THE OFFICIAL MAGAZINE OF THE SOCIETY OF FIRE PROTECTION ENGINEERS

FIRE PROTECTION Engineering

SUMMER 2004

Issue No.23

FOCUS ON PROTECTING FACILITIES

page 8

ALSO:

SFPE

FIRE PROTECTION **Engineering**

Fire Protection Engineering (ISSN 1524-900X) is published quarterly by the Society of Fire Protection Engineers (SFPE). The mission of *Fire Protection Engineering* is to advance the practice of fire protection engineering and to raise its visibility by providing information to fire protection engineers and allied professionals. The opinions and positions stated are the authors' and do not necessarily reflect those of SFPE.

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letters to the editor

The winter 2004 issue of *Fire Protection Engineering* contained three well-written articles addressing basic aspects of fire investigations. The articles, however, danced around the issue of professional qualifications required to provide this type of investigative engineering service.

The articles all paid homage to the Daubert rule that is used to "keep 'junk science' from the courtroom." However, there is a more significant requirement that applies to this application of engineering – professional licensing.

Like other skilled professions, such as the practices of medicine, accounting, and law, the practice of engineering is regulated and governed by state boards. [For engineering,] these boards require that anyone who offers engineering services to the public must meet rigorous academic and professional standards. Engineers are tested, serve internships, and pass background checks before they are licensed as Professional Engineers. Only engineers that are so licensed are eligible for public practice of the profession. Even then, engineers are required by the state boards to restrict their practice to areas in which they are qualified by training and experience.

With some variation, the state engineering boards define the practice of engineering as "rendering any service or creative work, the adequate performance of which requires engineering education, training, and experience in the application of special knowledge of the mathematical, physical, and engineering sciences to such services or creative work as consultation, investigation, evaluation, planning, and design of engineering works and systems... ."

The depth of knowledge that is applicable to the investigation of fires goes far beyond topical guides to the field, such as NFPA 921, *Guide for Fire and Explosion Investigations*. The scientific analysis of physical evidence to determine the cause and origin of a fire requires the application of multiple fields of engineering sciences, including physics, chemistry, materials science, thermodynamics, heat transfer, fluid mechanics, and mathematics. As such, the investigation of fires falls well within the definition of the practice of engineering.

The state engineering boards often do not enforce licensing requirements for consultants practicing a broad array of investigative services. With regard to the investigation of fires, this lack of enforcement of professional licensing requirements has resulted in a situation where a vast array of individuals with a broad range of academic qualifications (or lack thereof) now practice in the field.

The investigation of fires by unlicensed consultants is detrimental to the practice of engineering as a whole and to the practice of fire protection engineering in particular. As illustrated by Dr. Quintiere's article, "Opportunities to Learn from 9/11," the benefits and implications of engineering analysis of fires extend well beyond the courtroom. The professional analysis of fires continually improves scientific knowledge and provides for advancements related to life safety issues.

In sum, the investigation of fires is an application of the practice of engineering. It is hoped that licensed professional engineers and professional societies like the Society of Fire Protection Engineers recognize this and work to increase enforcement of state licensing regulations applicable to the practice of engineering by fire investigation consultants.

Michael Hanson, P.E.

EDUCATION DURING INSPECTIONS...

A valuable tool to prevent fires

By Ronald R. Farr,
Fire Chief/Fire Marshal
Kalamazoo Township, MI

Every day, thousands of fire inspections are conducted across the nation in an effort to identify fire code violations that jeopardize safety or could cause a fire.

The scenario: The fire inspector enters the premises, makes contact with the appropriate owner and/or management, and walks around looking for issues or activities that are in violation with the locally adopted fire code. Once identified, the owner and/or management are informed of what mitigation efforts are needed to comply with the applicable codes. A written report is prepared to document this inspection and the inspector moves on to the next occupancy. A follow-up inspection will occur sometime in the future.

The question that is presented is: Could we do more to promote a safer environment and prevent fires?

The answer is yes, by taking a proactive approach to fire safety and code enforcement through education.

For years, fire departments across the nation have delivered fire safety education programs to school children and other high-risk individuals so they know what to do in the event of a fire, and also what they can do to prevent fires. We need to take this educational (proactive) approach to the next level and teach our business owners and/or managers what they can do to prevent fires and, in the event an emergency occurs, the correct way to respond.

Several years ago, I participated in a fire safety seminar for local business owners, and this past year, I conducted a seminar for people who owned or managed public assembly occupancies. Invited to the first seminar were owners of local businesses, mostly mercantile, who wanted to know more about preventing fires and what they could do to make their occupancies more fire safe as well as comply with code-related issues. As a follow-up to the Rhode Island tragedy, a second seminar was conducted, which was directed at public assembly occupancies. Invited to attend were owners, managers, and/or employees of these facilities.

The format for both programs involved a basic look at fire behavior, a general overview of fire code requirements, and then an overview of standards specific to their certain occupancies.

The overview of fire behavior, demonstrated the power of fire and permitted participants to learn what really happens when fire strikes. Video footage of various fires was shown to help illustrate this. “Many participants voiced shock at how fast the fire spread and how little time a person really has to react to an emergency.”

Attendees then learned about general fire code requirements applicable to all occupancies as well as requirements specific to their occupancy. Time was spent identifying the reasoning behind the requirements and the increased level of safety provided when these requirements are followed. Again, comments heard included: “I had no idea we couldn’t do that,” or “I had no idea we were required to do that.”

There was time provided at the end for questions and answers, and in both cases, the value of these presentations was highlighted in active participation from attendees to identify solutions to specific problems they had. Attendees at both programs indicated that, although they felt comfortable being able to react properly to a fire in their homes, they learned important safety issues not normally considered.

The value associated with this type of fire safety education is now even more important with buildings being constructed with a performance-based design. Much emphasis is being placed on educating the fire service about performance-based design, but this education also needs to be transmitted to building owners and/or managers. Property owners and managers need to understand how buildings are designed, how these designs will affect the building’s performance in an emergency, what impact changes could have on the original design, and what needs to be done to verify that the building is maintained in accordance with the design.

This educational approach is not limited to programs that have been described in this article but can be included in the day-to-day contact that a fire inspector has with the business community. An excellent time to start the educational process is when the inspector is conducting fire safety inspections in occupancies within the community. Many of these inspections give the fire inspector an excellent opportunity to inform the owner/manager not only what is wrong and what they need to do to correct the deficiency that has been identified, but what they can do to prevent it from reoccurring. Many times, this contact is one-on-one and is vital in helping the owner/manager to begin the learning process. This process will increase the owner’s/manager’s fire safety awareness and alter their behavior accordingly. This awareness will greatly increase fire safety and make inspections more of a learning experience for the owner than an enforcement effort.

This extra time spent can be a valuable tool in reducing the probability of losses due to fire.

New Information on Manufacturing, Installation of Hollow Metal Doors and Frame

The Hollow Metal Manufacturers Association (HMMA) division of the National Association of Architectural Metal Manufacturers (NAAMM) announces the publication of three Tech Notes designed to clarify misconceptions related to the manufacture and installation of hollow metal doors and frames. The publications are “Defining Undercuts” (HMMA-810 TN01-03), “Grouting Hollow Metal Frames” (HMMA 820 TN01-03), and “Continuously Welded Frames” (HMMA-820 TN02-03).

HMMA also publishes the *Hollow Metal Manual*, containing 15 sections covering standards for manufacturing, hardware selection, installations and fire-rated applications, and guide specifications for doors and frames for a variety of applications.

For more information, visit www.hollowmetal.org.

SFPE Supports Fire Sprinkler Incentive Act

The Society of Fire Protection Engineers (SFPE) recently announced its support for the Fire Sprinkler Incentive Act of 2003. The bill is assigned to the House of Representatives’ Ways and Means Committee (H.R. 1824). In April, there were over 110 Democratic and Republican cosponsors for the legislation.

Passage of the legislation would modify the current U.S. federal tax code to classify fire sprinkler systems as five-year property for purposes of depreciation. This action would allow building owners to depreciate the cost of a sprinkler system over an accelerated schedule, and would allow cost recovery in a much shorter time frame than offered by the current tax codes.

For more information, visit www.sfpe.org.

WPI Names New Firesafety Director

Kathy A. Notarianni has been named the new director of the Center for Firesafety Studies at Worcester Polytechnic Institute (WPI). She will be the center’s second director, succeeding founding center director David A. Lucht, who steps down after more than 25 years in the position. Lucht will remain at WPI in a full-time position with the university’s division of Development and University Relations.

Notarianni joins WPI in July after finishing her duties as project leader and research engineer with the National Institute of Standards and Technology (NIST).

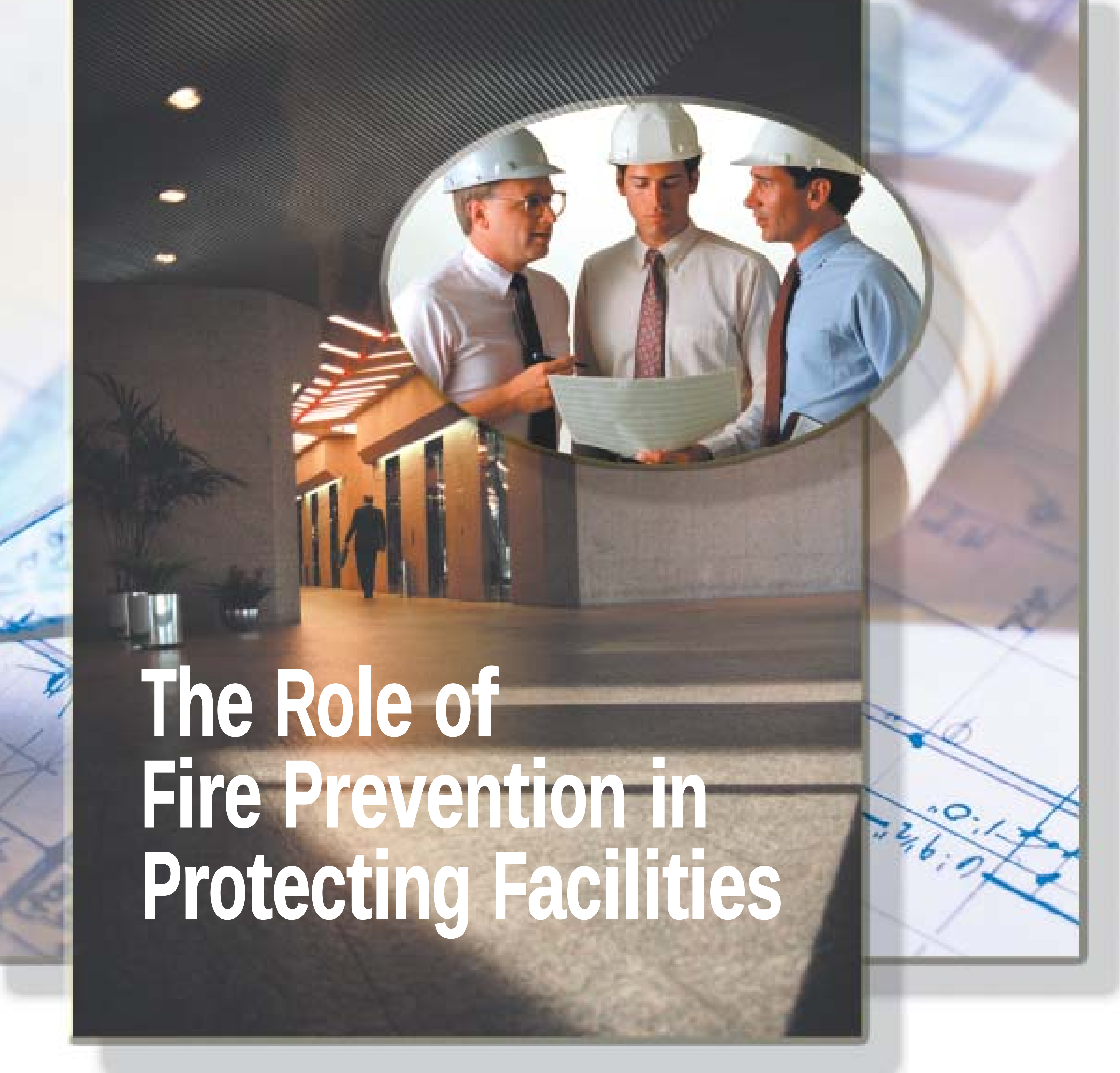
For more information, visit www.wpi.edu.

Congress of Infrastructure Security to Be Held in November

The Infrastructure Security Partnership (TISP) presents the Third Annual Congress on Infrastructure Security for the Built Environment, hosted by the Society of American Military Engineers (SAME). The conference will be held November 7-10, 2004, in St. Louis.

TISP acts as a national asset, facilitating dialogue on domestic infrastructure security and offering sources of technical support and comment on public policy regarding security of the nation’s built environment. The Partnership leverages members’ collective technical expertise and research and development capabilities. A fundamental goal of the Partnership is to reach and include all stakeholders potentially affected by disaster, and to provide technical assistance and information to the Office of Homeland Security.

For more information, visit www.tisp.org.



The Role of Fire Prevention in Protecting Facilities

By Mark Blank

Benjamin Franklin hit a bulls-eye when he wrote, “An ounce of prevention is worth a pound of cure.” Little did he know, but the ever-imaginative author of *Poor Richard’s Almanac* could easily have been referring to the “penny-wise and pound-foolish” approach to business planning that prevails today—particularly with respect to property loss prevention.

Despite the many advances in understanding and protecting against modern-day fire hazards, fire remains the leading cause of property loss at commercial and industrial facilities worldwide.

In the first four months of 2003, the FireNet Industrial Accident Database (www.fire-net.org) recorded 57 significant industrial fires and/or explosions throughout the world, 75% of them in the United States.

These accidents cost businesses millions of dollars in property damage and lost business, plus significant intangible expenses – including lost market share, lost jobs, and business downtime. The sad reality is that most, if not all, of these fires could have been prevented or controlled to minimize property damage if proper construction and fire protection systems were in place.

With each of the incidents, a breakdown existed in fire prevention planning or implementation, allowing the unplanned event to occur, and in all likelihood, more than a few of these facilities had experienced "near-miss" fire events in their recent history.

One challenge may lie in different interpretations of fire prevention. For many people, the term "fire prevention" stirs up images of safe-smoking practices, fire extinguisher training, and emergency evacuation plans. For more experienced individuals involved in property conservation, the term "fire prevention" may bring thoughts of general ignition source controls, safe flammable-liquid handling, and maintaining emergency exits.

Truly effective fire prevention considers all of the following factors:

- Site selection
- Construction
- Facility layout and storage, and
- Human factors.

These factors are addressed to a certain degree in local fire and building codes, but those codes should be considered a minimum. It is important that facility owners understand their own unique hazards, which may mean additional safety features and procedures are needed.

SITE SELECTION

The site-selection phase of a project is the most opportune time to address the often overlooked potential hazards that could be posed by neighboring properties. When loss prevention concerns are identified early, the facility owner has the opportunity to evaluate the risks and property protection challenges, and to choose the highest level of protection when it is most affordable.

Fire and explosion exposure from neighboring properties will vary greatly, depending on the size of the facilities, building construction, occupancy of the neighboring property, and presence of special hazards in both manufacturing processes and storage facilities. It is rare that one company or tenant can influence another to reduce the risk exposure it represents. Rather, fire prevention in this situation hinges on understanding the exposure hazard involved and evaluation of physical protection schemes that will isolate a facility in the event of an exposure fire.

When determining fire risk, the potential magnitude of natural hazards, like windstorms, floods, and earthquakes, should be considered. An earthquake, flood, or windstorm can cause "fire-following" incidents with shaking movement, floating/flying debris impact, or securement breakage under buoyancy stress. Chemical-handling equipment, flammable-liquid system piping and tanks, and fixed fuel-supply systems can be vulnerable to breakage from natural hazard events, even where securement or bracing have been provided. Likewise, fixed fire protection systems can be vulnerable to impairments from these same natural hazard forces, creating the potential for a catastrophic fire.

Where a company already owns a facility exposed to natural hazard conditions, the likelihood of a "fire-following" event can be reduced by providing safety controls and additional equipment bracing (e.g., seismic shutoff valves on fuel or process flammable liquid/gas piping systems, proper buoyancy hold-down straps for hazardous materials tanks, etc.). These precautions will reduce potential damage or prevent the release of hazardous materials.

CONSTRUCTION

Fire hazards can be reduced by designing and maintaining a building using either noncombustible or limited-combustible construction materials or systems approved by an independent, nationally recognized testing and certification laboratory. Also, manufacturer's installation guidelines and associated approved requirements should be followed. As detailed in FM Global Property Loss Prevention Data Sheet 1-1, *Firesafe Building Construction and Materials*: "The principal fire-safety advantage of noncombustible or limited-combustible (Class 1) construction, as compared with combustible construction, is its limited fire spread. The recommended construction does not contribute significant fuel to a fire originating in the contents of the building or allow fire spread via the construction where there is only a localized fire exposure."

Building construction materials hazards are not limited to exterior construction. Combustible interior construction insulations, facings, and enclosures can create some of the most severe fire hazards within a facility. Depending on business occupancy and the sensitivity of operations to nonthermal damage, true noncombustible construction may be the option of choice to maintain a firesafe building.

The use of plastic has become very common in the construction industry, due to plastic's lower purchase costs, lighter weight for shipping and installation handling, superior thermal insulating qualities, washable surfaces, and architectural flexibility (Exterior Insulation and Finishing Systems – EIFS). But these desirable qualities are accompanied by potentially severe fire risks when nonapproved plastic construction materials are installed and when proper fire-protective thermal barriers are not included in the installation design.

Many plastic products that are not approved for specific construction applications are marketed as "fire-retardant." These unrated products may have fire-resistive qualities to withstand low-heat-exposure ignition sources within small-scale applications. However, when installed in full-scale construction systems with industrial occupancy hazards present, these products often burn like untreated, standard petroleum-based plastics. Standard automatic sprinkler systems may not be capable of controlling a fire within this type of construction. Companies, in fact, often install special fire protection systems to protect unrated plastic-in-construction assemblies, such as insulated sandwich panels.

Concealed, combustible spaces are another fire hazard, because these areas typically are not easily accessible for inspection or emergency response. Combustible construction in concealed spaces is more prevalent in older facilities or at complexes of multiple, connected buildings that were built at different times. This construction hazard condition also exists within new facilities, where wood-frame construction is used or where plastics in construction are involved (e.g., exposed foam plastic insulation within office ceiling spaces).

Because combustible, concealed spaces are not directly visible, the fire hazard often goes unnoticed. Most combustible, concealed spaces have openings or penetrations connecting to normally occupied areas. This provides paths for sparks or flames to travel during maintenance work or if a fire starts through some other means. Ignition sources are sometimes provided within the combustible, concealed space in the form of electrical lighting or ventilation equipment. Identifying combustible, concealed spaces is a major step in managing this hazard and should be followed by:

- properly sealing off all penetrations into the area,
- implementing ignition source restrictions in/around the area (e.g., hot work, smoking, open electrical equipment), and
- labeling the area as an unusual or high-hazard location.

Unless the combustible construction within the concealed space can be effectively isolated with a proven thermal barrier, providing some form of automatic fire protection in these spaces (such as automatic sprinklers) is always advisable.

FACILITY LAYOUT AND STORAGE

Planning the layout of a facility by separating dissimilar occupancies is another step in the process of creating a firesafe environment. Some facilities are simply not compatible with each other, just as the storage of dissimilar chemicals in the same area is an unsafe practice. Production areas often contain readily available, open-ignition sources as part of normal process operations (e.g., welding operations, molding machine heaters, process furnaces or ovens). Keeping these areas free of combustible materials is fundamental to effective fire prevention. The use of fire or partition walls between dissimilar occupancies (production and warehousing) is an excellent concept of fire prevention that has been somewhat lost in today's approach of having direct, unimpeded access to all areas of industrial buildings.

Special hazards, such as flammable liquids or combustible dust, are unique fire prevention challenges because of their inherent volatility and ease of ignition under the slightest of process or handling upset conditions. Proper design of process or storage areas for special hazards requires a clear understanding of the risks involved and the options available to manage them safely.

By locating special hazards within cut-off fire- and/or explosion-rated areas designed to contain these hazardous environments, protection can be provided through practical, localized management of facility and operating conditions. Fixed, closed systems using proper materials/components for transfer and dispensing of hazardous materials reduce the potential for an unplanned product release. The provision of automatic safety interlocks on all special hazard process systems/equipment, activated by process controls or fire protection systems and backed up by remote, manual emergency stop stations, will limit the extent of a process upset and emergency fire condition.

Providing dedicated rooms or areas for facility support services, such as electrical supply/distribution equipment and building heating systems, isolates these potential ignition sources from process and storage combustibles. In addition, maintaining a controlled environment can extend the life of the equipment while reducing the ignition source potential.

HUMAN FACTORS

The human factor hazards at every facility may well represent the most challenging component of effective fire prevention. Without effective training, independent follow-up audits, and senior management commitment, people are likely to be inconsistent in their understanding and respect for fire hazards. Having a strong human-factor awareness culture within a facility will greatly reduce the risk of an unplanned fire event or related near-miss incident. The basic controls needed to effectively manage human-factor hazards include:

- Senior management commitment – the key to effective implementation and maintenance of human factors hazards control policies;
- Ignition source control – hot work, smoking, temporary electrical, static electricity;
- Facility and equipment maintenance (including safety control testing);
- Loss prevention inspections (including testing of fire protection equipment);
- Housekeeping practices;
- Operator training – production equipment, facility vehicles, building service equipment;
- Fire protection equipment impairment management;
- Management of outside contractors; and
- Property supervision (facility security).

A firm foundation for human-factor fire prevention can be established by combining policy statements that communicate the required human factors culture with formal procedures for the daily management of these hazards.

Managing personnel is another human-factor hazard often overlooked by companies, and it has the potential to minimize the effectiveness, or even circumvent, established fire prevention programs within a facility. A loss of staff can result in a loss of experience, knowledge, and key members of the property loss prevention team. Businesses that do not use a process to understand the potential risks of personnel change at a facility place themselves in a position of vulnerability from a fire prevention perspective. Ensuring new staff are adequately trained is paramount to reducing risks and room for error. Key areas that should be addressed through training include impairment procedures, hot work control, working with contractors, emergency response, and recovery.

A NECESSARY EXPENSE

Every day, companies throughout the world accept business risks in the normal course of managing their organizations, but many do not seriously include fire prevention policies and practices in their business models. The costs of effectively implementing a fire prevention culture within a company are often viewed as unnecessary. Some in the business world might call this approach a calculated risk. But perhaps a more appropriate view of this business model is one of a risky gamble. Proper fire prevention can help a business avoiding becoming the next statistic. ▲

Mark E. Blank is with FM Global.

Integrating Fire Prevention with Performance-Based Design

By Jane Lataille

INTRODUCTION

Even when protective systems work as designed, fires can still cause substantial damage. Among the consequences of fire requiring cleanup or repair are:

- Direct fire damage;
- Damage from contact with burning materials;
- Damage from exposure to heat;
- Contamination by smoke, soot, acids, and other products of combustion;
- Contamination from released chemicals, such as chlorine;
- Saturation with liquids released from breached containers;
- Damage from exposure to water from sprinklers and hose streams;
- Damage from collapse of burned materials or structures;
- Accumulation of burned residues;
- Penetration of odors; and
- Environmental damage.

Other concerns include harm to the public, harm to employees, and lost work time.

Recovering from fire can also affect normal business operations. Customers who are forced to use a temporary supplier might decide to stay with that supplier. Competitors can use the opportunity to solicit new customers even if business operations are not affected.

For these reasons, preventing fire is more desirable than controlling it. The many fire prevention measures now available include selecting equipment that incorporates engineered fire prevention systems, designing fire-safe processes, implementing appropriate management fire prevention programs, and developing new fire prevention designs.

FIRE PREVENTION MEASURES

Preventing fire involves controlling combustibles, oxygen, and ignition sources. The most effective way to do this depends on building occupancy and processes. Fire prevention measures can be implemented through engineered systems, administrative procedures, or a combination of these. Documenting the selected fire prevention measures is just as important as documenting the fire control features of a performance-based design.

Engineered Systems. Many system designs incorporate engineered fire prevention components. Classic examples include the combustion safeguards installed on fuel-fired equipment to prevent fires and explosions, oven ventilation systems designed to keep vapors below 25% Lower Explosive Limit, and explosionproof electrical equipment to contain explosions without causing damage. To remain dependable, these systems must be properly designed and regularly inspected, tested, and maintained. In addition, the rooms or equipment for which these systems are designed should not be changed without reviewing the fire prevention measures.

Administrative Procedures. Management fire prevention programs establish administrative procedures intended to prevent fire. Effectively implementing these procedures requires sincere and proactive management commitment. Programs essential for preventing fire must be monitored like any other design assumption.

Examples of fire prevention programs are operator training for normal startup, operation, and shutdown; off-normal; and emergency conditions (Safe Operating Procedures). Other examples include training programs for storage practices and use of lift trucks in a warehouse; no-smoking programs; and programs for hot work and preventive maintenance.

Procedures are usually more difficult to "keep in service" than engineered controls. Dependence on procedures can make a facility vulnerable, particularly when trained operators are sick, personnel turnover is high, or program budgets are cut.

The key elements for maintaining a successful fire prevention program are preventive maintenance, monitoring, and management of change. Preventive maintenance programs should take steps to:

- Identify all equipment, systems, and devices requiring preventive maintenance.
- Determine appropriate type(s) of preventive maintenance, including visual inspections, offline and online testing, regular calibrations and lubrication, and repairs and replacement.
- Determine appropriate frequencies for the maintenance.
- Document the types and frequencies of maintenance.
- Assign responsibilities for conducting the maintenance.
- Keep written records of maintenance activities.
- Screen records for trends requiring changing the procedures.

Monitoring programs are developed and implemented as follows:

- Document all fire prevention measures.
- Determining how to verify whether the measures are in place.
- Develop a list of things to be checked.
- Determining appropriate frequencies for checking each item on the list.
- Assign responsibilities for conducting the loss prevention inspections.
- Keep written records of inspections.
- Screen records for possible changes.

These monitoring programs would audit all the other facility fire prevention programs, such as operator training, hot work, and performance of regular facility inspections.

Management of change programs should include a process for submitting proposals for modification, as well as a system for handling changes discovered during inspections. Reviewing the potential effects of alterations is best done before implementing the change, and this practice should be encouraged. However, changes are sometimes made without the benefit of prior review. In that case, they should be reviewed as soon as possible afterward.

The sidebar lists some common fire prevention measures.

INTEGRATION WITH PERFORMANCE-BASED DESIGN

Fire prevention measures have direct bearing on fire performance, and they are an integral part of a facility's performance-based design. The stakeholder's objectives could include minimizing the consequences of a particular fire scenario rather than preventing it. (See Chapter 6 of the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings.*[1]) Or later in the design process, it may be decided that preventing the sce-

Fire Prevention Measures

Following are examples of common fire prevention measures that can be taken to eliminate chance of fire.

- Combustion safeguards for fuel-fired equipment;
- Ventilation of areas to keep vapors below ignitable levels;
- Explosionproof or intrinsically safe electrical equipment, heaters, and other energy sources to be used in electrically hazardous (classified) locations;
- Fire-safe design of thermal heat transfer systems;
- Fail-safe design of hazardous chemical processes; and
- Prevention of fires in warehouses.

Performance-based designs should incorporate and document all of these measures. Examples of measures to document for prevention of fires in warehouses are:

- Fork lift recharging procedures
- No-smoking programs
- Procedures for storage practices (not mixing commodity classes, not stacking too high, not putting storage in aisles, etc.)
- Operator training

Fire Prevention in Performance-Based Design

Four areas of particular concern in integrating fire prevention in performance-based design are:

- Developing Design Fire Scenarios
- Analyzing Risk
- Monitoring Conditions Against Design Assumptions
- Managing Change

Three Examples of Integrating Fire Prevention Measures

Example 1 – Laboratory Using Chemicals

A stakeholder reports that an average of 10 lb/sq ft (50 kg/m^2) loading of ordinary combustibles can be expected in a laboratory using chemicals. The protective system can be designed to control a design fire with that loading (including an appropriate safety factor). Or options to reduce the loading can be explored. For example, dedicated storage areas outside the area of the design fire can be provided, and loading can be reduced in the area of concern.

In this example, the risk analysis should factor in the likelihood that combustible loading exceeds the assumed amount. The monitoring program should document the designated storage areas for combustibles, as well as the combustible loading that the laboratory protective system is designed to control. The management of change program should also document these items for reference when changes to laboratory operations are being considered.

Example 2 – Hydraulic Presses

Ten hydraulic presses are to be installed, each containing 500 gallons (2 m^3) of combustible hydraulic oil. The protective system can be designed to control a hydraulic oil fire in the entire manufacturing area. Or a central hydraulic oil reservoir for all the presses can be provided in another area. Another option would be to explore whether the particular presses chosen can use a noncombustible or less hazardous fluid.

The fire prevention for the central oil system should include engineered process safety controls to keep hydraulic oil from entering the manufacturing area. This could include:

- Interlocks for oil level, pressure, and temperature;
- Dikes and drains for the main oil reservoir;
- Excess flow valves on the oil lines to each press; and
- Preventive maintenance on pumps and piping.

The risk analysis should consider the failure modes of all equipment, safety systems, and management programs pertaining to both the central oil system and the presses. The monitoring program should include review of inspection, testing, and maintenance records.

Example 3 – Deflagration Hazard

A process contained inside a room presents a deflagration hazard. This hazard could be controlled by an explosion suppression system. Or the room could be designed to either vent the deflagration or withstand it. Another option would be to design the deflagration hazard out of the process.

Designing out the deflagration hazard could include:

- Specifying particular vessels, pumps, piping, and fittings;
- Limiting material holdup;
- Limiting material feed rates;
- Controlling process reaction rates;
- Interlocking critical process parameters, such as flow, temperature, level, concentration, cooling, ventilation, and agitation;
- Running under an inert atmosphere;
- Installing gas detection; and
- Providing emergency venting, drainage, and ventilation.

The systems and procedures used to make the process safe must be documented in the risk analysis, facility monitoring, and management of change programs. In addition, if the risk of deflagration is still high enough to warrant control, installing an explosion suppression system might still be considered.

In ways similar to the above examples, every fire prevention measure established for a facility can, and should, be integrated with the performance-based design.

nario is preferred to controlling its consequences.

Improved performance achievable through fire prevention programs can be a strong economic incentive for implementing them. But maintaining the improved performance requires upkeep of the fire prevention programs, which is not as easy as it sounds. Fire prevention programs must be well documented so they can be properly modified in conjunction with any future building or occupancy changes.

The Fire Protection Engineering Design Brief should summarize all the fire prevention measures necessary to assure the validity of the performance-based design, including both engineered systems and management programs (Chapter 11 of the *SFPE Guide*). The level of detail in the design brief can help assure that the facility continues to operate within the design boundaries.

Four areas are of particular concern in integrating fire prevention features into a performance-based design: the design fire scenarios (Chapter 8 of the *SFPE Guide*), risk analysis (Appendix E of the *SFPE Guide*), monitoring facility conditions against design assumptions, and managing change. The last two items are not part of the design itself, but are important in assuring that the design basis remains valid.

Design Fire Scenarios. Performance-based fire protection design assumes a particular set of design fires. The goal is to control these fires in accordance with the stakeholder's objectives.

Design fires are based on specific conditions expected at the facility with sufficient conservatism, or safety factors. The design is valid only as long as the conditions still apply or as long as any different conditions fall within the bounds of the design fires. Documenting these conditions is critical to the design.

Fire prevention measures may make it possible to eliminate some design fires from consideration in a performance-based design. For example, a supply tank for flammable liquid could be relocated, so the contents of the tank need not be considered in a particular design fire. The tank then should not be moved again without review through a management of change process.

On the other hand, design fires not already considered may have to be included unless adequate fire prevention measures are taken. For example, if combustible materials are excluded from a design fire on the grounds that they are far enough away not to become involved, then the continuity of combustibles between them and the design fire must be maintained sufficiently low so the assumption remains valid.

To integrate fire prevention with design fire scenarios, one must:

- Explore all possible fire prevention measures.
- Select fire prevention measures appropriate for the design.
- Explain which fires are not design fires on the grounds that prevention measures will not allow them to occur.
- Document the selected fire prevention measures.
- Add the assumptions associated with the fire prevention measures to the assumptions inherent in controlling the design fires.

Risk Analysis. If the stakeholder's objectives state a desired level of risk, then a performance-based design would calculate the risk associated with that design. In determining likelihood of fire control, risk management must account for the probability of all possible fire sources and all possible failure modes of protective systems.

Risk analysis should also account for the probability of a fire prevention system or procedure failure. Determining this type of probability for engineered fire prevention systems is similar to determining the probability of failure of a fire control feature. Determining the probability of failure of fire prevention programs is more difficult because procedures are more intangible than physical systems. Nevertheless, estimating this probability is still important.

Monitoring Conditions Against Assumptions. Routinely confirming that design assumptions are still being met assures that the protection remains effective. This is normally done by conducting fire prevention inspections. For the monitoring to be effective, all conditions that could affect the design must be known. The Fire Protection Engineering Design Brief should summarize all the conditions that should be monitored to assure maintaining the design basis (Chapter 11 of the *SFPE Guide*).

An effective monitoring program is the strongest defense against fire. This program should monitor the performance-based design assumptions, fire prevention programs, and how well fire prevention measures are working. It should also effectively correct any deficiencies that are found. For example, rather than correcting a recurring problem at every loss prevention inspection, the monitoring program should find and correct the root cause of the problem.

Managing Change. Fires happen because things change. If changes are found that affect the validity of the fire protection design, the results of the change must be analyzed and managed. The management of change program should review both the protective and preventive aspects of any discovered or proposed changes.

Change can be found during routine monitoring, or it can be planned. If change is found during monitoring, not only should the change be properly integrated into the design, but the management of change program should take any actions needed to assure that future changes are reviewed in advance. Reviewing change is best done before it is implemented.

Codes now recognize fire prevention as part of performance-based design. *NFPA 1: Uniform Fire Code,*[2] addresses fire prevention issues in Chapter 5. The *ICC Performance Code for Buildings and Facilities*[3] addresses them in Chapter 16. These codes cite the principles of performance-based design; experience in fire protection engineering is needed to apply the codes to specific facilities. See the previous sidebar for three examples of integrating fire prevention measures with these four facets of performance-based design.

Maintaining the fire prevention programs associated with performance-based designs can be challenging. These programs can be complex and require extensive tracking to properly implement. They require many resources, including time, equipment, personnel, and ongoing budgets.

After a facility is built, the expected level of performance should be reflected in the facility's fire experience. Fire experience worse than expected would indicate that the fire prevention programs are not working as anticipated. In such a case, fire prevention programs would need thorough review and correction. However, proper monitoring of fire prevention programs should pick up problems before they are reflected in fire experience.

CONCLUSIONS

Performance-based design can, and should, integrate all appropriate fire prevention measures. These measures, and all the building and occupancy features on which they depend, must then be fully documented so that no changes affecting fire prevention are made without review through a management of change program. The fire prevention measures assumed in the design must then be implemented, monitored, and maintained. Keeping fire prevention programs working requires many resources and constant vigilance. (See sidebar.) ▲

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REFERENCES

1 *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, Society of Fire Protection Engineers, Bethesda, MD, 2000.

2 NFPA 1: *Uniform Building Code*, National Fire Protection Association, Quincy, MA, 2003.

3 *ICC Performance Code for Buildings and Facilities*, International Code Council, Falls Church, VA, 2003.

Keeping Fire Prevention Programs Working

Many resources are required to keep fire prevention programs working with performance-based designs, including the following:

- Detailed documentation as part of the performance-based design;
- Management commitment and involvement;
- Trained staff;
- Adequate, ongoing budgets;
- Adequate time to implement programs;
- Inspection, testing, and maintenance programs;
- Inspection, testing, and maintenance equipment;
- Auditing programs;
- Management of change programs;
- Tracking of information; and
- Programs for follow-up and taking corrective actions.

Improving Fire Prevention through Fire Hazards Analysis

By David Tomecek, P.E., and Bradley Smeaton

New pieces of equipment and techniques for fire mitigation seem to become available every day. New automatic sprinklers, detection devices, or emergency response methods are constantly being developed. This visible focus on fire control technologies might lead one to think that fire prevention is a thing of the past. To the contrary, fire prevention is more relevant than ever. Fire inspections and other traditional fire prevention techniques have proven themselves over time, but the use of new analysis methods is creating an opportunity for rational applications of fire prevention requirements that might not be evident to the casual observer.

Basic approaches to fire safety design acknowledge that fire prevention is an important facet of overall fire safety. This is clearly illustrated at the very top of the NFPA Fire Safety Concepts Tree,[1] which is routinely relied upon as a framework for comprehensive approaches to fire safety design (see Figure 1). However, by using a more formalized approach to fire hazards analysis, issues related to fire prevention can be identified that are not necessarily addressed by prescriptive controls or fire protection systems. The use of a fire hazards analysis framework can identify the limits of traditional approaches and can be used to structure and integrate fire prevention and protection programs accordingly. Combining fire hazards analysis with risk assessment, system design, and performance-based analyses, specific fire prevention needs can be identified and effective controls can be developed.

WHAT IS A FIRE HAZARDS ANALYSIS (FHA)?

There is no specific definition of a fire hazards analysis but there are several ideas to keep in mind. An FHA should include a comprehensive evaluation of the causes of, impacts from, and consequences of fire in a specific location. It is a process, in a building, considering the effects of engineered systems, administrative programs, and manual intervention.

To a limited extent, an FHA is performed whenever fire or life safety design or evaluation is undertaken. When making decisions regarding the capabilities of engineered systems, the design must consider the type, quantity, and location of combustibles in the area protected. The design of sprinkler systems for high-piled storage requires an evaluation of the commodity classification and configuration of the storage. Performance-based design for egress systems and structural fire resistance also require consideration of the fires that might occur. Regardless of whether a prescriptive or performance basis is used, a fire prevention element is inherently introduced into each of these scenarios and is crucial to the success of the system.

On a larger scale, developing a formal FHA for a process, building, or multibuilding complex can identify concerns beyond a specific system or condition. Documenting an FHA and carrying it forward for the life of a building or process is rarely done, and structured fire prevention plans are not often considered part of design solutions. However, formalizing an FHA via a structured framework can have many benefits. One is that the analysis can introduce fire prevention elements as solutions to specialized concerns that typical fire protection strategies either cannot address or cannot do as cost-effectively. Often these solutions are more complex than those offered in traditional fire prevention methods or programs (such as periodic "combustible loading" inspections, signage, or housekeeping) and require higher levels of attention and management. They can also be much more effective tools than one-dimensional reliance on engineered systems.

The insurance industry has been tracking buildings and facilities with written evaluations for decades. Several of the larger insurers have even standardized their ideolo-

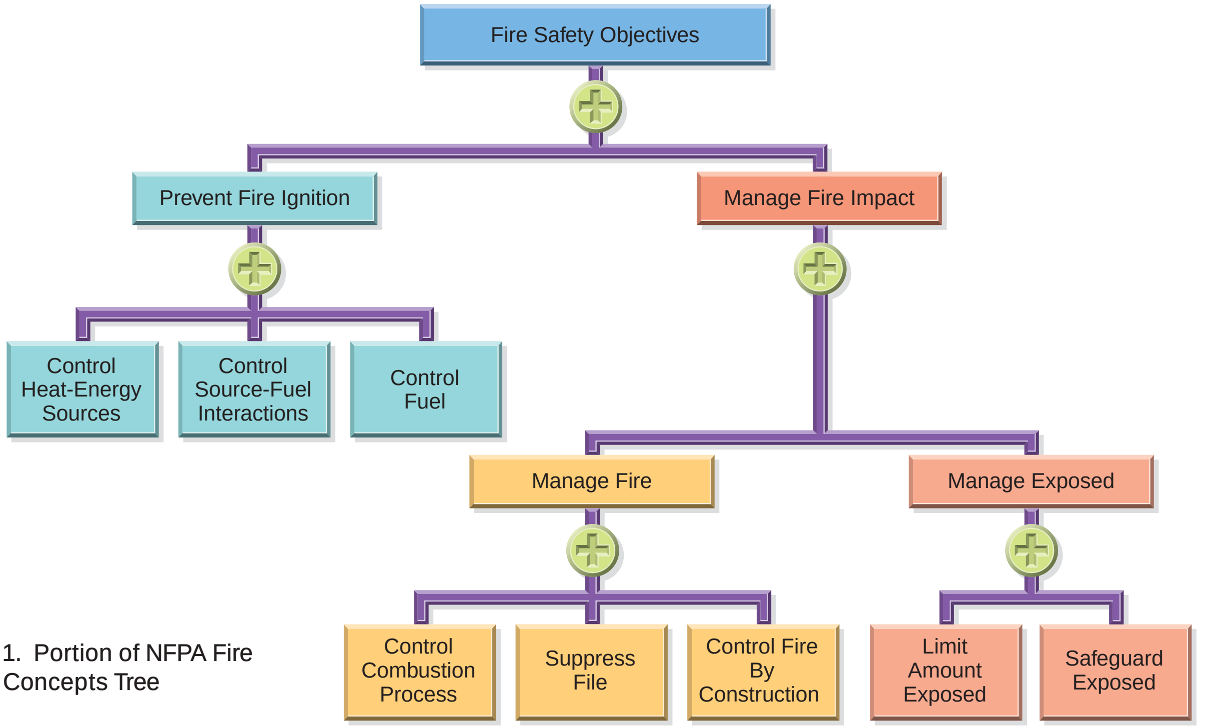

Figure 1. Portion of NFPA Fire Safety Concepts Tree

gies into loss prevention standards and policies. Large corporations with national and international interests have followed suit, establishing their own policies and guidelines. In both cases, fire prevention strategies are considered alongside their mitigation counterparts as part of an overall approach.

Several United States federal government departments began following this same pattern as early as the 1960s. The General Services Administration (GSA) developed a performance-based framework that defined a set of expectations for FHA and used it as a basis for alternatives to prescriptive codes and standards, particularly for historic and existing structures. The Department of Defense (DoD) and the Nuclear Regulatory Commission (NRC) have, or are in the process of developing, their own methodologies. Notable, however, is the FHA framework used by the Department of Energy (DOE).

THE DEPARTMENT OF ENERGY APPROACH

The DOE approach to FHA is a model that allows for individual buildings or processes to be evaluated using both prescriptive and performance-based methodologies to achieve specific fire safety goals. By requiring a thorough evaluation of many elements of a fire safety program, the DOE process compares fire risk against established criteria. Additionally, comparative risk on a case-by-case basis can be assessed against fire safety concerns that are not so easily defined, such as release of hazardous materials, business interruption, and damage to items of national interest. The DOE approach advocates strong, comprehensive fire safety strategies, giving weight to fire prevention plans and administrative programs, as well as to active and passive fire control requirements and engineered systems. The FHA methodologies and implementation structure provide this capability, and the result is a rational reliance on specific fire prevention controls. The approach and methodology is included in *DOE Orders 420.1A and 440.1A*, as well as the associated fire safety program implementation guide. These documents can be found on the Internet at http://tis.eh.doe.gov/fire/ or http://www.directives.doe.gov/.

The strength of the DOE approach begins with acknowledgment of the need for fire safety by the Secretary of Energy. Several memoranda from the Secretary have been issued, reinforcing the need for a strong fire safety program, and particular aspects of the program when necessary. Overall policies are established in documents known as Orders. The DOE Orders contain the overriding criteria for establishing fire safety programs, including the need to perform FHA on "all nuclear facilities, significant new facilities, and facilities that represent unique or significant fire safety risks."[2] Discreet expectations are described in guides, manuals, and handbooks that are prepared by the Headquarters division responsible for program development.[3, 4] DOE contractors at individual operating sites generally have implementing procedures that define how FHA documentation will occur. While there are a number of sites and frameworks, the general criteria that is evaluated is common to all of them, since it is prescribed by the DOE (see inset).

The DOE approach requires that qualified fire protection engineers perform FHA, and establishes expectations as to capabilities and level of experience required to perform such analyses.[3, 5] By doing so, an established minimum level of consideration is anticipated to be given to the identified criteria. Further, the detail of the evaluation is expected to be sufficient to be used as input to other DOE evaluations, including those for nuclear safety, criticality safety, hazardous material storage and release, and general industrial hazards. These related evaluations present risk information to DOE relative to other hazards and programs with which fire safety is related.

Using this framework, fire hazards can be defined and compared to existing engineered systems and manual intervention methods to determine if specific objectives can be achieved. From the description of fire hazards, specific fire scenarios of concern arise. Qualitative or quantitative methods can be used to develop consequences for both mitigated and unmitigated conditions. The resulting consequences can then be evaluated with respect to probability of occurrence, direct financial losses, indirect business interruption, effects on workers and the surrounding public, and other tangible and intangible consequences.

In many cases, the analysis may point out the limitations of engineered systems or the inadequacies of traditional fire prevention approaches. In these cases, quantitative methods such as fire models are used to more discreetly analyze a scenario. From that quantitative analysis, specific improvements related to fire prevention and/or fire protection strategies result.

FHA-based evaluations routinely lead to changes in a particular suppression system, modifications to a mechanical process, replacement of materials with their less flammable or noncombustible counterparts, or installation of location-specific engineered controls. Also, changes in existing inspection, testing, and maintenance programs might come about, based on the identification of significant need for a change to improve the operational reliability of a particular engineered system. It is likely, however, that fire prevention issues will be identified as well.

The DOE approach to fire hazards analyses contains the following information, as well as their interrelation with fire safety criteria established in DOE Orders, Standards, Guides, and Handbooks.

- Description of construction
- Description of critical process equipment
- Description of high-value property
- Description of fire hazards
- Description of operations
- Potential for a toxic, biological, and/or radiation incident due to a fire
- Natural hazards (earthquake, flood, wind) impact on fire safety
- Damage potential: Maximum Possible Fire Loss (MPFL)
- Fire protection features
- Protection of essential safety class systems
- Life safety considerations
- Emergency planning
- Fire Department/Brigade response
- Recovery potential
- Security and Safeguards considerations related to fire protection
- Exposure fire potential and the potential for fire spread between two fire areas
- Effect of significant fire safety deficiencies on fire risk

IDENTIFICATION OF FIRE PREVENTION NEEDS THROUGH FHA

While building codes, fire protection standards, loss prevention guidelines, and other such documents identify required engineered systems and controls for general situations, the engineered controls may not be adequate to achieve the desired level of fire safety for the existing or anticipated conditions determined as part of the FHA. In fact, an FHA frequently reveals that engineered controls for a particular situation offer little or no benefit, particularly if those controls carry significant short- and long-term costs. It is under such conditions that specific fire prevention measures can often be introduced as a cost-effective alternative.

Traditional fire prevention measures typically focus on general strategies such as reduction or elimination of combustibles and/or ignition sources. The FHA framework refines this approach to provide mitigation approaches to specific concerns, as opposed to a generalized condition of safety. From the analysis, specific issues of fire spread, smoke movement, damage to specific pieces of equipment, and dangers to life safety can be identified. If required engineered features do not adequately address such issues, discreet fire prevention measures may be available to mitigate the condition. Control of combustibles around specific pieces of equipment may be needed. The use of grounding in situations not normally required could be used to eliminate ignition sources. Conditions where specific fire prevention programs or strategies can be relied upon as part of an effective fire safety design for a unique application are routinely identified through the use of formalized FHAs such as that used by DOE (see inset).

To illustrate, consider the design of smoke control systems. In designing smoke control for atria, a fire size must be chosen in order to perform the various calculations needed to design the system. That design fire inherently defines a fire prevention control (i.e., maximum allowable design fire) that would need to be continually maintained for the future of the facility. Future furnishing purchases and arrangements would need to correspond to the original fire assumptions, and purchases and installations coordinated accordingly. Furthermore, the introduction of additional combustibles for receptions, demonstrations, holiday decorations, and other events would need to be closely observed to ensure that the design-basis fire size is not exceeded. Failure to control combustibles within the space would invalidate the design of the smoke control system and could potentially place people exiting the building in danger.

Using this type of analysis, time-honored fire prevention programs can take on new importance. In cases where hot work is determined to be a fire hazard beyond that generally assumed, the implementation of a structured approval process would reduce the probability of a resulting fire. Approving the type and arrangement of personal space heaters could become a required compensatory measure in an existing file storage area that is otherwise unprotected. An FHA points out whether these seemingly routine fire prevention items are really simple property loss issues or are intrinsic to a much more serious fire protection and loss prevention program.

IMPLEMENTING FIRE PREVENTION CONTROLS

With few exceptions, implementing fire prevention controls re-

A Simple Example

Performance Criteria

A large manufacturer of computer hardware examines its production stream and determines that the loss of production in a particular plant cannot exceed two weeks. Any recommendations must be limited in cost, as the company is experiencing financial difficulties.

Fire Scenario and Hazards Analysis

From observed conditions, a scenario is identified that involves a small quantity of combustibles in the operations computer control room. The type, quantity, and location of combustibles were found via modeling to be inadequate to activate the room's fire sprinkler system, which is the only provided suppression system. As well, the resulting fire was determined to be limited enough to not cause thermal damage to the computer cabinet and the electronics inside. The resulting smoke, on the other hand, would damage the equipment and require replacement schedules in excess of the allowed two weeks.

Evaluation of Strategies

Engineered systems, such as clean agent extinguishing systems, could be recommended. However, the financial situation of the company requires the evaluation of alternatives. The provision of combustible controls can produce the desired effect at a significantly reduced cost. The control could be simply the elimination of combustibles that are not related to the computer equipment, including the removal of cushioned furniture, plastic storage containers, and cardboard boxes.

In addition, controls on ignition sources could be instituted. Disallowing repair operations utilizing soldering irons and other hot surfaces from the room could be an instituted control. Eliminating cooking and heating appliances like coffee pots and space heaters could be another. Consolidation and control of the use of extension cords and multiple outlet devices (like surge protectors) is yet another possible control.

Impacts and Implementation

The impact of each of these strategies must be evaluated against their cost and the ability of the company to implement and maintain them. Once established, the controls must be periodically evaluated to ensure they continue to address the initial concern.

quires time, effort, and funding. As a result, there is generally a tendency to use the easiest methods possible. Posting of signs, daily checklists, random inspections, and other means are often employed as low-cost methods. In other cases, such as instances where the controls are part of a performance-based fire safety design, a more rigid implementation is necessary. Assignment of duties to specific employees, specialized compliance forms, operational checklists, periodic management oversight, and validation by the local Authority Having Jurisdiction could be needed if the situation is identified to have regulatory concerns or is of significant importance.

How thoroughly fire prevention precautions should be implemented depends on many factors. Usually, fire prevention techniques are applied equally to all situations and with equal vigor. Fire prevention methods driven by FHA will likely require more rigorous implementation because of the risks involved. It is necessary as part of the FHA to assess the risk posed by a particular condition and the effect the prevention control has upon minimizing that risk. However, how to best implement the control is a management decision outside the FHA. Factors that influence that decision include, but are not limited to:

- The significance of the risk on an absolute scale (i.e., compared to specified success criteria);
- The significance of the risk on a relative scale (i.e., compared to other risks that could also lead to unacceptable conditions);
- The impact the fire prevention control has upon the risk;
- The level of difficulty in implementing the control;
- The level of difficulty in enforcing the control;
- The cost of the control versus the benefit obtained; and
- The posture toward fire prevention of the people involved.

Cost is always a factor and is sometimes difficult to evaluate when comparing long-term administrative costs against a potential fire loss. There are various cost-analysis schemes that can be undertaken depending on the risk being evaluated. A simple evaluation may compare direct costs against possible loss. Such an evaluation is suitable when the risk is fairly clear. However, risks that are not so well defined may require more detailed cost evaluation to convince all parties involved that the implementation is worthwhile.

Performance-based design introduces a twist to this concept in that the difficulty of implementation and enforcement is unknown, as is the posture of the people involved. In public buildings, the emphasis of an FHA is different because the primary issues are related to life safety. While specific fire prevention assumptions may be justified as part of an analysis, reliable implementation is really the key. Issues such as how to insure long-term validity of vital assumptions, who is responsible, and how failures of those assumptions will be corrected are important implementation factors. In fact, administration of FHA assumptions and outcomes are likely to be an important key to how successful performance-based fire protection designs will be.

KEEPING THINGS CURRENT

To be effective, the FHA needs to be a living document. Periodic reviews and updates should occur to reflect any changes to the original analysis. Large facilities or complexes with multiple operations that are dependent upon each other for successful production may be continuously expanding, replacing equipment, or improving existing operations. Specific construction projects tend to focus on the applicable requirements for the project itself, with collateral considerations limited to the direct impacts on available utility loads, exposures, and integration of existing fire protection features. A project could actually impact the original assumptions and implemented controls established based on the initial FHA performed years prior. In addition, the original FHA may not account for changes in management, ownership, or shifting regulatory requirements.

For example, assume an existing analysis for a facility determines that fire prevention controls for a facility were unnecessary even though there are deficiencies identified in the building's automatic sprinkler system. This result was based on an overall fire loss that is an acceptable risk based on noncritical or easily resumed operations. A new construction project is initiated to relocate a new operation in the existing facility that contributes a significant and unique process that is critical to the corporate mission. The project engineer's review is generally focused on the specific portion of the structure to be modified, assuming existing conditions outside of the project scope are acceptable and do not require review. However, the new project shifts the conclusions of the existing analysis and places the critical operation and complex-wide production at risk. This concern may not be recognized for years and could result in much higher costs for implementing controls or correcting the sprinkler protection. Establishing a periodic review and update cycle for the FHA that is performed can assist in avoiding this problem. Additionally, maintaining a complex-wide or facility-wide document that is a required input to any project ensures that new risks or changes to previous risk assumptions are addressed. ▲

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REFERENCES

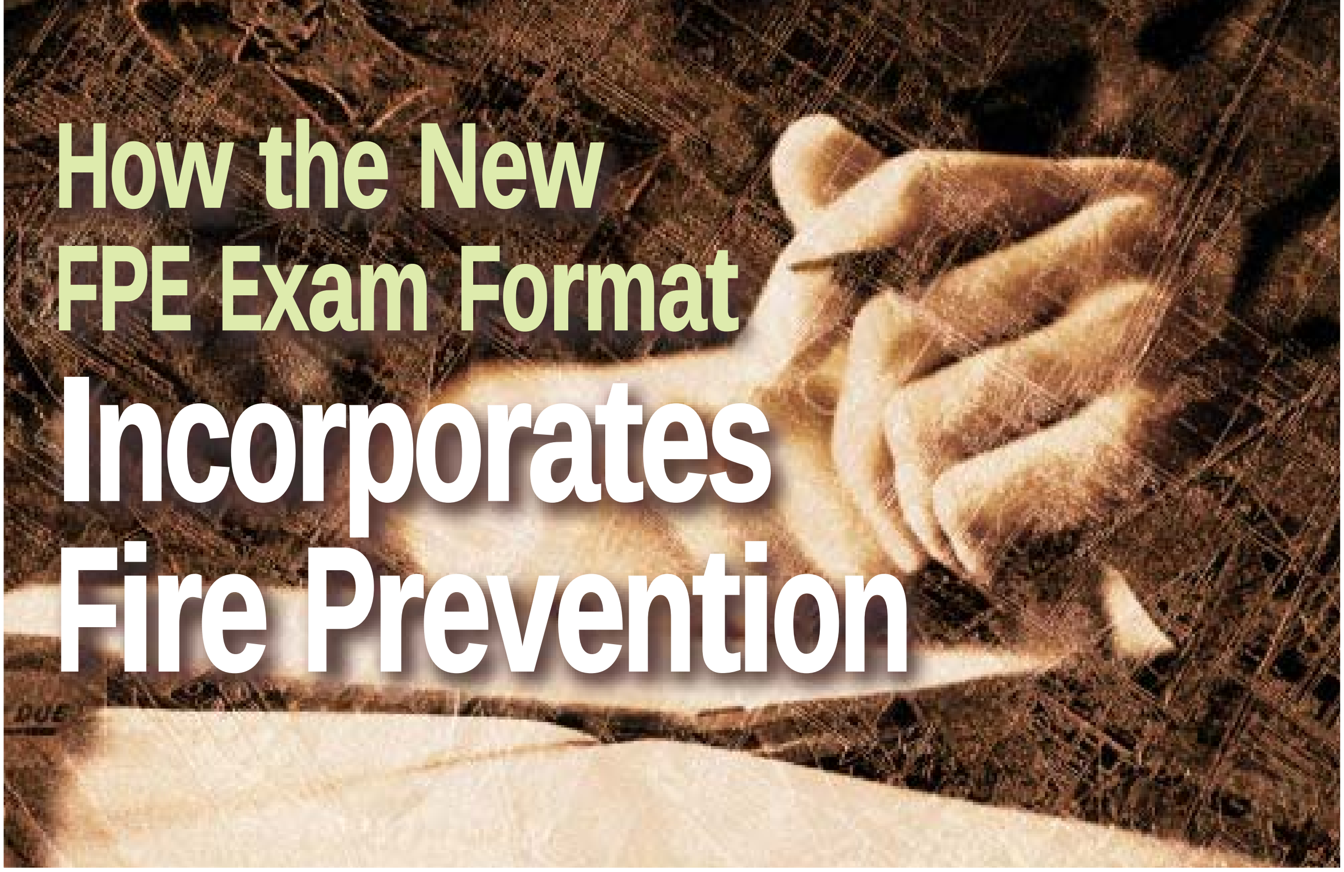
1 NFPA 550, "Guide to the Fire Safety Concepts Tree," National Fire Protection Association, Quincy, MA, 2002.

2 *Department of Energy (DOE) Order 420.1A, Facility Safety*, U.S. Department of Energy, Washington, D.C., May 20, 2002.

3 *DOE Guide G-420.1/B-0:G-440.1/E-0, Implementation Guide for Use with DOE Orders 420.1 and 440.1: Fire Safety Programs*, U.S. Department of Energy, Washington, DC, September 30, 1995.

4 *DOE Handbook DOE-HDBK-1062-96, DOE Fire Protection Handbook*, U.S. Depart- ment of Energy, Washington, DC, 1996.

5 *DOE Standard DOE-STD-1137-2000, Fire Protection Engineering Functional Area Qualification Standard,* U.S. Department of Energy, Washington, DC, July 2000.



How the New FPE Exam Format Incorporates Fire Prevention

By Ralph Kerwin, P.E.

Most fire protection engineers who become licensed in the United States achieve that license by passing the Principles and Practice Exam in Fire Protection Engineering (FPE exam).

The purpose of the exam is to set a threshold for the technical knowledge required of a hypothetical fire protection engineer who is "minimally competent" to safeguard public health, safety, and welfare in the course of performing his or her professional duties. Once every decade, the national governing society, The National Council of Examiners for Engineering and Surveying (NCEES), requires that the Society of Fire Protection Engineers polls licensed practicing fire protection engineers (both members and nonmembers) and reevaluate which areas of knowledge should be known by this minimally competent engineer. The engineers selected for this reevaluation are free to completely redefine the existing exam categories, so when a new survey is completed, the results redefine the "the basics" of fire protection engineering for the purposes of the FPE exam for the next ten years.

A new survey was conducted in 2002. In dramatic contrast to reevaluations of the past 20 years, the results show significant changes in how fire protection engineers view their field. New technical content has been recognized, and some of the traditional areas of practice have been reduced or eliminated to make room. This article looks first at the general changes in the exam format and then focuses specifically on the treatment of fire prevention as an exam topic.

Table 1. Comparison of old and new exam formats

Exam Category	Old Exam Items in Dedicated Category	New Exam Items in Dedicated Category
Water Supplies	10	0
Building Systems	10	16
Fire Protection Systems*	30	28
Fire Prevention**	20	8
Hazard and Risk Analysis	10	28

* consists of old categories "Water-Based Suppression Systems," "Non-Water-Based Suppression Systems," and "Detection and Alarm Systems."

** consists of old categories "Planning and Design of Fire Prevention" and "Implementation and Monitoring of Fire Prevention"

OVERVIEW OF THE NEW FPE EXAM FORMAT

Detailed category breakdowns for the old and new exam formats are shown in Tables 2 and 3. Comparing the organization schemes at a glance is difficult. To aid the comparison, Table 1 shows divisions that roughly follow the old exam outline, with some topic areas consolidated to allow for ease of comparison.

By comparing changes in item counts between these five exam categories in Table 1 then comparing them with the detailed breakdowns in Tables 2 and 3, the following changes can be seen in what constitutes fire protection engineering basics for the "minimally competent engineer":

1. The Water Supplies category has disappeared as a dedicated topic, and has in fact been designated as two of eight optional subcategories under "Water-Based Fire Protection Systems." This change appears to represent a shift of focus away from areas of fire protection emphasized in traditional insurance and municipal grading practices, and towards more quantitative, theory-based categories.

2. The Building Systems category has increased in size by 60%. The increase becomes even more significant when one considers that "Smoke Management Systems" is no longer a part of this category. The category of the "Means of Egress" remains about the same (five items). While the "Building Construction" subcategory has doubled in size from five to ten items. The introduction of nationally recognized (vs. regionally recognized) model building codes appears partly responsible for this increase, as basic building code subcategories such as "height and area limits" are now listed. The increase in the building construction category is welcome. The topic was previously underrepresented relative to its practical and theoretical importance in fire protection engineering practice.

3. The category of **Fire Protection Systems** has experienced a significant decrease. The loss appears deceptively minor – less than 10% overall by item count-until one considers the individual subcategories. The old "Non-Water-Based Suppression Systems" (now "Special Hazard Systems") has decreased by 60% (ten items to four), while "Smoke Management Systems" is now a dedicated subcategory in this section equal in importance to "Special Hazard Systems." Fire alarm has been reduced by 30% (to seven items from ten), and even the "Water-Based Suppression Systems" category has taken a hit, since it now contains subcategories for water supplies and fire pumps that were previously separate. It also now contains foam and water mist systems, which used to be placed under "Non-Water-Based Suppression." "Explosion Protection" is now assigned a dedicated category of three items. This explicit recognition of explosion protection is very much in keeping with a larger trend toward emphasizing quantitatively well-modeled phenomena. Also in line with this trend, note that the three "Special Application" fire protection system categories (Special Hazard Systems, Smoke Control, and Explosion Protection and Prevention) have a disproportionately large number of topics compared to their point values. The fire protection engineers surveyed for the new format focused a great deal of attention on these topics relative to their overall category size. This level of detail will encourage a larger variety of questions in these areas.

Table 2
1992 Fire Protection Engineering Examination Specifications

Category (Knowledge Area) and Topics	Items
1. PLANNING AND DESIGN OF WATER SUPPLIES	10
Water supplies dedicated to fire protection; public water supplies	
2. PLANNING AND DESIGN OF BUILDING SYSTEMS	10
Structural fire resistance; fire barriers; opening protection; means of egress; construction materials; smoke management systems; building use and occupancy	
3. PLANNING AND DESIGN OF WATER-BASED SUPPRESSION SYSTEMS	10
Specifying, evaluating, testing, and maintaining sprinkler and water spray systems; fire and explosion suppression systems	
4. PLANNING AND DESIGN OF NON-WATER-BASED SUPPRESSION SYSTEMS	10
Specifying, evaluating, testing, and maintaining CO_2, dry chemical, foam, and alternate agent systems; fire and explosion suppression systems	
5. PLANNING AND DESIGN OF DETECTION AND ALARM SYSTEMS	10
Specifying, evaluating, testing, and maintaining heat, smoke, and flame detectors; alarm and supervisory systems	
6. PLANNING AND DESIGN OF FIRE PREVENTION	10
Control of combustible materials, ignition sources, and oxidizing sources	
7. IMPLEMENTATION AND MONITORING OF FIRE PREVENTION	10
Inspection, testing, and preventive maintenance; process safety; hazard abatement	
8. RESEARCH AND DEVELOPMENT OF HAZARD AND RISK ANALYSIS	10
Quantification of frequency and severity of fire events; estimation of time available for occupant egress from rooms; analysis of damage potential to exposed objects from fire or explosion	

4. Fire Prevention has taken the biggest hit of all. From having 25% of the exam items dedicated to this one topic in two categories, there are now only eight items (10% of exam items) dedicated specifically to the topic of "Fire Prevention," and they are in a section named "Fire Protection Management," that does not contain the phrase "fire prevention" at all. A further discussion of this area is reserved for the second half of this article.

5. In line with the increased emphasis on quantitative methods, the old category of **Hazard and Risk Analysis** has grown dramatically, with an increase of almost 200% (from 10 to 28 items). Apparently, a large number of practicing fire protection engineers see the rapidly maturing analytical methods as part of basic fire protection engineering knowledge. The recognition of these new categories is a primary factor responsible for the restructuring of the exam format and the complementary downsizing of the Water Supply and Fire Prevention categories. Of special note, there is an entirely new (to the exam) topic, "Human Response," which attempts to model human behavior during emergency notification scenarios.

FIRE PREVENTION IN THE FPE EXAM: STILL THERE BETWEEN THE LINES

The change in fire prevention treatment within the FPE exam is worth a detailed look, as it represents a significant emerging shift in emphasis for the field of fire protection engineering. As shown in Table 2, this topic was previously addressed in two categories – "Implementation and Monitoring of Fire Prevention" and "Planning and Design of Fire Prevention."

Although the phrase "fire prevention" no longer appears in the exam, the topics that make up the old category of "Implementation and Monitoring of Fire Prevention" have not simply vanished in a puff of smoke. As Table 2 shows, the three subcategories were "Inspection, Testing, and Preventative Maintenance," "Process Safety," and "Hazard Abatement." Each of the topics in these categories has been carried over in some form to the new format:

1. Inspection, Testing, and Maintenance – This topic has been preserved as an optional topic without even a name change under the new category "Fire Protection Management." It shares the category with two other fire prevention topics discussed in Item 3 below. This category alone carries eight items. Inspection, testing, and maintenance issues are critical to fire protection system reliability, and the topic lends itself well to the multiple-choice question format. These features may account for its relatively strong showing in the new format.

2. Process Safety – Process safety monitoring and implementation have typically appeared in the exam as questions concerning industrial flammable liquids operations. Such questions may still appear in "Information Sources for Analysis" under the optional subcategory "Functional Use and Operation of Facility." Given the fact that this is one of eight optional subcategories in this area, however, the number of Process Safety items will be diminished under the new format. Another area that may contain process-related topics is "Risk Analysis Techniques," since the available applications have been developed primarily for industrial situations, particularly those involving flammable and combustible liquids.

3. Hazard Abatement – The contents of this category have transferred over to the new category "Fire Protection Management" as two separate topics. The first is "Facility System Impairment Procedures," a self-explanatory title. The second is "Capabilities and Limitations of Design." The location of this subcategory under "Fire Protection Management" hints that it refers to management of environments to avoid invalidating fire protection system design limitations. Control of penetrations in fire barriers,

Table 3
2002 Fire Protection Engineering Examination Specifications
(Effective 2004)

Category	Items
KNOWLEDGE AREA I. FIRE PROTECTION ANALYSIS	(16)
A. TYPES OF ANALYSIS	10
1. Hazard analysis techniques (e.g., estimating fire scenario severity)	
2. Risk analysis techniques (e.g., likelihood, severity)	
3. Economic analysis techniques (e.g., cost benefit, life cycle)	
4. Limitations for analyses	
B. INFORMATION SOURCES FOR ANALYSIS	6
1. Functional use and operation of facility (e.g., industrial processes, occupancy, facility contents)	
2. Acceptable thresholds (e.g,. maximum temperature, heat flux, gas concentration)	
3. Codes and standards	
4. Occupancy, hazard, and commodity classifications	
5. Fire test methods (e.g., classification, product, or material characteristics)	
6. Fire test data interpretation techniques	
7. Exposures (e.g., proximal distance from hazards)	
8. Technical drawings, schematics, and plans (e.g., contract documents, shop drawings, riser diagrams)	
KNOWLEDGE AREA II. FIRE PROTECTION MANAGEMENT	(8)
A. FIRE PROTECTION MANAGEMENT	8
1. Capabilities and limitations of the design	
2. Facility system impairment procedures	
3. Inspection and maintenance frequencies	
KNOWLEDGE AREA III. FIRE SCIENCE AND HUMAN BEHAVIOR	(12)
A. FIRE DYNAMICS	8
1. Fire and smoke behavior	
2. Fire growth	
3. Combustion	
4. Plume entrainment and temperature	
5. Materials properties (e.g., heat of combustion; ignitability; thermal, mechanical, flammable, and explosive limits)	
6. Heat transfer from fire and smoke	
B. HUMAN RESPONSE	4
1. Evacuation movement	
2. Human performance capabilities	
3. Human response to fire cues (e.g., alarm, smoke, and heat)	
4. Timed egress analyses	
KNOWLEDGE AREA IV. FIRE PROTECTION SYSTEMS	(28)
A. WATER-BASED FIRE SUPPRESSION SYSTEMS	10
1. Design criteria (e.g., water flow densities, pressure requirements, design areas)	
2. Hydraulic calculation techniques	
3. Pipe sizing techniques	
4. System types (e.g., wet and dry pipe, preaction, foam, water mist)	
5. System components (e.g., sprinkler types, valves, flow detection, pipe material selection, cross connection control, bracing)	
6. Placement (e.g., obstructions, environmental considerations)	
7. Water supply and distribution (e.g., public, private, storage tanks)	
8. Fire pumps and controllers	
B. SPECIAL HAZARD SYSTEMS	4
1. Design criteria	
2. Design method (e.g., total flooding or local application)	
3. Pipe sizing	
4. System types (e.g., CO_2, clean agents, dry chemical)	

continuted

Category	Items
5. System components	
6. Agent storage	
7. Personnel safety	
8. Controls (e.g., actuation, prealarm, release, detection)	
9. Collateral damage (e.g., toxic or acid byproducts)	
10. System interlocks (e.g., damper, process shutdown)	
11. Test methods (e.g., enclosure integrity test, environmental concerns)	
C. FIRE DETECTION AND ALARM SYSTEMS	7
1. Design criteria (e.g., sequence of operation, initiating device selection, and spacing)	
2. System types (e.g., addressable, hardwired)	
3. System components	
4. Initiating devices (e.g., type, placement, performance)	
5. Environmental effects on initiating device placement (e.g., air velocity, temperature)	
6. Notification appliances (e.g., type, placement, performance, voice communication)	
7. Circuit classification and wiring methods	
8. Survivability	
9. Power supplies	
10. Building control functions and system interfaces (e.g., elevator recall, HVAC, smoke control, door releases)	
11. Monitoring (e.g., central station, proprietary)	
12. Test methods (e.g., verify sequence of operation)	
D. SMOKE MANAGEMENT SYSTEMS	4
1. Design criteria (e.g., objectives, equipment survivability, pressure limits)	
2. System types (e.g., pressurized stairwells, zone smoke control, venting)	
3. System components	
4. Fluid mechanics (e.g., vent flows, plug-holing)	
5. Environmental effects (e.g., stack effect, wind)	
6. Initiating mechanisms	
7. Power supplies	
8. System interfaces (e.g., fire alarm, HVAC)	
9. Test methods (e.g., model code requirements, verify sequence of operation, component performance, safety)	
E. EXPLOSION PROTECTION AND PREVENTION SYSTEMS	3
1. Design criteria (e.g., maximum pressure, ventilation rates, agent concentration)	
2. Design methods (e.g., suppression, inerting, isolation, venting)	
3. Agent types (e.g., gas, dry chemical)	
4. Venting (e.g., location, sizing)	
5. System components (e.g., enclosure construction, agent delivery, piping, ventilation configuration)	
6. Personnel safety	
7. Controls (e.g., actuation, detection, release)	
8. Collateral damage (e.g., adjacent structures or exposures)	
9. System interlocks (e.g., dampers, process shutdown)	
10. Test methods (e.g., other system survivability)	
KNOWLEDGE AREA V. PASSIVE BUILDING SYSTEMS	(16)
A. BUILDING CONSTRUCTION	10
1. Construction types (e.g., combustible, noncombustible, fire-resistive, frame)	
2. Construction materials (e.g., roofing, sheathing, insulation)	
3. Height and area limits	
4. Building separation distances	
5. Interior finish (e.g., flame spread rating, critical radiant flux)	
6. Structural fire resistance (e.g., calculation methods, substitution rules)	
7. Compartmentalization/separation (e.g., fire, smoke)	
8. Vertical openings	
9. Protection of openings (e.g., penetration seals, joint systems, dampers, doors)	
B. MEANS OF EGRESS	6
1. Design criteria	
2. Exits (e.g., types, remoteness, travel distances, number, capacity)	
3. Means of egress components (e.g., exit access, exit, exit discharge)	
4. Component details (e.g., stairwells, corridors, doors, hardware)	
5. Occupancy types (e.g., assembly, detention, business)	
6. Occupant load	
7. Emergency lighting	
8. Marking of means of egress	

control of combustible materials storage height and content in sprinklered warehouses, and control of flammable liquid storage conditions are all obvious examples of this topic. Taken together, these two topics capture a large portion of what would have been previously termed “Hazard Abatement.”

In contrast to the Implementation and Monitoring issues, the “Design and Implementation of Fire Prevention” topics appear to have gone underground. The increased emphasis on quantitative methods of risk and hazard analysis has resulted in a disappearance of this category as a dedicated topic for the exam. In practice, this may mean a lessened emphasis on certain traditional “fire prevention triangle” concepts in the exam, although other concepts such as probability-related topics may actually increase in importance.

The idea of the fire triangle is summarized precisely by the one topic of the old “Planning and Design of Fire Prevention” category – “Control of combustible materials, ignition sources, and oxidizing agents.” The loss of this category as a dedicated topic in the new exam will probably lead to a de-emphasis of ignition control. This topic crops up primarily in the context of flammable liquids. Such questions might still appear in the new topic area “Functional use and operation of facility,” but they will have a lot of competition from other orphaned process-related topics. Many of the individual topics regarding control of combustible materials and oxidizers will still be present, but scattered in various places between the two categories of “Fire Protection Analysis” and “Fire Dynamics.” The one exception to this lower profile for fire prevention design items will be probabilistic risk analysis questions, which will probably show up more consistently and explicitly than they have in the past.

Significant changes have occurred to the fire protection licensing exam that reflect the new analytical tools available to practicing fire protection engineers. Fire prevention remains an integral part of the knowledge base of the practicing engineer and will continue to be addressed in the exam in a variety of ways, even though the words “fire prevention” no longer appear in the exam specification. ▲

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Projected-Beam Smoke Detectors – More Than Just a Substitute for Spot Detectors

When smoke detection is the objective, projected beam smoke detectors can have a measurable performance advantage over spot-type smoke detectors. Projected-beam smoke detection can actually be more sensitive to real fires, yet less prone to nuisance alarms. Great taste and less filling. Is it possible to have both? For smoke detection, at least, the answer is a qualified yes.

This article gives some basic background on how projected-beam smoke detectors work and how they are modeled. Then, a temporal fire analysis is used to test the hypothesis of whether projected-beam detectors can actually respond before a grid of spot-type detectors. Basic engineering principles are used to show how projected-beam smoke detectors are less prone to most sources of nuisance alarms.

BASIC OPERATION

Projected-beam smoke detectors are light-obscuration detectors. They project a beam of light from a source, across a space, to a receiver. The unit is calibrated to respond when the amount of light reaching the receiver falls below some preset threshold. Projected-beam smoke detectors generally have adjustable response thresholds – typically between 20% and 70% total obscuration. Some may have several sensitivity settings, others only "low" and "high" sensitivity settings.

Projected-beam smoke detectors also analyze the rate of change of the received light. Very slow reductions in light received are interpreted as either component degradation or a buildup of dust and dirt on the unit's housing, and will result in a trouble signal rather than an alarm signal. Similarly, sudden changes that are caused by some type of obstruction, such as a solid object placed in the light path will result in the transmission of trouble rather than alarm signals. However, tests using large spills of aviation fuel showed that a rapid buildup of smoke could cause a projected-beam smoke detector to think that it was being blocked.[1] For this reason, some detectors may have a setting to allow total or rapid blockage to generate an alarm signal. This should only be used where very rapid smoke layer development is possible.

TRADITIONAL USE

Projected-beam smoke detectors are traditionally used as a substitute for a

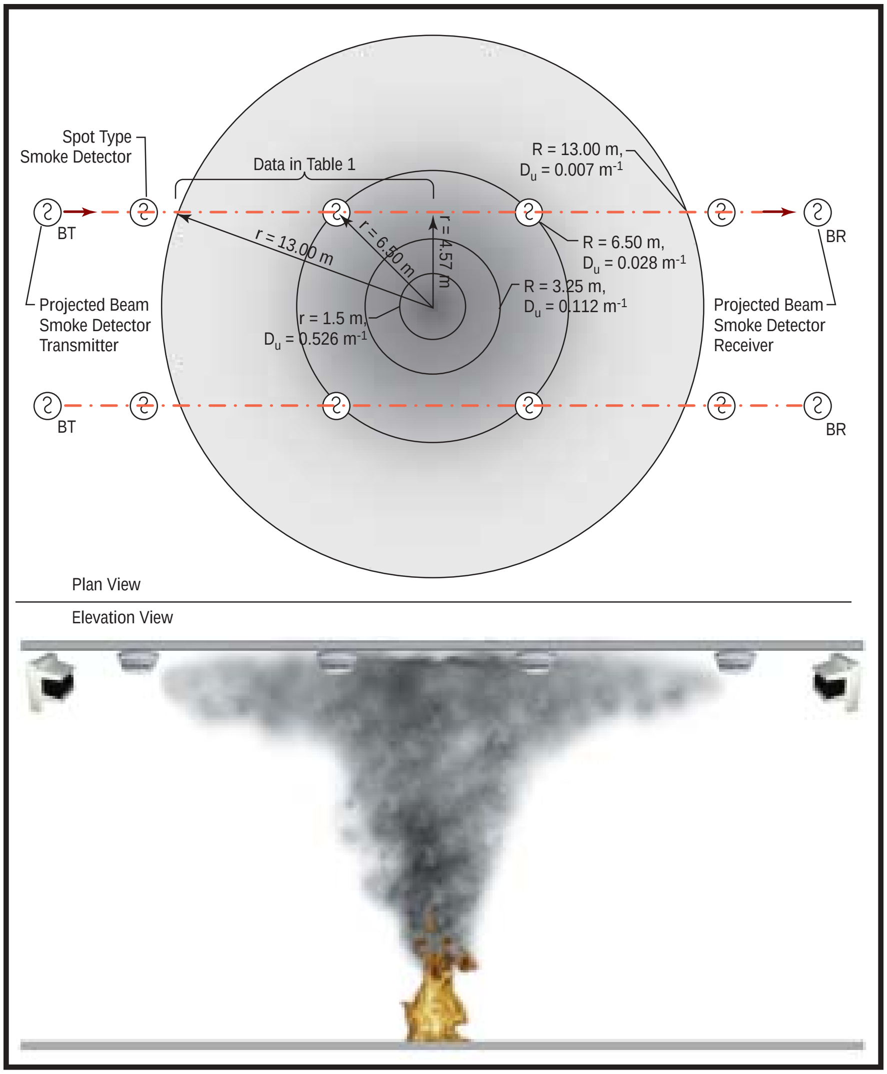

Figure 1 - Plume and Ceiling Jet

string of spot-type detectors in situations where the installation, testing, and maintenance of spot-type detectors are difficult. For example, in spaces with high ceilings, once construction has been completed and the space is occupied, it is often difficult to reach the ceiling without the use of heavy, cumbersome lifts.

On the other hand, projected-beam smoke detectors mounted at ceiling level on or near the side walls can more easily be reached with an extension ladder. Often, maintenance and testing can be done using a long pole to hold cleaning rags or optical filters. Because of this, use of projected-beam smoke detectors in large atria, places of worship, exhibit halls, and other high-ceiling spaces has probably eliminated many nuisance alarms that would have resulted if spot-type detectors had been installed but not properly tested and maintained.

MODELING SMOKE AND PROJECTED-BEAM SMOKE DETECTORS

For projected-beam-type detectors, fire or smoke models that calculate the optical density per unit length, D_u, in a space or the total optical density in the path of the detector, D, may be used to estimate when the detector would respond. Manufacturers' specifications will typically indicate at what levels of total obscuration or total optical density the detectors respond.

It is easier and more convenient to use optical density (D) or optical density per unit length (D_u) as opposed to the percent obscuration (*% Obs.*) or percent obscuration per unit length (*% Obs./m* or *% Obs./ft*) when talking about projected-beam smoke detectors. This is because light attenuation is logarithmic and *% Obs./ft* multiplied by the path length does not give the correct total *% Obs*. For example, 2.0%/ft of obscuration over a path of 20 ft is not 40% total obscuration – it is 33%. However, 2.0%/ft is equal to a unit optical density of 0.0088 ft^{-1} or 0.029 m^{-1}, and can be directly multiplied by the path length of 20 ft or 6.09 m to get a total optical density of D = 0.18. (Note that optical density is not expressed as a unit.) Converting between optical density and percent obscuration is possible by back-calculating the ratio of the initial light beam strength, I_0, to its attenuated strength, I. See page 4-22 of "Design of Detection Systems" in the *SFPE Handbook of Fire Protection Engineering* for the equations.[2] The other advantage to using optical density is that there are direct correlations between visibility in a smoky environment and the optical density.[3]

Many fire models estimate the unit optical density D_u in a uniform upper layer or volume. This is referred to as zone modeling. The optical density over the entire length of the beam is then determined by multiplying D_u by the path length, l. The path length is the distance between the source and receiver of the projected beam smoke detector or that portion of the beam length that has smoke in it. This method assumes homogenous distribution of smoke throughout the path, an assumption that may not be valid.

Another method to model the response of projected beam type detectors is to calculate the unit optical density, D_u, at several discrete points or in several discrete grid sections between the source and the receiver of the projected-beam smoke detector. This is a form of field modeling. The optical density per unit length is then multiplied by the length of that particular grid segment. The total optical density of the path is then the sum of all of the densities for the individual segments or grid volumes.

Table 1 – Optical Density Across a Path

r (m)	D_u (m^{-1})	Δx (m)	D_{ux} (m^{-1})	D_x	Location
4.57	0.057	-	-	-	Point on detection line closest to fire.
4.75	0.052	1.30	0.055	0.071	
5.00	0.047	0.73	0.050	0.037	
5.25	0.043	0.56	0.045	0.025	
5.50	0.039	0.48	0.041	0.020	
5.75	0.036	0.43	0.037	0.016	
6.00	0.033	0.40	0.034	0.014	
6.25	0.030	0.38	0.032	0.012	
6.50	0.028	0.36	0.029	0.010	Closest spot type detector.
6.75	0.026	0.35	0.027	0.009	
7.00	0.024	0.33	0.025	0.008	
7.25	0.022	0.33	0.023	0.008	
7.50	0.021	0.32	0.022	0.007	
7.75	0.020	0.31	0.020	0.006	
8.00	0.018	0.31	0.019	0.006	
8.25	0.017	0.30	0.018	0.005	
8.50	0.016	0.30	0.017	0.005	
8.75	0.015	0.29	0.016	0.005	
9.00	0.015	0.29	0.015	0.004	
9.25	0.014	0.29	0.014	0.004	
9.50	0.013	0.29	0.013	0.004	
9.75	0.012	0.28	0.013	0.004	
10.00	0.012	0.28	0.012	0.003	
10.25	0.011	0.28	0.012	0.003	
10.50	0.011	0.28	0.011	0.003	
10.75	0.010	0.28	0.010	0.003	
11.00	0.010	0.28	0.010	0.003	
11.25	0.009	0.27	0.010	0.003	
11.50	0.009	0.27	0.009	0.002	
11.75	0.009	0.27	0.009	0.002	
12.00	0.008	0.27	0.008	0.002	
12.25	0.008	0.27	0.008	0.002	
12.50	0.008	0.27	0.008	0.002	
12.75	0.007	0.27	0.007	0.002	
13.00	0.007	0.27	0.007	0.002	Leading edge of ceiling jet.
Total Optical Density Across the Path				0.313	

ENGINEERING ANALYSIS AND APPLICATION

To test the hypothesis of whether projected-beam smoke detection is more sensitive than spot-type smoke detection, it is easiest to analyze both in a simple fire scenario. While the model described above for projected-beam detectors is fairly simple, the modeling of spot-type detectors is much more complex. It may not be possible to model spot-type detectors with the degree of accuracy and resolution needed for many modeling objectives.[4, 5] No attempt will be made to determine when either type of detection would respond. However, making some simplifying assumptions permits an order-of-magnitude comparison of the two detection systems.

Assume a fire occurs under a high, flat ceiling and that a plume and ceiling jet develop as shown in Figure 1. The worst case occurs when the fire is located at a maximum distance from a spot-type detector or the beam of a projected-beam smoke detector. In this example, the spot-type detectors are arrayed approximately 9.1 m (30 ft) apart. If projected-beam smoke detectors are used, each row of spot-type detectors might be replaced by a beam detector as shown.

Ignoring externally driven airflows, at ceiling level the smoke is generally most dense near the plume where it impinges on the ceiling and turns to form a jet. As the jet moves away from the plume, the mass density of smoke decreases due to dilution and volumetric expansion.[6] It will be assumed that the optical density is proportional to the mass density of smoke. However, in a real fire, the change in optical density in the jet may not directly follow the mass density. This is because as the smoke particles move away from the fire, they cool and collide with other particles and may even continue to react. Agglomeration and coagulation, as well as chemical reactions, will result in changes in particle size, even with the same mass density. Light attenuation is actually composed of absorption, refraction, and reflection, which vary in a nonlinear relationship with particle size.[7] Again, this is a simplifying assumption for illustrative purposes.

For this example, a fire model might be used to generate data such as that in the first two columns of Table 1. In this case, the data are a "snapshot" at the time when the unit optical density at the nearest spot type detector is approximately $D = 0.028\ m^{-1}$ (2%/ft). Most spot-type detectors are calibrated to operate in a laboratory test when the level of a gray, cellulosic smoke outside of the detector chamber is between $0.014\ m^{-1}$ and $0.058\ m^{-1}$ (1%/ft and 4%/ft). So the data in Table 1 represent the condition at a time when the nearest spot-type detector might respond. The question is, what does the projected-beam smoke detector see at this point in the fire development?

In Table 1, r is the radial distance from the center of the fire plume to some point along the smoke detection line. D_u is the unit optical density at that point. The first data point is midway between the two center spot-type smoke detectors. The last data point in the table is on the detection line, at the leading edge of the ceiling jet. Assuming the ceiling jet to be symmetrical, the same data would exist traversing the detection line in the opposite direction. In the table, the distance between a data point and the previous data point is calculated and shown in the table as Δx. D_{ux} is the average of the unit optical density along that small segment Δx. D_x is the total optical density across that small segment Δx: $D_{ux} = \Delta x.\ (D_{ux})$. The total optical density for all of the segments in the table is 0.313 (51% Obs). The total optical density for the entire path of the beam detector through the ceiling jet is twice that, or 0.626 (76% Obs). Again, note that the conversion to % Obs. is not linear.

Since some projected-beam smoke detectors can be set to respond at levels as low as 0.097 optical density (20% Obs.), it is possible to have detection occurring before a spot-type detection system.

The hypothesis can be approached in another way by considering the conditions at the nearest spot-type detector at the "time" when a projected-beam detector alarms, if set to operate at some particular optical density.

The above analysis was done for one set of conditions, with one set of assumptions. Other scenarios can be tested, and many will show that the opposite is true; spot-type detectors may respond before a projected-beam detector. What are the dominant variables that affect which type is likely to respond first? The most obvious factor affecting response is the sensitivity of the detectors – beam or spot-type. But it is useful to look at those factors which are a part of the basic operating principle for the two types of smoke detection.

The variable designers do not control that greatly affects response is the ceiling height or, more accurately, the clearance between the fire and the ceiling. This affects the air entrainment into the plume. The greater the height of the plume, the more air that is entrained,[6] lowering the mass density of smoke and lowering the optical density. A greater height puts the advantage on projected-beam smoke detection since it integrates all smoke in its path. A higher ceiling clearance requires a larger fire to produce a higher localized concentration of smoke to alarm a spot-type detector. Advantage: projected-beam smoke detection.

When a fire is closer to the ceiling, it is more likely that a localized concentration of smoke will reach a spot type detector before a sufficient "cloud" develops to alarm the projected beam smoke detector. Advantage: spot-type smoke detectors.

Other sources of air dilution will generally result in a larger, less dense smoke layer. Thus, a fire may have to put a lot more particulate into that larger volume before a localized concentration of smoke reaches a spot-type detector's alarm threshold. Advantage: projected-beam smoke detectors, since they integrate the smoke in their path.

Another important variable is the color of the smoke, which affects both projected-beam smoke detectors and spot-type photoelectric smoke detectors, but not spot-type ionization smoke detectors. Spot-type photoelectric smoke detectors work by sensing scattered and refracted light. Projected-beam smoke detectors respond when light is scattered, refracted, or absorbed by the smoke. Advantage: projected-beam smoke detection.

OTHER ADVANTAGES AND DISADVANTAGES

A small insect that manages to get past the bug screen of a spot-type smoke detector can easily cause an unwanted alarm. It would take quite a large swarm of insects to set off a projected-beam smoke detector. Advantage: projected-beam smoke detection.

One potential source of nuisance alarms is tobacco smoke. A smoker can produce a localized cloud of smoke sufficient to alarm a spot-type smoke detector. However, even exhaling directly into the path of a projected-beam smoke detector will not produce sufficient total optical density to cause an alarm. On ceilings over about 3.0 m, even spot-type smoke detection systems can be made relatively immune to tobacco-caused nuisance alarms by setting their sensitivity at about 0.045 m^{-1} (3.1 %/ft) or less. (Note that less sensitive means a higher optical density alarm threshold.) However, as noted above, as ceiling height increases, the detection of real fires may be better achieved by using projected-beam smoke detection. Advantage: projected-beam smoke detection. One caution, however: on lower height ceilings, projected-beam smoke detectors are more likely to experience intermittent blocking of the beam by persons carrying tall objects or working on ladders.

An additional advantage for projected-beam smoke detectors is their operating temperature range. Some available units operate at temperatures as low as -30 °C (-22 °F) and as high as 54 °C (130 °F). Spot-type smoke detectors typically have an operating range of 0 °C - 38 °C (32 °F - 100 °F). This permits the use of projected-beam smoke detectors in a wider range of environmental conditions.

The analysis above has assumed smooth ceilings where both types of detectors can be mounted on or close to the ceiling. A problem arises with non-smooth ceilings – those with structural beams projected down below the ceiling level. Many jurisdictions, at least in the United States, require compliance with NFPA 72, the *National Fire Alarm Code.*[8] That code clearly requires spot-type smoke detectors to be placed on the ceiling, in the pockets formed by beams or other obstructions under certain height, beam depth, and beam spacing conditions. However, the code does not address the use of projected-beam smoke detectors under non-smooth ceilings. It refers only to compliance with manufacturers' installation instructions. A review of several manufacturers' installation guides showed no information for the use of projected-beam smoke detectors below the structural beams on non-smooth ceilings. Because there is a minimum spacing requirement between the transmitter and the receiver (on the order of 9 m - 15 m), they often cannot be installed in the structural beam pockets. To understand the problem and the possible solutions, it is necessary to understand the underlying performance issues.

The requirements in NFPA 72 for the spacing and location of spot-type smoke detectors on beamed ceilings are the result of computer field modeling for detector response when a growing fire reaches approximately 100 kW heat release rate.[9] In the annex of NFPA 72 (A.5.7.3.2.4(B)), it is noted that, under other performance scenarios, it is possible to place smoke detectors on the bottoms of structural beams. The example given is the detection of a 1,000 kW fire where the ceiling is 8.53 m or less. Thus, the code opens the possibility for the performance-based design of projected-beam smoke detection systems. ▲

REFERENCES

1 Gott, J.E., Lowe, D.L., Notarianni, K.A., and Davis, W.D., "Analysis of High Bay Hangar Facilities for Fire Detector Sensitivity and Placement." Naval Facilities Engineering Command, Alexandria, VA. National Institute of Standards and Technology, Gaithersburg, MD. NIST TN 1423; 325 p. February 1997.

2 Schifiliti, R.P., Meacham, B.E., and Custer, R.L., "Design of Detection Systems," *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, 2002.

3 Drysdale, D.D., *Introduction to Fire Dynamics*, 2nd Edition, John Wiley and sons, Chichester, England, 1999.

4 Schifiliti, R.P., and Pucci, W.E., *Fire Detection Modeling: State of the Art*, the Fire Detection Institute, 1996.

5 Schifiliti, R.P., "Fire Detection Modeling – The Research-Application Gap," *Proceedings of the AUBE '01, 12th International Conference on Automatic Fire Detection*, NIST, Gaithersburg, MD, March 2001.

6 Alpert, R., "Ceiling Jet Flows," *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, 2002.

7 Mulholland, G., "Smoke Properties and Production," *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, National Fire Protection Association, Quincy, MA, 2002.

8 NFPA 72, *National Fire Alarm Code*, National Fire Protection Association, Quincy, MA, 2002.

9 Forney, G., Bukowski R., and Davis, W., "Field Modeling: Effects of Flat Beamed Ceilings on Detector and Sprinkler Response," Technical Report, Year 1: International Fire Detection Research Project, National Fire Protection Research Foundation, Quincy, MA, October 1993.

Editor's Note – About This Article

This is a continuing series of articles that is supported by the National Electrical Manufacturer's Association (NEMA), Signaling Protection and Communications Section, and is intended to provide fire alarm industry-related information to members of the fire protection engineering profession.

Case Study Using SAFIR to Predict Fire Resistance of a Column in a Performance-Based Environment

By Flora F. Chen and Daniel F. Gemeny, P.E.

The application of engineering analysis to building structures is one aspect of fire protection engineering, and performance-based design in particular, that has been gaining momentum over the past decade. With the advent of faster, more accessible computing power, it has become feasible to undertake complicated analyses of how building elements, such as columns, beams, girders, and the like, respond to severe fire loads. In particular, the finite element model, SAFIR, is useful in this regard, enabling the fire protection engineer to not only predict the heat transfer to a structural element, but also how the element will react under its given lateral and gravity load conditions. SAFIR is a computer program developed by J. M. Franssen at the University of Liege in Belgium.

BACKGROUND

The new performing arts facility owned by The Orange County Performing Arts Center (OCPAC) consists of a 2,000-seat Concert Hall, as well as a 500-seat Music Hall. The main lobby at the front-of-house consists of interconnected volumes resulting in an atmospheric and visual interconnection of interior spaces with one another as well as with the exterior environment via a prominent glass curtain wall located on the north face of the facility.

A unique design consisting of steel-encased reinforced concrete columns was selected as the means to support the glass curtain wall and roof assembly above the main lobby. The California

Building Code requires that structural members in the applicable construction type provide minimally three hours of fire resistance. However, due to the presence of the exterior structural steel (used predominantly for lateral load resistance), it was not possible, from the standpoint of the prescriptive codes, to determine the degree of fire resistance offered by the columns.

The most common method of assessing fire resistance is to carry out a full-scale fire-resistance test. There are only a small number of column furnaces in the world, and as a result, it is extremely difficult to undertake such a full-scale test from a logistical standpoint. In addition to the obvious concerns associated with time and complexity, there is often a substantial cost associated with furnace testing. For example, a standard full-scale test of an unloaded three-meter (10-foot) column exposed to fire for three hours could easily cost US$35,000, not including incidentals. For a load-bearing test, this cost would be much higher. In the specific case of this project, where the length of the column is over 21 meters (70 feet), it was generally acknowledged that it would be impractical, if not impossible, to carry out a full-scale fire-resistance test.

Accordingly, the OCPAC design team realized an alternative approach to evaluate the performance of the custom column design would be appropriate. The fire-resistance rating of an element can also be estimated by approved calculation methods, which are explicitly permitted by most codes such as the *Uniform Building Code*, that is applicable to this project. Computer models, such as SAFIR, have been shown to be a powerful tool in conducting these kinds of calculations.

FIRE RESISTANCE AND FIRE SEVERITY[1]

The fundamental step in designing structures for fire safety is to verify that the fire resistance of the structure (or each part of the structure) is greater than the severity of the fire to which the structure is exposed.

Fire resistance is a measurement of the ability of the structure to resist collapse, fire spread, or other failure during exposure to a fire of specified severity. Fire severity is a measure of the destructive impact of a fire, or a measure of the forces or temperature that could cause collapse or otherwise lead to failure as a result of the fire. There are several different definitions of fire severity and fire resistance, leading to different methods of comparison. The verification may be in the *time* domain, the *temperature* domain, or the *strength* domain. These comparisons can be confusing if not made correctly, so it is important that the designer understand the differences clearly.

The fire severity used for design purposes depends on the regulatory environment and on the design philosophy. In a prescriptive code environment, the design fire severity is usually specifically prescribed. In a performance-based code environment, the design fire severity is usually a complete burnout fire or the equivalent time of a complete burnout fire. In some cases, the design fire may be a shorter time, allowing only enough time for occupants to escape, or for the fire department to affect rescue or fire-fighting operations.

Fire resistance of any building element depends on many factors, including the severity of the fire, the material, the geometry and support conditions of the element, restraint from the surrounding structure, and applied load at the time of the fire. The fire resistance of a column in a storage warehouse characterized by a significant fuel load, for example, would be less than that of an identical column in an atrium, where the fuel load would be expected to be very limited.

THE CASE STUDY

Columns in Question

The SAFIR computer program was used to analyze a novel structural, and aesthetically sensitive, architectural design. The focus of the analysis was on determining the degree of fire resistance afforded by the steel-encased reinforced concrete column. The column is subject to various lateral and gravity loads applied over a span exceeding 21 meters (70 feet) in height. Figure 1 depicts the cross-section of the column. The cross-section is representative of other columns within the Main Lobby.

Undertaking the Analysis

The failure criterion for fire-resistance testing of a column is stability. To meet

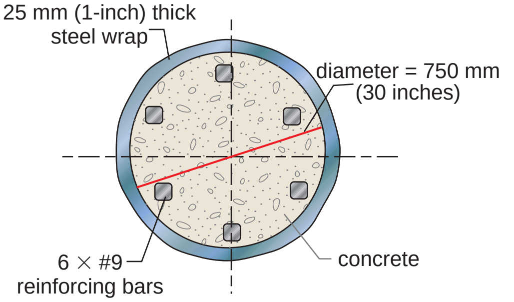

Figure 1. Section of the Column

the stability criterion, the column must perform its load-bearing function and carry the applied loads for the duration of the test, without structural collapse.[1] Therefore, the verification of column fire resistance in the strength domain is appropriate for this analysis. This means comparing the applied load at the time of the fire with the load capacity of the structural members during the course of the fire.

The process of calculating structural fire behavior consists of three essential steps. SAFIR, as well as most other finite element models, works on the basis of temperature boundary conditions. The first step is to determine a time-temperature curve. Options include applying a measured real fire temperature curve, or a standard fire curve (e.g., ISO 834[2] or ASTM E 119[3]), or a parametric curve to model the fire severity.

The second step is to predict the temperature distribution inside the structural members, referred to as *thermal analysis*.

The third step is to determine the response of the structure due to static and thermal loading, referred to as *mechanical* or *structural analysis*. Figure 2 depicts the process of calculating the strength of a structural assembly exposed to a complete burnout of a fire compartment, including key considerations made by the fire engineer at each step of that process.

Determination of the Time-Temperature Curve. Depending on the nature of a space, including its use and the anticipated combustible fuel loading, as well as the risk tolerance of the jurisdiction, a number of approaches should be considered with respect to the selection of the fire load that will be applied to the structural element. One option is to utilize a standard time-temperature curve, as shown in Figure 3. Yet another option would be to use published

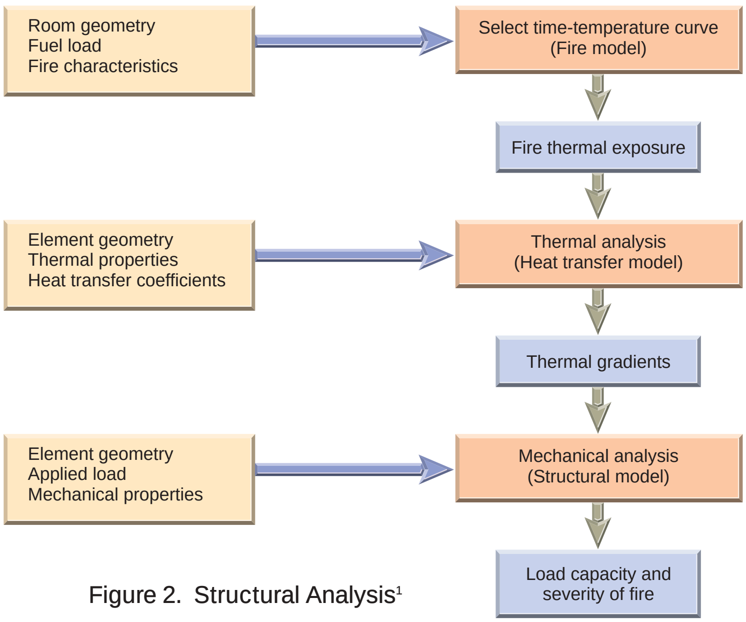

Figure 2. Structural Analysis[1]

curves, which have been derived from computer calculations based on anticipated fuel loading, such as the Swedish fire curves developed by Magnusson and Thelandersson[4] depicted in Figure 4.

Many countries use the International Standard ISO 834 or have national standards based on ISO 834. The ASTM E 119 standard fire is used widely in the United States. The ISO 834 standard fire is generally comparable but more severe than the ASTM E 119 standard fire (Figure 3). Therefore, the ISO 834 standard time-temperature curve was considered in this analysis.

Swedish fire curves[1] are widely referenced time-temperature curves for real fire exposure. They are derived from heat balance calculations, using Kawagoe's equation for the burning rate of ventilation-controlled fires. As is evident from the declining temperature over time, these curves reflect the effects of changing fuel load and ventilation during the course of a real fire.

Experiments show that maximum temperature occurs in the space with a ventilation factor of 0.08 $m^{1/2}$ to 0.15 $m^{1/2}$.[1] These experiments considered post-flashover fires, where all combustibles are involved in fire. Therefore, the Swedish fire curve with a ventilation factor of 0.12 $m^{1/2}$ was analyzed, as shown in Figure 4. As the rising branch of the curve for a ventilation factor of 0.04 $m^{1/2}$ is very similar to the Standard Fire curve,[1] the Swedish fire exposure with a ventilation factor of 0.04 $m^{1/2}$ was also analyzed to consider a slower fire with a longer duration. The temperature conditions are believed to be conservative for several reasons. The main lobby is such a large space that it is unlikely that a flashover would occur, so the temperature would be lower than the Swedish fires. The temperature would be lower further due to the heat loss to the atmosphere and surrounding walls within the tremendous volume of the lobby, even without considering the impact of the smoke-removal system that was designed for the main lobby.

The Swedish fire curves with a fuel load of 300 MJ/m^2 of total surface area was applied in the analysis. Note that the units of fuel load are MJ per m^2 of total surface area (not MJ per m^2 of floor area, which is more often used in the design calculations). The 2001 California Fire Code indicates that potential heat of combustible furnishing and decorative materials within atria should not exceed 21,000 J/g (9,000 Btu/lb). Therefore, the assumed fuel load is equivalent to 86 kg/m^2 (17.5 lb/ft^2) of floor area. In concert with the nature and daily usage of the Main Lobby at OCPAC, the fuel in the space was limited (confirmed through discussions with the facility ownership). Therefore, the fuel load of 300 MJ/m^2 of total surface area is a very conservative assumption for the subject space.

The Swedish fire curve is a more realistic fire exposure in regard to the ISO 834 Standard Fire curve, which is a test fire created in a furnace. Therefore, in consideration of the performance objectives of the project, the Swedish fire was applied to assess the fire resistance of the column in this project. Complementing this analysis, scenarios using the ISO

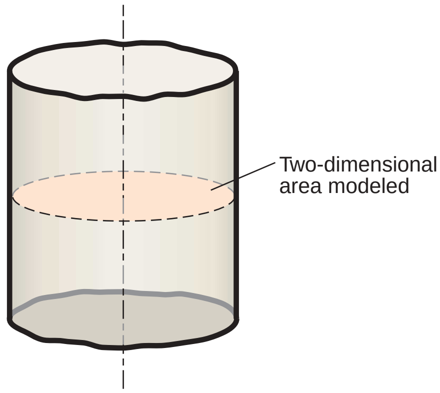

Figure 5. Cross-Section of Column

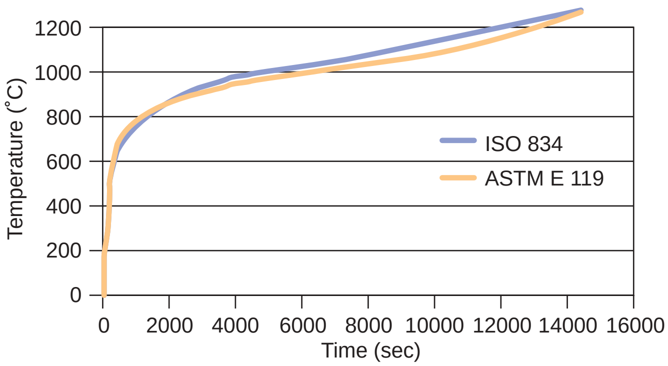

Figure 3. SO 834 Standard Fire and ASTM E 119 Standard Fire

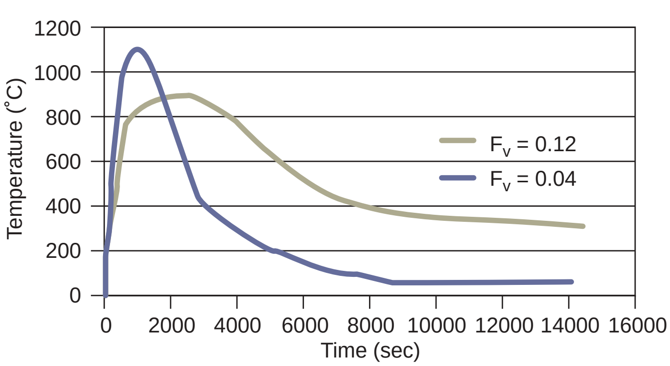

Figure 4. Swedish Fire Curves[1] (300 MJ/m^2 Total Surface Area, Ventilation Factor=0.12, and 0.04 $m^{1/2}$)

834 Standard Fire were also analyzed to get a better feel of the safety margin afforded by the column design.

Thermal Analysis. Thermal analysis is an essential component for calculating fire resistance because the load capacity of a structural member/assembly depends on its internal temperature. When a column is exposed to a fire, a temperature gradient occurs within the column. For the OCPAC column, the heat transfer was assumed to be dominated by two-dimensional heat transfer, meaning that the majority of heat transfer would not be in the direction parallel to the column, but in the direction perpendicular to the column from the surface of the column to the inside. This assumption is conservative, since it ignores the heat capacity of the entire column.

The temperature was assumed to be nonuniform, resulting in a horizontal temperature gradient within the column (Figure 5) as a function of time. As a further simplification, the round column was approximated as an octagon with an equal area of cross-section. Figure 6 illustrates the modeling approximation.

The SAFIR algorithm performs a temperature calculation successively by either uniform or nonuniform time steps for each of the elements. SAFIR is able to provide the temperature distribution at any time step and temperature development at any nodes of interest. Figure 7 shows an example of a visual result of the thermal analysis with temperature distribution across the column section at 3,600 seconds. It can been seen that the temperature distribution near the steel tends toward uniformity. This result is expected due to high specific heat of steel. The temperature distribution in concrete is characterized by gradients because the specific heat of the concrete is relatively low and it takes time for the heat to transfer from the outside to the core of the column.

Figure 8 and Figure 9 reveal the nature of the temperature development at some nodes of interest under the exposure of the ISO 834 standard fire and the Swedish fire, respectively. For the Swedish fire exposure, it can be seen that the temperature of the steel skin decreased with the decay of the fire (Node 24), while the temperature of the column concrete core (Node 1 and Node 10) kept increasing (refer to Figure 6 for the location of the nodes). This finding reveals the principle that fires with a lower temperature but a longer duration sometimes can be more destructive to structural assemblies than those with a higher temperature but a shorter duration.

The Mechanical Analysis. The final step in analyzing the fire resistance of the subject column is to verify that the fire resistance of the element is greater than the severity of the fire to which the structure is exposed in the strength domain.

Mechanical/structural analysis was used to calculate the deformation of the structure under the applied loads, as well as the corresponding structural reactions of the member. At an elevated temperature, both the yield strength of the reinforcing steel and compression strength of the concrete is reduced. The material properties are nonlinearly temperature-dependent, and the effect of thermal strain is present. To take into account all these factors, the results from the thermal analysis and material properties were imported into the model to perform the mechanical analysis.

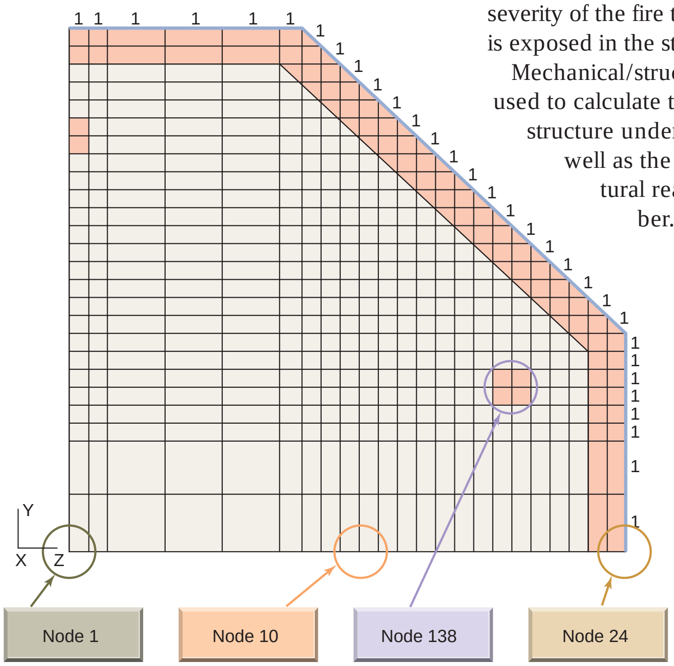

Figure 6. One-Fourth of Column Section

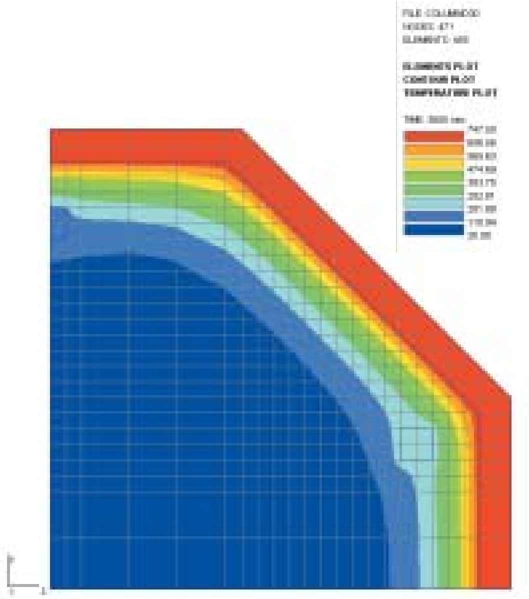

Figure 7. Temperature Distribution at 3600 Seconds

As shown in Figure 10, the column was divided into 27 elements in the mechanical/structural calculation. The applied loads were divided into three generalized structural categories, inclusive of point loads, distributed loads, and moments. The structural loads were applied on the column as point loads. The wind load was simplified to be a distributed load. The column had a fixed connection with the foundation. At the top end of the column, vertical movement was allowed, but horizontal movement was limited. SAFIR performed a mechanical calculation for each column element at each time step. The model calculated the displacement at each node as well as the internal force distribution, such as the bending moment and axis force for each element. As a result of this piecewise calculation, it became possible to predict the occurance of localized failures in the column without having to assume that the column as a whole has failed, as is the case in many simplified hand calculations. Ultimately, the analysis is discontinued when the specified time has passed or when the column as a whole fails.

CASE STUDY RESULTS

The total height of the column studied for the Orange County Fire Authority (OCFA) was 21.3 meters (70 feet), spanning two levels from the ground floor.

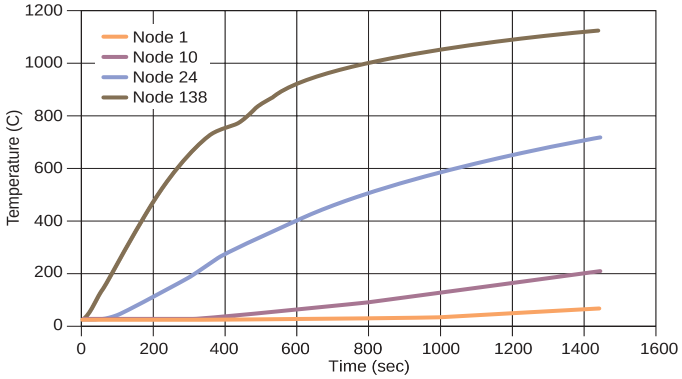

Figure 8. Time-Temperature Plot – Standard Fire Exposure

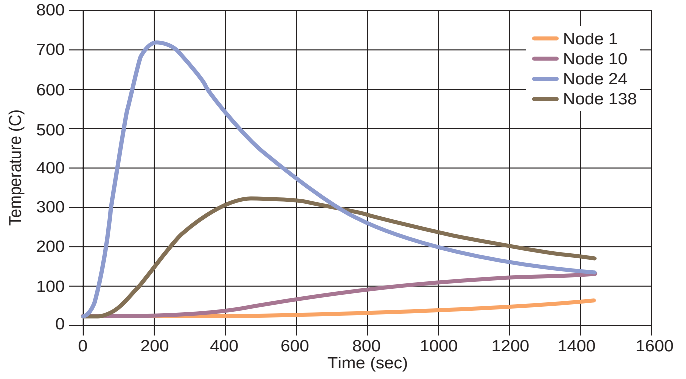

Figure 9. Time-Temperature Plot – Swedish Fire Exposure (F_v=0.12)

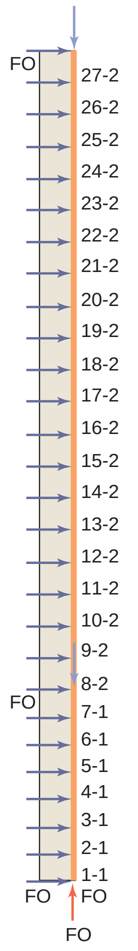

Figure 10. Application Loads on the Column

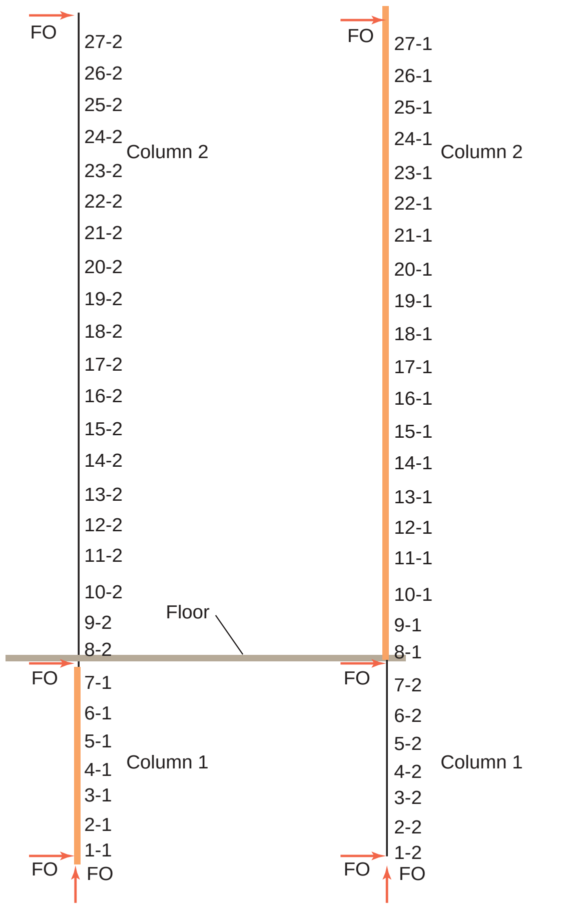

Figure 11. Load Application and Fire Exposure
Column Elements with a Suffix of "1" Are Exposed to Fire

The floor elevation was 5.6 meters (18.5 feet). The column was divided into two portions, including a column element on Level 1 (between elevation of 0.0 and 5.6 meters, hereafter called "Column 1") and column element on Level 2 (between elevation of 5.6 to 21.3 meters, hereafter called "Column 2"). A two-hour floor assembly separated Column 1 from Column 2.

Since the two-hour floor assembly would substantially reduce the fire exposure from one floor to the other, the analysis assumed that only one portion of the column would be exposed to the fire at any given time. For example, as depicted in Figure 11, when a fire occurred on the lower floor, only Column 1 was exposed to the fire. Column 2 would not be exposed to the fire and was assumed to be at ambient temperature.

One concern might be that the floor is rated two hours and that the fire would expose both of the columns simutaneously after two hours. The failure criteria for a floor are stability, integrity, and insulation. Any failure of these criteria will result in the failure of the floor assembly, although the floor failure in its integrity and insulation would not significantly impact the fire exposure of the column. At the time of the failure of the stability criterion, the fire might expose both of the columns simultaneously. This worst scenario was taken into account. It is unlikely that fire would expose the column along all its length, which is over 21 meters (70 feet). The only possible premise for these scenarios would result from flashover in the atrium. This event is unlikely, however, as demonstrated in the previous discussion. Actually, full exposure of each column has been a conservative assumption in the subject space, where fuels are very limited.

Scenarios considered in this design and the predicted performance of the column by the SAFIR model for a duration of four hours are summarized in Table 1.

In the scenarios using Swedish fires, failure was not predicted within a four-hour time frame, and it was determined that the only result would be deflections so minor as to go undetected by the human eye throughout the duration of the fire.

In the redundancy analyses using the

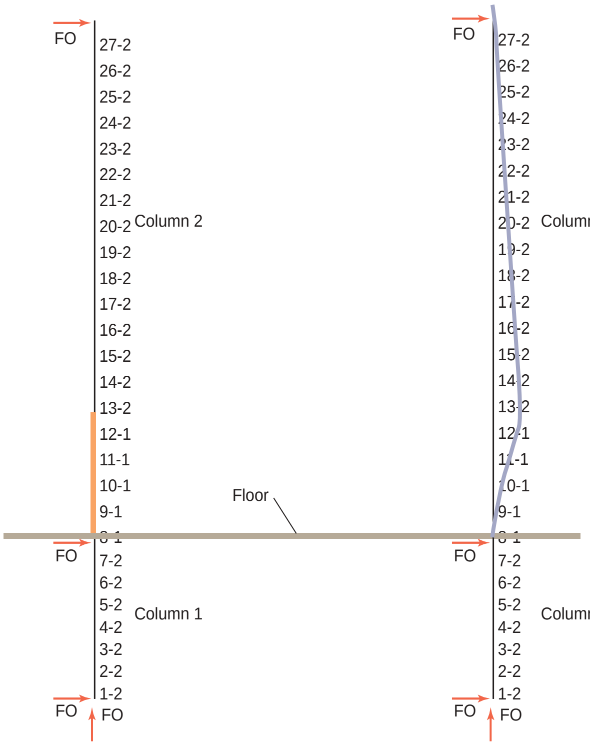

Figure 12. Column Performance in Scenario 10

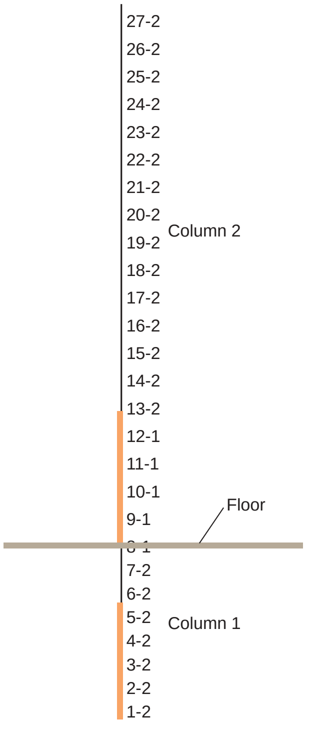

Figure 13. Column Fire Exposures in Scenario 12

Standard Fire Curve, the model predicted that failure would not occur within the given time frame, except in Scenario 9 and Scenario 11, due to excessive displacement after 6,300 seconds of standard fire exposure to Column 2, and 5,730 seconds of standard fire exposure to Column 1 and Column 2 simultaneously. Taking a closer look at the fire exposure of Scenario 9, it is evident that the modeled fire severity was far greater than would be expected in the actual building. This discrepancy occurs because the model assumed the temperature outside the column would be akin to the standard fire curve for the entire 15.7-meter length of the column. Neglecting the fact that the building itself was of noncombustible construction, one would not expect to see temperatures anywhere near those prescribed in the Standard Fire Curve over such a length of column in a large volume characterized by the heat loss behavior typical of most atria. Therefore, the significance of this failure was not deemed to be critical in the process of ascertaining the acceptable level of risk. For the same reason, the failure of Scenario 11 was not critical either. ▲

Flora F. Chen is formerly with Rolf Jensen & Associates, Inc., and Daniel F. Gemeny is with The RJA Group, Inc.

REFERENCES

1 Buchanan, A.H., *Structural Design for Fire Safety*, John Wiley & Sons, LTD, 2001.

2 ISO 834, “Fire-resistance Tests – Elements of Building Construction,” International Organization for Standardization, Geneva, 1999.

3 ASTM E 119-95a, “Standard Test Methods for Fire Tests of Building Construction and Materials,” American Society for Testing and Materials, West Conshohocken, PA, 1995.

4 Magnusson, S.E., and Thelandersson, S., “Temperature-time curves of complete process of fire development,” ACTA Polytechnica Scandinavica, Civil Engineering and Building Construction Series No.65, Stockholm, 1970.

Table 1. Summary of scenarios considered and expected performance

Scenario	Fire	Location of the Fire	Fire Exposure	Reference Figures	Performance of the Column
1	Swedish Fire Curve (F_v=0.12$m^{1/2}$)	Lower floor Column 1	Full exposure *5.6 m (18.5 ft)*	Figure 11	No failure
2		Upper floor Column 2	Full exposure *15.7 m (51.5 ft)*	Figure 11	No failure
3		Both floors Column 1 and Column 2	Full exposure *21.3 m (70 ft)*		No failure
4	Swedish Fire Curve (F_v=0.04$m^{1/2}$)	Lower floor Column 1	Full exposure *5.6 m (18.5 ft)*	Figure 11	No failure
5		Upper floor Column 2	Full exposure *15.7 m (51.5 ft)*	Figure 11	No failure
6	ISO 834 Standard Fire Curve	Both floors Column 1 and Column 2	Full exposure *21.3 m (70 ft)*		No failure
7		Lower floor Column 1	Full exposure *5.6 m (18.5 ft)*	Figure 11	No failure
8			Partial exposure *4.6 m (15 ft)*		No failure
9		Upper floor Column 2	Full exposure *15.7 m (51.5 ft)*	Figure 11	Failure at 6300 s
10			Partial exposure *4.6 m (15 ft)*	Figure 12	No failure
11		Both floors Column 1 and Column 2	Full exposure *21.3 m (70 ft)*		Failure at 5730 s
12			Partial exposure *4.6 m (15 ft) in Column 1 and 4.6 m (15 ft) in Column 2*	Figure 13	No failure

Resources

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3rd International Symposium
Belfast, United Kingdom
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October 6-8, 2004
5th International Conference on Performance-Based Codes and Fire Safety Design Methods
Info: www.sfpe.org

October 20, 2004
Computational Simulation Models in Fire Engineering and Research
Santander, Spain
Info: grupos.unican.es/gidai

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International Symposium on Tunnel Safety and Security
Greenbelt, MD
Info: www.ni2cie.org

November 29-30, 2004
Fire Risk Evaluation to European Cultural Heritage
Ghent, Belgium
Info: www.firetech.be

December 6, 2004
Symposium on Firestopping
Washington, DC
Info: www.astm.org

Products/Literature

Fire Code Inspection Software

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www.tiscor.com
—TISCOR

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www.kidsmartcorp.com
—KidSmart Corp.

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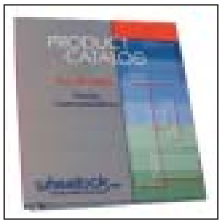
www.vikingcorp.com
—Viking Corp.

Security Products Catalog



Wheelock, a manufacturer of security products for the commercial marketplace, has introduced a binder catalog that includes the company's complete product line of life safety and communications equipment. New products include high-intensity multicandela strobes, Series S UL®-listed 8-in. Speaker and Speaker Strobe, and Powerpath MP. All pages are available under the 2004 Catalog section at the company's Web site.

www.wheelockinc.com
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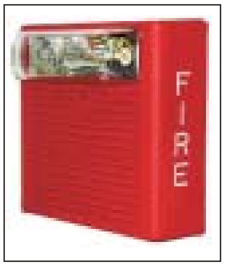

Wheelock introduces a line of high-intensity, multicandela strobe appliances for large applications, available in two versions: the field-selectable 115/177 ceiling-mount or the 135/185 wall-mount. They are available on Wheelock's Series AS Audible Strobes, Series RSS Strobes, Series E and ET Speaker Strobes, and Series CH Chime Strobes.

www.wheelockinc.com
—Wheelock, Inc.

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www.systemsensor.com
—System Sensor

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—FM Global

BRAINTEASER

Substitute a unique integer from 1 to 9 for each different letter in the subtraction problem below.

$$\begin{array}{r} \text{F I R E} \\ -\ \text{H E A T} \\ \hline \text{O U T} \end{array}$$

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

Solution to last issue's brainteaser

An examination is being taken by a student who has not prepared for the exam. The exam consists of 80 multiple choice problems, each problem having four possible choices. Assuming that each problem has only one correct answer and the student needs 20 correct answers to obtain a passing score, what is the probability that if the student guesses at each problem, the student would receive a passing score?

Since there are four choices for each problem, the probability of getting any problem correct by chance is 1/4, or 0.25, and the probability of getting any problem incorrect by chance is 3/4, or 0.75. For an exam with 80 questions, the probability, p, of getting a given number, n, correct is $p = 0.25^n \times 0.75^{(80-n)}$. Additionally, there are $\frac{80!}{(80-n)!n!}$ possible combinations of getting n problems correct. Therefore, the probability of getting any 20 problems correct is equal to $0.25^{20} \times 0.75^{(80-20)} \frac{80!}{(80-20)!20!} = 0.10$, or approximately 10%. However, any number of correct answers greater than or equal to 20 would also yield a passing score. Therefore, the probability of getting a passing score would be

$$\sum_{n=20}^{80} 0.25^n \times 0.75^{(80-n)} \frac{80!}{(80-n)!n!} = 0.54 = 54\%.$$

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Establishing Safety Factors

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

Safety factors are frequently used in performance-based designs to deal with uncertainty or provide a margin of safety between what would be considered acceptable and unacceptable outcomes. Safety factors can compensate for uncertainty in engineering methods, data, and public risk tolerance. In most cases, these safety factors are developed on an ad-hoc basis, since generally few fire protection engineering methodologies provide specific safety factors. For example, a safety factor of two seems to be frequently used.[1] However, since safety factors are critically important for the protection of public health, safety, and welfare, they deserve careful consideration.

In structural design, safety factors are applied to both increase the expected loads and to decrease the resistance to the loads that a structure provides.[2] For example, in bridge building, safety factors are used to ensure that a bridge built of the weakest conceivable batch of steel would support the load associated with the heaviest possible truck rumbling across the bridge under the worst possible weather and traffic conditions.[3]

In fire protection engineering analyses, uncertainty may come from several sources, such as:[4]

- Theory and model uncertainties;
- Uncertainty regarding input data;
- Limitations in the applicability of calculation methods;
- Selection of design fire scenarios;
- Uncertainty in human behavior; and
- Uncertainty in risk perceptions, attitudes, and values.

Safety factors to compensate for these uncertainties can be developed in several ways. These include:[1]

- Reducing the predicted time available before hazardous conditions develop or increasing the time estimated to be required prior to the onset of hazardous conditions;
- Reducing the criteria representative of the onset of hazardous conditions or increasing the estimation of a hazard, such as the size of a fire; and
- Adjusting values used as input to calculations or models.

Ideally, if sufficient data are available, safety factors can be developed by comparing calculations to available data and determining how much the data vary from calculated values. Three of SFPE's engineering guides[5, 6, 7] have developed safety factors in this manner. Based on comparisons of predictions with available data, safety factors recommended when using the methods identified in the guides range from 1.5 to 3.7.

Safety factors are generally increased when public safety or welfare is at stake. For example, design structural loads are increased by importance factors, which are larger for buildings in which large numbers of people might congregate, or buildings which perform vital public safety roles.[2] Similarly, the safety factor that is used for a cable that drives a dumbwaiter is smaller than that used for a freight elevator, which is in turn smaller than that used for a passenger elevator.[1] However, while engineers can develop safety factors associated with uncertainty or limitations of methods in isolation, developing safety factors representative of public risk tolerance requires broader input from those potentially affected.

Since there is generally more uncertainty in fire protection designs than in structural designs, safety factors are a critical component of performance-based fire protection design. However, safety factors should be established with care, since selecting too low a safety factor could result in a design that would not be safe under some conditions, while too large a safety factor would lead to a design which is overly expensive to build.

REFERENCES

1 Fleming, J., "Safety Factor(s) and Deterministic Analysis," Final Proceedings – SFPE Symposium on Risk, Uncertainty, and Reliability in Fire Protection Engineering, Society of Fire Protection Engineers, Bethesda, MD, 1999.

2 Lucht, D., "Public Policy and Performance-Based Engineering," Proceedings – 1996 International Conference on Performance-Based Codes and Fire Safety Design Methods, Society of Fire Protection Engineers, Bethesda, MD, 1996.

3 Petroski, H., *To Engineer Is Human –The Role of Failure in Successful Design*, Barnes and Noble Books, New York: 1994, referenced in Fleming, J., "Safety Factor(s) and Deterministic Analysis," Final Proceedings – SFPE Symposium on Risk, Uncertainty, and Reliability in Fire Protection Engineering, Society of Fire Protection Engineers, Bethesda, MD, 1999.

4 *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, Society of Fire Protection Engineers, Bethesda, MD: 2000.

5 *Engineering Guide: Assessing Flame Radiation to External Targets from Pool Fires*, Society of Fire Protection Engineers, Bethesda, MD, 1999.

6 *Engineering Guide: Predicting 1st- and 2nd-Degree Skin Burns from Thermal Radiation*, Society of Fire Protection Engineers, Bethesda, MD, 2000.

7 *Engineering Guide: Evaluation of the Computer Fire Model DETACT-QS*, Society of Fire Protection Engineers, Bethesda, MD, 2002.