a long-term knowledge base. Although application of the results will be more limited, bringing closure to just one issue through empirical testing has been and will continue to be important in the future.

To support performance-based designs using models having wide application, fundamental or first-principal research is vital if the necessary databases and test protocols are to be developed in a reasonable time frame. Building and promoting a solid argument – performance-based design will advance faster if there is a greater focus on fundamental research instead of relying on empirical testing – is not an easy task.

By its nature, fundamental research is time-consuming to do. It is also time-consuming to gain wide acceptance of the results. Further, in any fundamental research program, failure to achieve the desired ends in an acceptable time period is common. By contrast, empirical

TYPE OF INVESTIGATION	CHARACTERISTICS	APPLICATION TO PERFORMANCE-BASED DESIGNS	LIMITATIONS
Fundamental Research	Development of first-principal scientific knowledge.	Foundation for engineering protocols, models, simulations, and instruments.	No immediate application of results; scarcity of researchers.
Applied Research	Use of existing scientific protocols and instruments to resolve specific design issues.	Confirmation of fundamental research; closing limited knowledge gaps.	Expensive; results might not be applicable for wide set of designs or engineering tools.
Empirical Testing	Large or intermediate simulation testing representing particular occupancy or construction types.	Closing knowledge gap for a limited set of design conditions.	Very expensive; few generalized solutions; replication difficult.
Specification Testing	Pass/fail tests using standardized furnaces, instruments, and physical setups.	Nil.	Only supportive of prescriptive codes. Questionable scientific basis in other applications.

Table 1. Common investigations.

test programs usually involve well-understood objectives, definable times, and a high level of confidence in the expenditures needed to execute the program. Because of the need for immediate results, however, failure of an empirical test program is rarely an accepted outcome.

Therefore, from an economic perspective, the chances of immediate payback to its business and its customers appear to be better with a short-term, empirical, or standardized fire test project rather than through a more fundamental fire research approach. The prospects for obtaining timely solutions and a useful result are better, and there is significantly less risk of failure or exceeding budgets.

This dilemma is not unique to the fire protection engineering discipline. Every industry makes allocation decisions between fundamental research, which could result in great advances in product design and development, and ordinary testing that might be needed to extend the application of existing technologies.

ECONOMIC ARGUMENTS FOR FUNDAMENTAL FIRE RESEARCH

So why would any business invest in long-term, fundamental research? It has higher risk. It takes longer. It has uncertain costs. Customers and financial markets probably will not appreciate it. It may not even result in solving an immediate or even long-range customer problem or in new product development.

A model attempting to develop consistently funded fundamental research through the private sector must address two basic hurdles:

• Management, investors, and even employees are more interested in today's financial performance than promises for tomorrow. This is particularly true of manufacturing industries where fire performance is usually only one of many performance criteria and a product's life cycle is increasingly shorter.

• Limited empirical testing will almost always be more appreciated because the results will be perceived as creat-

ing market value by enhancing product acceptance, helping resolve customer problems or reducing risk in today's world.

In 1998, the National Science Foundation funded a survey of corporations to determine what, if anything, drove their research and development work. The survey resulted in defining six predominant drivers as to why corporations do fundamental research. They were:

• To generate new sources of wealth.
• A corporation's technology depends on the science behind it.
• It improves the recruiting of talented, creative staff throughout the organization.
• It can lead to or at least create the promise of great discoveries of proprietary value.
• It helps the corporation benefit from the spillover from the technology revolution.
• At the end of the day, research is perceived to pay off.

Although these drivers are applicable to fire research one way or another, five especially support the need for fundamental research in the development of performance-based codes and standards.‡ For example:

1. To Generate New Sources of Wealth.

This has to be an obvious output of any research effort. While it is common to think of "wealth" as increased profits and market value, knowledge is also a measurable form of wealth. Companies with a rich knowledge base are usually successful in developing new and innovative products and services at reduced cycle times. Knowledge management can also be used in other ways:

• To manage enterprise risk far more effectively;
• To be able to anticipate their competition and move more proactively;
• To be more effective in strategic planning in technical areas;
• To anticipate a customer's changing needs; and very importantly;
• To be able to spread increased knowledge into other areas of the en-

terprise's business and enhance operations in unaligned areas.

2. Technology Depends on Science.

The NSF study cited the relationship of science and technology to citations for patent applications. Historically, most "prior art" citations were to previous patents. In the last decade, however, patent citations that referred to the scientific literature increased at a rate of over three times that of applications referring to prior art. While part of this increase is attributable to better database searches and to Patent Office diligence in assuring full disclosure, it nevertheless highlights that fundamental research is increasingly finding its way into application. The same should be true for fundamental fire research.

3. It Can Lead to Discoveries of Great Proprietary Value.

Industries such as the pharmaceutical and technology sectors have long invested in fundamental research, and their record in developing new and innovative products that spring directly from fundamental research is legendary. Building a first-principle platform of data, scientific protocols, and readily available instrumentation should allow construction and interior finishing material manufacturers to achieve similar, profitable results.

4. Spillover from the Technological Revolution.

Most of the knowledge gained from doing long-range research is not generated by the business doing the research. In 1998, the NSF estimated that about $U.S. 50B of research was completed and made available to the public. The government, universities, public grantees, and nonprofit organizations did this research. In fact, only 8% of the papers published in the scientific literature were from corporate research scientists.

The NSF study concluded that, regardless of the industry, a company that does not engage in fundamental, long-range research will find themselves at a serious disadvantage to those that do. For example:

• Such a company would not have the scientists who, as an outcome of do-

ing background research, tend to bring valuable information, data, and knowledge generated by others into the company, often in areas not within their particular expertise.

- Even if they discovered research of value, their staff would not be sufficiently skilled to be able to appraise its potential importance to the business. There would be a very high probability that such information would not be used or, even worse, be used inappropriately.

- Almost certainly, they would not be able to easily spin the information and knowledge they have into new products and services.

- Finally, they would probably not have easy access to networks of research organizations and individuals who could be of assistance in helping solve problems and plan future improvements in their product and service base.

Of all of the good reasons for a business that produces products and services that relate to fire-related codes and standards to do or support fundamental research, the last might be the most important. In mature disciplines, it is increasingly more difficult to make major technological breakthroughs. Most research outputs tend to be incremental gains rather than giant leaps forward. Because the knowledge base is more limited, this is not true for fire research. Every business has limitations in human and financial resources, however, so knowledge must be obtained from external, reliable sources. Being part of a research network can be of great value in accessing knowledge, especially as new, innovative strides are made in understanding the dynamics and chemistry of fire.

5. Research Pays.
At the end of the day, a business needs a payback for its investment in research – including fundamental research. Unfortunately, proving that fundamental research pays is difficult and varies from industry to industry. The pharmaceutical and technology industries are very different from the basic metals, electronics, or diversified chem-

ical industries. These latter, mature industries experienced their technology breakthroughs decades ago, making it difficult to argue for further investment in truly fundamental research. By contrast, NSF cited surveys of patents and the perceived scientific reputation of companies. They observed that in the technology industry there was a tight link between a company's scientific reputation and a better-than-average return on its stock.

Performance-based fire safety codes and standards are new and demand high-level engineering expertise. Therefore, companies producing products used in performance-based fire safety applications have the opportunity to build technical reputations that could provide direct payback, not only through increased patents and the continuous introduction of innovative products, but also by developing greater market value for their shareholders.

Financial and competitive measures are not the only way to prove "research pays." Financial analysts are reviewing the "value" of intellectual capital, and accountants are discussing ways to include it on their books as an asset. The term "value creation" is increasingly being used to describe the establishment and management of a business's core research portfolio. Instead of solely emphasizing "beat the competition" or "improve shareholder value," value creation focuses on the customer by continuously bringing new and superior products or services to them. In many cases, small advances can result in quantum leaps in perceived value, and that can lead to one of the most critically sought-after objectives of any business – namely, customer loyalty.

A FIRE RESEARCH VALUE PROPOSITION

The premise that performance-based codes will allow construction of all types of buildings that will not only be more cost-effective but safer as well offers the opportunity of creating a new value proposition for fundamental fire research. This value proposition should be brought to bear on the next generation of fire research. The public will be looking for buildings and other occu-

pied spaces that are economic, attractive, durable, and safer from fire (and other perils). That expectation should help build the incentive for investment in fundamental fire research so that codes and standards will be based on information that is rigorous, consistent everywhere, and easy for the practitioner and the enforcement communities to apply.

Lacking rigor, consistency, and universal application, the advancement of fire-safe designs will suffer. Furthermore, a lack of uniformity in data management, model integrity, and test methods will influence international trade of products designed to meet a variety of different performance-based codes and standards. In addition to the direct economic loss through lost sales and additional friction costs, progress in reaching the overall objective of safer homes, safer workplaces, and safer public buildings will also be impeded.

SOME SUGGESTIONS FOR MOVING AHEAD

In countries that have promulgated performance-based codes and standards, their actual deployment has been hindered by several factors. The first is the lack of fundamental, first-principle research data that can be used across a wide variety of building design, use, and architectural variations. There is no internationally accepted "data dictionary" that defines first-principle data elements and how they should be measured. Even with the most fundamental scientific instrumentation, measurements from laboratory to laboratory may vary and not be suitable for use in all models. This lack of uniformity in fundamental data definitions and their associated measurement technology is critical and should be addressed as a first priority.

Second, the comfort zone with performance-based fire codes is low. Besides the limited data and protocols, general performance design criteria have not been agreed on. For example, agreement has not been reached on the most important critical performance design criteria – namely, whether building design viability should only be long enough to allow occupant egress and/or prevent exposures to neighbor-

ing structures, or whether the design should be able to survive most foreseeable fire events. Recently, this discussion has widened to include maintaining structural viability for the time emergency personnel might need to treat or evacuate injured occupants.

Because of such uncertainties, prescriptive codes are still commonly used for most structural and personnel egress designs. Until there is greater confidence in the data and protocols, and universal understanding of both, deployment of performance-based codes will be hampered. To overcome this, there has to be a broad-based consensus on what parameters will be used in these codes and protocols. Further, in the interest of timeliness, there also has to be willingness for all research organizations to collaborate and share fundamental data so that duplication of research programs can be avoided. Several ways to start this journey are proposed:

- *Develop a Business Model Supporting Fundamental Fire Research.* First, develop an overall strategy that identifies a realistic vision and very specific goals that everyone – owner, designer, manufacturer, and the enforcement communities – can buy into. The strategy should identify the infrastructure needed to support the gradual emergence of these codes and standards. Finally, typical of any business model, the strategy should reflect the costs and realistic estimates of the time needed to achieve key milestones. In the cost analysis, the strategy should also attempt to quantify the cost savings that are potentially available if performance-based codes can succeed.

- *Create an International Consortium of Research Organizations to Implement the Strategy.* Because of the small number of truly qualified researchers in any one country, it would be highly desirable to involve all global scientists in both developing and implementing the strategy. The consortium should also be responsible for assuring the technical applicability and integrity of scientific thesis, test protocols, instrumentation, and reproducibility of any research results proposed for use in any Code

or Standard. The international aspect of the consortium will also foster the acceptance of product test standards across many countries, thereby promoting acceptances of products and facilitating trade.

- *Consciously Strategize to Create "Spillover."* Fire research crosses most scientific and engineering disciplines, and there are many opportunities for synergy and "spillover" from other disciplines. Creating opportunities to piggyback fundamental research experiments from both fire and other disciplines just by providing additional instrumentation or just collecting additional data points could provide other investigators useful information with minimal impact on cost or cycle time. Networking researchers will minimize the chances of experimental duplication (save for referee projects as required for scientific verification of results and calibration of instruments). There are models for this level of cooperation in medical research, and these models can serve as a basis for establishing similar networks for fire research.

- *Build a Research Infrastructure.* Reaching agreement on a common language for data management, measurement technologies, engineering models, and test protocols, and making it available worldwide are essential. If this foundation isn't built, there is a very real risk of creating a modern-day scientific Tower of Babel. Progress will be slowed while technical arguments rage over which protocols are the best or the most accurate or the most appropriate for this material or that application. The building of this critical foundation can and should be started immediately by the world's existing fire research community.

- *Communicate, Communicate, Communicate.* Finally, every business strategy includes a communication strategy. Very clearly, any arguments for enhanced fundamental fire research needs one as well. ▲

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* Friction costs are the additional and often hidden costs associated with delays in gaining approvals from the various authorities having jurisdiction of a novel – but perhaps perfectly appropriate – design, technology, construction material, or other product. These delays usually result from unfamiliarity with the proposed design, and that can often lead to redesign or other costly rework.

† The term "Enforcement Community" includes any entity or individual involved in the review and signoff of a design and associated materials of construction, finish, or other safety systems. Besides building inspectors and fire marshals, entities such as insurance companies and especially the building owner or his/her representative are included within the "Enforcement Community."

‡ Although "Improves Recruiting" is not directly tied into the development of performance-based codes and standards, the existence of an effective, long-term research capability has always been a major asset to a company when recruiting top-quality people – technical or otherwise – because such companies are viewed as being stable and progressive. Certainly, companies involved in the fire protection engineering industries need quality people if they expect to effectively compete.

FULL-SCALE SPRINKLERED FIRE TESTS

By David P. Nugent

One of the primary reasons for conducting full-scale sprinklered fire tests is to generate new sprinkler system design criteria. The goals of these tests may also include evaluating tenability during egress of occupants or minimizing damage to building and contents in the event of a fire. Occasionally, these tests are also conducted to validate existing sprinkler system design criteria if the basis for the criteria's existence is unknown or questionable. Full-scale sprinklered fire tests can also be utilized to recreate conditions associated with a fire loss.

When these tests involve stored commodities, such as found within a warehouse, fire tests are typically conducted to evaluate the ability of sprinkler systems to control or suppress a fire involving these commodities.

In addition to sprinkler system design criteria, other prominent variables require evaluation. These include the storage arrangement, ceiling height, and ignition scenario. Vertical and horizontal physical barriers may also be considered in conjunction with in-rack sprinklers placed within rack storage arrays. Other variables that can influence the rate of heat release and the ability of sprinkler systems to control fires are often explored. This may include commodity physical and fire hazard properties, as well as specific container and packaging materials, if used.

While small- and intermediate-scale fire tests can play an important preliminary role, the results of extensive sprinklered fire testing have illustrated that data extrapolation from such tests does not replace full-scale sprinklered testing.[1, 2, 3] Furthermore, current computer fire model simulations do not replicate the recorded experimental data as well as the visual observations generated during full-scale sprinklered fire tests.

TEST DESIGN

Typically, full-scale sprinklered fire tests seek to mimic actual conditions such that the growth rate, magnitude, and effect of sprinkler operation can be reasonably predicted should a fire occur in a facility using test-based design criteria. The objective of this representation is to obtain an insight into what likely would be expected.

Typically, these tests have been performed in specially designed facilities under controlled conditions. The facilities that have been typically used in the U.S. for full-scale fire testing include FM Global (formerly Factory Mutual Research), Southwest Research Institute, and Underwriters Laboratories.

Limitations, Assumptions, and Safety Factors Associated with Full-Scale Fire Test-Derived Design Criteria

When establishing the test conditions to be evaluated, preference is usually given to employing a so-called "credible worst-case scenario." This can ensure that users have confidence in the data and the resulting design criteria that may be developed. However, this selection process is based upon certain assumptions that must be indicated, along with any limitations that may be associated with the test results, and safety factors associated with design criteria.

Users of full-scale fire test-derived criteria must be aware of some of the limitations, assumptions, and safety factors:

Sprinkler System – For optimum sprinkler design, facility designers and operators can use full-scale fire test-derived design criteria. However, the system must be inspected, tested, and maintained on a scheduled basis to ensure that it remains within the limits of the test parameters.

Two safety factors typically employed involve the selection of the sprinkler system discharge density and the design area of operation. Typically, fire test planners select a given sprinkler system discharge density which they intend to ultimately use for design purposes. This discharge density is then held constant throughout the fire test. If the test is successful, code or standard writers may then develop sprinkler system design criteria based upon this chosen discharge density applied over the entire design area.

However, the pressure in sprinkler systems typically decreases as more sprinklers open beyond the first sprinkler to operate. If properly designed, sprinkler systems are capable of supplying the design density over the entire design area. Therefore, in the event of a fire, and upon actuation of the initial few sprinklers, the discharge density will be much higher than if supplying the design discharge density over the entire

design area. This is beneficial, provided that the discharge pressure is not excessive with a system using smaller-orifice sprinklers. This can result in atomization of the water droplets, compromising the penetrability of the sprinkler discharge into the storage array.

The other safety factor involving the system design area results from how test results are developed into sprinkler system design criteria. Usually, the system design area is much larger than the area associated with the number of sprinklers that operated in a fire test or series of tests. This could offset some of the downside resulting from a sprinkler plugged by debris during a fire.

Ignition Scenario – Igniters typically used in full-scale fire tests can consist of one of several types. The so-called "point igniters," consisting of cellucotton rolls soaked in a flammable liquid, have been used with "ordinary commodities", containerized combustible liquids, and other materials. Pool fire and spill fire igniters have been used with fires involving containerized flammable liquids. As with other test parameters, selection of igniter type should be based upon a "credible worst-case scenario."

However, it is not always possible to accommodate every possible scenario. For example, a recent fire test program that focused on flammable liquid storage in 55 gal. (208 l) steel drums utilized a burning 2 gpm (7.6 lpm) spill rate flowing for 30 minutes. If a 55 gal. (208 l) steel drum was punctured and completely emptied prior to ignition, an explosion might initially ensue upon ignition, followed by a large pool fire. This of course might render the sprinkler system ineffective.

Storage Array – The integrity of the storage array can have an effect on the outcome of a fire, which is a significant variable. For example, if a burning storage array containing plastic pellets collapses or the packaging breaks open, the resultant spillage could fill the flue

spaces with loose pellets, resulting in greater fire control.

Conversely, if this array were replaced with containers of flammable liquids, collapse could result in an uncontrolled fire due to the resultant burning liquid spill. Full-scale fire test-derived criteria can also be very specific on storage height. Increasing storage heights beyond what was tested may increase the likelihood of an uncontrolled fire, should a fire occur.

Ceiling Position – The height of the ceiling has been indicated as a prominent variable when conducting these tests. Generally speaking, at lower ceiling heights, sprinkler discharge will achieve greater penetration into the burning storage array. Additionally, ceiling slope may also be a factor for consideration.

Major fire test centers have historically used flat ceilings. Therefore, sprinkler system design criteria developed for warehousing is based upon flat ceilings. While most large storage facilities have used ceilings involving various roof slopes, the full effects of sloped ceilings on ceiling sprinkler system performance has not been fully investigated.

Test Commodity – Full-scale fire test-derived protection criteria can be very specific to commodity type. Aside from storage height variables, changes in commodity type are one area most likely to be encountered throughout the lifetime of a warehouse. For example, a given commodity and its packaging may have initially been constructed of metal, wood, and paper, but may now be all plastic, presenting a greater fire challenge.

Pass/Fail Criteria
Ideally, when progressing through a series of fire tests, one variable will be changed while keeping all other conditions constant between tests. This would allow for a correlation between one variable and any changes realized in subsequent test results. Prior to the commencement of any testing, a set of

Fire Test Program Involving Flammable Liquid Filled 55-Gallon Relieving-Style Steel Drums

Several years ago, a consortium of companies and organizations undertook a full-scale fire test program to develop design criteria that would allow better utilization of warehouse space.* The maximum allowable palletized storage height for "protected storage" of 55-gallon (208 l) steel drums was restricted to 2-high in the 1996 edition of NFPA 30. Obviously, "maximizing the warehouse cube" is preferable to constructing additional warehouses.

Therefore, one of the program objectives was to develop design criteria that could later be codified, allowing for 3- and possibly 4-high palletized drum storage of nonreactive Class IB liquids. Another objective of the program was to explore the effectiveness of plastic plugs and venting pressure under fire conditions, when placing the plastic plugs into two openings in the top of the drums. The benefits of relieving-style containers to prevent violent ruptures and an accompanying fireball were realized in previous test programs.

The sprinkler system design criteria for 2- drum-high palletized storage of nonreactive Class IB liquids in the 1996 edition of NFPA 30 were based upon a limited amount of interpolated data. The research team also wanted to determine if the then-current criteria were valid.

A total of eight comparative full-scale sprinklered fire tests were conducted at Southwest Research Institute. The commodity that was tested was flammable liquid-filled, 55-gallon (208 l), relieving-style steel drums using 2-, 3-, and 4-drum-high palletized arrays. In the final 4-drum-high palletized storage test, a total of 144 heptane-filled drums were used.

Water- and foam-water-based closed-head sprinkler systems were utilized. These systems were designed to produce sprinkler discharge densities of 0.30 gpm/ft^2 (12 mm/min.), 0.45 gpm/ft^2 (18 mm/min.), and 0.60 gpm/ft^2 (24 mm/min.). The sprinklers were rated at 286°F (141°C) and were standard response. The sprinkler system was installed beneath a 33 ft. (10 m) ceiling.

This ignition scenario was intended to simulate a leaking drum due to puncture from an industrial truck tine. In terms of spill igniter location, this actually exceeded what would be considered a "credible worst-case scenario." The spill location was placed in a flue space within the storage array and located at the bottom of the top tier of drums. This created a severe three-dimensional spill fire.

A drum puncture could not actually occur in this manner but was chosen to ensure credible results. A 2 gpm (7.6 lpm) heptane spill rate was used continuously until the contents of a filled 55-gallon (208 l) drum were emptied within the array. An ignition delay ranging between 10 seconds and 1 minute was also used. Therefore, the test results and resultant design criteria would be associated only with an immediate or near-immediate ignition scenario.

Test results were based upon the following instrumentation readings and visual observations:
- Ceiling gas temperatures
- Ceiling steel temperatures
- Number of operating sprinklers and operating times
- Drum pressures
- Drum temperatures
- Drum condition

pass/fail criteria should be developed and used to evaluate test results.

Typical pass/fail criteria for sprinklered fire tests involving stored commodity consist of the following:

- Sustained (≥ 2 min.) ceiling steel temperatures above 1000°F (538 °C).
- Excessive number of operating sprinklers (sprinkler-type-dependant).
- Fire travel across open aisle space and involvement of target commodity.
- Fire travel throughout test array including qualitative damage assessment of test and target commodity.
- Insufficient fire involvement of test commodity due to improper igniter selection.

Other criteria can be utilized depending on test commodity and conditions.

Use of Test Results

Ultimately, the results of these tests may be used to obtain an approval or listing of a new sprinkler, or to obtain a equivalency to an existing code requirement from an authority having jurisdiction. In addition, the design criteria may be adopted or codified in a code or standard (see side bar).

CHALLENGES WITH LARGE-SCALE TESTING

When planning and executing these tests, three of the more frequently experienced challenges are funding, access to previously generated experimental data, and locating a test facility willing to conduct experiments with hazardous chemicals.

Costs

The costs associated with the test commodity, technical expertise, use of test facilities, and disposal and cleanup, can easily be tens of thousands of U.S. dollars per test. In some instances, the benefit may be realized in future construction costs by developing a more cost-effective design. In others, it may also be based upon the realization that if a fire occurs in a facility using questionable design criteria, a catastrophic fire

The failure criteria were as follows:
- Ceiling steel temperature in excess of 1000°F (538°C)
- Excessive number of operating sprinklers
- Severe drum bulging
- Severe jetting
- Drum pressure in excess of 25 psi (172 kpa)
- Pile collapse
- Violent rupture of a drum

The results of these tests demonstrated that the design criteria for 2-drum-high

palletized storage of nonreactive Class IB liquids in NFPA 30, 1996 edition, was valid. Additionally, new design criteria were developed for 3- and 4-high palletized drum storage. More specifically, a sprinkler system discharge density of 0.45 gpm/ft² (18 mm/min.) produced results consistent with the stated pass criteria for the 3-drum-high test array. A sprinkler system discharge density of 0.60 gpm/ft² (24 mm/min.) produced satisfactory results consistent with the stated pass criteria for the 4-drum-high test array.

The results of this test program and a proposed set of design criteria were submitted to the technical committee responsible for NFPA 30. The committee accepted the proposal, and the new criteria appear in the 2000 edition of this code.

* Garabebian, A., Performance Testing of Automatic Sprinkler Systems in the Protection of Palletized, 55-Gallon Storage of Heptane in Self-Relieving Style Steel Drums, Southwest Research Institute, San Antonio, TX, SwRI Project No. 01-2016-001, January 1999.

loss may result. While some of the decision to proceed with a test program can be based upon savings to actual construction costs, an evaluation of perceived risk typically has driven the decisions to proceed.

These issues lead to a limited pool of dollars to work with and often times restrict the number of experiments that can be conducted. This can lead to a situation where code writers are basing new code requirements on single or a small group of related tests. This is often offset by considering like test results and interpolating between related tests or applying a safety factor.

Access to Data

Previous fire test data are not always readily available from fire test facilities or their parent organizations, as well as other program sponsor(s). For example, various National Fire Protection Association (NFPA) technical committees have been the recipient of numerous fire test reports generated over the years to support proposed changes to the NFPA fire codes. While these reports are theoretically in the public domain, a central repository and a system of cataloging and accessing these reports are nonexistent.

Additionally, many sprinklered fire test reports are never placed in the public domain for a variety of reasons. These reports may reflect unfavorably on issues related to the test sponsor(s), or the reports may have been considered propriety in nature.

There are two notable exceptions to this situation. *The Directory of Fire Tests Involving Storage of Flammable and Combustible Liquids in Containers* is a publication available through the Society of Fire Protection Engineers which summarizes the results of 136 sprinklered fire tests.[4]

Furthermore, GE GAPS (formerly IRI) has donated to National Institute of Standards and Technology a total of five reports that cover a limited number of sprinklered fire tests. The fire test programs that these reports describe focused on containerized storage of flammable liquids, wood pallets, in-rack sprinklers, and duct-mounted sprinklers. These reports can be downloaded from the NIST Web site, http://fire.nist.gov/bfrlpubs/testdata/.

An additional benefit to an open exchange of data would be a better understanding of building and fire codes and standards. For example, the aforementioned directory has been referenced in two successive editions of NFPA 30, Flammable and Combustible Liquids Code.[5] This code is the only code that cross-references each set of criteria in the sprinkler protection tables with a single test or group of fire tests. This enables users to make informed decisions through better understanding the basis and any limitations, assumptions, and safety factors associated with the protection criteria.

Hazardous chemical fire testing presents unique challenges. If the test commodity involves materials not considered "ordinary combustibles," issues will arise involving the test facility's ability and willingness to conduct any experiments. For example, materials that produce very high heat release rates, or generate liquid runoff and smoke that is considered toxic or corrosive may require special provisions. The test facility may not be willing to conduct such tests if the testing presented an undue risk to personnel, the environment, or the test facility. Additional considerations involving compliance with environmental regulations may also prove problematic. ▲

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THE FIRE DYNAMICS SIMULATOR

IN FIRE PROTECTION ENGINEERING CONSULTING

CASE STUDY

By Jason Sutula

In the Spring 2002 issue, the first part of this article demonstrated several ways in which the Fire Dynamics Simulator (FDS)[1, 2] was being used to assist in solving real-world engineering problems. This second part of the article provides a case study of a fire investigation, reconstruction, and analysis in which an FDS model was used, qualitatively, to provide guidance in assessing which of two possible fire scenarios was more likely to have occurred.

BACKGROUND

A fire occurred in a residential structure in the early morning of September 30, 1996. At the time of the fire, three people were in the residence, two parents (age 81, male, and age 57, female) and their adult son (age 31). The two-story house was composed of typical wood frame construction and was built in approximately 1971. The first floor included a living room and dining room in the front of the house and a family room, kitchen, and den/storage room with an adjacent bathroom in the rear of the house. The second floor had four bedrooms and one bath. The master bedroom was at the head of the stairs on the second floor. Figures 1 and 2 depict north side and south side views of the geometry of the residence.

The family room, which was situated in the back left portion of the first floor (see lower right corner of Figure 2), was approximately 6 m (20 ft) long by 3.7 m (12 ft) wide with a large window and an exterior door located in the west wall. The room had a brick fireplace along the south wall and plywood paneling along the other three walls. A substantial fuel load was present in the room at the time of the fire. The fuel load included a three-cushion couch (with integral recliners at either end) along the east wall, a two-cushion love seat along the west wall, and a lift-type recliner chair near the north wall by the doorway to the kitchen. In addition, there were several small tables and a television. The family room also had wall-to-wall carpeting over the original hardwood floor.

The fire was first reported via 911 by

Figure 1. Geometry of residence (view from the front of the house, north face).

Figure 2. Geometry of residence (view from the rear of the house, south face).

centage of total hemoglobin in the form of COHb in the blood, was reported as 45 percent. Incapacitation of a victim due to carbon monoxide poisoning typically occurs with COHb greater than 30 percent, and death usually occurs above 50 percent, though research has shown that both incapacitation and death can occur at lower percentages.[3]

Police and fire officials conducted a cause and origin investigation. Their investigation determined that the fire originated in the family room in the left rear of the first floor. Examination of the scene revealed heavy burn damage to most of the furnishings in the family room. Heat and smoke damage was observed throughout the rest of the house with some fire extension into the kitchen and hallway adjacent to the family room.

Further investigation of the burn damage in the family room showed substantial damage to the couch, the love seat, and the lift chair. The greatest damage to the couch was at the north end (toward the kitchen) with damage decreasing toward the south end (toward the fire place). A similar damage pattern was noted on the love seat including greater damage high up on the back of the love seat. The lift chair showed greatest burn damage to the east (toward the couch). The wood paneling and studs behind the couch showed damage beginning behind the north end of the couch with a "V" pattern toward the south (fireplace). In addition, the carpet in the center of the room was heavily damaged including a substantial area where the carpet and padding had been consumed in the fire, revealing the hardwood floor underneath. The hardwood floor showed irregular discoloration in the center of the room where the carpet had been completely burned. Because of the irregular pattern on the hardwood floor, samples were taken of the carpet, padding, newspaper (used between the padding and the hardwood floor to stop squeaks), and floorboards by fire investigators and sent to a laboratory to test for the presence of flammable or combustible liquids.

the son at 4:30 a.m. The first person to respond to the emergency call was a police officer who arrived at the scene at approximately 4:35 a.m. The son met the officer on the north side of the residence. They proceeded to the south side of the house. The officer reported that the large bay window on the southeast corner of the house had broken out and flames were venting through it. The officer found the mother on the back porch at the southwest corner of the house. The mother was found conscious and alert but suffering from burns to her hands, upper body, and head, including singed hair.

The first fire department units arrived at approximately 4:40 a.m. and the fire was declared under control at 5:03 a.m. A fire department search of the house found the father dead in the bathroom

in the right rear of the first floor near the back door exit to the porch where the mother was found by the police officer. The mother was treated at the scene for burns and smoke inhalation and then transported to the hospital. After initial treatment in the emergency room, she was transferred to the Burn Unit of a second hospital. She ultimately died of complications from previous health conditions and injuries sustained from the fire. The son was also transported to a hospital and was treated for burns and smoke inhalation and then released.

An autopsy performed on the father revealed that he had nonlethal burns to his head and upper torso and had suffered smoke inhalation. He was declared dead by smoke inhalation as a result of carbon monoxide poisoning. His carboxyhemoglobin (COHb), or the per-

THE SON'S STORY

The son was interviewed by investigators and gave the following account of the fire. He stated that his mother had gone to bed at approximately 8:30 p.m. on the night of the fire. His father subsequently went to bed at about 11:30 p.m. The son fell asleep watching television in the family room, woke up about 2:30 a.m., and went to his bedroom. He was awakened at just before 4:30 a.m. by his father's call for help from downstairs. He went downstairs to the family room in response to his father's call and discovered his father in his lift chair and his mother on the couch. Upon entering the family room, he observed his mother attempting to pat out a small fire on the couch with her left hand. He immediately went to the kitchen and got a pitcher of water. When he returned to the living room, he attempted to extinguish the fire with the pitcher of water but found that it had little effect on the fire. He advised his parents to get out and quickly retreated to the dining room to call 911. While on the 911 call, he observed his parents traveling across the kitchen toward the den/storage room (in the direction of the rear exit) as the fire continued to grow. Upon completion of the 911 call, he left the house through the front door. After retrieving some sweatpants from his car (he was originally wearing only a pair of boxer shorts), he went to the rear of the house to meet up with his parents. When he arrived at the back of the house, neither of his parents was visible. He opened the rear door and found his mother on the floor inside the door. He dragged his mother outside onto the porch but could not enter further to find his father because of the heat and smoke. He then went to the front of the house to await the arrival of emergency personnel. He met a police officer and accompanied the officer around back to his mother's location while advising the officer that his father was still in the house. Eventually, the son was taken to the hospital and treated for his smoke inhalation and burn injuries. The son suggested that the fire started as a result of his mother's mishandling of smoking materials.

THE INVESTIGATOR'S STORY

Based on the burn damage to the residence and the son's statement, the in-vestigation focused on the area near the north end of the couch. A lamp in this area was eliminated as a possible cause of the fire when an examination of the lamp and the adjacent outlet revealed no evidence of damage consistent with initiation of a fire. Careless use of smoking materials could not be eliminated based on the burn damage, the statements of the son, and evidence of other smoking materials throughout the first floor. Other possible accidental causes of the fire were eliminated. Initial investigation reports concluded that the fire was accidental as the result of careless smoking or improper disposal of smoking materials.

The laboratory report showed that the samples of carpet, padding, and newsprint were negative for common ignitable liquids, but that the floorboards showed trace amounts of weathered gasoline. After receiving this report, one investigator changed his fire investigation report to conclude that the fire was intentionally set by the son through the use of gasoline as an accelerant. The motives given for the son's actions were that he wanted to collect the assets of his parents and that he no longer wanted to provide physical care for them.

The fire investigator proposed the following account. While the parents were upstairs in bed, the son obtained 3.8 L (1 gallon) of gasoline and spread it on the carpet in the family room. He ignited the room on fire, grabbed the cordless phone, ran to the front door, went outside and shut the door, and waited for his parents to wake up. When they had been alerted to the fire, he called 911 from outside the house, held the door shut as his parents came down the stairs,

and forced them to traverse the house to the rear of the building where they succumbed to smoke inhalation.

MODEL SETUP

After examining the available data, it was determined that a computer model could be employed in an attempt to determine which of the two competing scenarios was more likely to occur. The Fire Dynamics Simulator (FDS) was chosen to perform the comparison because of the relative ease in which complex geometries can be represented within the code.

The geometry was first constructed in FDS to form an accurate three-dimensional representation of the structure of the house. Since no structural plans could be obtained, measurements were recorded from a site inspection of the residence. The model contained 900,000 cells and encompassed the entire house. Each cell within the house measured approximately 100 mm (4 in.) per side. After the geometry had been completed, the initiating fire scenarios had to be developed and placed into the model. The accidental scenario had two feasible initiating events, while the incendiary scenario only had one.

For the accidental scenario (Case 1), two different accidental ignitions were possible: smoldering ignition from a dropped cigarette or flaming ignition from a dropped match. Previous research has demonstrated that smoldering ignition generally takes between 30 minutes to two hours to transition to flaming.[4] The long time frame for a smoldering ignition led to the conclusion that the most likely ignition sce-
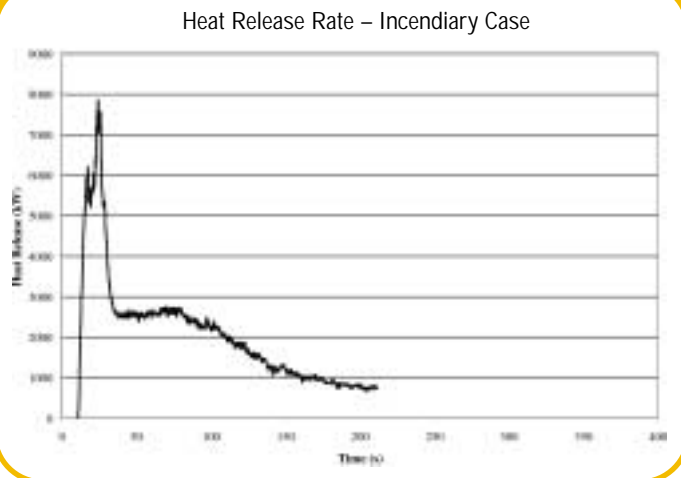
Heat Release Rate – Accidental Case
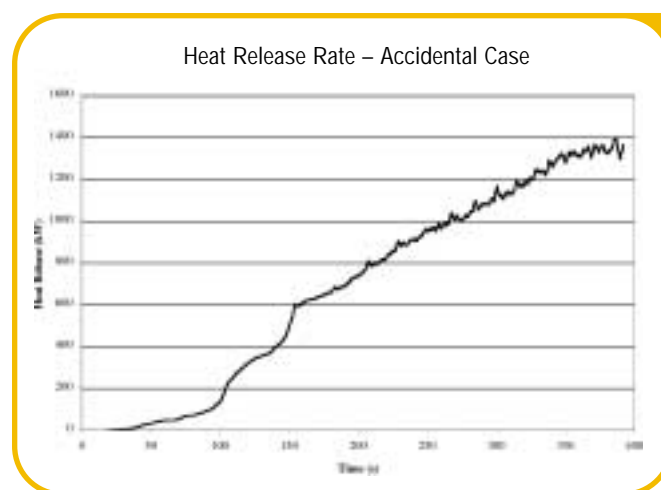
Figure 3. Convective heat release rate for the accidental fire scenario.

Figure 4. Cigarette initiated fire in the family room.

Figure 5. Convective heat release rate for the incendiary fire scenario.

The fire scenario in Case 2 was initiated by a large area of gasoline igniting, burning, and spreading quickly over a large surface area located on the floor in the middle of the family room. This surface area was approximately 6 m² (64 ft²) and contained 3.8 L (1 gallon) of gasoline. Similar to Case 1, the initiating event allowed surrounding materials to ignite based on the fire conditions surrounding them. Figure 5 shows the resultant convective heat release rate for the incendiary fire scenario. Figure 6 visually represents the early growth of the gasoline fire within the family room of the residence.

RESULTS AND DISCUSSION

The model produces various resultant quantities that can be analyzed for each scenario to determine which scenario is consistent with the available data provided by witnesses and other sources as required by the scientific method. In Case 1, the greatest interest is how the time to reach untenable conditions "fits" with the story of the accidental fire provided by the son. In Case 2, again of greatest interest is how the time to reach untenable conditions "fits" with the story proposed by the fire investigator. To decide which scenario is most consistent with either of the two proposed hypotheses, a quantity of data must be chosen to analyze such that a determination between the two scenarios can be made (e.g., temperature).

Figure 7 shows a temperature-time curve for the conditions present within the family room during both the accidental fire scenario and the incendiary scenario. When the couch is burning due to the accidental scenario, the fire grows relatively slowly and the tempera-

nario was a dropped match that caused a flaming ignition of the couch. For the incendiary scenario (Case 2), there was only one ignition scenario proposed: the son spread gasoline across the family room floor and then initiated ignition on the floor using a flame-producing element.

The FDS model allows a user to define a fire scenario in two different ways: (1) a fire can be completely described using a heat release rate curve or (2) the fire can be initiated using a small initial heat release and allowed to spread to other ignitable items. Both modeled cases utilized the second method of fire initiation. The main difference between the two cases exists in the manner in which each scenario was initiated.

The fire scenario in Case 1 was initiated by a small heat release rate curve placed on the couch in the family room simulating a small flaming match dropped on the couch. The curve allowed a short fire exposure to ignite the surrounding couch structure and grow from that point. Flame spread rates

along the couch were consistent with typical values obtained experimentally for lateral flame spread along a surface.[5] Figure 3 depicts the resultant convective heat release rate modeled during this fire scenario. Figure 4 visually represents the early growth of the couch fire within the family room of the residence (the fire surface appears an orange color, while the smoke layer surface throughout the house appears gray in color).

Figure 6. Gasoline-initiated fire in the family room.

tures within the room increase slowly over time. Conversely, the temperatures for the incendiary fire spike early in the fire and slowly subside. This indicates a strong difference in the resultant fire conditions from each fire scenario.

Examining the accidental fire and the data presented in Figure 7, the question must be answered as to whether or not the temperature within the family room over a period of time is tenable enough for the son's story to make sense. The son claimed that he observed his mother trying to pat out the fire with her left hand early on in the fire growth. This is consistent with temperatures early in the fire caused by a small fire on the couch and is consistent with the burn injuries observed on his mother's left hand.

Over the first 200 seconds of the accidental fire scenario, the temperature in the family room does not exceed 200 °C. It can be inferred then, for the accidental scenario, that for the first three minutes of the fire, the son would have had time to respond to his parent's call for help, attempt to put the fire out with a pitcher of water, call 911, urge his parents to leave the residence, and exit the house through the front door. The fire growth and tenability for this scenario are consistent with the story proposed by the son.

The incendiary scenario proposed by the fire investigator indicated that the son poured gasoline throughout the family room, lit the room on fire, and exited the building through the front door. Figure 7 clearly shows that the son would have to be moving very quickly to exit the residence without receiving significant burns. The fire investigator also specified that the parents were on the second floor asleep in their bed at the initiation of the fire. In order to explain the parents being found where they were after the fire, the investigator states that the parents awakened at some point, moved downstairs, could not open the front door, headed to the back door, and were found near the rear of the structure without severe burn injuries. For this to occur, the incendiary scenario must allow for temperatures cool enough to allow the parents to traverse the house over the course of a few minutes without being burned. Figure 7 indicates that conditions would have been severe enough to cause burns within the first 20 seconds from ignition. Figure 8 shows the temperature versus
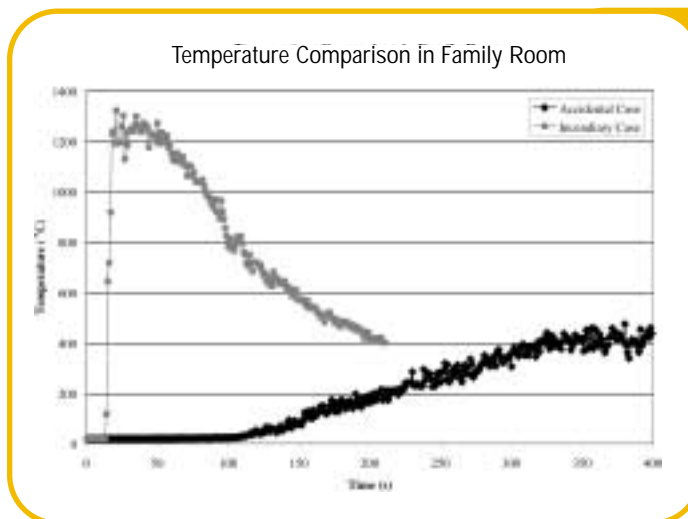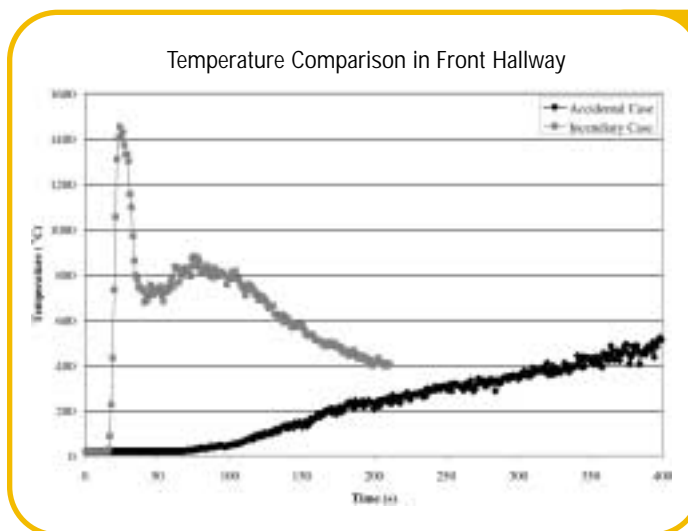
Temperature Comparison in Family Room

Temperature Comparison in Front Hallway

time in the front hallway near the stairs and the front door.

It is apparent from Figures 7 and 8 that the temperatures within the house quickly become untenable in the incendiary case. This result shows that if the parents were indeed in their bed asleep when the fire was lit, they would have most likely succumbed to the fire upstairs in their bedroom.

A conclusion that the son's version of events was most likely correct was confirmed by additional testing, which revealed that lead was present within the gasoline found in the floorboard samples. This discovery dated the gasoline to having been in the floorboards for over a decade and eliminated the fire investigator's proposed scenario. ▲

Jason Sutula is with Combustion Science & Engineering, Inc.

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5. Drysdale, D., "Spread of Flame," *An Introduction to Fire Dynamics*, John Wiley & Sons, 1999.

Products/Literature

Electronic Heat Detectors

The D603 and D604 are Electronic Rate-of-Rise/Fixed-Temperature Heat Detectors designed to work with Radionics D200 series 2-wire and 4-wire detector bases. They offer 12 or 24 VDC operation and are response-rated at 135°F in areas where ambient temperatures do not exceed 100°F. Another model, the D605 Fixed-Temperature Detector, alarms at 190°F.

www.radionics.com
—*Radionics Div., Detection Systems, Inc.*

Intelligent Fire Alarm

The IFC-640 is the newest member of the Metasys® family of intelligent fire alarm systems. Benefits include a highly configurable design, easy installation and programming, and dramatically improved fire detection and reporting speeds. A highly scalable system, configurations range from simple to large networks. The IFC-640 can use either CLIP™ mode protocol or the latest FlashScan™ communication technology.

www.johnsoncontrols.com
—*Johnson Controls*

Argon Fire Suppression Systems

Argon systems protect sensitive electronic equipment, clean room facilities, and any other areas where water or other agents could permanently damage inventory or equipment. Argon, a natural element, is safe for humans and the environment, with no global warming or ozone depletion potential and no chemical reaction. There is no messy residue for cleanup, and fire is often suppressed before damaging incidence or downtime occurs.

www.minimaxusa.com
—*Minimax GmbH*

Addressable Panel

Viking now offers the Fike Cheetah Addressable Release Control Panel option for the TotalPac system. This panel can handle the release of the preaction sprinkler system as well as the clean agent and addressable alarm system, eliminating the redundancy caused when using an individual panel for each system. Additionally, it can handle a larger area with up to 530 detectors custom-configured with several options including the "and/or" cross-zoning configuration.

www.vikingcorp.com
—*Viking Corp.*

Emergency Voice Evacuation System

The FireVac®IV is a fully automatic combination of a fire alarm and emergency voice evacuation system. Designed for projects requiring voice evacuation such as assisted living facilities, hotels, dorms, etc., it provides 50 Watts of audio power at either 25 Vrms or 70 Vrms. Features include eight selectable tones, protection cushions, and full supervision. Additional options may be added on.

www.firecontrolinstruments.com
—*Fire Control Instruments, Inc.*

Optical-Beam Smoke Detectors

New optical-beam smoke detectors are available in two versions to cover distances up to 160 ft. and 320 ft., providing protection for areas up to 8,000 sq. ft. and 16,000 sq. ft., respectively. They combine an infrared transmitter and receiver in one unit, so they need less cabling than two-part beam detectors, making installation fast and cost-effective.

www.ffeuk.com
—*Fire Fighting Enterprises Ltd.*

Ceiling-Mount Detector

Award-winning ceiling-mount detector features a 25-ft. mounting height. With three independent, adjustable PIRs and First-Step Processing, the DS9370 maximizes performance while reducing costly false alarms for applications such as warehouses, schools, department stores, factories, offices, etc. The unit provides up to a 70-ft./diam. coverage area for standard floor, pinpoint, and multilevel coverage.

www.dsworld.com
—*Detection Systems, Inc.*

Flow Switch Tester

Zonecheck® is a self-contained inline flow switch tester system that recirculates water within a fire sprinkler system, ensuring the flow switch is operating properly. It facilitates compliance to NFPA 25 requirements for quarterly flow switch testing without having to open the inspector's test connection, drain the water from the sprinkler system, and have to pay for the treatment/removal of the waste water that may contain damaging chemicals.

www.systemsensor.com
—*System Sensor*

Early Warning for Critical Facilities

Fenwal introduces an advanced version of its AnaLASER high-sensitivity smoke detection system. Designed to protect mission-critical facilities, the AnaLASER II provides very early warning in a fire emergency. This air-sampling smoke detector actively draws air from the protected space and analyzes it for the presence of smoke, using advanced Laser Particle Counting detection technology.

www.AnaLASER.com
—Fenwal Protection Systems

Fire Protection Solutions Brochure

Notifer's Product Information brochure highlights advanced network panel and peripheral devices designed to provide solutions for all fire protection needs. Illustrations show fire alarm control panels along with the features and options that are available. Among the systems highlighted are the UniNet™ 2000 integrated facilities monitoring network, the NOTI-FIRE-NET,™ and the Onyx™ Series NFS-640 Panel and its various network options. To receive a copy of this brochure, please call 203-484-7161.

www.notifer.com
—NOTIFIER

Chimney Flue Safety System

The AKSAL SYSTEM prevents the risk of fires in chimney flues. An automatic extinction system that is both economic and autonomous, it also functions without an electrical connection. The device is installed at the top of the chimney. Made of steel, it includes a base that adjusts to the chimney size, a protective hood, a mobile flue vent, the fire extinguisher system, and all operational mechanisms.

www.aksal.fr
—AKSAL

Fire Protection Fittings

The No. 67, Vic®-End II is an end-of-run fitting designed to quickly and economically end branch lines using a standard wrench. Designed to install easily with standard FireLock couplings, it allows direct head connections, sprigs, and drops. Available in 1¼, 1½, 2 and 2½-in. sizes, the fittings can be supplied with ½, ¾, or 1-in. female threaded (NPT) outlets. A BSPT option is available.

www.victaulic.com
—Victaulic

Internet-Based System Monitoring

SafeLINC is a new UL-listed product that allows authorized users, through an Internet connection, to access fire alarm system information from a personal computer, laptop, personal digital assistant, or pager. In the event of an alarm or trouble condition, SafeLINC automatically sends an e-mail to designated staff informing them of the situation.

www.simplexgrinnell.com/safe
—SimplexGrinnell

Fire Suppression Control System

Kidde announces the next generation of its fire suppression control system: the Kidde Gemini II. The semi-intelligent, conventional, microprocessor-based, single-hazard control panel is field-expandable to protect up to eight hazards with the use of multiple Remote Hazard Units (RHUs).

www.kidde.com
—Kidde Fire Systems

Resources

Professional Development Week from the Society of Fire Protection Engineers – September 16-20, 2002, Baltimore, MD

Fire Protection Strategies for 21st Century Building and Fire Codes
September 17-18, 2002

Co-Sponsored by: Society of Fire Protection Engineers and the American Institute of Architects

Intended for: This symposium is intended for all members of the building community including building owners, code officials, consumer groups, contractors, design professionals, product manufacturers, and researchers.

Description: It has often been stated that building code requirements are based upon historical fire experience. However, participants in the code development process now have access to improved fire data collection and analysis methods and analytical tools to assess fire risk and fire hazard. In addition, 21st century building products and designs will present new challenges for modern building fire safety. What are the appropriate fire protection strategies and can we prepare for the changes in the future?

Topics may include but are not limited to the following:
- New technologies – what are they are where are they coming from?
- What is the risk posed by vertical smoke movement?
- Rehabilitation codes for existing buildings
- Performance codes and alternative methods
- Determining requirements for building height and area
- Are current fire test methods adequate?
- Structural fire resistance criteria
- Urban wildland interface strategies
- Radiant heat transfer through openings
- Degrees of combustibility
- Evacuate or defend in place?
- When can firefighters and building occupants use the same stair?
- Rescue operations for individuals with disabilities
- Use of elevators during fire emergencies
- Should property protection be regulated?

Anyone who has participated in the development of building regulations will recognize the potential list of topics as items frequently debated or mentioned in support of or opposition to a proposed code change. The symposium will provide participants with an opportunity to discuss these items in far greater detail than permitted in the regulatory arenas.

World Trade Center Building Performance Study – Preliminary Lessons Learned
September 19, 2002

Co-Sponsored by: Society of Fire Protection Engineers and ASCE's Structural Engineering Institute

The collapse of some buildings and the survival of others affected by the New York World Trade Center incident on September 11, 2001 provided new information to the fire protection and structural engineering communities about the behavior of tall buildings exposed to fires. Join three members of the FEMA sponsored study team – William Baker, P.E., Partner, Skidmore Owings and Merrill, Jonathan Barnett, Ph.D., FSFPE, Worcester Polytechnic Institute and James Milke, P.E., Ph.D., FSFPE, University of Maryland, and structural engineer Robert Iding, Ph.D., Wiss, Janney, Elstner and Associates for this 1/2 day morning seminar to explore the preliminary lessons learned from the collapse. Presenters will review the findings of the FEMA sponsored investigation, including both structural and fire behavior, and provide insight on implications for the profession. A special focus on the need for interaction between the fire protection and structural engineering professional in design will be presented.

Advance Registration Fees:
(Must be received by August 16, 2002)
$150 SFPE/ASCE Member $195 Non-member

Late Registration Fees:
(Received after August 16, 2002)
$225 SFPE/ASCE Member $295 Non-member

Continuing Education Units (CEUs): The Society of Fire Protection Engineers will award 0.40 Continuing Education Units for attending the entire seminar.

Advance Registration Fees:
(Must be received by August 16, 2002)
$450 Enforcers
$525 SFPE/AIA Member $625 Non-member

Late Registration Fees:
(Received after August 16, 2002)
$525 Enforcers
$600 SFPE/AIA Member $725 Non-member

Continuing Education Units (CEUs): The Society of Fire Protection Engineers will award 1.60 Continuing Education Units for attending the entire symposium.

Performance-Based Design and the Codes
September 19, 2002

Intended for: This seminar is intended for engineers who apply performance-based codes and enforcement officials who review performance-based design or engineered alternatives to prescriptive codes.

Description: This 1/2 day afternoon seminar will review in detail the performance-based design process and its application with the ICC Performance Code for Buildings and Facilities and the performance options in the NFPA Life Safety Code and the NFPA Building Code.

This seminar will be divided into three sections. The first section will provide an overview of the performance-based design process contained in the SFPE Engineering Guide to Performance-Basd Fire Protection Analysis and Design of Buildings. This process identifies methods of defining a project scope, developing goals, objectives and performance criteria, selecting design fire scenarios, developing and evaluating trial designs, and preparing design documentation.

The second section will provide an overview of the ICC Performance Code for Buildings and Facilities, including a detailed synopsis of the fire protection requirements contained in the code. The use of the ICC Performance Code for Buildings and Facilities will be illustrated using a simple case study.

The third section will outline the use of the NFPA Building Code and the NFPA Life Safety Code for performance-based fire protection design. The fire protection performance-based requirements of both codes will be identified and illustrated using an example application to a building.

Advance Registration Fees: (Must be received by August 16, 2002)
$150 SFPE Member $195 Non-member

Late Registration Fees: (Received after August 16, 2002)
$225 SFPE Member $295 Non-member

Continuing Education Units (CEUs): The Society of Fire Protection Engineers will award 0.40 Continuing Education Units for attending the entire seminar.

For more information visit www.sfpe.org

UPCOMING EVENTS

October 31-November 3, 2002
Building Performance:
    Improving the Quality of the Built Environment
Washington, D.C.
Info: www.aia.org

May 8-10, 2003
Strategies for Performance in the Aftermath of the
    World Trade Center & the 2nd Global Leaders Summit
    on Tall Buildings
Kuala Lumpur, Malaysia
Info: www.cibklutm.com

June 23-25, 2003
Advances in Structures –
    Steel, Concrete, Composite, and Aluminum
Sydney, Australia
Info: www.civil.usyd.edu.au

June 24-27, 2003
Special Session on Applications of Information Technologies
    in Fire Safety
The Technical University of Gdansk, Poland
Info: www.icsc-naiso.org

August 3-6, 2003
Response of Structures to Extreme Loading
Toronto, Canada
Info: www.extremeloading2003.com

October 22-23, 2003
Building Fire Safety – Research, Practice, and Education
Brisbane, Australia
Info: www.qut.edu.au

B R A I N T E A S E R

Find the values of A, B, and C in the
following arithmetic sequence:

AB4, B03, B3C, BA1

Thanks to Jane Lataille, P.E., for
providing this issue's brainteaser.

Solution to last issue's brainteaser

Find the largest prime number that divides 87! + 88!.

87! + 88! = 87! + 88 × 87! = (1 + 88) × 87! = 87! × 89.
Since 89 is prime, that is the largest prime number that
divides the given sum.

Should SFPE Develop Standards?

Morgan J. Hurley, P.E.
Technical Director
Society of Fire Protection Engineers

A fundamental tenet of code and standard development is that anyone who is potentially affected by a code or standard must have the opportunity to input into the document when it is written or revised. For standards of practice, the affected group is the professional community in the relevant practice area.

Fire protection engineering "standards of practice" would include standards that define acceptable methods of practice, such as how to use specific calculation methods, and would not include testing, product or installation standards, or prescriptive design standards, which other organizations develop very well. "Standards of practice" would also not include codes, which define an acceptable level of safety for society, and therefore require opportunities for input from any member of the public.

In most mature engineering disciplines, the professional societies that represent engineering practitioners write standards of practice. Examples are the electrical, civil, and mechanical engineering communities. However, at the present time, standards that regulate fire protection engineering practice are written by organizations that do not exclusively represent the fire protection engineering profession. When standards of practice are written by organizations that do not exclusively represent the profession, there is the potential that people who are not knowledgeable in fire protection engineering concepts could influence the practice of fire protection engineering.

A model that is frequently cited as fire protection engineering matures is ASCE 7.[1] ASCE 7 serves two functions: (1) it defines the structural loads that a building should be designed to withstand, including combinations of loads, and (2) it provides calculation methods for determining how the loads act on a structure.

It could be argued that SFPE presently publishes standards of practice – that our engineering guides, such as the SFPE *Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, create a standard of care. However, since they are not written in mandatory language, they are viewed less favorably in code development and by some enforcement officials than formal standards.

At their June 2001 meeting, the SFPE Board of Directors began to consider whether SFPE should develop standards of fire protection engineering practice and directed the Technical Steering Committee to consider the positive and negative aspects of doing so.

The Technical Steering Committee identified several implications for SFPE if we were to develop standards. First, development of standards could create new resource demands, which could be significant.

Second, most methods of standards development would imply a change in the composition of the SFPE task groups that presently develop standards to achieve greater balance. At the present time, the engineering consulting community comprises a large percentage of task group membership.

Last, and perhaps most important, if SFPE does not develop fire protection engineering standards of practice, others will. With increased acceptance of performance-based design methodologies, SFPE has gained substantial visibility as an internationally respected source for fire protection engineering guidance. If we do not develop fire protection engineering standards of practice, we run the risk of losing this visibility and respect.

Even if we do begin to develop standards, we would still have the option to continue to develop engineering guides as we do now. These engineering guides could serve to support standards that are developed or could be stand-alone documents.

With input from the Technical Steering Committee, the SFPE Board of Directors has decided that SFPE should develop standards on a "pilot" basis. We are beginning to develop a set of procedures that meet ANSI criteria for standards development, without pursuing ANSI approval. With these procedures in hand, we will enter into discussions with potential partners that might be interested in collaborating with SFPE in the development of standards under our procedures (or similar procedures) on a pilot basis.

Developing formal standards would be a big step for SFPE, and we intend to proceed cautiously.

1 ASCE 7, "Minimum Design Loads for Buildings and Other Structures," American Society of Civil Engineers, Reston, VA, 1998.