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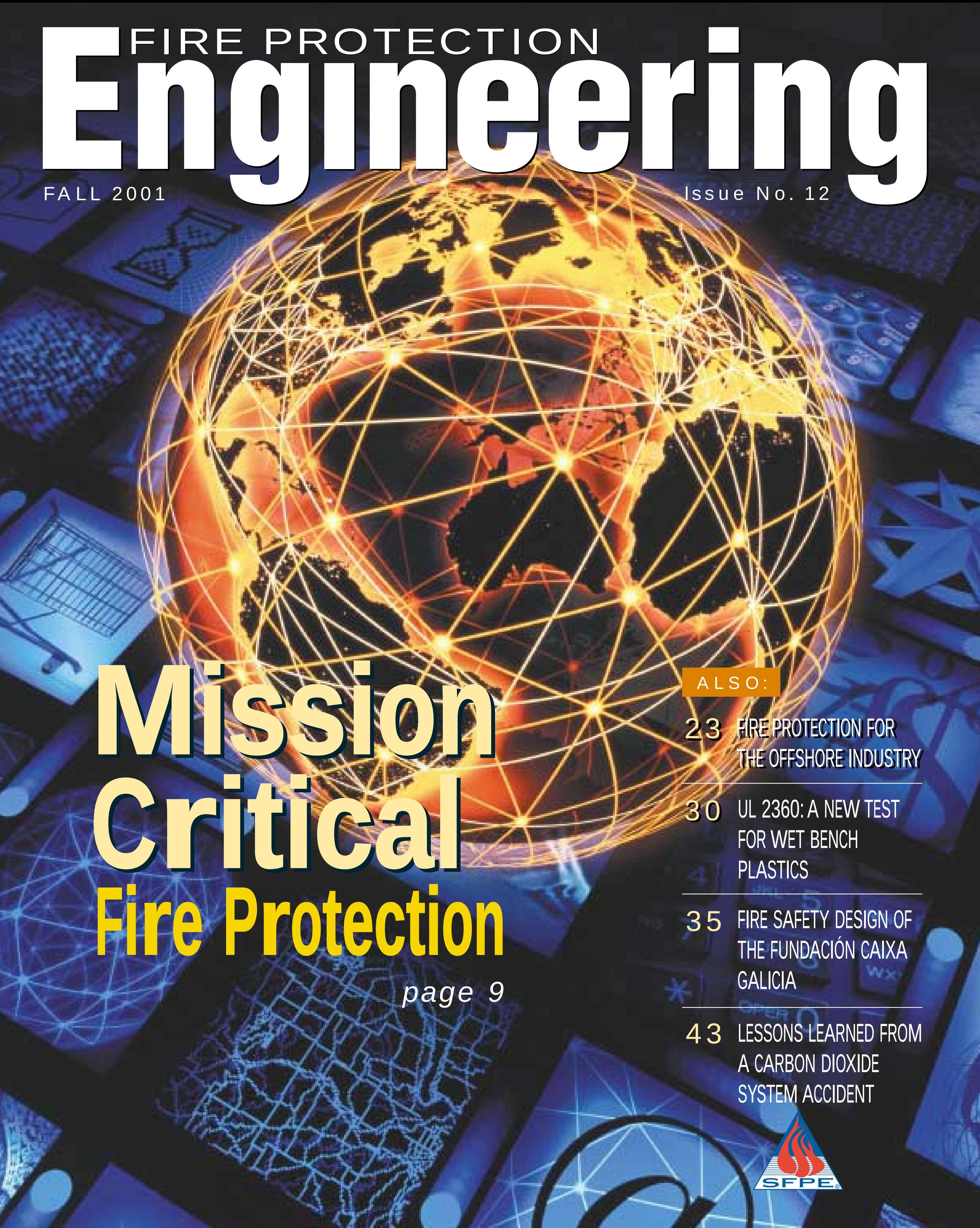
FIRE PROTECTION Engineering

FALL 2001

Issue No. 12



Mission Critical Fire Protection

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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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Cover illustration by Bill Frymire/Masterfile

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Loss Prevention Challenges in the Pharmaceutical Industry

By Greg Jakubowski, P.E., CSP

The pharmaceutical industry discovers, develops, manufactures, and markets a broad range of innovative products to improve human and animal health. Think of where the world would be today without penicillin, without vaccines that prevent a myriad of infectious diseases, and without modern products that control cholesterol, prevent heart attacks, ease pain, and reverse the anaphylactic effects of something as potentially life-threatening as a bee sting. Pharmaceuticals not only save lives but add significantly to quality of life, and do so while controlling overall health-care costs.

The pharmaceutical business is complex, with years, and sometimes decades, of research required to discover a beneficial molecule, test it for efficacy and safety, determine its value in the human body, and produce and distribute it. This complexity, and the length of time required to bring a product to market, engenders not only a highly competitive business environment, but also one that creates unusual loss prevention challenges. Even a small incident can prevent a product from coming to market for months, or perhaps years. This delay can have a devastating effect for patients that may have been awaiting a breakthrough treatment. Because of the complexity of this business, pharmaceutical facilities encompass a wide range of hazards, from bulk chemical facilities, clean production facilities, and laboratories, to warehouses and site utilities.

A primary goal of any loss prevention program in the pharmaceutical industry is to prevent an incident from occurring. If prevention is effective, extensive suppression efforts will not be needed, which is a philosophy not unlike that of many pharmaceutical products. Extensive process safety programs, chemical handling training, and site master planning assist in preventing incidents. However, there are numerous fire protection challenges facing the pharmaceutical industry today, including:

1. The ability to understand and apply the codes and standards of each country in which facilities are located. The business is growing significantly in South America, Asia-Pacific, and Africa.
2. Applying sprinklers that must meet extra hazard, quick response, and insurance company requirements while presenting clean surfaces in compliance with good manufacturing practices.
3. Effective control of static ignition sources in flammable liquid and dust operations.
4. Evaluating alternatives to sprinklers that not only minimize collateral damage, but also reduce the need for control of fire water runoff.
5. Minimizing loss potential in high-value research, manufacturing, and storage areas. This includes protection of susceptible areas from external hazards that may expose and impact our business.
6. Safe handling of flammable liquids in research laboratories.
7. Notwithstanding the pharmacological benefits of products to patients, avoiding exposure to employees or the environment of small amounts of active pharmaceutical or biological ingredients during an incident which can be a concern, especially in large-scale manufacturing operations.
8. Conducting safe construction and facility rehabilitation operations in and around operating plants.

Scientists and manufacturing employees who are used to demanding the application of excellent science in their daily operations demand the same standard of performance from fire and loss prevention experts when applying solutions to these challenges. At the same time, these challenges must be met in a cost-effective manner to meet, if not exceed, the expectations of our customers.

Effective efforts to control fires and innovative means of fire prevention are key challenges to the pharmaceutical industry as it strives to respond to society's needs for life-saving medicines and vaccines, improving quality of life, and having a positive impact on overall healthcare costs.

Greg Jakubowski, P.E., CSP, is with Merck Safety and Environment Engineering.

We are writing this letter to comment on the subject matter addressed in recent articles by Edward K. Budnick *("Automatic Sprinkler System Reliability*" page 7) and Bruce H. Clarke (*"Microbiologically Influenced Corrosion in Fire Sprinkler Systems*" page 14) in *Fire Protection Engineering* Issue No. 9. These articles both address matters associated with the reliability of fire sprinkler systems.

We agree that traditionally fire sprinklers have proven to be highly reliable devices, which serve as a first line of defense to insure the life and property safety in buildings in which they are installed. We also believe that by combining emerging new technologies and feedback from field service and testing records, newly developed fire sprinkler systems can even more reliable. However, we feel it important to share our observations relating to information on reliability of specific, existing systems as may relate to development of new fire sprinklers.

As Mr. Budnick points out, existing reliability data is mainly based on older styles of sprinkler heads. Data for newer fire sprinkler designs is generally not included. In addition, and of primary importance in his analysis, reliability of fire sprinklers is treated as a whole regardless of possible fundamental differences in design and operating principles on which individual sprinkler designs are based. We believe that fire sprinkler reliability information for different mechanical/design technologies should be compiled separately since the more widely accepted designs may work on quite different principles, and individual model types themselves can literally account for millions of installations.

If data from such analyses could be applied readily, "not acceptable designs" or designs with potentially low reliability could be isolated more readily and rejected than at present. In addition, this approach would provide an opportunity for the fire safety community cooperatively to develop reliability testing protocols for fire sprinkler and associated system components before new designs are introduced. Such an approach is absolutely consistent with assessments needed to better understand environmental or aging effects typified by the MIC problem which Mr. Clarke discusses in his article as well as the performance of the recently recalled Central Omega sprinklers.

Using the Omega case as an example, the reliability of that particular design degraded as a function of years in service. Test data accumulated in our laboratory, as well as test data collected by others involved in evaluations of Omega sprinkler reliability, demonstrated a consistent drop in reliability as number of years in service increased. We have seen, for example, reliability of Omega sprinklers we have evaluated drop below 70 percent after several years of service. The inference to be drawn from this is that resulting performance will be significantly less than the 90 percent-plus reliability one would expect an individual fire sprinkler to show to have as described in the Budnick article.

More recently, the Central GB family of sprinklers has been the subject of notifications from UL and Factory Mutual and an "Informational Bulletin" from the California State Fire Marshall warning of potential problems. Test results from evaluations of almost 300 GB heads taken from service for various periods of time at different locations without fire occurrence show a similar relationship between failure levels and years in service to that of the Omega models which were the subject of an earlier CPSC recall. These levels of reliability are unacceptable and suggest problems with product design and/or manufacture.

In terms of the subject matter of the Budnick article, it is clearly crucial to prevent production of low-reliability "not acceptable" designs in the future so that such sprinklers are not introduced to the market. Our community needs to learn from recent recalls and the information they have provided us, and we also need to prevent such failures from happening again.

Joseph B. Zicherman, Ph.D.
Fire Cause Analysis
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Editor's Note: Since the receipt of this letter, the manufacturer of the GB series of sprinklers, in cooperation with the U.S. Consumer Product Safety Commission, has announced a replacement program. Full information on the program and the specific models of sprinklers involved is available at www.sprinklerreplacement.com.

I am writing regarding the recent article "Automatic Sprinkler System Reliability" by Edward K. Budnick. While it is true that many of the fire sprinkler reliability studies are based on the use of older sprinklers, it's not as if we have no information on the performance of newer sprinklers.

Residential sprinklers, for example, have only been available since 1981. Of 551 fires in sprinklered residential occupancies reported to Operation Life Safety between 1983 and 1995, 90 percent were controlled by a single sprinkler, with another 8 percent controlled by two sprinklers operating. Scottsdale, Arizona, which published a report on 10 years of residential sprinkler use beginning in 1985, found that 41 of 44 fires (93 percent) were successfully suppressed by only one or two operating sprinklers. Two of the three fires that opened more than two sprinklers were flammable liquid arson fires. In Prince Georges County, Maryland, residential sprinklers have been required since 1992, and were involved in 83 fires by August of 1998. In 72 of them (87 percent) only a single sprinkler activated, with two sprinklers handling another 6 percent of the fires. The high percentage of one-sprinkler and two-sprinkler operations in all of these reports indicates that sprinkler reliability is not something of the past.

Recent fire sprinkler recalls and replacement programs attest to the sprinkler industry's commitment to near-zero tolerance of sprinklers that are not reliable. A substantial effort is underway to ensure that potential problem sprinklers do not remain in place to eventually damage the historically remarkable performance statistics.

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National Fire Sprinkler Association
Patterson, NY

New Research Results Promote K14 Guideline Revision

JOHNSTON, RI — New fire protection research by industrial and commercial property insurer FM Global and its affiliate Factory Mutual Research has identified an uncommon but realistic scenario where K14 Early Suppression-Fast Response (ESFR) sprinklers, used in some warehouse protection applications, may fail to perform as intended. Specifically, the findings revealed certain ignition scenarios can affect the K14 sprinkler's ability to suppress a fire in buildings over 40 feet (12.2 m) high.

As a result, FM Global no longer recommends to its policyholders the use of K14 sprinklers as an alternative to in-rack sprinklers in buildings over 40 feet (12.2 m) high. Rather, the company advises that a combination of in-rack and ceiling sprinklers be installed according to FM Global property loss prevention engineering guidelines.

The findings are the result of FM Global's long-range sprinkler technology research program. Additional research has revealed that this storage configuration issue does not affect K25 ESFR sprinklers installed in 45-foot (13.7 m)-high buildings nor K14 or K25 sprinklers installed in buildings up to 40 feet (12.2 m) high.

For additional installation guidelines on ESFR sprinklers, visit www.fmglobal.com or call FM Global Customer Services at 781.255.6681.

O-Ring Fire Sprinklers Recall Announced

WASHINGTON, DC — The U.S. Consumer Product Safety Commission (CPSC) and Central Sprinkler Company, an affiliate of Tyco Fire Products LP, of Lansdale, PA, are announcing a voluntary replacement program. The company will provide free parts and labor to replace 35 million Central fire sprinklers with O-ring seals. The program also includes a limited number of O-ring models sold by Gem Sprinkler Company and Star Sprinkler, Inc., totaling about 167,000 sprinklers.

Central initiated this action because it discovered the performance of these O-ring sprinklers can degrade over time. These sprinkler heads can corrode or minerals, salts, and other contaminants in water can affect the rubber O-ring seals. These factors could cause the sprinklers not to activate in a fire. Central is providing newer fire sprinklers that do not use O-ring seals and is voluntarily launching this program to provide enhanced protection to its sprinkler customers. This is the third-largest replacement program in CPSC history.

Central will provide, free of charge, replacement sprinklers and the labor needed to replace the sprinklers. Central will arrange for the installation by using either its own Central Field Service crews or by contracting with professional sprinkler contractors.

For more information, go to http://www.cpsc.gov/cpscpub/prerel/prhtml01/01201.html.

Telecommunications *and* e-Commerce

Providing Fire Protection for Mission-Critical Facilities

By Ray Schmid, P.E.

Many believe that the computer is humanity's greatest achievement. The past thirty to forty years have witnessed vast improvement on this amazing technological achievement and the benefits of advancements in information processing. Financial transactions, medical breakthroughs, power generation, the construction industry, national defense, and the globalization of economies are all due to the power of the computer and the sharing of information.

While the most obvious of these advancements may be the Internet, advancements in telecommunications technology have similarly revolutionized how businesses operate. As these technological breakthroughs continue, society becomes more dependent on their performance and reliability. For example, consider the importance of computer operations on air traffic control, nuclear power generation, national defense, surgical procedures, and financial transactions.

Maintaining the operability of computer networks, Web sites, and communications has become an absolute necessity, and there are a number of ways that businesses ensure their reliability. This article will discuss the way fire protection systems, both passive and active, are used to meet the important goal of continuous operation and mission continuity.

FUNDAMENTALS OF MODERN SYSTEMS

In order to fully understand the way fire protection systems are used to protect modern data centers and telecommunications facilities, it is important to understand the relationship between the computer hardware and the electrical and mechanical systems that serve them.

This relationship is most evident by the amount of heat that is generated by modern digital equipment, such as computer servers and telephone switching equipment. Older systems, as could be expected, were much larger and bulkier than today's digital equipment. Current digital hardware takes up far less space than earlier-generation equipment occupied and generates a large amount of heat that must be continuously removed. Depending on the specific equipment and its physical configuration, failure can occur within a matter of ten or fifteen minutes if continuous cooling is not provided. Typical mechanical systems that provide this cooling capacity will be discussed in more detail later in this article.

This "compression of technology" has obvious benefits, but there is another more intrinsic price to be paid. For example, telecommunications switching sites can now process calls at much higher rates in relatively small facilities, serving very large geographical areas as a result. Consequently, the importance of an individual site becomes that much more critical, since a fire at a single facility can have such a widespread effect.

Another example of this is a facility that maintains Web site hosting for businesses. Web site addresses have become as essential to a business as a phone number, allowing clients and customers the opportunity to view products and services, and more importantly, make transactions. As the value of Web sites increases, the need to have them continuously available increases as well, and many businesses expect guaranteed operability of the Web hosting center.

Continuous operation of a telecommunications facility, Web hosting center, or data center requires reliable, and in many cases, redundant power, cooling, fire protection, and security systems. Building and fire codes address some of these issues, but the unique requirements of these facilities demand much more. For a number of years, the National Fire Protection Association (NFPA) has published NFPA 75, *Protection of Electronic Computer/Data Processing Equipment*, to address fire protection requirements for computer rooms. Recently, the NFPA created a technical committee to assist in the development of a new standard, NFPA 76, *Protection of Telecommunications Facilities*. This standard will specifically address fire protection criteria for telecommunications facilities using both prescriptive and performance-based approaches.

These NFPA documents are not the only sources for determining appropriate fire protection requirements. FM Global also has requirements for these types of facilities that apply when the facility is insured by a Factory Mutual affiliate. These can also serve as good practice for those that are not insured by an FM affiliate. The Federal Communications Commission (FCC) is also concerned with reliability and operability of telecommunications facilities. In 1992, The Network Reliability Council, an organization chartered by the FCC, issued its *Report to the Nation*, which included recommended fire prevention and protection strategies for major telecommunications providers. The FCC continues the efforts of this organization, which is now known as the Network Reliability and Interoperability Council.

Although these regulatory forces exist and provide criteria for these facilities, arguably the most compelling factor driving the need for reliable systems is market forces. The competitive nature of the industries, be they telecommunications, e-commerce, the stock market, or financial institutions, simply demands mission continuity.

Mission continuity is assured for facilities through the use of redundant power supplies, redundant mechanical systems, and cutting-edge fire protection systems. Primary and secondary electrical switchgear, uninterruptible power supplies (UPS) and batteries, and standby generators provide self-sufficient electrical services. It is common for facilities to be equipped with sufficient standby generator capacity and fuel storage for more than a week of secondary power generation. Similarly, stored water may be provided to serve certain types of cooling systems should a failure of the public water supply occur.

DETECTION STRATEGIES

Sophisticated fire alarm and detection systems, fire prevention practices, compartmentation, fire suppression, and, in some instances, smoke management also serve to provide redundant levels of fire protection. Perhaps the most critical of these fire protection systems is in the area of detection. Detection systems serve the basic function of alerting building occupants of a fire condition, but are also used routinely to control the release of fire suppression systems such as preaction sprinkler and clean agent systems. Normally, these functions are controlled by standard spot-type ionization and photoelectric smoke detectors, although heat detection, flame detection, and other methods may be used where they are more appropriate for the specific hazard or application. Standard spot-type smoke detectors and other devices that detect fire conditions prior to the time at which they threaten the building or occupants are referred to as Early Warning Fire Detection (EWFD).

Probably the single most important factor affecting the design of EWFD

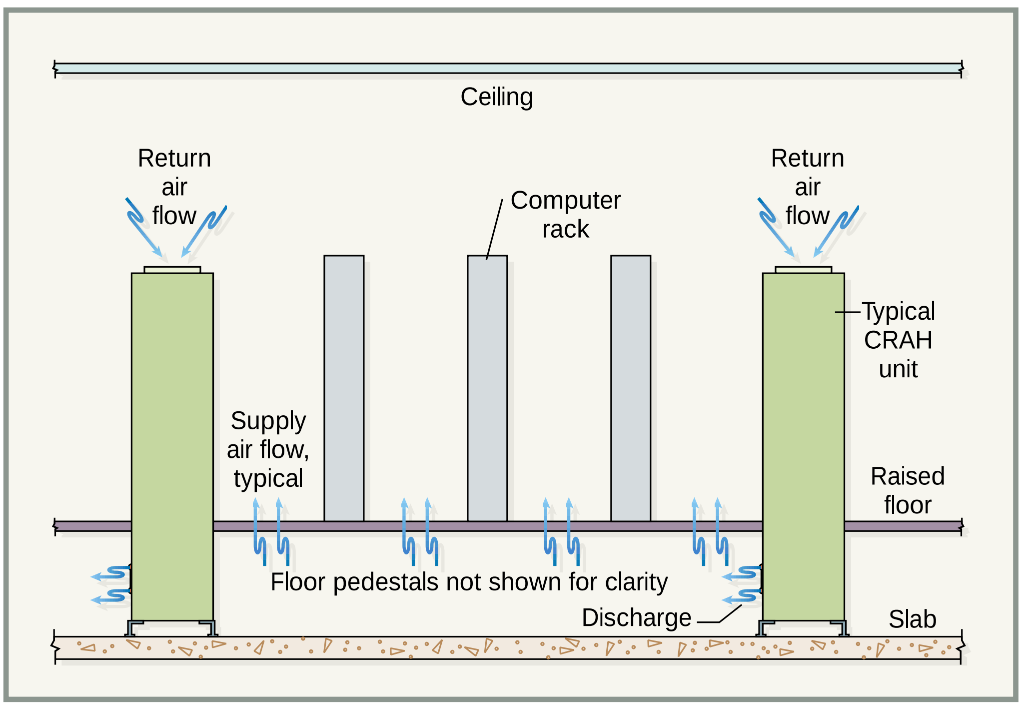

Figure 1. Typical raised-floor computer space airflow pattern

systems is the airflow conditions within the space. For example, Figure 1 shows a typical raised-floor computer space and the airflow patterns that are generated by the computer room air-handling (CRAH) units. In this example, the CRAH units draw air from a zone above the equipment racks (servers, switches, etc.) into the top of the CRAH unit. The air is conditioned and discharged at the bottom of the unit into the raised floor space. When the air is discharged into the raised floor, a pressure is developed which forces the air up through perforated floor tiles. Supply air in the raised floor can be 10°C (50°F) or less. As this air filters up through the equipment racks and adjoining aisles, the equipment is cooled. This continuous cooling process is essential to the data center or telecommunications equipment. Failure or shutdown of the cooling systems will require shutdown of the electrical power systems within a matter of minutes, which is literally a doomsday scenario for the facility.

While the basic concept is straightforward, the airflow patterns raise a number of important issues that affect smoke detector location and spacing. First, NFPA 72, *The National Fire Alarm Code* requires smoke detector spacing in areas of high air movement to be reduced. This reduction in normal spacing is dependant upon the rate at which air is circulated in the space, expressed as air changes per hour (or minute). It would not be at all uncommon to have a required spacing of as little as 11.25 m^2 (125 ft^2) per detector.

When designing EWFD for spaces containing modern computer and digital switching equipment, it is important to be aware of the differences between photoelectric and ionization detectors, and their performance in areas of high air movement. Photoelectric detectors perform better than ionization detectors in detecting smoldering fires that produce larger smoke particles.[1] Photoelectric detectors also tend to be less susceptible to high air movement, although there are a number of ionization detectors designed for installation in areas of high air velocity. Given that the types of fires likely to be generated in data centers and telecommunications equipment spaces are low-energy smoldering fires, it would follow that photoelectric detectors are probably more appropriate. In addition, multicriteria detectors and complex algorithms provided with some detection software are becoming more popular in mission-critical applications due their ability to more completely analyze fire signatures and screen out false signals.

BEYOND TRADITIONAL FIRE DETECTION

A reduction in spacing may be sufficient to accomplish the goal of detecting a fire condition and releasing a suppression system before the occupants of the facility are threatened. However, EWFD is generally considered to be incapable of detecting an incipient fire condition prior to the time at which it affects modern digital computer equipment. According to the FCC's Network Reliability Council *Report to the Nation*, as much as 95 percent of all damage caused to computer and digital switching equipment by fires can be characterized as nonthermal damage. What this shows is that the biggest risk to continuous operation in these facilities from fire is the smoke, not the fire itself. Smoldering combustion of one or two circuit boards may produce a heat release rate of one or two kilowatts. By comparison, the heat release rate from a typical trash can fire is on the order of 15 kW[2] or higher. However, relatively small amounts of smoke and hydrochloric acid, a common byproduct of combustion of PVC cables and digital circuit boards, can very effectively damage digital servers and switches.

Detecting combustion byproducts from these low-energy fires requires a more sophisticated technology. Two common methods of detecting fires of this magnitude are through the use of air-sampling smoke-detection systems or high-sensitivity laser spot detectors. Detectors such as these that can detect products of combustion before they substantially threaten equipment in the space are referred to as Very Early Warning Fire Detectors (VEWFD). When using these systems, the goal is generally to provide notification to facility staff that can then intervene to remove the failed unit from service, disconnect electrical service to the equipment rack, extinguish the fire with a hand-held extinguisher, or take other appropriate action. Due to their high sensitivity, VEWFD are not generally used to release fire suppression systems; however, in certain applications it may be appropriate to use them for this purpose. When using VEWFD to release suppression systems, isolation of the space from external smoke sources and nuisance alarms must be carefully controlled.

Air-sampling smoke detectors are probably the most common method of providing VEWFD. The detection systems normally consist of a detection unit, an aspirating air pump, a network of sampling pipes, and related appurtenances. The detection unit contains the air pump, the detector, power supply, filters, and electronic interfaces to provide annunciation and connection to external fire alarm systems or displays. System piping (typically 20 mm [0.75 inch] CPVC) is laid out in a systematic pattern, and small holes called sampling ports are drilled into the piping. The sampling ports are spaced according to the rules of conventional spot-type smoke detectors, unless a reduced spacing is desired based upon the risk factors associated with the hazard being protected. For example, the spacing of sampling ports may be reduced to 18 m^2 (200 ft^2) if earlier detection is desired. It should be noted that these detectors are more reliable in high air velocity environments and are not governed by the same rules as spot smoke detectors with regard to high air movement. The resulting piping and sampling ports form a "zone" of detection, since the detector cannot determine which sampling port(s) on a given pipe run is drawing in smoke.

Figure 2 shows a typical air-sampling system piping network. The detection system operates by drawing air in through the sampling ports, through the piping, and back to the detector where the sampled air is first filtered and then analyzed. The detector then determines whether the air sample is contaminated with smoke or is "clean." The detector may also have software that can analyze particle size to screen out unwanted alarms such as dust, insects, etc. The air is then vented back into the protected area. It is important to note that as smoke is drawn into one or more sampling ports, it could be mixed with noncontaminated air

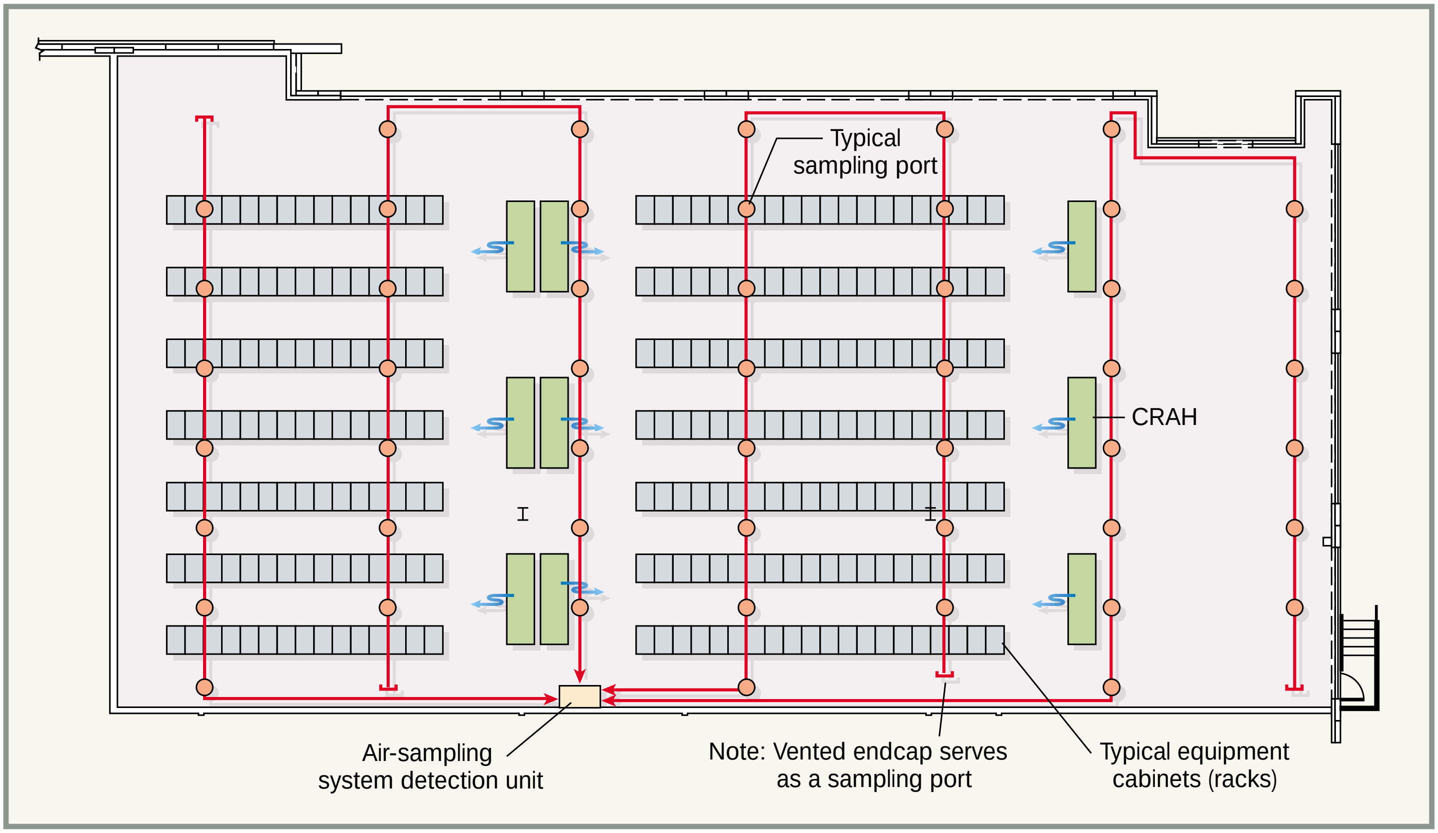

Figure 2. Typical air-sampling piping network

that is drawn in through other sampling points on the same piping run. This can result in the dilution of smoke as it is transported back to the actual detector for analysis. This dilution effect becomes more pronounced as the number of sampling ports is increased along a given pipe run. Therefore, a reduction in sampling port spacing (i.e., more sampling ports) needs to be balanced with the potential for diluting the smoke sample. In some cases, this may necessitate shorter pipe runs, additional detectors, or both.

When smoke is identified, the detector is normally capable of displaying a number of alarm "thresholds" that describe the level of smoke obscuration at the detector. These thresholds can be displayed at the specific detector, annunciated remotely, or transmitted to a conventional fire alarm control panel. When connected to a fire alarm control panel, the level of smoke obscuration can be used to perform different fire safety functions, depending upon the specific alarm threshold reached. For example, upon receiving a "Level 1" alarm from the detector, the fire alarm panel may initiate a supervisory alarm to alert facility staff of an abnormal condition at the detector. A subsequent "Level 2" alarm would indicate that the level of smoke sampled by the detector has increased, requiring compartmentation of the space. This may initiate closing smoke dampers, sending additional alarms to facility staff, or shutting down the air supply from outside the protected area. A "Level 3" alarm may result in activating the fire alarm system notification devices, releasing fire suppression systems, or transmitting an alarm condition to an off-site monitoring facility.

The functions described above are certainly not unique to air-sampling detectors. They can also be performed with high-sensitivity laser spot detectors. These detectors function much more like conventional spot smoke detectors; however, they are capable of identifying smoke obscuration levels much lower than conventional smoke detectors. For example, one manufacturer produces a detector that is capable of detecting smoke obscuration levels as low as 0.009%/m (0.03%/ft). At their most sensitive calibration, conventional smoke detectors generally detect smoke obscuration levels in the neighborhood of 0.15%/m (0.5 %/ft.). Air-sampling systems by comparison may be capable of detecting smoke obscuration levels as low as 0.005%/m (0.0015%/ft.). It is important to recall, however, that there is the potential for dilution of the smoke sample as it is drawn back to the detector. Therefore, the effective sensitivity at a given sampling port may not be substantially higher than that of a spot-type laser detector. The overall effectiveness of the two technologies is very much a function of the specific application; in particular, the ambient conditions and the desired performance objective.

Compared with air-sampling detectors, spot laser detectors have several key advantages and disadvantages. One of these is that they are point-addressable, allowing the fire alarm control panel to directly monitor the status of each device, perform sensitivity adjustments based upon time of day, adjust monitoring of adjacent or "shared" detectors, and allow for "cross-zoning" of detectors. However, since the detectors are spot-type devices, they are somewhat passive, relative to air sampling systems. In other words, they rely on sufficient thermal energy to be generated by the fire to transport the smoke to the detectors. Air-sampling systems can compensate for this transport lag somewhat by actively drawing in air from the space. Therefore, air-sampling systems are not totally dependent on thermal energy to transport smoke to the detector.

Since spot-type laser detectors rely on smoke transport and have the ability to make logical decisions among multiple detectors, in some cases it may be appropriate to design these detection systems to release fire suppression systems. In doing so, it would eliminate the need to have a system of EWFD to release suppression systems and a separate VEWFD system to alert facility staff of incipient fire conditions.

One other important aspect of VEWFD is detection for the return airflow to CRAH units and other HVAC systems serving the protected area. Since the rate of smoke generation in a low-energy smoldering fire is relatively small and the airflow velocities in the protected space can be quite high, the movement of smoke within the space tends to be dominated by the airflow patterns generated by the mechanical systems. For this reason, it is essential to provide VEWFD at the return side of the CRAH units, particularly in spaces with large clearances between the ceiling and the top of the equipment. Since the main concept of the CRAH units is to cool the space, it is unlikely that any smoke generated will have sufficient buoyancy to reach detection points at the ceiling. This is further compounded by the fact that the high airflows tend to pull any smoke back to the individual CRAH units, diluting it with clean air in the process. This phenomenon will be diminished as the ceiling height decreases or one or more CRAH units in the area of fire origin are not operating. Providing VEWFD exclusively at the ceiling level should be done only when it has been determined that the mechanical systems will not adversely impact smoke transport to ceiling-mounted detectors or sampling ports.

A variety of configurations, design schemes, and good practices should be observed when designing fire-detection systems for mission-critical facilities. While each method of VEWFD has advantages over the other, clearly the most appropriate system for a given application will depend on the type of facility being protected, the airflow patterns of the space, and the specific risk factors involved.

FIRE ALARM SYSTEM FEATURES

The overall fire alarm system design also plays an important role in maintaining continuous operation. For larger facilities having many detectors, the number of addressable points on a system can reach the thousands. Displaying alarm information clearly through the use of graphic displays, PC-based annunciators, and traditional LCD annunciators should be considered. In addition, providing multiple annunciators or paging systems can enhance the speed with which the facility staff can locate and isolate the source of the fire. Identifying each detector (or addressable point) by its room designation, column grid, and location (above ceiling, below floor, etc.) can also decrease the time needed to identify the source of the alarm and correct the problem.

Off-site monitoring is also important, particularly for facilities that may not be normally occupied. In many cases, the building code will require off-site monitoring of the fire alarm and suppression systems. Monitoring the system in accordance with Central Station requirements should be considered in most cases, unless equivalent reliability and performance can be provided by some other method. In some instances, it may be beneficial to transmit the alarms to a remote facility monitored by the owner.

MANAGING SMOKE MOVEMENT

The fire alarm and detection systems form the most critical element in protecting mission-critical facilities. They not only serve to detect and alert, but also control the release of suppression systems, initiate compartmentation features, and, in some cases, initiate smoke-management systems. Smoke-management systems continue to gain support in protecting these facilities due to the need to protect against non-thermal damage. One obvious way to prevent collateral damage of equipment from fire in a particular piece of equipment would be to simply exhaust the smoke. In theory, this is a good idea, but such a system must be carefully designed. As with any smoke control system design, there is a gap (or overlap, depending on how it is viewed) in responsibilities among mechanical, electrical, and fire protection trades. Programming the systems to close the correct dampers and initiate the proper fan sequences are an absolute necessity, and this programming logic must survive the test of time as mechanical systems are modified to accommodate changes in the facility's operation. Failure, in this respect, will likely create a situation that is worse than no smoke management at all.

In addition, the required zoning of the detection and smoke-management systems must also be coordinated. This is where the flexibility of addressable detectors becomes clear. With addressable detection, regardless of how the smoke zones are configured, the fire alarm system can be programmed to complement the smoke-management system. With zoned detection systems, this is simply not the case, and individual detection zones must be designed in concert with the smoke-management system. Coordinating zoning is frequently complicated by changes in wall locations that occur during construction.

Another consideration in the design of a smoke-management system is the size of the zone and the locations of supply and exhaust points. Exhausting smoke within a particular zone must be done in such a way that smoke will not be pulled across equipment racks that are remote from the source of smoke. This may require multiple exhaust air intakes and an analysis of how the smoke will move from the source to the intakes. For example, is it reasonable to assume that the smoke will rise up to the ceiling level and be pulled across the ceiling to the exhaust intake? This is probably not realistic for spaces that have airflow patterns dominated by CRAH units and a relatively small amount of smoke-production. In this case, the smoke-management system requires almost surgical precision in its design and must be carefully tailored to the geometry of the space and the airflow patterns present.

PASSIVE FIRE PROTECTION STRATEGIES

Compartmentation, housekeeping, and regulation of equipment also play important roles in fire protection design for these facilities. Smoke and fire barriers, dampers, fire doors, and staff training are essential to confining products of combustion and minimizing the damage should even a small fire develop. It may also be appropriate to locate the facility in a building of protected construction, particularly where evacuation may be impractical or a multitenant occupancy exists. Selection of equipment may also be an issue when the data center, particularly a Web hosting or colocation facility, is subject to transitory equipment and multiple clients. Equipment should be evaluated to ensure it is listed and is constructed of materials that do not have an unreasonable fire potential. Where the performance of equipment is questionable, segregation or elimination of the components should be considered.

Similarly, maintaining critical areas free of materials that simply have no place in a data center or telecommunications facility is also important. Contractor staging during renovations or new equipment installation should be confined to appropriate areas, so that excessive fuel loads that could overcome the fire protection systems do not exist within critical areas.

SPRINKLER PROTECTION

Should a fire develop due to an equipment malfunction, poor housekeeping practices, or even an act of God, suppression systems are relied upon to control or extinguish them. In many ways, these systems are a last line of defense in this type of facility. If they activate, it means that other efforts at detection, prevention, compartmentation, and control have at least partially failed. It also means that a significant amount of smoke and heat is being generated that will destroy electronic equipment in that space. The only question becomes how much damage can be limited.

In many cases, compliance with applicable building or fire codes will require sprinkler protection for the building. This could be triggered by provisions for unlimited area buildings, requirements for high-rise buildings, height and area restrictions for the building, local code requirements, or performance-based design goals. There also may be a requirement on the part of the building owner, insurance underwriter, or adjacent tenant that the building be fully sprinklered. While the use of alternative suppression systems may be an acceptable trade-off for specific areas, the use of these systems as an alternative to sprinkler systems generally requires the approval of the local code official. A redundant, directly connected complement of reserve agent would normally be required as well.

Regardless of the individual reasons for sprinkler protection of a critical facility, wet pipe systems may not be the preferred system. While the performance record of wet pipe system reliability is good and failures are rare, the presence of charged sprinkler piping over critical equipment and processes causes a substantial liability for facility owners. The added level of protection against accidental discharge or leakage that a preaction sprinkler system provides can be worth the additional upfront installation and long-term maintenance costs. By requiring activation of the EWFD system in order to charge the sprinkler system with water, an additional level of protection against unintended discharge is provided in the event piping is damaged by operations in the data center. A double interlock system also permits the sprinkler system piping to be monitored for integrity through the use of low-air pressure alarms connected to the facility fire alarm system. However, since this type of preaction system is more complex, additional failure modes are introduced, making proper inspection, testing, and maintenance of the systems more critical.

There are also sprinkler systems that are designed to cycle water flow on and off, depending on the fire conditions within the protected area. These systems can limit the collateral damage sprinkler system runoff may cause outside the protected area, such as an adjacent electrical switchgear room or battery room. This added benefit comes with an additional cost, since cycling systems generally require separate detection systems in addition to the EWFD system. In the past, another method of controlling excessive water damage was to use sprinklers that would cycle on and off based upon the temperature at the individual sprinkler. However, reported problems with leakage have reduced the popularity of "on-off' sprinklers, and at least one major manufacturer has stopped production due to low market demand. As indicated previously, any expected collateral damage from a catastrophic event or component failure should be compared with the potential decrease in reliability associated with a more complex system or device.

When designing preaction or cycling systems, it is important to consider the sprinkler system zones and locations of system feed mains in the design process. Sprinkler zones should be grouped logically based on building configuration, so that if a fire does occur, responding firefighters can quickly determine in which area of the facility the alarm has occurred. This is true of any sprinkler system design, not just mission-critical facilities. The locations of feed mains should also be coordinated with medium- and high-voltage electrical switchgear and uninterruptible power supply (UPS) modules. In certain instances, NFPA 70, *The National Electric Code,* prohibits the installation of sprinkler system piping from passing through rooms containing this type of electrical equipment. In such an instance, the only piping permitted would be the piping that was actually serving sprinklers within the electrical room or enclosure. It is a good practice to route distribution mains to individual preaction valves or riser rooms around critical electrical equipment rooms, so that if a leak were to develop, it would occur within a noncritical area, such as a corridor, office, or service area.

Another important consideration in sprinkler system design for these facilities is the need to pitch the system piping to the main drain. This is recommended even if the system piping is not installed in an area that is subject to freezing. The removal of water following a hydrostatic or trip test, or the flushing of the system is important since even a small amount of water has the potential to damage sensitive electronic equipment. Trapped sections requiring auxiliary drains create another opportunity for water to be present in the system if not completely drained following a test. In some cases, however, space limitations may require that an auxiliary drain be installed. In these situations, a good practice would be to limit the number of auxiliary drains needed through careful design. Auxiliary drains should also be clearly marked, even to the extreme, and extra effort should be made to ensure they are opened following any testing or trip of the system. Where pendant sprinklers are required, it may be desirable to install dry pendant sprinklers. Although an expensive option, this would eliminate the presence of water in individual sprinkler drops.

CLEAN AGENT SUPPRESSION SYSTEMS

In many cases, clean agent suppression systems can provide a level of fire suppression performance that sprinklers do not, allowing critical systems to continue to operate during system discharge. They also require very little cleanup following a discharge and are generally safer for building occupants than carbon dioxide or traditional inert systems. Two of the more common suppression agents are FM-200™ and Inergen™, although FE-13™, Argon, and others exist as well. Both systems operate in a manner similar to Halon systems in that the agent is stored in fixed containers and is discharged through fixed piping to discharge nozzles. The properties of these alternative agents, however, do not allow them to be used as a direct substitute for existing Halon installations. Therefore, piping systems, agent storage containers, nozzle placement, and system hardware may need to be redesigned when replacing an existing Halon installation.

Unlike sprinkler systems, clean agent systems are normally designed to discharge solely upon activation of the EWFD system within the protected area, permitting the suppression agent to be distributed early in the fire growth period. This allows the agent to suppress the fire before the heat release rate is low. In addition, the presence of a VEWFD system coupled with manual release stations allow facility staff the opportunity to discharge the agent even sooner in the fire growth period. Of note is that if the fire is of an electrical nature, as can be the case with cable fires, the energy source should be interrupted in order for the suppression system to be effective.

One very unique feature about Inergen™ systems is the ability for occupants to remain in the protected area following system discharge. Inergen™ is actually a combination of three gases (nitrogen, argon, and carbon dioxide) that basically inert the protected volume. Depending upon the design concentration selected, this would typically reduce oxygen concentrations within the protected area to approximately 12 percent, which is sufficient to extinguish fires involving most ordinary combustibles. While this concentration is also less than that required for humans to survive, the presence of additional carbon dioxide stimulates the body to breathe more deeply, increasing the absorption of oxygen by the body. This physiological effect allows humans to breathe normally, even in an oxygen-depressed atmosphere.

Another key difference between FM-200™ systems and Inergen™ systems is the delivery method and agent discharge time. FM-200™ systems are more like Halon systems in this regard and require the agent storage containers to be located inside or within close proximity to the protected area. This is driven by the dynamics of the two-phase flow that occurs when the system discharges. Also, since FM-200™ is a halogenated system, it must be completely discharged within 10 seconds. Inergen™, on the other hand, is stored and discharged as a gas. It operates at a higher pressure (approximately 15 MPa [2,175 psi] vs. 2.5 MPa [360 psi]), which allows the agent to be piped over a substantial distance. Since it is an inerting system, the maximum discharge time permitted by *NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems*, is 60 seconds.

There are many differences between the two systems that will affect whether or not they are appropriate for a given facility. Selection of equipment, overall performance, agent storage methods, and cost are but a few examples. Both systems, however, are widely accepted. In addition to clean agents, water-mist technology may be an acceptable alternative for certain applications. Although water mist systems have been shown to be effective in localized extinguishment of fires involving electronic equipment, their use as a total flooding system is still relatively new and unproven. Water-mist systems are an emerging technology that may prove to be an effective system for critical facilities in the near future.

Clean agent suppression and similar fixed systems necessarily rely on the integrity of the enclosure to help maintain appropriate concentrations of the agent and effectively control or suppress the fire. If the integrity of the enclosure is not maintained (for example, opened doors or holes in walls where cables have been run), then the agent would be less effective, or not effective at all. This is one reason that local authorities may not permit a direct "trade-off" between alternative suppression systems and traditional sprinkler systems.

CONCLUSION

The fire protection methods that have been discussed by no means represent a complete list of all the systems and strategies that are available to the fire protection professional. The best overall fire protection strategy for a specific facility is very much a function of acceptable risk levels, minimum code requirements, and interoperability of systems. System designs should be based upon a total fire protection approach, not simply individual systems pieced together by different trades. Only a total fire protection concept approach will integrate with the facility's goal of ensuring continuous operation.

Ray Schmid is with Koffel Associates, Inc.

REFERENCES

1 Mulholland, G., "Smoke Production and Properties," *SFPE Handbook of Fire Protection Engineering*, Second Edition, National Fire Protection Association, Quincy, MA, 1995.

2 Babrauskas, V., "Burning Rates," *SFPE Handbook of Fire Protection Engineering*, Second Edition, National Fire Protection Association, Quincy, MA, 1995.

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Proactive vs. Prescriptive Fire Protection for the OFFSHORE INDUSTRY

By John A. Alderman, P.E., CSP, and Marlon Harding, P.E.

ABSTRACT

Most companies have standards for fire protection on offshore installations. These standards typically are prescriptive in nature and require that fire protection be installed, generally, without regard to the actual hazard. Fire protection generally consists of passive fire protection, water and/or foam systems, and detection systems.

The fire protection community is slowly beginning to use performance-based criteria in determining appropriate fire protection. Performance-based criteria that uses the latest modeling programs to assess the hazards of fires and explosions on the offshore installation are beginning to grow. Based on the results of the risk calculations, the fire protection engineer can then determine the appropriate fire protection required for the hazard.

This paper addresses the use of performance-based criteria for fire protection in the offshore industry.

INTRODUCTION – MORE IS NOT ALWAYS BETTER

During the Piper Alpha incident in 1989, 168 people lost their lives as a result of an explosion and resulting fire. However, more fire protection might not have helped in that incident if it was not adequately matched with the actual risks associatred with the facility.

The amount of fire protection necessary in an offshore environment has always been subject to debate. Underprotection can lead to potential loss of life and property loss resulting in reduced production and possible environmental impact. Overprotection can lead to increased cost and maintenance. More importantly, protection based on standards rather than the actual hazard can lead to a false sense of security by management that the facility is safe.

PRESCRIPTIVE FIRE PROTECTION

With prescriptively designed fire protection, protection systems are installed based on specific guidance or requirements without much deviation. For example, one company provides two 0.157 m^3/s (2,500 gpm) fire pumps on all platforms, without consideration of the size of the platform or water demand. Prescriptive approaches to fire protection generally are a result of regulation, insurance requirements, industry practice, and company procedures. Table 1 illustrates examples of prescriptive approaches to fire protection. Each of these tend to be based on past incidents rather then trying to look forward and determine what could happen.

Table 1. Examples of Some Prescriptive Requirements

SOURCE	REQUIREMENT
Regulation	Mineral Management Service (MMS)
	US Coast Guard
	UK Health and Safety Executive (HSE)
Insurance	Active fire protection
	Passive fire protection
	Safety systems
	Specific equipment requirements for compressors and heaters
Industry Practice	American Petroleum Institute (API) • API 500 Electrical Classification • API 2030 Water Spray • API 2018 Fireproofing • API 2031 Gas Detection
	International Maritime Organization – Safety of Life at Sea (SOLAS)
	Classification Societies • American Bureau of Shipping (ABS) • Lloyd's Register • Det Norske Veritas (DNV)
	National Fire Protection Association (NFPA) • Fire Extinguishers • Carbon Dioxide Systems • Sprinkler Systems • Water Spray Systems • Fire Water Pumps
Company Requirements	Standards or procedures for: • Equipment spacing • Electrical area classification • Water spray and sprinklers • Fireproofing • Safety shutdown systems • Isolation and blowdown • Relief and flare design • Pressurization systems • Drainage

APPROACH TO PERFORMANCE-BASED FIRE PROTECTION

Performance-based fire protection is determined by conducting some form of analysis or calculations to define the fire protection required to mitigate the hazards. The risk analysis process frequently used in the offshore industry is illustrated in Figure 1.

HAZARD ANALYSIS

The first step in any performance-based approach is to conduct a hazard analysis. The hazard analysis techniques used to identify potential hazards in the process and facility are shown in Table 2. Typical offshore facilities where hazard analyses are performed include platforms; Floating, Production, Storage, and Offloading facilities (FPSO); Floating, Storage, Offloading facilities (FSO); drilling (such as jack-up, semi, or ship); Spars or Tension Leg Platforms (TLP); or any combination of these.

The outcome of the hazard analysis is a list of potential fire hazards that may occur on the facility. A partial list could include jet fire, pool fire, explosion, electrical fire, or Class A fire. The list would also include the corresponding location where each could occur. These hazards can then be turned into scenarios for further analysis.

CONSEQUENCE ANALYSIS

Consequence analysis is the process to determine the impact of the scenarios. For example, one scenario could be a seal failure that results in a vapor cloud forming with an explosion in the separation area if ignited. In assessing the consequences, two questions need to be answered:

- What is the range in size of the events that can occur?
- What is the impact of the event?

In assessing the impact, radiant heat, overpressure, toxic effects on the temporary refuge, evacuation routes, escape equipment, and offshore equipment that could be involved in escalation are normally taken into account.

Toxic effects can include products of combustion from fires, such as smoke, carbon monoxide, and hydrogen sulfide contained in the material.

In performing any consequence assessment, analytical tools can be very useful to determine the consequences of a scenario. In most cases, each scenario will have a variety of conditions that need to be evaluated in the consequence assessment. These include factors such as size of the release, orientation of release, temperature and pressure of operation, and weather conditions (that will all vary).

During the consequence analysis, it is necessary to determine the necessary sophistication of the models that will be used. Programs range from spreadsheets that use simple equations to Computational Fluid Dynamics (CFD) modeling that can take a day

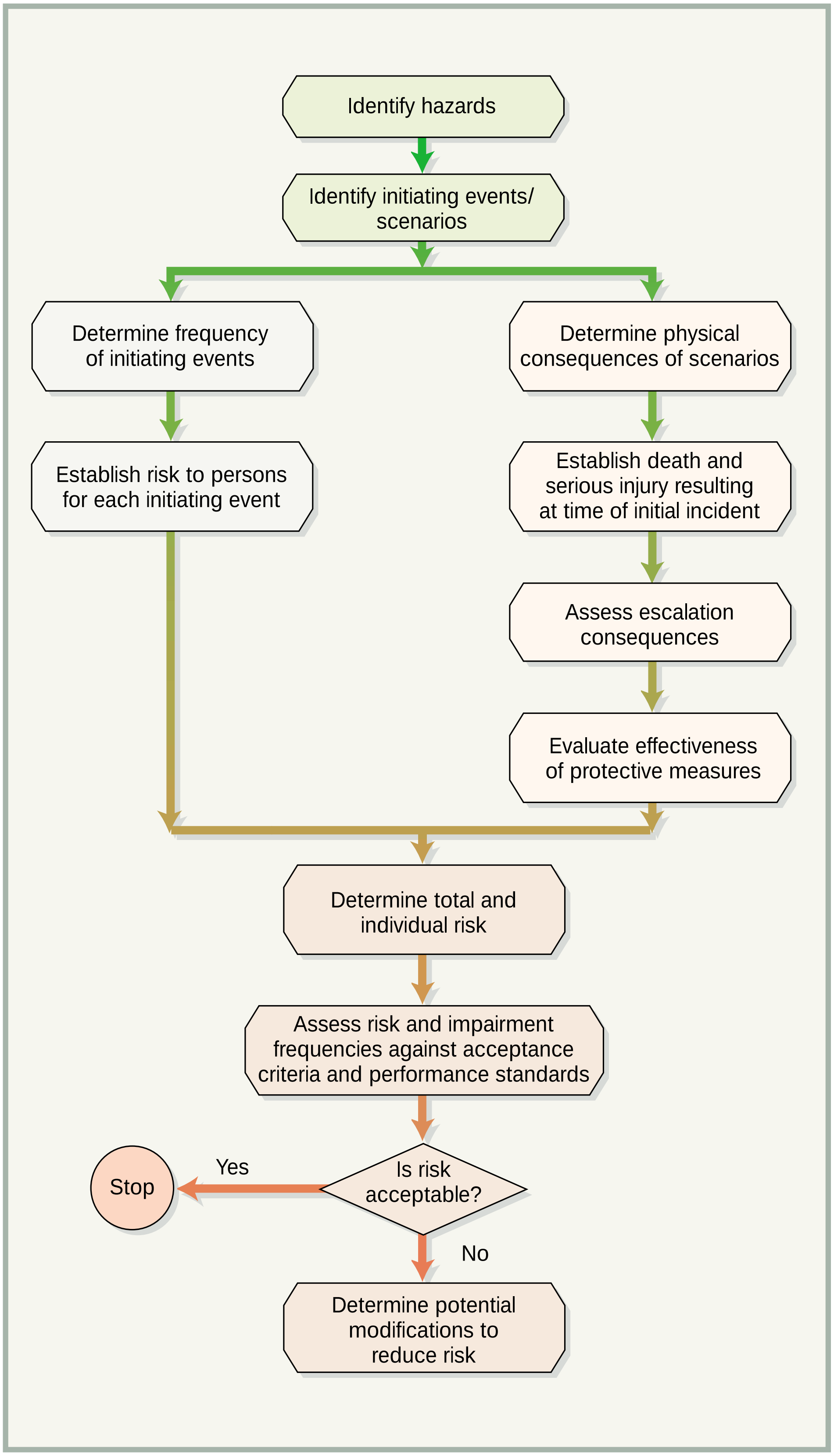

Figure 1. Risk Analysis Process

Table 2. Hazard Analysis Methods
• Checklist
• Hazard identification
• What-if?
• Hazard and operability study
• Failure modes and effects analysis

for one scenario evaluation. The models used depend on the level of the design, the time available to do the analysis, and the desired results. In the conceptual or feed-stage, simple models can be used, but as the design details increase, the complexity of the consequence analysis will also need to increase.

LIKELIHOOD DETERMINATION

If installed fire protection would be based on only the consequence analysis, then the offshore industry would be very well protected. In reality, the likelihood of the consequences must be taken into consideration. In determining the likelihood of the consequences, certain key information is required, such as the frequency of the initiating event, frequency of ignition, probability of escalation, likelihood that the weather will be favorable or not, etc. In any likelihood determination, there are generally a large number of scenarios to be analyzed.

Computer models are often used to perform the iterative process of evaluating each variable of each scenario.

RISK

Risk is the product of consequence and likelihood of each scenario. The risk for each scenario can be combined by specific areas or for the whole facility to obtain desired risk profiles. The risk is calculated using event and fault trees that take into account safety and protection systems.

The main problem associated with any risk assessment is the appropriateness of the data used in the calculations. Obviously, the use of generic industry data may result in risk numbers that vary widely. It is best if company-specific data can be used.

RISK TOLERANCE

After the risk is calculated, the results must be compared to either governmental or company criteria to determine if the risk is tolerable. If it is, then additional fire protection is not required and the level of fire protection used in the risk calculation is adequate.

If the level of risk does not meet the risk criteria, then additional protection may be required. The options for reducing the risk are selected and the analysis recalculated to determine the impact on the risk. In some cases, the options (for example, fireproofing on a quarters wall to reduce impact of jet fire) provide significant risk reduction, whereas others (water spray of offshore vessels to protect from jet fire) have very little impact on the risk.

One concept that has been used extensively in the North Sea is "as low as reasonably practical" (ALARP). Figure 2 shows the ALARP concept. This concept suggests that at some point the cost to mitigate a hazard is so high that it is no longer practical to implement the option.

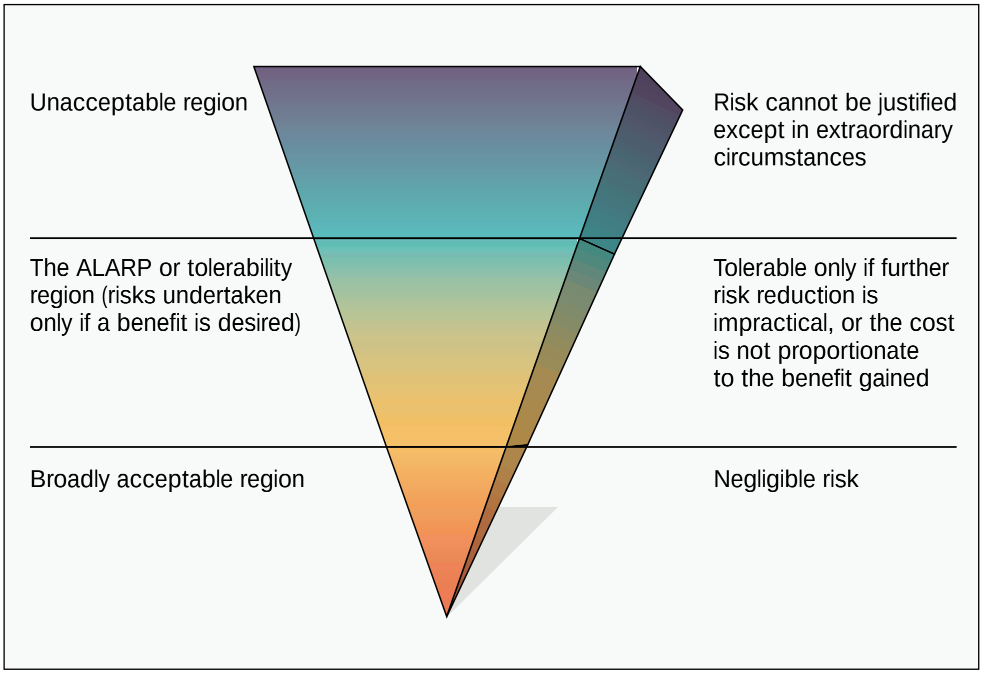

Figure 2. ALARP concept

OVERPRESSURE EXAMPLE

On facilities that produce hydrocarbons, there is always the potential for an explosion. The layout of a facility can exacerbate or reduce the impact of an explosion. Since the layout of facilities may change several times during the design, the explosion analysis needs to be rerun each time the design changes. The analysis will verify that an explosion can occur, calculate the resulting overpressure, and determine the design criteria for the blast wall. Using costly and time-consuming CFD modeling is not practical in this situation.

PC-CHAOS has been developed by Advantica Technologies through extensive full-scale explosion testing. In order to use PC-CHAOS, a three-dimensional model of the facility is required. This can easily be input from electronic files or by hand, if necessary. The program performs multiple runs of scenarios and can quickly be changed and rerun for layout changes.

The results of the calculations can be used to determine if a blast wall is required, the ideal location for the wall, and the resulting design criteria.

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UL 2360
A New Test For Wet Bench Plastics

By Jane I. Lataille, P.E.

When completed, the semiconductor chips in computers and other electronic devices can withstand the normal work environment. But while these chips are being made, they are highly sensitive to damage from even the smallest particles. This is why the semiconductor industry must process chips in rooms with highly controlled environments called cleanrooms.

Despite their high level of cleanliness, cleanrooms still have fire protection concerns. The wet benches used to clean chips between process steps are not only made of plastic, they contain heaters to heat baths of cleaning solvents and wiring to control automated processes. The concern is that a small wisp of smoke from overheated plastic can ruin millions of dollars of chips in process.

The semiconductor industry has long been aware of the risk associated with using plastic materials in cleanrooms. One way it has sought to manage this risk is by limiting the use of plastics in process equipment. However, some of the chemicals used in processing chips are not compatible with any other material. The semiconductor industry is therefore supporting the development of new plastics.

TEST BACKGROUND

Until recently, the only test for evaluating the combustibility of wet bench plastics was the Factory Mutual Research Corporation (FMRC) Test Standard 4910.[1] This test measures fire characteristics in a specially modified calorimeter. Fire propagation, smoke damage, and corrosion damage indices are then calculated from the measurements. It has been found that materials with a fire propagation index of less than 6 in this test are not self-propagating in the referred Parallel Panel test.

As the search for better plastics escalated, numerous plastics manufacturers expressed the need to test their own products during development. They were not able to run the FM 4910 test because the nonstandard test apparatus is not readily available and the test results were not reproducible. In addition, the test is complex and expensive. At the semiconductor industry's request, IRI and UL teamed up to explore whether a simple, reproducible test using standard apparatus could be developed. The ASTM E1354 test method for the Cone Calorimeter was selected for investigation.

With input from the semiconductor industry, IRI and UL decided to base the classification system resulting from the new test on fire propagation and smoke damage properties.

The project was divided into six tasks as follows:

1. Characterize the Parallel Panel test ignition source.
2. Conduct Parallel Panel tests on representative plastics.
3. Conduct ASTM E1354 cone calorimeter tests on the same plastics.
4. Correlate Parallel Panel and cone calorimeter test results.
5. Develop a classification scheme for the combustibility of semiconductor plastics.
6. Develop a UL standard for classifying semiconductor plastics.

Tasks 1, 2, and 4 were necessary to confirm that results from the new test would correspond with results from the larger-scale Parallel Panel test and to develop a meaningful classification scheme.

Samples of the following eight materials were tested:

- Polypropylene
- Fire-retardant polypropylene
- Takiron PVC™
- Corzan™

- Kynar HFP™
- Clear PVC
- Polycarbonate
- Halar 901™

This article summarizes the results of the six tasks in this project. For more complete information, see the UL report.[2]

CHARACTERIZING THE PARALLEL PANEL TEST IGNITION SOURCE

FM Test Standard 4910 describes the Parallel Panel test apparatus, which consists of metal frames for holding two 2-ft by 8-ft (0.6 m by 2.4 m) vertical panels 1 ft (0.3) apart. A 1-ft by 2-ft (0.3 m by 0.6 m) sand burner using propane fuel generates a 60 kW ignition source between the panels.

Both heat flux and smoke release from the sand burner were measured with noncombustible panels in the test frame. Heat flux data were used to select the radiant heat flux for exposing the plastics samples in Task 2. Smoke release data were used to compensate for differences in smoke generation between the Parallel Panel and ASTM E1354 Cone Calorimeter tests.

CONDUCTING PARALLEL PANEL TESTS ON THE SAMPLES

Three samples of each type of plastic were tested. Each test measured oxygen concentration, exhaust gas temperature, exhaust gas velocity, and smoke obscuration. Flame propagation was noted for each test.

The heat release rate was calculated from these measurements by means of the oxygen consumption technique using the following equation:

$$\dot{q} = k_p \times \frac{\dot{V}(0.2095 - x)}{T(1.105 - 1.5x)}$$

Where:
$\dot{q}$ = Heat release rate (kW)
k_p = Constant (kJ × K/m^3)
$\dot{V}$ = Volumetric flow rate (m^3/s)
T = Exhaust gas temperature (K)
x = Instantaneous mole fraction of oxygen

The value of the constant k_p includes factors for the heat release per kg of oxygen consumed, the ratio of the molecular weight of oxygen to air, the density of air at ambient temperature and pressure, the ambient temperature, and the calibration constant for the parallel panel apparatus.

The smoke release rate was calculated from the following equation:

$$\dot{s} = \frac{\dot{V}}{\ell} \times \ln\left(\frac{I_0}{I}\right)$$

Where:
$\dot{s}$ = Smoke release rate (m^2/s)
$\dot{V}$ = Volumetric flow rate (m^3/s)
ℓ = Path length (m)
I_0 = Reference light beam signal (V)
I = Instantaneous light beam signal (V)

The total smoke released was calculated as a time integral using the trapezoidal method. The specific extinction area is then the total smoke released divided by the sample mass loss:

$$\sigma = \frac{\int_0^{t_f} \dot{s}\,dt}{\Delta m}$$

Where:
σ = Specific extinction area (m^2/g)
$\dot{s}$ = Rate of smoke release (m^2/s)
Δm = Sample mass loss (g)

Table 1 shows the average results of the Parallel Panel test for each type of plastic.

CONDUCTING THE ASTM E1354 CONE CALORIMETER TEST

This test measures oxygen concentration, exhaust gas temperature, pressure difference across an orifice plate, and smoke obscuration. The heat release rate was calculated from these measurements by means of the oxygen consumption technique using the following equation:

TABLE 1
Average Results of Parallel Panel Test

Plastic	Flame Propagation [Ft (m)]	Peak Heat Release Rate (kW)	Peak Smoke Release Rate (m²/s)	Total Smoke (m²)	Sample Mass Loss (g)	Specific Ext. Area (m²/g)
Polypropylene	>8 (>2.4)	*	*	*	*	*
Fire-retardant polypropylene	>8 (>2.4)	*	*	*	*	*
Takiron PVC™	3.8 (1.2)	129	17.3	6107	7.88	0.759
Corzan™	4.0 (1.2)	122	6.9	2719	8.03	0.339
Kynar HFP™	6.5 (2.0)	219.3	18.3	4914	8.64	0.566
Clear PVC	4.2 (1.3)	192	26.1	11,420	8.94	1.275
Polycarbonate	>8 (>2.4)	*	*	*	*	*
Halar 901™	3.0 (0.9)	105.3	13.1	5386	6.06	0.890

* Tests terminated when flame height exceeded 8 ft (2.4m).

$$\dot{q} = k_c \times \sqrt{\frac{\Delta P}{T}} \times \frac{(0.2095 - x)}{(1.105 - 1.5x)}$$

Where:

$\dot{q}$ = Heat release rate (kW)
k_c = Constant ($kJ\sqrt{(m \times K)/kg}$)
ΔP = Pressure difference across orifice plate (N/m^2)
T = Exhaust gas temperature (K)
x = Instantaneous mole fraction of oxygen

The value of the constant k_c includes factors for the heat release per kg of oxygen consumed, the ratio of the molecular weight of oxygen to air, and the calibration constant for the Cone Calorimeter.

The total heat released was then calculated as a time integral using the trapezoidal method. Smoke release rate, total smoke released, and specific extinction area were calculated the same way as in the Parallel Panel test.

Table 2 shows the average results of the Cone Calorimeter test in the horizontal orientation for selected properties of the tested samples. Several other properties were measured or calculated in these tests. The tests were also done in the vertical orientation.

CORRELATING PARALLEL PANEL AND CONE CALORIMETER RESULTS

The data collected in the Parallel Panel and Cone Calorimeter tests were used to determine the Thermal Response Parameter (TRP), Fire Propagation Index (FPI), and Smoke Damage Index (SDI) as specified in the FM 4910 test. The TRP was determined from the following equation:

$$TRP = \sqrt{\frac{4}{\pi}\frac{1}{m}}$$

TABLE 2
Average Results of Cone Calorimeter Test in Horizontal Orientation

Plastic	Peak Heat Release Rate (kW)	Total Heat Unit Area (kW/m^2)	Peak Smoke Release Rate (m^2/s)	Total Smoke (m^2)	Sample Mass Loss (g)	Specific Ext. Area (m^2/g)
Polypropylene	6.0	179	0.11	29.3	52.4	0.557
Fire-retardant polypropylene	5.4	137	0.24	58.7	51.6	1.139
Takiron PVC™	1.6	45	0.13	37.2	67.3	0.552
Corzan™	0.7	24	0.06	6.9	72.5	0.094
Kynar HFP™	1.4	70	0.13	46.6	111.4	0.418
Clear PVC	1.7	64	0.25	72.5	75.5	0.960
Polycarbonate	2.5	182	o.14	88.0	95.8	0.918
Halar 901™	0.3	9	0.26	90.8	83.5	1.088

TABLE 3
Comparison of Parallel Panel and Cone Calorimeter Tests

Plastic	Peak FPI Parallel Panel	Peak FPI Cone Calorimeter (horizontal)	Peak SDI Parallel Panel	Peak SDI Cone Calorimeter (horizontal)
Polypropylene	*	20.5	*	1.34
Fire-retardant polypropylene	*	21.5	*	2.88
Takiron PVC™	4.5	5.0	0.39	0.32
Corzan™	1.0	0.5	0.04	0.01
Kynar HFP™	8.5	8.0	0.57	0.39
Clear PVC	13.5	14.0	2.00	1.58
Polycarbonate	*	9.0	*	0.97
Halar 901™	2.0	1.0	0.22	0.13

* Tests terminated wen flame height exceeded 8ft (2.4m).

This equation is derived from equations for flame height and flame propagation rate, and it is arranged to use measured and calculated data. (See the UL report for details.) The variable *m* is the slope of the line of least square fit in a plot of $1/t_{ig}^{1/2}$ vs. radiant heat flux. The tests measured the time to ignition, t_{ig}. The radiant heat flux was calculated from test measurements.

The *FPI* is then calculated as follows:

$$FPI = k\frac{(0.42\dot{Q}'')^{1/3}}{TRP}$$

Where:

k = Constant (1200 for Calorimeter horizontal orientation, 1000 for Parallel Panel)

$\dot{Q}''$ = Peak heat release rate per unit sample area (kW/m^2)

TRP = Thermal response parameter ($kW \times s^{1/2}/m^2$)

Finally, the *SDI* is:

$$SDI = FPI\frac{\sigma}{8500}$$

Where:

σ = Specific extinction area (m^2/kg)

Table 3 compares the *FPI* and *SDI* calculated from the Parallel Panel and Cone Calorimeter tests.

The table shows that *FPI* and *SDI* values obtained in the Cone Calorimeter correspond well with those obtained in the Parallel Panel test.

DEVELOPING A CLASSIFICATION SCHEME

Using the results of the eight plastics tested, UL developed two classification schemes, one a prescriptive scheme and one performance-based. The prescriptive classification scheme is shown in Table 4.

The performance-based classification scheme lists the properties of the tested plastics for use in fire hazard assessments. The properties are determined at a radiant flux of 50 kW/m^2.

Properties reported include the following:

Ignition Properties

- Critical Flux
- Thermal Response Parameter

Combustibility Properties

- Mass Loss
- Heat Release
- Smoke Release
- Effective Heat of Combustion
- Specific Extinction Area

DEVELOPING THE UL STANDARD

To conclude the project, UL developed the standard UL 2360 – *Standard Test Method for Determining the Combustibility Characteristics of Plastics Used in Semiconductor Tool Construction*. The first edition was issued on May 10, 2000. The standard will be reissued with minor revisions sometime in 2001.

CONCLUSIONS

UL 2360 is a simple, reproducible test for the combustion properties of plastics. It was developed from test information on plastics used in making wet benches for semiconductor industry cleanrooms. However, this test can also be applied to plastics used in other semiconductor tools, such as wafer stockers and tools for metal vapor deposition.

Wet benches are just one source of risk in the semiconductor industry. See NFPA 318[3] for information about other fire protection concerns of this industry.

Jane I. Lataille was formally with Industrial Risk Insurers.

REFERENCES

1 FM 4910, *FMRC Clean Room Materials – Flammability Test Protocol*, Factory Mutual Research Corporation, Norwood, MA.

2 *Report on the Research Investigation of the Combustibility of Plastics Used for Semiconductor Tools*, Underwriters Laboratories Inc., Northbrook, IL.

3 NFPA 318, *Standard for the Protection of Cleanrooms*, National Fire Protection Association, Quincy, MA, 1998.

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TABLE 4
UL 2360 Prescriptive Classification Scheme

Test	Property	Acceptance Criteria: Class 1: Non-propagating	Class 2: Limited Propagating	Class 3: Slow Propagating
ASTM E1354	FPI	6 or less	Parallel Panel required	Parallel Panel required
	SDI	0.4 or less	0.4 or less	<1
Parallel Panel	Propagation (ft)	4 or less	8 or less	8 or less at 10 minutes
	Pooling of melted material	No	No	No

FIRE SAFETY DESIGN OF THE FUNDACIÓN CAIXA GALICIA BUILDING IN SPAIN

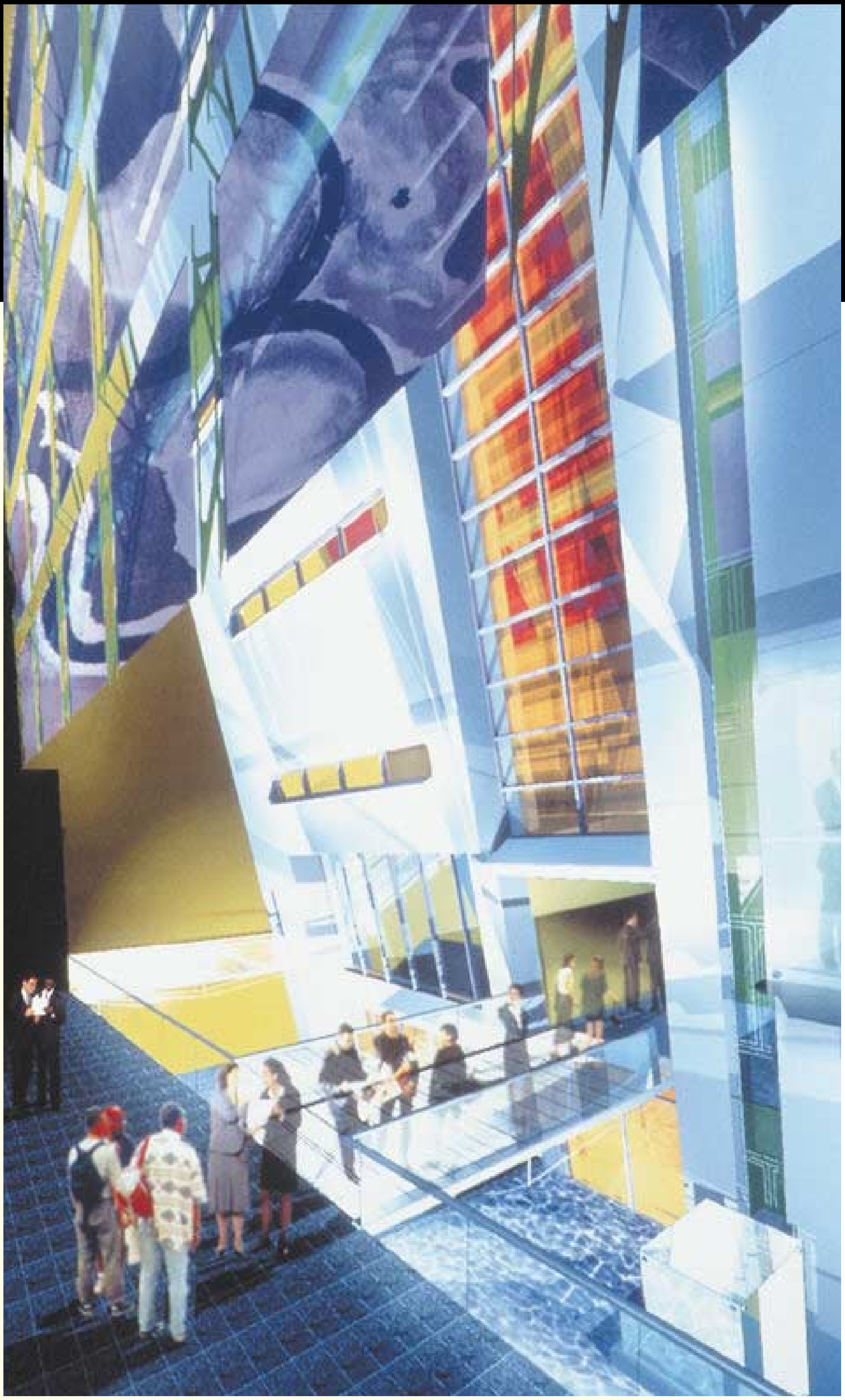

Figure 1. Caixa Galicia atrium

By George Faller, C.Eng

1. Introduction

The "Caixa Galicia" is a prominent Spanish bank that has traditionally promoted the arts in Galicia, a region in the northwest of Spain. In the mid-1990s the "Fundación Caixa Galicia" expressed their intention to build a new cultural centre to display its impressive collection of local artwork.

The building that was envisioned was one that would be accessible to the public at street level, one that would have a solid appearance but be full of light, and the intention was that the building should be a work of art in itself.

The site measures approximately 20 m across by 30 m long, and the new building will be hemmed in between two existing six-story buildings. The new building has six-stories above ground level, with a roof height to match the eaves level of the adjacent buildings. The ground to fourth floor levels consisted of galleries and associated public areas, with the top two levels dedicated to administrative use. To meet the functional area requirements of the brief on a restricted site, four basement levels were introduced to accommodate additional public gallery space, an auditorium, and a services plant level.

An important feature of the design was an atrium that bisects the building, allowing natural light to penetrate at all levels over the full height and depth of the building. The atrium forms a "canyon" above the public thoroughfare at street level, dividing the building in two parts, and open circulation bridges link the accommodation on either side. Due to the space restrictions of the site, the two escape stairs from the upper levels have been superimposed, one above the other in a "scissors" arrangement, and located to one side of the atrium. One of the two stairways in the "scissors" arrangement is a protected stair, the other an open stair. Escape from the galleries located on the side remote from the protected stair is via open bridges through the atrium.

2. Fire Safety Design

The fire safety design for the building was based on the Spanish national code NBE-CPI/96.[1] This code had no prescriptive guidance that adequately addressed the fire safety issues presented by this design. Key elements of the design were evacuation of the upper gallery areas via open bridges through the atrium, evacuation of a 300-seat auditorium in the third basement level, full-height glazing separating the galleries from the atrium, and appropriate fire-resistance requirements for the structure and separating elements.

3. Smoke Control in the Atrium

Evacuation of galleries on the first to fourth floors of the building takes place via two open bridges at each level, which link the two sides of the building either side of the atrium. These galleries are served by two protected stairways, both of which are on the same side of the atrium. There is therefore the possibility that people would have to travel over the open bridges and through the atrium "canyon" to the protected stairs on the other side to make their escape.

The accumulation and control of smoke in the atrium was a fundamental issue that had to be addressed to ensure safe egress in the event of a fire at one of the lower levels. The fire strategy attempted first of all to minimise the risk of smoke ingress into the atrium by a combination of:

i. fire-resistant separation of fire loads from the atrium, and
ii. local smoke control with mechanical extraction.

Smoke from a fire in the accommodation on either side of the atrium was controlled at all levels by a combination of these two methods. The atrium base, however, could not be treated in the same way. Although it is a "street" thoroughfare, which under normal circumstances would be free of any fire load, there is always the possibility that someone could, either inadvertently or maliciously, introduce a fire load into this space.

To investigate the effects of this scenario, a 1.5MW design fire was assumed, representing about 3m^2 of a typical retail premises fuel load with a maximum heat release rate of 500 kW/m^2. It would be difficult to imagine a fire source of this magnitude being left unattended in the "street" area for a building such as this with a high level of security and management, but a number of design guides stipulate this as a minimum design fire size.

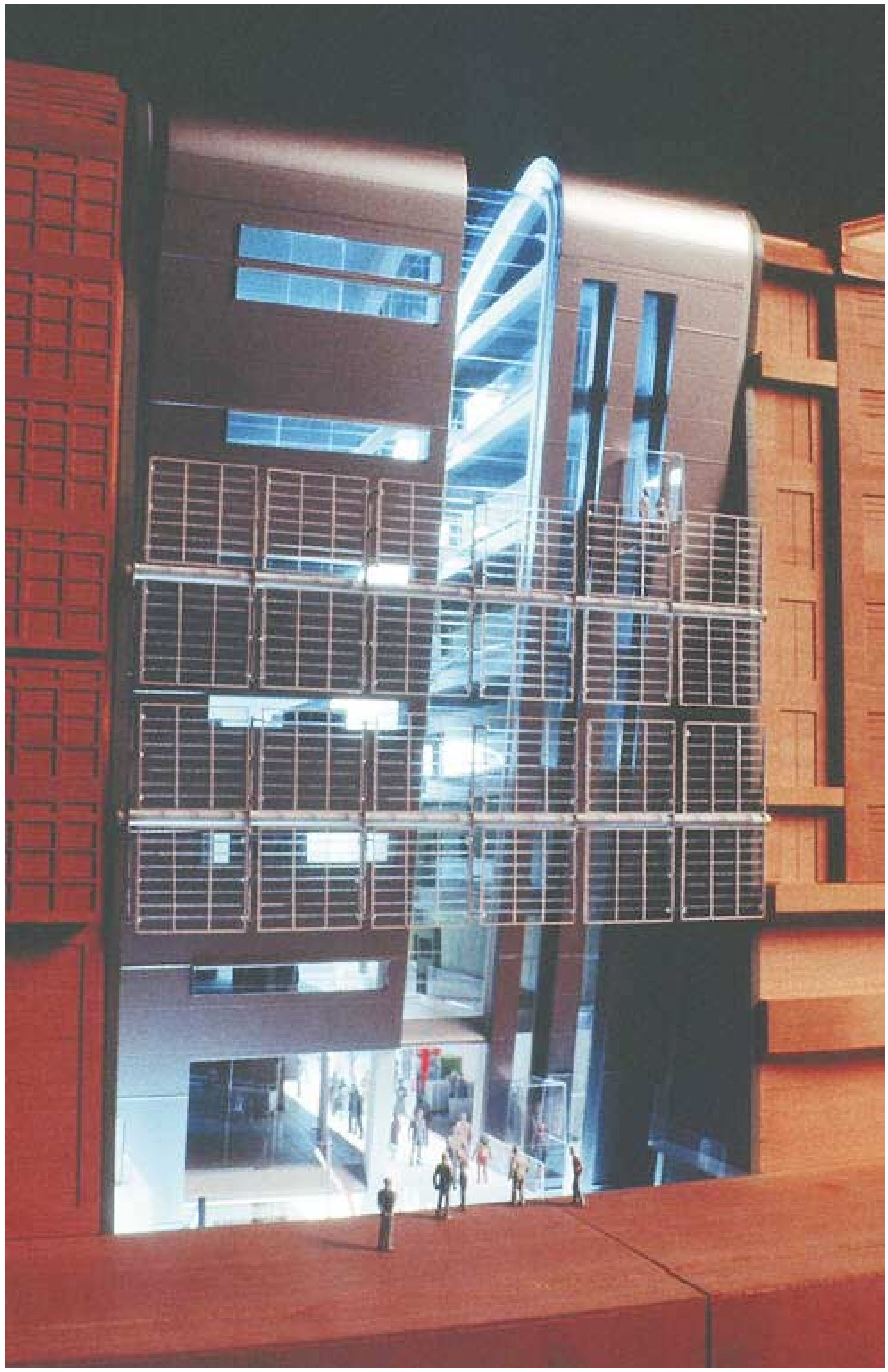

Figure 2. Smoke in atrium from a fire in the open "street"

Using automatically driven roof vents, a system of natural ventilation was used to manage the smoke from this design fire. The natural ventilation system was designed so as to ensure tenable conditions within the atrium for a period of time well in excess of the calculated egress time.

It was found to be impractical to remove smoke at such a rate that it would not build down to any open

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bridge level, so there was a possibility that some people escaping through the atrium would have to move through the smoke in order to reach the protected stairways. An analysis was done to determine the smoke temperature and density of smoke particulates in the atrium, and from this the visibility, at any given time.

Due to the shallow depth of the gallery spaces on either side of the atrium, escape distances to the protected stairs are relatively short. Furthermore, clear views into the atrium from all accommodation areas would enhance early awareness of any smoke accumulating in the atrium, and gallery management procedures ensure that trained staff would be in attendance in the public areas at all times. Given these characteristics, an upper limit to the total time for evacuation of the upper levels into one of the two protected stairs was calculated to be less than 3 minutes.

With the limiting parameters for tenability assumed to be a smoke temperature of 60°C and visibility of more than 10m, it was found that acceptable conditions were maintained in the atrium for more than twice the evacuation period.

Tenability of the open bridge links is therefore maintained during the escape period, even for this unlikely scenario. The situation is shown schematically in Figure 2.

4. Fire Resistance Requirements

The height of the top floor of this building is in excess of 28 m, and therefore the Spanish NBE-CPI/96 code recommended a minimum 3-hour fire-resistance period for the structure. A further implication of the strict code interpretation would have meant that the separating elements between the gallery accommodation and atrium would require a fire rating of 90 minutes. In order to allow natural lighting of the galleries at all levels, the architect wanted full-height glazing along the gallery/atrium interface. Even it were possible to achieve a 90-minute fire-resisting glazed partition to the galleries with acceptable framing details, it would have been prohibitively expensive.

Figure 3. Section through the Caixa Galicia atrium bisecting the building

However, it was obvious from the outset that the gallery fire loads were much lower than the fire load density of 750 MJ/m^2 typically associated with such a "public assembly" building.[3] There were also large areas of potential ventilation from the gallery levels into the atrium. Therefore, Article 14(a) of NBE-CPI/96 was used, which states that the designer has the choice of either adopting the tabulated fire-resistance values or to determine the value by analytical means using approved calculation methods.

In the Caixa Galicia building, the fire loads in the galleries are less than normal for public assembly buildings, and the compartment sizes are far smaller than the limiting dimensions assumed for the tabulated fire-resistance values. Furthermore, it is unlikely that the fire loading for this building could change significantly without a major refurbishment. It was felt, therefore, that a performance-based approach should be used to derive a fire-resistance period more appropriate to this particular building.

The method adopted for the calculation of the fire-resistance period was based on the "equivalent time" calculation approach given in the Eurocode ENV 1991-2-2: 1996[2], which takes the following form:

$$t_{e,d} = q_{f,d} \times k_b \times w_t$$

where

$t_{e,d}$ = equivalent time of fire exposure (minutes)

$q_{f,d}$ = design fire load density (MJ/m^2)

k_b = conversion factor for thermal properties of enclosure

w_t = ventilation factor

TABLE 1 Fire load densities	
Occupancy	**Fire load densities (MJ/m^2)**
Office	570
Assembly (entertainment)	750
Shops and Commercial	900
Gallery	250

TABLE 2 Calculated fire resistance periods					
Occupancy	**Height (m)**	**t-equivalent (minutes)**	**Risk Factor(1)** **Consequence**	**Risk Factor(2)** **Probability**	**Calculated Resistance (minutes)**
Ground Floor Gallery	0.00	33	0.8	0.8	21
Ground F1 Bookshop	0.00	65	0.8	0.8	21
Upper Levels Gallery	17.10	24	1.1	0.8	21
Upper Levels Offices	29.70	29	1.6	1.2	56

As a basis for the calculations, fire loads appropriate to the use of the different areas were taken from statistical data based on a comprehensive survey carried out on buildings throughout Europe.[3] The fire load densities used for the different areas in the Caixa Galicia building are given in Table 1, and it can be seen from this how the fire loads can differ substantially from the values assumed in the code tables.

The thermal inertia of the compartment is represented by the factor k_b and can be quite easily calculated once some basic fitting out details are known, or alternatively a conservative default value can be used. The ventilation factor is calculated from a formula based on the compartment geometry; height, floor area, and area of ventilation openings.

The "*t*-equivalent" value, therefore, can readily be calculated for each compartment using the relationship given above.

But fire-resistance periods given in national regulations take into account factors other than fire load and ventilation – they make allowance for ease of escape, access for firefighters, the probability of a fully developed fire occurring, and the consequence of structural failure. The "*t*-equivalent" value on its own, therefore, cannot be equated to a fire-resistance period.

The fire-resistance values were calculated by multiplying "*t*-equivalent" time period with factors for quantifying the risk of structural failure, as suggested in a UK *'National Application Document*,[4] intended to supplement Eurocode guidance. The application of these "gamma factors" ((1) and (2)) relate the "*t*-equivalent" values to a fire-resistance period by associating the risk of failure with height of building above access level. The derivation of the "gamma factors" for the NAD[4] approach was done in such a way to ensure that the fire resistance values calculated using the "*t*-equivalent" approach are similar to the prescriptive code values and, as such, have no deeper scientific basis. The method, however, does give the designer some flexibility when the fire load or ventilation conditions are different to the typical values assumed for the code tables. The results from applying the approach outlined above to a number of floors is given in the Table 2.

The method used for calculating the fire-resistance period described above also recognises the role of sprinklers in controlling the size of a compartment fire and makes allowance for this by means of an additional reduction factor. In the later development of the design, sprinkler protection was introduced into the Caixa Galicia building at all levels as a property protection measure. This introduced an additional factor of safety into the design that was not used in the derivation of the fire-resistance values given above.

By using this "first principles" approach, it was determined that a 60-minute fire-resistance period was adequate for the structure of the Caixa Galicia building. The main benefit of this approach in this case was that it could be used to justify a 60-minute compartmentation between floors, which allowed us to use a standard 30-minute fire-resistant glazing to separate the galleries from the atrium.

George Faller is with Arup Fire.

REFERENCES

1. *Norma Básica de la Edificación*, NBE-CPI/96: "Condiciones de protección contra incendios en los edificios," CSCAE, 1996.

2. Eurocode 1: *Basis of Design and Action on Structures*, Part 2.2 – Actions on Structures Exposed to Fire, DD ENV 1991-2-2:1996.

3. CIB W14 Workshop. Design Guide – Structural Fire Safety, *Fire Safety Journal*, March 1986.

4. BSI, *National Application Document, Eurocode 1*: Basis of Design and Action on Structures, Part 2.2 – Actions on Structures Exposed to Fire for use in the UK, DD ENV 1991-2-2:1996

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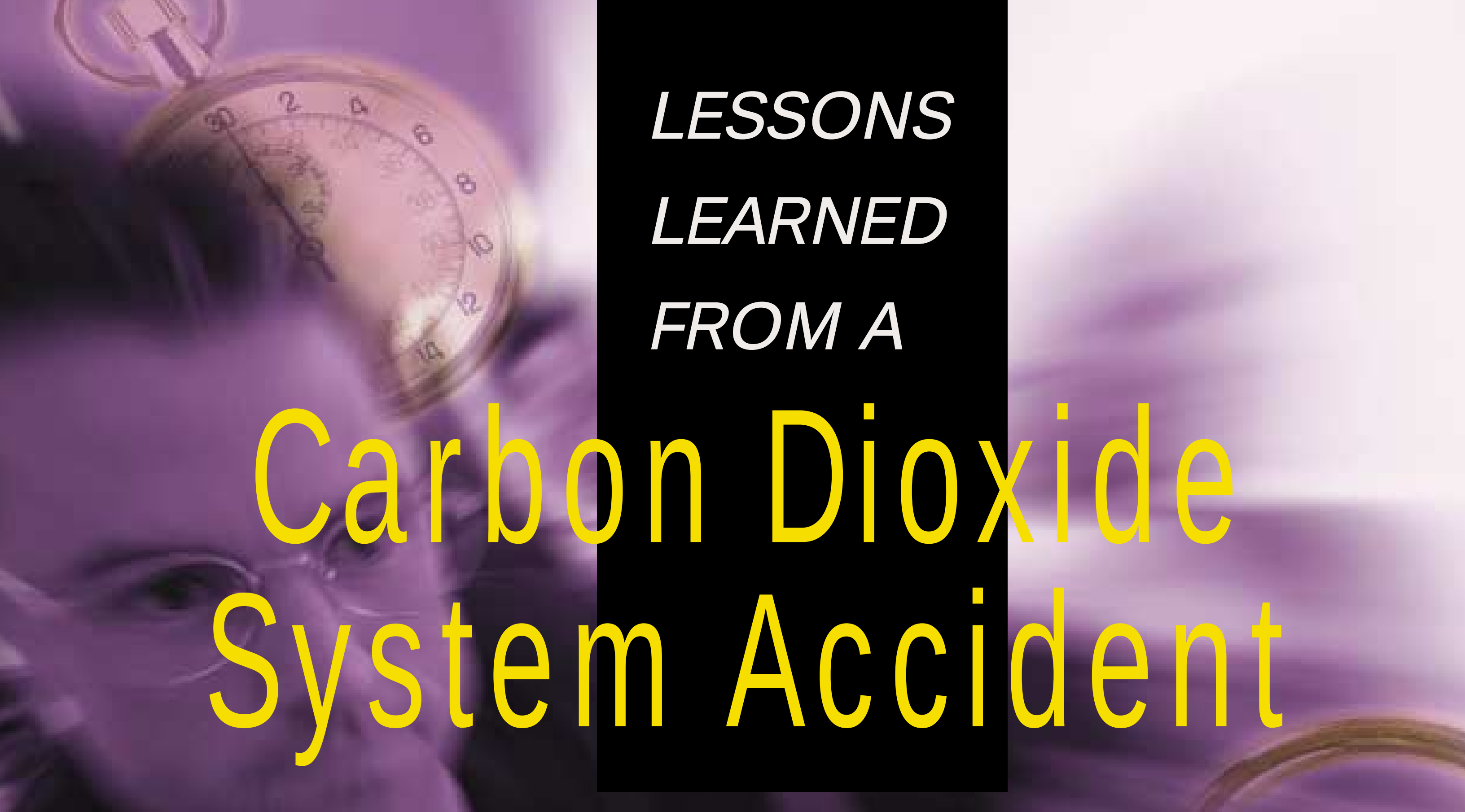

LESSONS LEARNED FROM A Carbon Dioxide System Accident

By Morgan J. Hurley, P.E, and James G. Bisker, P.E.

A high-pressure, total-flooding, carbon dioxide extinguishing system discharged without warning during routine maintenance of electrical equipment resulting in one fatality and several serious injuries. At the time of the accident, the newly installed system releasing panel was electronically disabled and considered out of service, yet it still actuated the system when work crews disconnected primary power to the panel.

Several lessons can be learned from this accident. In particular, designers must examine personnel safety in the context of possible special extinguishing system failure modes as well as the protection of the facility from attack by fire.

BACKGROUND[1]

The Idaho National Engineering and Testing Environmental Laboratory (INEEL) is a government-owned, contractor-operated facility located in a rural area of southeastern Idaho. The site houses nuclear reactors that are used for testing and research, fuel storage buildings, and miscellaneous support infrastructure.

Building 648 is a two-story building that contains electrical support equipment for a reactor and support facilities within the Test Reactor Area. The building is protected with a carbon dioxide (CO_2) extinguishing system, with automatic sprinklers installed in an adjoining emergency generator room. The CO_2 system was originally installed in 1971 and consists of a fire-detection system, 2,500 kg (5,500 lb) of carbon dioxide stored in 55 high-pressure bottles, and discharge piping and nozzles. The CO_2 system was designed to achieve a 50 percent concentration of carbon dioxide.

The fire-detection system consists of a releasing panel, initiating devices, notification devices, and actuation devices. Initiating devices include 14 heat detectors, two manual pull stations, two manual CO_2 releasing stations, and a waterflow detector for the building's dry pipe sprinkler system. Notification devices include building evacuation signals. Actuating devices include releasing circuits for the CO_2 supply and an interface circuit that allowed the fire alarm to be monitored by the facility's fire alarm reporting system.

The CO_2 system was designed to be released upon a signal either from the fire-detection system or manually via an emergency release lever located in the CO_2 storage shed. The fire-detection system was programmed to discharge the CO_2 upon activation of a heat detector or upon activation of one of the two manual CO_2 releasing stations. The emergency release lever in the storage shed was not connected to the fire-detection system.

When the CO_2 system was discharged via the fire-detection system, discharge was accomplished by operation of two electrically operated control heads. The control heads were connected directly to two of the 45 kg (100 lb) CO_2 storage bottles. Operation of a control head released the CO_2 from the bottle to which it was connected, which pressurized the discharge manifold. Pressuriza- tion of the discharge manifold opened pressure-operated valves on the other CO_2 storage bottles. The CO_2 would then flow through a piping network and discharge out of nozzles located in Building 648. Manual operation of the emergency release lever would directly release the CO_2, independent of the fire-detection system. See Figure 1 for a diagram of the CO_2 system arrangement.

The CO_2 and fire-detection systems incorporated two distinct time delays. The control panel was programmed with a 30-second delay. Upon operation of either a heat detector or a manual CO_2 releasing station, the control panel was programmed to sound the evacuation signals immediately and begin a 30-second

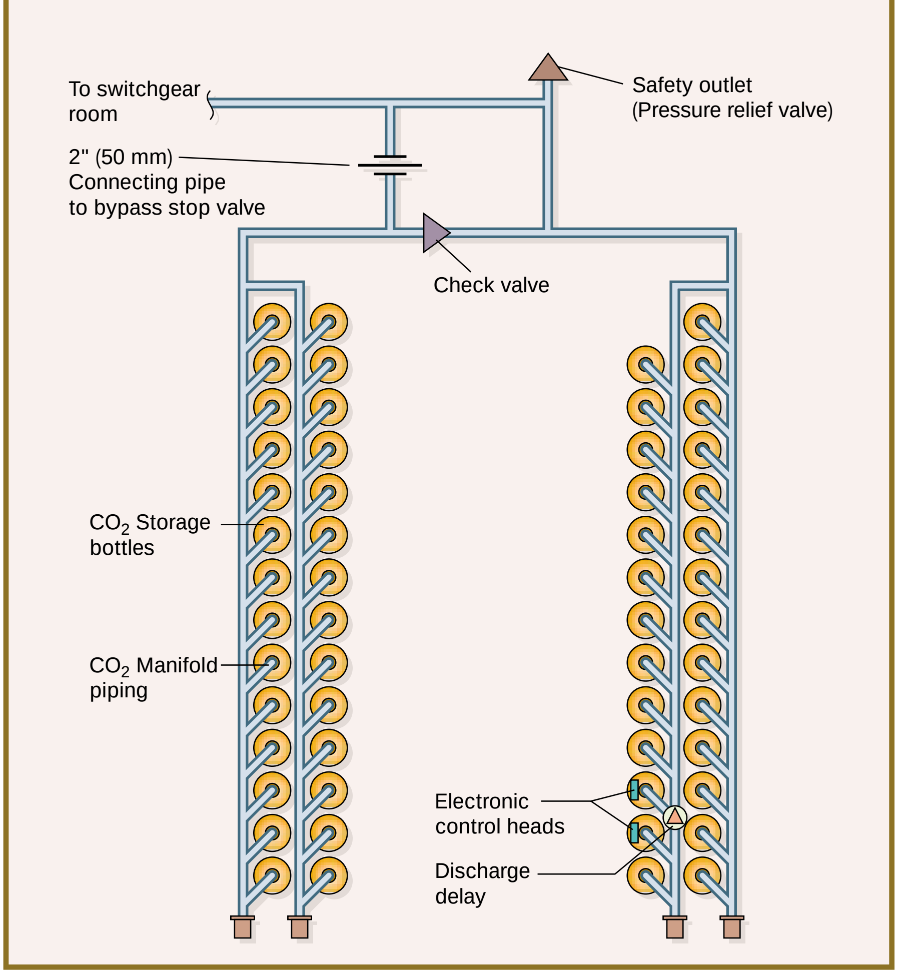

Figure 1. CO_2 system arrangement[1]

time delay sequence, after which the control panel would actuate the control head solenoids.

An additional 25-second mechanical delay device was installed between the CO_2 storage bottles and the discharge piping to the building. This mechanical delay would automatically retard the discharge of CO_2 and only required the pressure of the CO_2 for its operation. With the combination of the delay programmed into the control panel and the mechanical delay, the evacuation signals would sound for a total of 55 seconds prior to the discharge of CO_2 when discharge was initiated via the fire-detection system.

THE ACCIDENT[1]

On the afternoon of July 29, 1998, workers were preparing to perform preventive maintenance of the electrical switchgear in Building 648. The CO_2 system was electronically impaired by programming the control panel not to activate the control heads located on the CO_2 bottles.

Later, the work crew began opening circuit breakers in preparation for the preventive maintenance work. Shortly after the last breaker was opened, the CO_2 system discharged, creating "near zero visibility."[1] While the evacuation alarms may have briefly sounded for less than one second, they did not continuously sound in conjunction with the CO_2 release.

After the CO_2 discharge, the workers ran towards the exits, which were visible since they were held open by cables running into the building from portable generators. Eight of the workers were able to exit on their own; however, five remained inside of the building and were rendered unconscious by the CO_2. Three were later rescued by the workers who had earlier escaped, which left two people remaining in the building. One of the remaining workers was later revived, and the other perished.

INVESTIGATION BY DOE[1]

Following the accident, the Department of Energy conducted an investigation to determine the causes of the accident. The accident investigation determined that a likely cause of the CO_2 system release was the transmission of a spurious signal to the control heads, which occurred when the power to the control panel was disconnected.

During a recreation of the events leading up the accident, the circumstances that would have led to another CO_2 discharge were duplicated when primary power was disconnected from the control panel. When primary power was disconnected from the control panel, a spurious and momentary signal developed in the releasing panel's energy power supply and charging circuitry that migrated through the releasing circuits, causing the control solenoids to actuate and the evacuation signals to momentarily sound. The evacuation alarms again failed to continuously sound for a duration that would adequately warn building occupants.

While the malfunction of the control panel was the direct cause of the accident, several contributing factors were identified, which included:

- The releasing panel did not monitor discharge of the CO_2 system.
- The alarm sounded for an insufficient period of time prior to the CO_2 discharge.
- The CO_2 system was not equipped with a mechanism that would have supported lockout.
- The releasing panel was not equipped with a supervised circuit disconnect switch and had to be electronically disabled for work in the facility.

HAZARDS OF CARBON DIOXIDE EXTINGUISHING SYSTEMS

Carbon dioxide is a commonly used extinguishing agent. According to the Environmental Protection Agency, CO_2 is used in approximately 20 percent (based on cost) of all special hazard fire protection systems.[2] The U.S. EPA also estimates that special hazard applications comprise 20 percent of all fire protection system applications;[2] therefore, CO_2 systems comprise approximately 4 percent of all fire protection systems.

Carbon dioxide possesses several properties that make it a desirable fire protection agent. These include:[2]

- CO_2 is noncombustible and does not produce other hazardous substances when heated (as some "clean agents" do).
- CO_2 is stored in a pressurized state, and the pressurization alone is sufficient to propel the gas into a protected space.
- CO_2 leaves no residue following a discharge.
- CO_2 does not react with most other materials.

- Since it is a gas, CO_2 provides "three-dimensional" protection, i.e., it can protect spatially complex hazards such as printing presses or marine engine rooms.
- CO_2 does not conduct electricity.

Although CO_2 is a naturally occurring substance, produced, for example, by fires and breathing, it also can pose dangers in high concentrations. At low concentrations (~4%), CO_2 is relatively benign.[2] However, at greater concentrations, CO_2 is lethal to humans, and at concentrations greater than 17 percent, death can occur in less than one minute. Other adverse physiological effects can occur from exposures less than 17 percent, including headache, shortness of breath, and unconsciousness.[2]

The minimum design concentration of CO_2 for fire suppression varies with different fuels and ranges from 34 percent to 75 percent.[3] Most CO_2 system applications are at the low end of this range. Nevertheless, at a minimum design concentration of 34 percent, all total flooding systems create an environment that is lethal to humans.

Carbon dioxide for extinguishing systems is typically stored in a liquid form. When CO_2 is discharged, the endothermic expansion absorbs heat, and the discharged CO_2 is cold enough to cause water vapor in the air to condense into small droplets, creating a fog. This fog can obscure visibility, making egress more difficult.

Walking speed through nonirritating smoke has been shown to decrease as the smoke concentration increases.[4] Since the effect of nonirritating smoke on humans would primarily be a reduction in visibility, it can be concluded that the decrease in visibility caused by the fog created by CO_2 discharge would also decrease walking speed.

Taken together, these two effects demonstrate the importance of evacuating all people from a protected space before CO_2 discharge. Since for systems installed to extinguish surface fires, a CO_2 design concentration of at least 34 percent must be achieved within one minute,[3] a lethal environment would be created very quickly, and evacuation times would increase due to the reduction in visibility.

ANALYSIS OF CONTRIBUTING CAUSES IDENTIFIED BY DOE

Lockout

The U.S. Occupational Safety and Health Administration (OSHA) lockout provisions are contained in 29 CFR 1910, subpart J. The scope of 29 CFR 1910, subpart J, (contained in 29 CFR 1910.147(a)(1)(i)) states that the regulation applies to "the servicing and maintenance of machines and equipment in which the unexpected energization or startup of the machines or equipment, or release of stored energy could cause injury to employees."[5]

"Lockout" is defined as "the placement of a lockout device on an energy isolating device... ensuring that the energy isolating device and the equipment being controlled cannot be operated until the lockout device is removed."[5]

NFPA 12 also contains lockout requirements. The edition of NFPA 12 that was in effect at the time of the accident stated:[3] "To prevent accidental or deliberate discharge, a 'lockout' shall be provided when persons not familiar with the systems and their operation are present in a protected space." The 2000 edition of NFPA 12 added a definition of "lockout" that parallels the OSHA definition.

While the CO_2 system was not fitted with a lockout device that would have met the definitions contained in the OSHA rules, INEEL operating procedures called for removal of the electronic control heads "prior to maintenance that could cause a release of CO_2."[1] However, at the time of the accident, the control panel was used to electronically disable the system in lieu of removing the control heads.

Engineering Controls

The National Fire Alarm Code (NFPA 72) requires that[6] "the operation of an automatic fire suppression system installed within the protected premises shall cause an alarm signal..." The National Fire Alarm Code also states that "the operation of... fire extinguishing system(s) or suppression system(s) shall initiate an alarm signal by means appropriate to the system, such as agent flow or agent pressure, by alarm-initiating devices installed in accordance with their individual listings."

The CO_2 system at the INEEL was installed to operate the evacuation alarm and began counting down the logic-based predischarge delay simultaneously. However, because the control panel did not intentionally operate the control heads, the predischarge alarm did not sound.

Operation of the CO_2 system was accomplished via two means – upon a signal from the control panel or by manual release at the CO_2 storage. This latter means of operation is referred to as "emergency manual operation" by NFPA 12.[3] Emergency manual operation is required by NFPA 12 for all CO_2 system valves.[3] Because the control panel did not monitor release of the CO_2 system, operation of the emergency manual control would have caused the CO_2 system to discharge, without sounding the evacuation alarms or notifying response organizations.

NFPA 72 also requires that fire alarm systems used for releasing service be provided with a supervised disconnect switch to allow for system testing without activating the fire suppression system. Had this switch been provided at this site, it could have been used to physically separate the releasing panel from the CO_2 control heads as opposed to disabling the releasing panel electronically. Since this switch is not required as a condition for listing as a releasing panel, design engineers must specify and verify its installation.

It is noteworthy that the appendix to the 1996 edition of the *National Fire Alarm Code* contained explanatory material (in A-5-7) that stated that evacuation alarms may be initiated by the fire-detection system. While this explanatory material was deleted in the 1999 edition of the *National Fire Alarm Code*, it is likely that there are many CO_2 systems and other releasing panel controlled suppression systems in service that are configured in a similar manner to the CO_2 system at INEEL.

OTHER AVAILABLE TECHNOLOGY

With the exception of "small" systems, defined as those with less than 140 kg (300 lb) of CO_2 storage, marine CO_2 systems in the U.S. incorporate a number of features that are not required in their land-based counterparts. Neither automatic nor electronic operation is permitted in marine CO_2 systems; operation must be by mechanical means. In marine CO_2 systems, electronic pre-discharge delays are not permitted. Predischarge delays must also be mechanical and depend only on the pressure of the CO_2 to operate. Also, the audible evacuation alarms used in marine CO_2 systems must be powered by the CO_2 pressure; electronic alarms are not permitted.[7]

The types of components that are used in marine CO_2 systems are readily available and provide an increase in safety over the types of components typically used in shore-based systems. Although they are not required in shore-based systems, their use should be considered since they would eliminate many readily foreseeable failure modes that could lead to injury or death of people in a space protected by CO_2.

IMPLICATIONS FOR CO_2 DESIGN

The CO_2 system in Building 648 nearly complied with NFPA 12 and NFPA 72. However, the accident could have been prevented by one of two methods: (1) the provision of pressure switches in the CO_2 discharge piping upstream of the mechanical delay that would cause the evacuation alarm to sound, or (2) the provision of mechanically operated CO_2-powered sirens in the CO_2 discharge piping that operated by the pressure of the CO_2 alone.

While the provision of a lockout device or a circuit disconnect switch potentially could have prevented the accident, given that it would require a deliberate action to operate, and that the procedures that were in place to remove the control heads were not followed, it is suggested that a lockout device alone is not sufficient. Addition- ally, a failure mode would still be present where the system can discharge without the evacuation alarms sounding.

This accident demonstrates that code compliance alone may not be sufficient for CO_2 system design, and engineers should consider possible failure modes and effects during the design of CO_2 systems. Similarly, existing CO_2 systems should be evaluated to determine whether they provide adequate worker safety.

Morgan Hurley is with the Society of Fire Protection Engineers. James Bisker is with the U.S. Department of Energy.

REFERENCES

1 "Type A Accident Investigation Board Report of the July 28, 1998, Fatality and Multiple Injuries Resulting from Release of Carbon Dioxide at Building 648, Test Reactor Area Idaho National Engineering and Environmental Laboratory," U.S. Department of Energy, EH2PUB/09-98/01A1, September, 1998.

2 "Carbon Dioxide as a Fire Suppressant: Examining the Risks." EPA430-R-00-002, U.S. Environmental Protection Agency, 2000.

3 NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*, National Fire Protection Association, Quincy, MA: 1993.

4 Jin, T., "Studies on Human Behavior and Tenability in Fire Smoke," *Fire Safety Science: Proceedings of the Fifth International Symposium*, Dr. Y. Hasemi, Ed., Society of Fire Protection Engineers, Bethesda, MD: 1997.

5 29 CFR 1910.147

6 NFPA 72, *National Fire Alarm Code*, National Fire Protection Association, Quincy, MA: 1999.

7 46 CFR 76.15.

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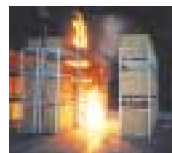

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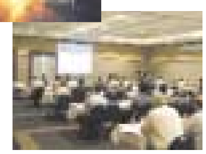

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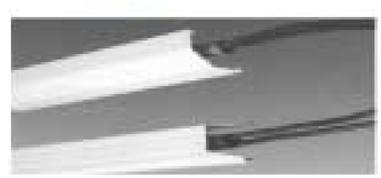

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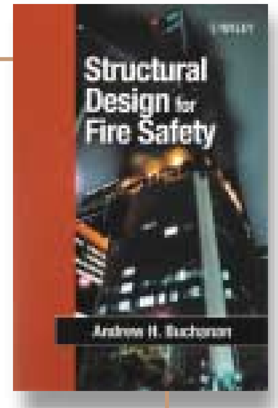


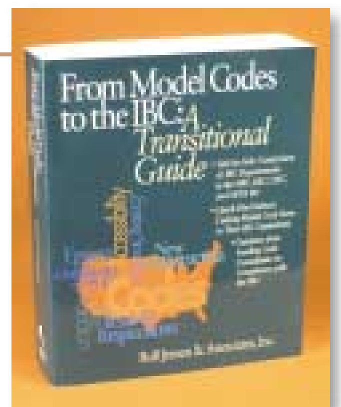
Structural Design for Fire Safety
Andrew H. Buchanan,
University of Canterbury, New Zealand

Presenting a comprehensive overview of the fire resistance of building structures, this text provides expert guidance on:

- Interpreting code requirements for fire safety
- Understanding the concepts of fire severity and fire resistance
- Estimating time-temperature curves for fully developed compartment fires
- Understanding the behavior of structural elements and buildings exposed to fires
- Designing steel, concrete, and timber structures to resist fire exposure
- Assessing the fire performance of existing structures

Published in 2001 by John Wiley and Sons.

Price: SFPE Member, $118.00; Nonmember, $150.00



From Model Codes to the IBC: A Transitional Guide
The IBC is different from every other building code you've ever referenced. This user-friendly, 900-page guide includes side-by-side comparisons of IBC requirements to the National Building Code (NBC), Standard Building Code® (SBC), the Uniform Building Code©®(UBC), and NFPA 101® Life Safety Codes. The guide also features a quick-find index linking model code items to their IBC equivalents. Published in 2001 by Protection Knowledge Concepts.

Price: SFPE Member, $91.99;

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Principles of Fire Behavior, James G. Quintiere, Ph.D.
Provides a comprehensive treatment of fire behavior for the firefighter, building official, investigator, and product manufacturer. Includes chapters on heat transfer, ignition, flame spread, fire plumes, heat flux, and other topics. Special sections on combustion products and compartment fires help readers understand principles of fire behavior in specific situations.

Price: SFPE Member, $49.00;

Nonmember, $60.95

The Technical Basis for Performance-Based Fire Regulations: A discussion of capabilities, needs, and benefits of fire safety engineering
In January of 2001, the United Engineering Foundation, in cooperation with SFPE, sponsored a conference in San Diego, CA, designed to further develop the SFPE Research Agenda for Fire Protection Engineering. Three keynote lectures and four focused sessions on current knowledge and research needs resulted in the next step in better defining the technical basis for performance-based fire regulations. The conference report, prepared by Geoff Cox, conference organizer, can be found at SFPE's Web site at www.sfpe.org.

Clean Agent Systems Video Series
This special hazards fire protection program compares the clean agent systems on the market today. The 4-tape program covers agent types and typical applications to NFPA and EPA regulations and maintenance guidelines. Published in 2001 by Protection Knowledge Concepts.

Price: SFPE Member, $249.00; Nonmember, $299.00

Design of Water-Based Fire Protection Systems, Robert M. Gagnon, P.E. This abundantly illustrated, step-by-step approach is a vital reference for every designer of fire protection systems. Hydraulic calculations of the most commonly encountered water-based fire protection systems are addressed in detail, and a disk is included. The latest technology in water-spray and water-mist systems is presented. Published in 2001 by Delmar Publishers.

Price: SFPE Member, $62.50;

Nonmember, $77.95

Design of Special Hazard and Fire Alarm Systems, Robert M. Gagnon, P.E. This is the most current guide to the design of state-of-the-art special hazard and fire protection systems. It provides information on a simplified methodology for calculating special hazard systems, with illustrations and solved examples in each of 15 chapters. Includes a chapter on ethical practice. Published in 2001 by Delmar Publishers.

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UPCOMING EVENTS

November 10-14, 2001
NFPA Fall Meeting
Dallas, TX
Info: www.nfpa.org

December 2-5, 2001
Symposium on Thermal Measurements: The Foundation of Fire Standards
Dallas, TX
Info: www.astm.org

December 3-6, 2001
5th Asia-Oceania Symposium on Fire Science & Technology
Newcastle, Australia
Info: http://www.eng.newcastle.edu.au/cg/AOSF-ST5/welcome.html

January 10-11, 2002
The 3rd International Forum on Safety Engineering and Science (IFSES III) Virtual Symposium
Info: http://hugoniot.chem.t.u-tokyo.ac.jp/IFSES3-1.htm

March 18-19, 2002
Structures in Fire
University of Canterbury,
Christchurch, New Zealand
Info: http://www.civil.canterbury.ac.nz

March 20-22, 2002
4th International Conference on Performance-Based Codes and Fire Safety Design Methods
Melbourne, Australia
Info: www.sfpe.org

May 19-23, 2002
NFPA World Fire Safety Congress and Exposition
Minneapolis, MN
Info: www.nfpa.org

UPCOMING EVENTS

BRAINTEASER

The difference between any two numbers in the set {2, 3, 4} is equal to their greatest common factor. The same is true of any two numbers in the sets {6, 8, 9, 12} and {8, 9, 10, 12}. Find a set of five numbers for which this is true.

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

Solution to last issue's brainteaser

Starting with the letter A, number the letters in the alphabet in order from 1 to 26. Using these values for the letters, find a word with the product of 69,888.

Answer: "Pump"

CORPORATE 100

The SFPE Corporate 100 Program was founded in 1976 to strengthen the relationship between industry and the fire protection engineering community. Membership in the program recognizes those who support the objectives of SFPE and have a genuine concern for the safety of life and property from fire.

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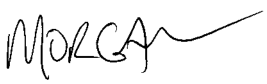
A Paradigm Change



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

Performance-based fire protection design requires doing many things differently than prescriptive-based design. Some of these differences are obvious; for example, the use of more sophisticated models and calculation methods and the amount of engineering analysis required. However, there is a key difference that is not always immediately obvious: the metric that an engineer uses to gage the acceptability of their own design.

In the case of prescriptive-based design, determination of what general design attributes constitute an acceptable level of safety is one step removed from the engineer. These determinations were made during the development of codes and standards and by governmental jurisdictions as they decided which codes and standards to adopt and what amendments, if any, to impose.

With such designs, a designer needed only to ensure that all attributes of a design fit within the minimums and maximums specified by a code or standard to determine if their design was acceptable. Similarly, from an enforcement standpoint, verification that a design complied with the code or standard was relatively straightforward. The engineer's final metric of success was frequently whether or not enforcement officials accepted the design.

However, with performance-based design, the attributes of an acceptable design are not as clearly stated. While an "acceptable level of safety" is still established through the development and adoption of codes and standards, the responsibility falls to engineers to specify a design that is acceptably safe – and to demonstrate why the design is sufficiently safe. Before asking enforcement officials to evaluate a design, the engineer should first prove to himself or herself that the design is safe. In fact, the engineer should be their own worst critic, as the engineer who prepared a design has the best perspective of whether or not the design provides an acceptable level of safety.

Models, correlations, and other engineering methods are often used during the development of a performance-based design to establish the design attributes and to verify that the design meets the performance criteria in the design fire scenarios selected. Each of these models and correlations will have a limited range of applicability. Similarly, input data that is used in the models or correlations will only have a limited range of applicability. Also all models, correlations, and data have some uncertainty associated with them.

There is nobody better suited to consider the applicability of the models, correlations, and data that is used in the development and evaluation of performance-based designs than the engineer that performed the analysis. While enforcement officials or third-party engineers may review a performance-based design, they will not consider the development of the design and the selection of methods and data as closely as the engineer who developed the design did.

No engineer would intentionally prepare a design that he or she knew did not provide an acceptable level of safety. In most cases when designing to prescriptive codes and standards, code compliance is sufficient to provide an acceptable level of safety. However, when using models or other engineering methods to develop or evaluate a performance-based design, an engineer must first evaluate the applicability, limitations, and inherent assumptions of the methods and data used to fully understand the level of safety provided.