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The Liquefied Natural Gas (LNG) Industry and Fire Protection Regulations

The evolution of passive fire protection and facility siting guidelines for LNG plants.
By Harri Kytomaa, Ph.D., P.E. and Trey Morrison, Ph.D., P.E., Exponent Inc.

How Much Dust is Too Much Dust?
Update on NFPA standards that address combustible dusts.

Industrial Fire Protection
Considerations for both new designs and existing facilities.
By Jonathan M. Eisenberg, P.E., Rolf Jensen & Associates, Inc.

Flammable & Combustible Liquids Hazards
Understanding liquid properties in order to formulate an effective prevention and mitigation strategy.
By David P. Nugent, Valspar Corporation

Applications of Fire Detection, Alarm and Signaling Systems in Industrial Occupancies
Configurations commonly used in industrial, factory, storage, and high-hazard occupancies.
By Robert P. Schifiliti, P.E., FSFPE, R.P. Schifiliti Associates, Inc. on behalf of NEMA
For several years, the Society of Fire Protection Engineers has promoted a set of “messages” that are intended to help raise the awareness of fire protection engineering and attract people into the profession. These messages include:

- Fire protection engineers are in high demand
- A career in fire protection engineering pays well, provides an opportunity for world travel, and gives the opportunity to work in a variety of work environments
- Fire protection engineers make the world a better place

These messages are largely targeted towards people – mostly younger people – who are considering a career choice. These messages identify some of the reasons why fire protection engineering makes such a great career.

Of course, there are other reasons as well. Some of these reasons will resonate more with older adults – people who are about the age of the parents of the people who are targeted by the three messages shown above. These messages resonate even more given the softness of the current global economy.

For one, even during the current economic climate, the unemployment rate among fire protection engineers is very low. When SFPE’s biennial profile of the profession was conducted last year, 5.5% of respondents in the U.S. indicated that they were unemployed at the time the survey was conducted. While this is far greater than the near-zero unemployment among fire protection engineers during better economic times, the rate is far lower than the overall unemployment rate in the U.S.

Presently, younger people have a higher unemployment rate than the whole population. According to the U.S. Congress Joint Economic Committee, one in five workers less than 25 years old was unemployed in 2010.\(^1\) Anecdotal information from schools in the U.S. indicate that graduates with degrees in fire protection engineering have little difficulty finding a job. The ability to easily find a job after graduation is one of the factors that college-aged people consider when making a career choice.

At the other end of the age spectrum, many older workers report concerns about age discrimination. According to the U.S. Department of Labor, the unemployment rate among older workers (aged 55 or older) was 7.1% in 2010.\(^2\) While this rate was below the unemployment rate for the whole U.S. population, older unemployed workers were found to have more difficulty finding a new job than younger workers, as measured by the median time that people who were unemployed were out of work.

Again, fire protection engineering offers a more promising outlook than other professions. While SFPE has not collected data in this area, anecdotal information suggests that older fire protection engineers do not experience the same difficulties with age discrimination that older people in some other professions do. As with any profession, keeping abreast of the state of the art keeps a professional more marketable throughout his or her career; this is just part of the job for fire protection engineers, where the codes and standards change on a regular basis.

Of course, both of these reasons further illustrate how the demand for fire protection engineers exceeds the supply. These are all good statistics to cite when speaking with people who are considering a career choice or parents of people who are considering a career choice.

References:

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

Fire Protection Engineering welcomes letters to the editor. Please send correspondence to engineering@sfpe.org or by mail to Fire Protection Engineering, 7315 Wisconsin Ave., Ste. 620E, Bethesda, MD 20814.
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“We are protected; we have automatic sprinklers at the ceiling.” Nice assumption but, unfortunately not always true. Automatic sprinklers can protect a wide range of occupancies. One only needs to look at NFPA 13, the annex of which contains numerous examples of the occupancy classes from light hazard to extra hazard.

But, there are times when automatic sprinklers are not sufficient to limit property damage or reduce the risk of a process to an acceptable level. Some equipment and processes may warrant additional levels of protection beyond what a sprinkler system alone can provide. In the early years of sprinkler system development, high-risk locations and hazards were identified as a result of a loss. Lessons learned from these events resulted in additional protection being provided on a go-forward basis, or as an immediate retrofit when risk was found to be particularly severe.

Nowadays, the fire protection engineering discipline has established robust techniques available to identify and evaluate hazards and risk. SFPE’s Engineering Guide to Fire Risk Assessment provides the framework for identifying hazards and quantifying risk. Another potential source for guidance is SFPE’s Engineering Guide to Performance-Based Fire Protection.

Hazard identification usually focuses on equipment and processes that represent a heat or ignition source or a fuel source. Once the hazards are identified, various protection options or scenarios can be contemplated. The next step is to estimate the risk of the various scenarios. Both the frequency and severity or consequence of the scenario influence the overall risk. The process of estimating risk can be an involved and time-consuming task. For example, the engineer is faced with obtaining or calculating frequencies and probabilities. And, in many cases, this data is not readily available in the public realm.

In the commercial property insurance industry, a fire hazards assessment is usually conducted in lieu of the fire risk assessment. With this, the uncertainties of whether a fire will occur or a system will operate are not explicitly addressed. Murphy’s Law is generally assumed to hold true – the first assumption is “anything that can go wrong, will go wrong.” Therefore, ignition is always assumed. The fire hazards assessment will typically include identifying the hazard(s) and exploring protection options. And, protection options are not limited to fire suppression. A wide range of improvements from system design changes to reduce the risk to installing safety interlocks to shut down equipment in a safer manner could be recommended.

In some cases, reductions in property damage and/or business interruption may be calculated to show the value of various protection options. Of course, with these cost-benefit estimates, the consequences are quantified but not the frequency. The type of extinguishing agent can also have a significant impact on property damage and business interruption. Some equipment may be more susceptible to damage by one extinguishing agent versus another. Also, potential extended clean-up issues from one suppression agent over another could result in a quantifiable increased interruption to business operations.

Looping back to the start of this article, we revisit the question, “When are ceiling-level sprinklers not enough?” Three such examples are included in reply:

- Equipment that is handling a combustible material and represents an inherent ignition source where ceiling sprinklers may be sufficient protection by “Code” but the lack of ignition source control results in an unacceptable risk (so, we do consider frequency after all). A classic example is a pneumatic conveying system requiring proper grounding and bonding to prevent the build-up of static electricity that could ignite the combustible materials being conveyed.

- Equipment containing combustible materials that are shielded from ceiling sprinklers, such as large ovens containing combustible materials.

- Equipment containing combustible materials of a type, quantity, or form that if ignited cannot be controlled by ceiling-level sprinklers, such as dip tanks containing flammable or combustible liquids, processes containing flammable gases or equipment or areas representing explosion hazards. This is where we get into some very serious hazards.

One of the more significant challenges in assessing industrial fire hazards is providing cost-effective solutions with a proven track record. No one wants to reinvent the wheel – it is just not that efficient. NFPA occupancy-based documents are a good source to find this information. And, of course, another source are those commercial property insurers who often have internal or external guidance to offer – much of which was literally vetted by paying the claims on actual fires.

Paul Hart and Bruce Clarke are with AIG.
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Standards Development Organizations File Lawsuit

Three standards development organizations (SDOs) – National Fire Protection Association (NFPA), ASTM International (ASTM), and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) – have filed a lawsuit against Public.Resource.org (Public Resource) to stop copyright infringement, ensure that the development of the codes and standards in the United States are done at the highest levels of excellence, and to protect public health and safety.

For more than a century, both the private-sector as well as government entities have relied on mission-driven, self-sustaining, independent, not-for-profit SDOs to develop “voluntary consensus standards.” The SDOs underwrite the substantial costs of developing standards, in whole or in significant part, by relying on revenues from the sales and licensing of their copyrighted standards. This funding model allows SDOs to remain independent of special interests and to develop up-to-date, high quality standards.

According to the SDOs, Public Resource has been copying and uploading copyrighted standards developed by private sector SDOs, without the copyright owners’ authorization. The lawsuit does not seek monetary damages from Public Resource or its founder. It seeks simply to stop the illegal posting of copyright protected materials.

NEMA Releases New Training Manuals

The National Electrical Manufacturers Association (NEMA) Section on Signaling Protection and Communications — comprised of fire and life safety industry experts — has released a library of application guides and manuals on fire detection, emergency communication, and life safety based on national fire and life safety codes and standards.

The manuals address advancements in fire detection, notification, and life safety such as intelligibility of emergency voice communication systems, carbon monoxide detection, multi-criteria fire detection, and new alarm communication methods, and provide an overview of the basics of life safety systems for those just entering this field.

For more information, go to nema.org.

Fire Hazards Associated With the Bulk Storage of Lithium-Ion Batteries

Commercial and industrial property insurer FM Global has completed the first-ever large scale fire tests of lithium-ion (li-ion) batteries in warehouse storage and released a research technical report describing the associated fire hazards and protection recommendations for rechargeable batteries.

Among the key findings:

- Li-ion batteries present several unique fire hazards when involved in a fire, due to an ignitable electrolyte liquid contained within such products.
- Densely packed li-ion cylindrical cells and polymer cells behave differently than li-ion power tool packs in such fires.
- When bulk stored in corrugated board cartons, early fire extinguishment and cooling of the li-ion batteries is imperitive to properly protect a facility.
- Existing protection solutions used for other types of high hazard products and materials can be effective for protecting li-ion batteries stored in bulk arrangements.

The complete scientific research findings are available in a downloadable technical report “Flammability Characterization of Lithium-Ion Batteries in Bulk Storage” at www.fmglobal.com/researchreports. Videos from three fire tests, which were part of the research, can be viewed on YouTube.
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Liquefied Natural Gas (LNG) facilities are constructed according to “Liquefied Natural Gas Facilities: Federal Safety Standards”¹ and regulated by the Federal Energy Regulatory Commission (FERC). FERC has worked closely with the Pipeline and Hazardous Materials Administration (PHMSA), part of the U.S. Department of Transportation (DOT), to provide interpretations and guidelines to meet these regulations. The U.S. federal regulations incorporate NFPA 59A,² which is a prescriptive standard. The objectives of the U.S. federal regulations and NFPA 59A are to keep the fire and explosion hazards onsite (i.e., within
the facility boundaries) in the event of a loss of containment event.

When liquefied, natural gas is a refrigerated cryogenic liquid that boils at -162°C. Spills of LNG from low-source pressures can be conveyed safely to impounding areas or a sump to minimize the size of resulting flammable vapor clouds as the cold liquid boils on the warmer ground. Pressurized releases may produce liquid sprays or flashing jets, which can create larger flammable vapor clouds.

In either case, natural gas vapor clouds are unlikely to produce damaging overpressures if ignited. There have been very few major incidents involving LNG terminals or shipping. The most severe incident occurred in Cleveland, Ohio, in 1944. A more recent incident occurred at the Skikda facility in Algeria in 2004 when the vapors of a flammable refrigerant release were ingested by a steam boiler. The flammable vapor cloud explosion killed 27 workers onsite.

NFPA 59A\(^2\) prescribes a series of 10-minute-duration design spills (also called single accidental leakage sources).
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not cross the property boundary that can be built upon.

Practically, the property boundary that can be built upon has been treated as the line beyond which the facility no longer has administrative control. In addition, the radiant heat flux from pool fires within impoundment areas must be shown not to exceed 5 kW/m$^2$ (1,600 BTU/hr ft$^2$) across this boundary. The areas within these boundaries are termed “exclusion zones” where the potential fire hazard exists, and the public cannot be exposed to this hazard.

FERC specifies that only passive mitigation strategies can be applied to meet the exclusion zone requirements and does not allow for active systems to be used to meet the criteria. Thus, shorter duration releases based on detection and emergency shutdown procedures have not been acceptable, even though NFPA 59A does address this option, and such technologies are widely used.

Many of the exclusion zone analysis requirements are stated broadly in NFPA 59A and require considerable interpretation for the spill and leak scenarios that need to be considered. Over the past decade, FERC has clarified its interpretation of the federal requirements by means of formal letters, less formal precedent-setting memoranda as well as data requests to specific projects requiring certain analyses to be performed. These interpretations continue to evolve over time, with the continual introduction of new analytical tools and new hazard criteria by FERC.

The 2013 edition of NFPA 59A and recent FERC interpretations, memos, and guidance have introduced risk-based analysis approaches that deviate from the original prescriptive approach in the 2001 edition of NFPA 59A. The new Chapter 15 “Performance
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Risk-based approaches such as QRA assign risk by aggregating the likelihood or probability of scenarios with the consequence in terms of injury or fatality of susceptible populations. QRA is required by the European code. FERC requires release scenarios to be selected according to FERC-generated generic failure rates without consideration for the consequence portion of the risk assessment.

FERC has also expanded the consequences to be analyzed to include vapor cloud explosion hazards of flammable refrigerant releases from liquefaction processes, which were not present in import terminals because they only vaporized LNG. Although the changes to the required analyses of fire hazards are complex, some change has been necessary due to the anticipated growth of the U.S. LNG liquefaction infrastructure. This article provides a brief background of changes in the LNG industry in the U.S. and the evolution of current passive fire protection and facility siting guidelines.

LNG IN THE U.S. BACK THEN: IMPORT TERMINALS

The North American LNG industry experienced a surge in growth in about 2003 when the industry believed that existing North American natural gas production was going to be overtaken by increasing demand from power generation, chemical feedstock applications, and domestic use. At that time, there were only four operating LNG import terminals to provide the gas supply: Cove Point, MD; Everett, MA; Elba Island, GA; and Lake Charles, LA.

The worldwide shipment of LNG
occurs via ocean-going tanker ships. Import terminals receive the LNG, store it in large cryogenic tanks, and vaporize it into the nation’s gas pipeline network. In 2004-2005, the need to import gas into the U.S. prompted a major effort to develop the terminal infrastructure to receive imported LNG.

At its peak, around 2006, dozens of terminals on the West, East and the Gulf Coasts sought to receive permits for construction. The first to be constructed was the Cheniere LNG terminal in Sabine Pass, LA, and others followed on the East and Gulf Coasts. Unfortunately for the owners, the expected gas demand did not materialize, causing many of the projects to stall and new terminals to remain underutilized.

### Import Terminal Fire Protection Considerations

During this time period, FERC applied the 2001 edition of NFPA 59A to identify single accidental release scenarios that needed to be analyzed as part of the application process. Two types of hazardous outcomes were analyzed: radiant heat flux from LNG pool fires and flammable vapor dispersion. LNGFIREIII is the PHMSA-approved software package for modeling LNG pool fires. The software calculates the radiation heat flux for LNG pool fires based on a prescribed surface emissive power (SEP) and a cylindrical flame geometry that is based on the impoundment area. FERC recently confirmed that this approach adequately represents the radiant heat from LNG pool fires based on recent large-scale LNG pool fire tests conducted by Sandia National Laboratories. LNGFIREIII remains the primary code for calculating heat flux, but the requirements for calculating vapor dispersion have undergone many changes.

In mid-2005, at a time when only import terminals were being considered on U.S. shores, FERC required evaluations of vapor dispersion from full cross-section pipe breaks at the tanker ship unloading line and from high-pressure flashing jets at small-diameter attachments to the transfer piping for instrumentation or pressure relief, at flanges, and at valves or other equipment connections. Based on these requirements, a wide variety of single accidental leakage sources, ranging from valve packing and flange leaks to full cross section ruptures of ship unloading lines, were analyzed by applicants in their FERC submittals.

The primary analytical tool used at that time for the analysis of vapor dispersion was the integral vapor dispersion model, DEGADIS. DEGADIS was used to compute the vapor dispersion from evaporating LNG that was spilled into sumps or impoundment areas. The practice was to calculate the source term based on a rate of evaporation.
that was determined by transient heat conduction from the concrete surface. This vapor source was then input into a code called SOURCE5 that accounted for vapor hold-up within the impoundment area. This gave a time delay and a rate of spill of vapors out of the impoundment area, which was input into DEGADIS to calculate the extent of the ½ LFL cloud.

**LNG IN THE U.S. TODAY: EXPORT TERMINALS**

Around 2010, industry began to develop plans for natural gas liquefaction facilities to export LNG as a result of the natural gas surplus from recent production of natural gas from shale formations. Many of the proposed liquefaction facilities were put forth by previously approved LNG import terminals, the first being Cheniere’s Sabine Pass terminal. It was followed by Freeport LNG and Cameron LNG, among others.

Previously, North America only had one LNG export facility. It was in Alaska on the Kenai Peninsula, approximately 100 km from Anchorage. The Kenai LNG plant began operating in 1969, and was recently taken offline.

Refrigeration processes and the associated plants that are used to liquefy natural gas are considerably more complicated than import regasification terminals. FERC’s limited experience with liquefaction and industry’s rush to develop this new infrastructure forced FERC and DOT (PHMSA) to re-evaluate their requirements. Over a period of two to three years, FERC issued a sequence of new interpretations for required fire and explosion hazard analyses. The most significant changes required a new approval methodology for vapor dispersion software tools, a new method of
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identifying single accidental leakage sources, and the introduction of vapor cloud explosion calculations for flammable refrigerants.

**IMPROVED VAPOR DISPERSION MODEL REQUIREMENTS**

An absence of consistent guidelines on the performance of vapor dispersion software prompted a study sponsored by the Fire Protection Research Foundation. The final report of this study proposed a formal process for the approval of analytical tools for vapor dispersion at LNG facilities. The resulting Model Evaluation Protocol (MEP) requires prospective models to be compared to a database of spill tests on ground and water, and associated vapor dispersion measurements that were conducted over the past decades. The National Association of State Fire Marshals (NASFM) commissioned an independent review of the MEP to assist local and state emergency response officials. This review in part concluded that the MEP was unnecessarily long and complex.

Four years after publication of the MEP, two commercial software products were approved by DOT (PHMSA) in 2011. These were the PHAST Version 6.6/6.7 and FLACS Version 9.1 computer codes. The MEP review process was elaborate, and it took considerable time for the respective software developers to compile their MEP cases and for the regulators to approve them. In addition to DEGADIS, these two software packages are approved for vapor dispersion analyses today.

PHAST is commercial software that uses the Unified Dispersion Model (UDM) to calculate vapor dispersion following a two-phase pressurized release or an unpressurized release. It models near-field and far-field jet...
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dispersion, droplet evaporation in the air, rainout (droplets hitting the ground), liquid pool spread, vaporization and subsequent heavy gas dispersion. These features have been essential for analyzing FERC-required pressurized LNG or liquid refrigerant jetting and flashing scenarios. PHAST only accounts for flat ground, and therefore cannot accommodate complex geometries such as tanks, buildings, and walls that are typically present at LNG facilities.

The FLACS software can model vapor dispersion scenarios and vapor cloud explosions in three dimensions. This CFD model discretizes the domain using a rectangular grid. FLACS has a routine called FLASH that can be used to model high-pressure jetting and flashing releases. It also contains a liquid spill model to calculate the spread of LNG or refrigerants over the ground. The model calculates heat transfer to the liquid and its evaporation. Currently, FLACS is the only model approved by FERC that can be used to model the vapor clouds resulting from liquid spills into trenches. FLACS also is the only approved model that can be used to determine the effect of structures and vapor fences on the flammable vapor cloud dispersion.

Currently, FLACS is the only model approved by FERC that can be used to model the vapor clouds resulting from liquid spills into trenches.
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The Latest Single Accidental Leakage Requirements

In 2010 and 2011, FERC’s single accidental leakage scenarios were prescriptive in that the hole size had to be chosen based on pipe size and later pipe length. These criteria were superseded in 2012 by the requirement that single accidental leakage sources be selected for analysis if the likelihood of failure is greater than $3 \times 10^{-5}$ failures per year. A detailed discussion of the criterion’s development and application is provided elsewhere.

FERC staff provided a table of yearly failure rates for piping and other equipment. All single accidental leakage sources that need to be considered are now selected based upon the length of the piping system and the resulting failure rate for a given hole size. Once selected, the scenarios are analyzed using the approved commercial software.

This latest change was a paradigm shift from a strict prescriptive approach to one that is based on a probabilistic criterion, even though the consequences remain prescriptive: the exclusion zones must remain within the boundaries of the facility. This paradigm shift constitutes a step closer towards the European Standard, which is entirely based on Quantitative Risk Analysis (QRA).

Vapor Cloud Explosion Hazards

Unlike LNG regasification-only facilities, liquefaction plants contain flammable refrigerants in significant volumes. Common refrigerants include chlorofluorocarbons, ammonium, carbon dioxide, and non-halogenated hydrocarbons. In most refrigeration cycles, the mixed refrigerant may include varying concentrations of nitrogen, methane, ethane, ethylene, propane, and iso-pentane.

Some of the refrigerants are generally more reactive than natural gas. That is particularly the case.
with ethylene, which can undergo vapor cloud detonation. As a result, refrigerants introduce the risks of vapor cloud explosions that did not previously exist with import terminals. The Jan. 19, 2004, Skikda Algeria liquefaction plant accident involved a refrigerant vapor cloud explosion that killed 27 workers.\textsuperscript{15}

NFPA 59A does not address this risk. FERC\textsuperscript{16} now requires applicants to analyze vapor cloud explosions associated with worst-case flammable gas releases, to identify the 1 psi (7 kPa) over-pressure boundary and to analyze the associated offsite consequences of 1 psi (7 kPa) and greater overpressures.

**Passive Mitigation Techniques**

Passive mitigation techniques that are often used to contain the \( \frac{1}{2} \) LFL cloud within the property include the following:

- Relocation of LNG and refrigerant storage and piping elements to increase the distance to the property boundary.
- Changes to the LNG and refrigerant flow design, by changing the size of piping, capacity and number of pumps, and process conditions. These can reduce the worst case release flow-rate.
- Changes to the refrigerant storage capacity and the amount of refrigerant that can be released.
- The use of vapor fences and other obstacles to contain the LNG and refrigerant vapor cloud during a release.

Terminals have adopted various vapor fence strategies in the past, including long and tall fences, placing fences near the source to reduce its momentum, as well as using short fences to increase turbulence and mixing the cloud with air.

In conditions where an impoundment area, sump, or conveyance trench is located near a property boundary, the extent of the vapor cloud from a spill into this area can be addressed by selecting a concrete mixture that has a low thermal conductivity. Cryogenic liquid spills on concrete evaporate due to heat conduction from the substrate to the cold cryogenic pool. This is the dominant mode of evaporation in the early stage when evaporation rates are at their highest. Therefore, by selecting low density, heat

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capacity, and thermal conductivity concrete, the $\frac{1}{2}$ LFL clouds can be shortened considerably.

**Harri Kytomaa and Trey Morrison** are with Exponent, Inc.

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8. SOURCES, Trinity Consultants, Dallas, TX, 2004.
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HOW MUCH
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Recently, the NFPA standards that deal with combustible dusts have been going through significant revisions. The interest in these documents has been spurred by a number of large-loss incidents in the recent past and the reaction by federal regulatory agencies. The respective technical committees have worked to develop criteria in their standards that address these hazards.

The first revision was to move the recommended area limitations when using the prescriptive dust layer depth criteria in NFPA 654 and NFPA 664 from the annex of each standard into the body of the standard, making them mandatory. The second was the introduction of a calculated maximum permissible mass of dust for a compartment based upon the deflagration metrics of the dust and the compartment dimensions.

**THE INCLUSION OF AN ENFORCEABLE AREA LIMITATION**

The 2006 edition of NFPA 654 had an accumulated dust layer criterion that read:

6.2.3.1 When separation is used to limit the fire or dust explosion hazardous area, the hazardous area shall include areas where dust accumulations exceed 1/32 in. (0.8 mm) or areas where dust clouds of hazardous concentrations exist, unless otherwise permitted by 6.2.3.2.

6.3.2.3 The requirement of 6.2.3.1 shall not apply to dust accumulations with a bulk density less than 75 lb/ft$^3$ (1,200 kg/m$^3$) where the allowable thickness can be prorated by the following equation:

$$\text{Allowable thickness (in)} = \frac{(1/32)(75)}{\text{bulk density (lb/ft}^3)}$$

The requirements in this section were essentially the same as those initially adopted in the 1997 edition. This section was used as the basis for determining where there was a hazard of propagating...
deflagration (“flash fire”) through the building interior, triggering the requirement to manage that hazard. The annex text directed the user to Annex D, which provided a rough calculation that was used to support the recommendation that the dust accumulation should not exceed 5% of the floor area or 1,000 ft², whichever is smaller.

Similar language and calculations were used in the 2007 edition of NFPA 664. The Technical Committee on Wood, Paper and Cellulosic Materials, which is responsible for NFPA 664, arrived at a 1/8-inch (3 mm) dust layer criterion as its trigger for hazard management. If one corrects for the differences in the bulk density and the net heats of combustion for the “bounding value” combustible dusts addressed in each standard, the two standards permitted similar energy density per unit area of accumulation.

These requirements in the body of the standard and the recommendations in the annex have been in each standard for a number of revision cycles, initially appearing in the 1997 edition of NFPA 654 followed by the 1998 edition of NFPA 664. Consequently, there was a 14-year time period during which loss history suggested that the language in the standard was working. There were no dust deflagration events known to the technical committees where a facility complied with the requirements of the standard yet suffered a propagating deflagration or “flash fire” through the facility interior.

During the 2013 revision cycle for NFPA 654, the area limitation was moved into the body of the text via a “Tentative Interim Amendment.” The same area limitation was incorporated into the revised text for the 2012 edition of NFPA 664. The justification for these changes was based on the permissible dust mass calculation used in the “mass method” proposed for the 2013 edition of NFPA 654.

The area limitations increase the conservatism of each standard. In 1983, FM published “Dust Explosion...”

<table>
<thead>
<tr>
<th>Loss Incident</th>
<th>Reported Dust Layer, in (mm)</th>
<th>Particulate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malden Mills</td>
<td>6 – 12 (150 – 300)</td>
<td>Flock fiber</td>
</tr>
<tr>
<td>Jahn Foundry</td>
<td>4 – 6 (100 – 150)</td>
<td>Phenolformaldehyde resin</td>
</tr>
<tr>
<td>Hayes-Lemmerz</td>
<td>2 (50)</td>
<td>Aluminum dust</td>
</tr>
<tr>
<td>West Pharmaceuticals</td>
<td>3 – 5 (70 – 130)</td>
<td>Polyethylene powder</td>
</tr>
<tr>
<td>Deltic Lumber</td>
<td>4 (100)</td>
<td>Wood dust</td>
</tr>
<tr>
<td>Imperial Sugar</td>
<td>4 – 12 (100 – 300)</td>
<td>Sugar</td>
</tr>
<tr>
<td>Hoeganaes-Riverton, NJ</td>
<td>2 – 4 (50 – 100)</td>
<td>Iron dust</td>
</tr>
</tbody>
</table>

Table 1. Dust Layer Data for Recent Large-Loss Dust Explosions (Data from the author’s reconstruction project files)
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Propagation In Simulated Grain Conveyor Galleries.\textsuperscript{3} This research showed that very small dust accumulations, smaller than those permitted by the NFPA standards, could propagate a flame front in simulated grain elevator galleries. However, the authors of that research cautioned that the results should not be extended to other compartment geometries, and a number of other variables had not been studied.

A survey of some large loss incidents suggests a different problem. Table 1 shows the reported dust layers extant immediately prior to the explosion.

These losses occurred where the dust layers are orders of magnitude thicker than that permitted by either NFPA 654 or NFPA 664, even before the area limitations were introduced. But, in each case, the thickness of the accumulated fugitive dust layer was substantially greater than the layer thicknesses permitted by the relevant standard (with the exception of those facilities falling under NFPA 61\textsuperscript{4}, which has no dust layer criterion).

This loss history suggests that the dust layer thickness at which a propagating deflagration or “flash-fire” becomes a likely possibility is some thickness between the former prescriptive layer thickness criteria in the relevant standards and the thicknesses shown in Table 1.
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PERMISSIBLE DUST MASS CALCULATION

For the 2013 revision of NFPA 654, the technical committee responsible for the standard adopted a permissible alternative to the prescriptive layer depth criterion. The alternative was based upon relations for determining the maximum permissible dust mass for a building compartment before that compartment had to be designated either an “explosion” or a “flash fire” hazard. Different equations were derived for the two different hazards.

The general form of the equation for explosion hazard is:

\[ M_e = \frac{P_{es}}{P_{max} DLF} \left[ C_w AH \right] \frac{1}{\eta_D} \]

Where:

- \( M_e \) = permissible dust mass, kg
- \( P_{es} \) = compartment enclosure strength, bar
- \( DLF \) = dynamic load factor (1.5)
- \( C_w \) = concentration at which \( P_{max} \) is attained, kg/m\(^3\)
- \( P_{max} \) = maximum deflagration pressure, bar
- \( A \) = compartment area, m\(^2\)
- \( H \) = compartment height, m
- \( \eta_D \) = entrainment efficiency factor (0.25)

This relation was derived from the partial volume deflagration relation in NFPA 68.\(^5\) The objective of this relation is to predict at what dust loading the building structural integrity becomes at risk. The relation yields the quantity of dust sufficient to exceed the strength of the weakest element of the building compartment enclosure, presuming a worst-case concentration throughout
the compartment interior. It assumes that only a fraction (25%) of the accumulated dust is suspended from the accumulation layers.

The general form of the relation for the “flash fire” case is:

$$M_f = p C_w \left( \frac{P_i}{P_{\text{max}}} \right) \frac{AD}{\eta D}$$

Where:
- $M_f$ = permissible dust mass, kg
- $p$ = probability of flame impingement, (5%)
- $P_i$ = initial pressure during ASTM E 1226 test
- $D$ = height of a person, 2.0 m

This relation is derived from the Annex D calculation in the 2006 edition of NFPA 654. The objective of this relation is to calculate the fraction of the building interior that will be occupied by both a deflagration flame front and a person. It...
also assumes that only a fraction (25%) of the accumulated dust is suspended from the accumulation layers.

Recent dust explosion losses can be reviewed to analyze these correlations. Deltic Lumber was a planer mill, running kiln-dried softwood lumber. The building was approximately 200 ft. (60 m) by 240 ft. (70 m) with a ceiling height of approximately 24 ft. (7.3 m).

From this author’s investigation of the event, the accumulated fugitive dust layer was approximately 4 in. (100 mm) deep near the planer and diminished to almost none at the opposite side of the building. Using an average of 2 in. (50 mm) for the calculations, the NFPA 654 mass method yields a permissible dust mass of 100 kg for the explosion scenario and the “flash-fire” scenario.

Converting these masses to an average accumulation depth over the building floor yields a thickness of approximately 0.08 mm (0.003 in.). These layer depths are two orders of magnitude smaller than the prescriptive layer depth criterion that has been in NFPA 654 from 1997 through 2012. The building suffered a loss of approximately 5% of its surface covering, even though it exceeded the accumulated dust load sufficient for building “explosion” by a factor of approximately 1,000. The deflagration impinged on two of the 12 employees in the building.

A second case is the explosion at Hayes-Lemmerz, Huntington, IN. The building area involved was approximately 100 ft. (30 m) by 75 ft. (23 m) with a ceiling height of approximately 24 ft. (7.3 m). From this author’s investigation of the event, the dust accumulations were reported by witnesses and survivors to be approximately 2 in. (50 mm) deep on the tops of the equipment, lights, roof support beams, ducts, and piping.

Assuming that the accumulation area was 25% of the floor area due to the nature of the facility, the NFPA 654 mass method yields a permissible dust mass of 20 kg for the explosion scenario and 13 kg for the “flash-fire” scenario. By converting these masses to an average accumulation depth for the building surfaces that were accumulating dust, one yields thicknesses of 0.1 mm (0.004 in.) for the explosion scenario and 0.07 mm (0.003 in.) for the “flash-fire” scenario. These layer depths are a full order of magnitude smaller than the prescriptive layer depth criterion that has been in NFPA 654 from 1997...
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through 2012. The building envelope was ruptured over approximately 10% of its area.

Similar results are obtained when the explosions at Jahn Foundry and Malden Mills are considered. Indeed, applying the bulk density of commonly encountered particulates to the example calculation in the current Annex D of NFPA 654 and applying that volume of dust over the entire compartment area, one obtains layer depths that are on the order of 0.1 mm (0.004 in.) to 0.2 mm (0.008 in.). Again, these values are approximately an order of magnitude more stringent than the prescriptive layer depth criteria.

POSSIBLE SOURCES OF ERROR

One possible issue is the 25% entrainment fraction that is used. Possible variables are whether the entrainment fraction is uniform for all materials, whether it stays the same over time and space, and over variations in environmental conditions such as temperature and humidity. The calculations assume that the entire entrainable fraction will be entrained at the same time. The calculation assumes adiabatic conditions, but the deflagration flame will lose heat to the building structure and all the equipment housed within it.
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From the above, there seems to be a case for questioning whether the validation inadvertently overlooked some factors in the course of developing these new criteria for the new dust standards.

John M. Cholin is with J.M. Cholin Consultants, Inc.

References:


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When starting out on an industrial facility project, there are questions to ask to get the “lay of the land.” One of the first pieces of information to learn is the process description – starting with the incoming raw materials (how they are delivered, stored, and transferred into the batch or continuous process areas of the facility).

The next step of the study of the process is to understand the conditions. Possible hazards stem from how the raw materials are stored and transferred to the manufacturing process, whether the process is a chemical synthesis or simply a mixing process, the temperature and pressure conditions, the duration of the process and what role the operations staff plays. Other factors to consider include whether there is a purification or drying step, how the final product is packaged and stored, and how the finished goods are stored.

It is important to develop an understanding of the unit operations and processes at the facility. This includes a study of process & instrumentation
diagrams (P&IDs) as well as narrative process descriptions. A full listing of the hazardous materials—with chemical names, solution concentrations, and container sizes and types—is essential to begin the analysis.

**CODES & STANDARDS**

Many codes and standards on the industrial/chemical side contain applicable requirements and valuable information. One of the roles of the FPE is to identify the applicable codes and standards for a specific industrial process and help a facility operator understand how they apply to a certain situation.

The applicable codes for industrial/chemical facilities contain requirements that connect directly with an understanding of the engineering basis for manufacturing processes and facility design. An existing facility may not be able to implement all of the applicable requirements immediately or even in the first year after a survey or audit. One of the most important tasks when analyzing an industrial facility is to help categorize recommendations into priorities so facility managers can put together a compliance plan. Relevant factors that may influence the compliance plan include the source of the requirement (e.g., code, standard, or underwriting requirement), how the requirement applies to the specific site condition, and recommended options and solutions.

Underwriting requirements also can have a significant impact on the design and operation of an industrial operation. The FM Global datasheets provide requirements for many types of industrial facilities. Underwriting requirements are often a good source of information for a specific hazard or type of industrial process and augment the available codes and standards.

**FM Global Datasheets 7-44** and **7-91** contain technical information that can be utilized during the design process. For example, a site layout that includes a chemical process will have specific set-back and separation distance requirements based on the hazard involved. Similarly, a hydrogen storage and dispensing installation can turn to the FM Global recommendations and loss history to address certain hazard concerns, such as exposure to adjacent equipment and protection of process piping systems. Local fire officials often put confidence in underwriting requirements as an aid to their understanding and level of comfort that a complex industrial or chemical process is being adequately reviewed.
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FIRE SUPPRESSION AND DETECTION SYSTEMS

There are several factors to consider when designing a fire suppression or detection system in an industrial facility. Many facilities have multiple chemical processes that may each have a different set of hazard criteria. What this means is that the fire suppression and detection system design approaches for adjacent areas in a plant may be different.

It is necessary to be aware of these conditions and take care not to specify a system that may interfere with the effectiveness of a nearby system. Also, one may deal with classes of materials that are incompatible.

For example, a process enclosure containing water-reactive materials may be adjacent to a process that handles pyrophoric gases. The protection schemes for these two processes are quite different. It may be necessary to protect the water-reactive process enclosures with CO₂ and simultaneously cool adjacent outdoor pyrophoric-containing equipment with water spray.

The suppression approach and agent should be developed by considering the compatibility of materials in storage and in open or closed process equipment. The Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities³ provides information on fire suppression and detection approaches for an industrial site.

The initial step in the evaluation of hydraulic demand for an industrial plant is a hazard analysis of the materials being stored and processed. For water-based fire suppression systems, the hazard analysis provides an estimate of the size of the site fire water loop, as well as any fire pumps and fire water storage tanks.

New technologies in fire detection/suppression systems provide additional options. There are more gas and flame detectors available than in the past, which enables the fire protection engineer to specify additional methods for detection of gases.

Also, for some of the water-reactive chemicals, compatible automatic suppression systems are now available.

Lastly, technologies such as water mist suppression are an addition for facilities that need to contain and treat sprinkler discharge. For example, bio-containment facilities require drainage of sprinkler discharge to a biological “kill” system in the building prior to discharge to the municipal sewer.⁴

The use of alternate fire suppression agents can require a performance-based analysis that compares the combustible loading in the process area against the performance of the suppression system. Biosafety in Microbiological and Biomedical Laboratories (BMBL)⁴ includes guidelines for fire protection system design in bio-containment facilities.

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For example, a facility that handles pyrophoric gases will likely require a Group H-2 occupancy classification per the International Building Code (IBC). The corresponding fire resistance of the building will be impacted. The best suppression method is often to shut off the gas flow via an interlock with a gas and flame detection system.

Raw material solvent distribution and waste collection systems are becoming more commonplace, even in laboratory buildings. Fire protection considerations for such installations include leak detection for transfer piping and organic vapor (LEL) detection at the point of use, as well as static discharge concerns. Considerations that should be addressed include the rate of transfer of the flammable liquid, the propensity to create a static charge, how the static charge could be equalized and dissipated, and what type of pump or inert gas will be used.

A plant with a bulk combustible liquid process may need a foam/water suppression system for both external (monitors) and internal tank protection (foam pourers). The analysis should look at conditions such as the chemical composition and physical properties of the process fluids and the type of fire events that could occur. An understanding of the process chemistry and operating conditions is necessary for sizing and placement of equipment such as external tank monitors, internal nozzles or pourers, and detection devices.

VENTILATION SYSTEMS

Ventilation systems may be needed for industrial facilities. They provide a controlled working environment for the plant operations staff and minimize the risks to exiting occupants in a spill, release, or fire event. To this end, there are often requirements for dedicated exhaust systems from certain areas, with limitations on the routing of the exhaust to the outdoors. Also, some process areas may need low elevation supply and exhaust to get a complete air change for vapors that are heavier than air.

A fire hazard analysis, such as calculation of flammable vapor concentrations in dispensing and processing areas, can also be performed. The industry standard is to remain below 25% of the lower explosive limit (LEL). However, facility constraints may result in scenarios where concentrations can exceed 25% of the LEL. For example, certain pharmaceutical processes require re-circulation of the room exhaust to maintain area cleanliness levels. Calculation of the vapor concentration with exhaust recirculation can be done and may indicate that 25% of the LEL will be exceeded. This may be acceptable, provided that an explosion prevention method is employed. Possible approaches could include LEL detection interlocked with a purge exhaust rate. Discussions with facility staff are needed, so there is agreement on alarm and interlock points, as well as emergency evacuation and fire department response.

Features such as real-time exhaust monitoring can automatically alert the facility staff to a chemical release or loss of ventilation, initiate their emergency response, and log the data and time to help determine the cause of the event.

ELECTRICAL AND POWER SYSTEMS

One of the most common discussions in industrial facility design concerns the electrical and power
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There should be a clear agreement on what systems should be on emergency or standby power, and for how long. It may be necessary for both supply and exhaust to be on emergency power to allow for continuous air circulation and to meet door opening force requirements. If only the exhaust is on the emergency generator, the reduction of vapor concentration will be limited, and egress could be difficult.

Industrial plants have many hazardous electrical classification challenges, where equipment may not be procured as Class I or II, Division 1 or 2, and meet the requirements of the National Electrical Code. NFPA 497 and NFPA 499 are valuable tools that are used to delineate the extent of electrically classified areas. NFPA 496 is another reference for purged or pressurized enclosures, such as control rooms on the interior of a plant.

**CONTROLS AND INTERLOCKS**

Every industrial facility has many special detection devices, alarms, and interlocks. The key is to understand and document how the controls and interlocks will function and what will occur when they are activated. Documentation should address the alarm points, who responds to an alarm, the response procedure, whether the entire facility should be evacuated and, if so, whether workers need to secure processes and hazardous materials prior to leaving the building.

Detection and controls need to correspond to the specific hazard. For example, if one specifies a flame detector and interlocks for hydrogen dispensing, the detector must be capable of seeing the hydrogen flame in the UV/IR spectrum.

As a followup to industrial fire protection design work, a site visit is often conducted to review controls and interlocks and verify that they meet the requirements of the initial hazard analysis and specialty code review. It is good practice for the fire protection engineer to witness the acceptance testing of these systems and confirm that they are consistent with the sequence of operations and performance that were recommended.

Jonathan M. Eisenberg is with Rolf Jensen & Associates, Inc.

References:
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Managing hazards associated with flammable and combustible liquids requires a comprehensive strategy tailored to the conditions of their use. While preventive measures, such as spill prevention and ignition control, should receive the utmost attention, measures to mitigate fires and explosions should also be addressed. A strategy relying solely on prevention could be ineffective as unforeseen circumstances may arise.

The primary objective should minimize the life safety risk associated with the use of these materials. Other secondary consequences, such as environmental exposure, business interruption, and property damage, should also be factored into the strategy. This strategy should consider various scenarios, such as the potential for static pool fires, two dimensional flowing fires, three dimensional spill fires, as well as pressurized or spray fires. Also, explosions can result from combustion of vapors in either a confined or unconfined setting.¹
Measures to prevent and mitigate incidents can include various engineering and administrative controls. As a general rule, engineering controls, both passive and active, are preferred over administrative controls as they reduce the human factor. However, both are necessary as part of an overall protection strategy. There are many codes, standards, and guidelines that offer recommendations or requirements for these controls.²,³,⁴,⁵,⁶,⁷

**INHERENT HAZARD**

Flammable and combustible liquids possess a range of physical, ignition, combustion, and reactivity properties that define the hazards of these materials. Some of these properties can also affect the ability to control or extinguish fires. Additionally, these hazards can be magnified when these liquids are subjected to elevated temperature and/or pressure and are handled in large volumes.

When compared to ordinary materials, such as wood, paper, and plastic, the properties of flammable and combustible liquids require extraordinary measures to prevent and mitigate fires and explosions. A complete understanding of these properties is essential before effective loss prevention and mitigation strategies can be implemented.

It should be noted that a number of important risk-related
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properties are not typically included in Material Safety Data Sheets (MSDS). Other references are required to obtain this data.

IGNITION PROPERTIES AND LIQUID CLASSIFICATION

The most common method to classify liquids is the "closed cup" flash point, and for some materials, also boiling point. Flash point is the minimum temperature of a liquid at which sufficient vapor is given off to form an ignitable mixture with air. When ignited, it will produce a flash fire, but not necessarily continuous flaming combustion over the surface of the fuel sample.

There are a number of hazard classification systems and associated definitions in use for flammable and combustible liquids. This includes the UN Globally Harmonized...
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System of Classification and Labeling of Chemicals (GHS)\(^2\) and NFPA 30.\(^3\)

The NFPA 30 classification system is as follows:

**Flammable Liquid**
- **Class IA** – Flash Point < 73 °F (22.8 °C) & Boiling Point < 100 °F (37.8 °C)
- **Class IB** – Flash Point < 73 °F (22.8 °C) & Boiling Point ≥ 100 °F (37.8 °C)
- **Class IC** – Flash Point ≥ 73 °F (22.8 °C) & < 100 °F (37.8 °C)

**Combustible Liquid**
- **Class II** – Flash Point ≥ 100 °F (37.8 °C) & < 140 °F (60 °C)
- **Class IIIA** – Flash Point ≥ 140 °F (60 °C) & < 200 °F (93 °C)
- **Class IIIB** – Flash Point ≥ 200 °F (93 °C)

Table 1 lists ignition properties for a sample of flammable liquids and is sorted from lowest flash point to highest. Properties associated with electrostatic ignition include electrical conductivity, minimum ignition energy (MIE), and charge relaxation times. The auto ignition temperatures (AITs) are also shown.

Flash point is not an indicator of the risk associated with an electrostatic ignition or auto ignition. For example, acetone has a lower flash point than heptane. However, heptane has a longer charge relaxation time and lower auto ignition temperature than acetone. Acetone is also more conductive than heptane\(^1\),\(^4\),\(^7\),\(^9\).

NFPA 77\(^5\) defines a liquid as conductive if its conductivity is greater than 10,000 picoSiemens (pS) per meter, semi-conductive if its conductivity is between 50 and 10,000 pS/m, and nonconductive if its conductivity is less than 50 pS/m.

<table>
<thead>
<tr>
<th>Material</th>
<th>NFPA Class</th>
<th>Flash Point °F (°C)</th>
<th>Boiling Temperature °F (°C)</th>
<th>Electrical Conductivity (pS/m)</th>
<th>MIE (mJ)</th>
<th>Charge Relaxation Time (s)</th>
<th>Auto Ignition Temperature °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diethyl Ether</td>
<td>IA</td>
<td>-49 (-45)</td>
<td>95 (35)</td>
<td>30</td>
<td>0.29</td>
<td>1.4</td>
<td>356 (180)</td>
</tr>
<tr>
<td>Acetone</td>
<td>IB</td>
<td>-4 (-20)</td>
<td>133 (56)</td>
<td>6 x 10(^6)</td>
<td>0.19</td>
<td>3.2 x 10(^-5)</td>
<td>869 (465)</td>
</tr>
<tr>
<td>Heptane</td>
<td>IB</td>
<td>25 (-4)</td>
<td>209 (98)</td>
<td>&lt; 1 x 10(^1)</td>
<td>0.2</td>
<td>~ 100</td>
<td>399 (204)</td>
</tr>
<tr>
<td>Isopropyl Alcohol</td>
<td>IB</td>
<td>53 (12)</td>
<td>181 (83)</td>
<td>3.5 x 10(^8)</td>
<td>0.53</td>
<td>5 x 10(^-7)</td>
<td>750 (399)</td>
</tr>
<tr>
<td>Ethyl Alcohol</td>
<td>IB</td>
<td>55 (13)</td>
<td>173 (78)</td>
<td>1.35 x 10(^5)</td>
<td>0.23</td>
<td>1.6 x 10(^-3)</td>
<td>685 (363)</td>
</tr>
<tr>
<td>Styrene Monomer</td>
<td>IC</td>
<td>88 (31)</td>
<td>295 (146)</td>
<td>10</td>
<td>—</td>
<td>2.2</td>
<td>450 (232)</td>
</tr>
</tbody>
</table>

Table 1. NFPA Classification & Various Ignition Properties\(^4\),\(^7\)
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Liquids being at an elevated temperature can also be ignited when their temperature reaches the auto ignition temperature (AIT) and are released into the atmosphere.

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than 50 pS/m. Thus, diethyl ether, heptane and styrene are considered non-conductive, as are other hydrocarbons.

Heptane will not readily dissipate an accumulated electrostatic charge unless treated with an anti-static additive or a sufficient amount of time has passed, as indicated with its charge relaxation time. It is important to understand all these properties as they relate to the conditions of use and not rely solely on flashpoint. Depending on circumstances, flash point alone might not be the most significant measure of ignition risk.

Electrostatic discharges have been implicated as the ignition source in many fires and explosions. However, this potential source of ignition is not always apparent nor is it always understood. The minimum ignition energies for the liquids in Table 1 range from 0.19 mJ to 0.53 mJ. The energy level where a person may feel an electrostatic discharge, around their home for example, is approximately 1 mJ.\(^7\)

Another important parameter is the fire point, which can be equal to or just slightly above the flashpoint of some liquids. As defined by NFPA 30,\(^3\) the fire point is “the lowest temperature at which a liquid will ignite and achieve sustained burning when exposed to a test flame in accordance with ASTM D 92, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester.”\(^10\) Liquids that have a flash point and not a fire point are excluded from certain provisions in NFPA 30.
Liquids being at an elevated temperature can also be ignited when their temperature reaches the auto ignition temperature (AIT) and are released into the atmosphere. As defined by ASTM E659, 11 auto ignition temperature is “the ignition of a material, commonly in air, as the result of heat liberation due to an exothermic reaction in the absence of an external ignition source, such as spark or flame.”

Process conditions where flammable or combustible liquids are used under pressure also should be understood. Atomization of an ignitable liquid through an inadvertent leak will lower the effective flash point. This atomization produces an aerosol cloud having an effect as if the vapor pressure of the material were increased. A liquid considered as combustible at atmospheric pressure could behave as flammable if a sufficient ignition source were present near a spraying or misting discharge. 4

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity (Water = 1)</th>
<th>Water Solubility</th>
<th>Flammability Range LFL – UFL (% by vol.)</th>
<th>Heat of Combustion Btu/lb. (kJ/g) (Net)</th>
<th>Self-reactive or Unstable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diethyl Ether</td>
<td>0.7</td>
<td>No</td>
<td>1.9</td>
<td>36</td>
<td>Yes</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.8</td>
<td>Yes</td>
<td>2.5</td>
<td>12.8</td>
<td>No</td>
</tr>
<tr>
<td>Ethyl Alcohol</td>
<td>0.8</td>
<td>Yes</td>
<td>3.3</td>
<td>19</td>
<td>No</td>
</tr>
<tr>
<td>Heptane</td>
<td>0.7</td>
<td>No</td>
<td>1.0</td>
<td>6.7</td>
<td>No</td>
</tr>
<tr>
<td>Isopropyl Alcohol</td>
<td>0.8</td>
<td>Yes</td>
<td>2.0</td>
<td>12.7</td>
<td>No</td>
</tr>
<tr>
<td>Styrene Monomer</td>
<td>0.9</td>
<td>No</td>
<td>0.9</td>
<td>6.8</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2. Physical, Combustion & Reactivity Properties 1, 4
Xerxes Corporation is North America’s leading manufacturer of fiberglass storage tanks with over 200,000 installed. Designers, installers and owners of fire-protection systems are increasingly recognizing that fiberglass underground storage tanks are ideally suited for storage of standby water.

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The water solubility of these liquids is also indicated. Water dilution of a burning liquid from a sprinkler system may not be an effective means to mitigate a fire as too much water may be required. However, blends consisting of flammable or combustible liquids and water do present a lower risk than when pure materials. The flash point and fire point of a water-diluted flammable or combustible liquid will increase and the heat of combustion would be reduced.

It is also worth noting the differences in heat of combustion between the listed materials. Acetone and the alcohols have approximately 65% of the energy potential of hydrocarbons. For ignition of a flammable vapor to occur, the vapor concentration must be within the flammability range. For example, styrene monomer has a lower flammable limit (LFL) of 0.9 % and an upper flammable limit (UFL) of 6.8 %. These flammable limits are defined as the concentration of vapor in air that can support combustion of the vapor.

If ignition of a flammable atmosphere were to occur, mixtures slightly above stoichiometric would prove to be most energetic and have the lowest minimum ignition energy (MIE). The MIE is the minimum electrical energy necessary to ignite a vapor within the flammable limits of a given vapor. It should be noted that these limits apply to mixtures with air. If replaced with oxygen, it would substantially raise the UFL.

Another property unique to styrene is its ability to undergo exothermic self-reactivity. This reactive monomer can undergo a violent self-reaction or polymerization generating sufficient heat and pressure to burst process vessels or storage containers. Phenolic inhibitors are added to monomers to retard self-reactivity. These inhibitors must be
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<table>
<thead>
<tr>
<th>Material</th>
<th>Organic Family</th>
<th>Water Solubility</th>
<th>Minimum Application Rate or Density gpm/ft.² (mm/min)</th>
<th>AR-AFFF Foam-Solution % Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>Ketone</td>
<td>Yes</td>
<td>0.34 (1.4)</td>
<td>3%</td>
</tr>
<tr>
<td>Isopropyl Ether</td>
<td>Ether</td>
<td>Slightly</td>
<td>0.30 (12.2)</td>
<td>3%</td>
</tr>
<tr>
<td>Isopropyl Alcohol</td>
<td>Alcohol</td>
<td>Yes</td>
<td>0.29 (11.9)</td>
<td>3%</td>
</tr>
<tr>
<td>n-Butyl Acetate</td>
<td>Ester</td>
<td>Partially</td>
<td>0.26 (10.4)</td>
<td>3%</td>
</tr>
<tr>
<td>Ethyl Alcohol (Denatured)</td>
<td>Alcohol</td>
<td>Yes</td>
<td>0.24 (9.8)</td>
<td>3%</td>
</tr>
<tr>
<td>Heptane</td>
<td>Hydrocarbon</td>
<td>No</td>
<td>0.22 (9.0)</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table 3. Foam-Water Extinguishing Data for Representative Flammable Liquids

---

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maintained at certain concentrations and may need to be replenished as they are consumed over time.

If nitrogen is used to inert the vapor space above the liquid, the presence of dissolved oxygen above a minimal level is required for effective inhibition.

**FIRE CONTROL AND EXTINGUISHMENT**

Water can be used to control flammable and combustible liquids fires under certain conditions. However, foam-water is more effective as it has the ability to extinguish pool fires. An aqueous film-forming foam (AFFF) can be used with hydrocarbons, and an alcohol-resistant aqueous film-forming foam (AR-AFFF) is required for polar or water soluble flammable and combustible liquids.

The ability to extinguish flammable and combustible liquid pool fires with foam-water is a function of certain liquid properties. An example of this behavior can be illustrated when reviewing minimum application rates of foam-water on various pool fires.

Spray sprinklers are commonly used to discharge foam-water on flammable and combustible liquid fires. For example, Table 3 lists the minimum application rate or density for foam-solution per the UL Fire Protection Equipment Directory using K 8 (115) spray sprinklers. This data is developed using the UL 162 test protocol. It utilizes a 50 ft.² (4.6 m²) pan fire, and spray sprinklers deliver foam-solution directly onto a burning liquid pool.

Acetone, a water soluble ketone, requires a higher minimum application rate or density than heptane, a
hydrocarbon. Also, as with the other partially oxygenated hydrocarbons, acetone requires a 3% foam-water concentration whereas 1% is sufficient for heptane. The water soluble or polar materials are destructive to the foam layer blanketing the burning pool, thereby rendering them more difficult to extinguish.

David P. Nugent is with Valspar Corporation.

References:
5 NFPA 77, Recommended Practice on Static Electricity, National Fire Protection Association, Quincy, MA, 2007.
13 Crowl, D. Minimize the Risks of Flammable Materials, American Institute of Chemical Engineers, New York, April 2012.
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Fire detection, alarm and signaling systems play an important role in industrial fire protection. That role can be one of an upfront starring actor, or it might be more of a supporting role.

Building, fire and life safety codes use different terms to describe occupancies that a lay person would group wholly into the category of “industrial occupancies.” The International Code Council (ICC) family of model codes has a “factory” use group while the National Fire Protection Association (NFPA) family has an “industrial” occupancy. Both have a “storage” category that might also fit the situation.

The ICC codes have limits on the quantities of hazardous materials, which define the point at which a use group (factory, storage or other) becomes a “high hazard” use group. NFPA’s building and life safety codes have similar limits on the quantities of hazardous materials that define when the hazard of the contents warrants additional prevention and protection measures beyond what the base occupancy might be required to have. In other words, in the ICC codes, the quantities and types of materials might change the use group from “factory” or “storage” to high hazard while...
NFPA codes would retain the occupancy designation, but impose additional requirements.

As with any fire prevention or protection project, new or existing, the engineering team must carefully study and document the process, storage and materials as well as the property characteristics that all affect the code requirements. This article will not try to enumerate what specific codes might require. Instead, it will illustrate detection, alarm and signaling system configurations commonly used in these industrial, factory, storage and high hazard occupancies. It will also introduce some newer applications that are gaining popularity as business owners and insurers seek to further reduce the risk of property and mission interruption losses below the levels afforded by code compliance.

Many, but not all, industrial, factory and storage operations are located in large volume spaces. The high volume provides a large “sink” for heat and smoke and many ways for occupants to move away from fires.

Except for some storage occupancies, the large volume also provides good sight lines for occupants to see fire or smoke long before it directly threatens them or their safe egress from the space. Even in congested, large-volume storage spaces, a hidden fire will likely be smelled by occupants or will activate sprinklers before threatening occupants.

These conditions contribute to long available safe egress times (ASET) relative to the onset of conditions hazardous to the occupants. Without any high hazard conditions or materials, a basic fire alarm system would not be required by most codes to have any occupant notification capability in the building, provided that there was supervision of any required sprinkler systems at an attended location such as a supervising station meeting the requirements of NFPA 72.1

The typical baseline system would monitor sprinkler waterflow switches and sprinkler valve tamper switches. There would be no other automatic fire detection devices and no required occupant notification appliances. An historical provision contained in NFPA 72 would require that such a system have at least one manual fire alarm box (pull station) located as required by the authority having jurisdiction.1 The box provides a way to transmit a fire alarm signal to the supervising station in the event that the sprinkler waterflow switches are taken off-line for testing or maintenance. This presumes that the method used to place the system “on test” leaves the manual fire alarm box in service.

In some jurisdictions, the mechanical codes might require the installation of duct smoke detectors when the supply or return volumetric airflow exceeds certain limits. The return side duct smoke detection is intended to prevent the recirculation of smoke in a building.

In a multistory building, duct smoke detectors are required to be located at the point where the air return joins a common return to the air handler. The detector serving the air return for the fire floor would eventually operate and shut down the system to prevent continued circulation of the smoke-laden air. However, due to dilution rates, there may already have been some recirculation of smoke to the common air handler and back to all floors served by the system.2,3 Occupants on other, non-fire, floors may smell the smoke before the duct smoke detectors will operate.

However, in a large-volume factory or storage space, such as that shown in Figure 1, there might be several rooftop units serving a single, wide-open fire area. Each unit might serve an
HVAC zone, or section of the factory floor, without any dividing walls delineating the next HVAC zone.

Even if the delay caused by potential smoke stratification is ignored, the delay in the response of a conventional air return duct smoke detector could be considerable due to smoke dilution at the air return point. If there are occupants in the area, they may smell and see smoke before conventional duct smoke detectors operate. Also, in most manufacturing facilities, smoke detection, whether area type or in ducts, would be difficult to access for periodic inspection, testing and maintenance, and would be prone to nuisance activations caused by the normal presence of fumes or particulates. Instead of using duct smoke detectors, one should consider shutting down the air handlers upon activation of any manual fire alarm box or sprinkler waterflow switch.

In certain situations, mission continuity and property protection might warrant additional protection above that provided by automatic sprinklers alone. Examples might include pharmaceutical production and storage, food storage facilities and certain one-of-a-kind production facilities.

Fire detection, alarm and signaling systems can play a vital role in risk reduction by helping to control fires at early stages or by initiating smaller, controlled, manual suppression efforts before fires grow to the size needed to initiate automatic sprinkler operation."

In high-volume manufacturing and storage spaces, video image smoke and fire detection systems and highly sensitive smoke detection systems using special spot or air-sampling type detectors can be used to provide early detection. Projected beam smoke detectors also provide earlier detection than conventional smoke detectors, while being less prone to nuisance sources and easier to access, test and maintain. These systems can all be designed and deployed to provide variable signaling that depends on the conditions and the desired responses.

Signaling systems also serve as the central point for monitoring the status of other critical fire protection and facility infrastructure systems such as private and public water supplies, fire pumps, generators, elevators and process control equipment. Increasingly, they are being integrated with emergency communications systems, mass notification systems and facility paging and information systems. When the design team fully understands the owner’s needs, goals and objectives, a fire detection, alarm and signaling system can be designed as an integral part of the solution that eliminates redundant systems and reduces initial and life cycle system costs.

Robert P. Schifiliti, P.E., FSFPE, is with R.P. Schifiliti Associates, Inc.

Editor’s Note: Robert Schifiliti has been the regular author of the NEMA supplement since it began running in these pages in 2002.

References:
1 NFPA 72, National Fire Alarm and Signaling Code, National Fire Protection Association, Quincy, MA, 2013.
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The low frequency sounder and sounder strobe devices are easily retrofitted into existing SpectrAlert Advance notification applications while delivering greater flexibility for the new code requirements.
This new guide, co-published by the International Code Council (ICC) and Society of Fire Protection Engineers (SFPE), identifies critical fire safety challenges unique to very tall buildings. *Engineering Guide: Fire Safety for Very Tall Buildings* examines how these special challenges can be addressed worldwide through an integrated performance-based design.

This engineering guide was written in response to an increase in the global design and construction of very tall buildings. Building codes in some countries may not contemplate all aspects of fire safety in very tall buildings—some of which approach a half mile, or 800 meters, in elevation. Buildings that are hundreds of meters tall pose challenges far different from those in average-sized tall buildings.

The guide emphasizes the importance of taking an integrated approach to the design of fire safety in tall buildings based on expected fire performance. This integrated approach looks beyond compliance with codes and standards, and considers how the height of the structure impacts fire safety and how various fire safety systems complement each other to achieve fire safety goals. These systems include smoke control, fire suppression, building evacuation, structural fire resistance and fire fighter access.

The *Engineering Guide: Fire Safety for Very Tall Buildings* recommends performing a fire risk analysis to determine how best to address the fire safety challenges unique to a specific building. Although fire hazards in very tall buildings are similar to those in shorter buildings, the consequences of a fire can be more severe given the large numbers of occupants, the inherent limitations in egress, and the sheer height of the structure. The risk analysis will identify which hazards should be addressed by the design, where the hazards may include accidental fires, fires following earthquakes, or terrorist threats.

*Engineering Guide: Fire Safety for Very Tall Buildings* is available for purchase in hardcopy

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**SFPE Reference/Answer Manual for the P.E. Exam in FPE, 4th Edition**

The new 4th Edition of SFPE’s Principles and Practice of Engineering (PE) Examination in Fire Protection Engineering covers all of the technical subjects on the National Council of Examiners for Engineering and Surveying exam specification. The Reference Manual includes sample exercises on concepts that may be encountered in the PE exam. Also included are objectively scored timed sample problems that are equivalent to PE exam problems in length and difficulty. The answers to all of these exercises and problems are published in a companion answer manual.

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10TH INTERNATIONAL CONFERENCE ON PERFORMANCE-BASED CODES AND FIRE SAFETY DESIGN METHODS

Pushing the Boundaries...

CALL FOR PAPERS

SUBMISSION DEADLINE: 6 DECEMBER 2013

SHARE YOUR EXPERTISE, SHOWCASE YOUR KNOWLEDGE, AND HELP SHAPE THE FUTURE OF PERFORMANCE-BASED FIRE SAFETY DESIGN BY PARTICIPATING IN THIS BIENNIAL CONFERENCE

SPECIFICATIONS FOR SUBMISSIONS

PERFORMANCE-BASED CODES
Abstracts are solicited relating to performance-based regulatory structures, performance-based codes and performance-based standards. Viewpoints are invited on the infrastructure needed for the successful implementation of performance-based codes (education, professional registrations, enforcement, legal environmental, etc.). Perspectives are also sought on experience (both positive and negative) associated with use of performance-based codes, both in Australia and abroad.

PERFORMANCE-BASED DESIGN
Abstracts are invited on fire safety engineering methods in use or under development. Viewpoints are also sought on dealing with uncertainty and new research findings relevant to performance-based design. Case studies without generalizable results are typically not acceptable.

AUDIENCE
The participants in this conference will be professionals involved in fire safety engineering, regulation development and enforcement, testing, standards of development, and development of engineering design methods.

SUBMITTAL REQUIREMENTS

Those wishing to present papers should submit a one to two page abstract to the conference secretariat by 6 December 2013. The conference language is English.

The extended abstracts should identify the topic being addressed, the approach used or suggested for addressing the topic, and results or recommendations. All topics relevant to performance-based codes or fire safety design methods will be considered.

Please include the name, address, phone number, and email address of the corresponding author with all submitted abstracts. If accepted, completed papers will be due by 18 July 2014.

Submit abstracts to conference@sfpe.org and include “AUSTRALIA CONGRESS 2014” in the subject line of the email.
RESOURCES

UPCOMING EVENTS

October 9–10, 2013
Eurofire 2013
Basel, Switzerland
Info: www.eurofireconference.com

October 22–23, 2013
Fire New Zealand Conference and Exhibition
Auckland, NZ
Info: www.sfpe.org.nz

October 24–26, 2013
9th International Conference & Exhibition: Fire India – 2013
Mumbai, India
Info: www.ifeindia.org

October 27–November 1, 2013
SFPE 2013 Annual Meeting: Professional Development Conference and Exposition
Austin, TX, USA
Info: www.sfpe.org/SharpenYourExpertise/Education.aspx

November 14–15, 2013
Tüyak 2013 Fire and Security Symposium and Exposition
Istanbul, Turkey
www.tuyak2013.com

February 10–14, 2014
The International Association for Fire Safety Science (IAFSS) 11th International Symposium on Fire Safety Science
Christchurch, NZ
Info: www.iafss.org/symposium/11th-symposium/

March 12–14, 2014
6th International Symposium on Tunnel Safety and Security
Marseille, France
Info: www.istss.se

June 9–12, 2014
NFPA Conference & Expo
Las Vegas, NV, USA
Info: http://nfpa.typepad.com/conference/

October 1–2, 2014
FIVE 2014: 3rd International Conference on Fires in Vehicles
Berlin, Germany
Info: www.firesinvehicles.com

BRAINTEASER [Problem/Solution]

Problem

A farmer has a circular plot of grass of radius R. The farmer wants a sheep to graze on the circular plot, but the farmer doesn’t want the sheep to eat more than half the grass. If the farmer attaches the sheep’s leash at the center of the circle, how long should the leash be?

Solution to Last Issue’s Brainteaser

How many squares?

Answer: 14. There are nine 1 x 1 squares, four 2 x 2 squares, and one 3 x 3 square.
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www.3m.com/firestop
—3M Fire Protection Products

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The Advanced Multi-Criteria Fire/CO Detector (AMCF/CO) combines fire and carbon monoxide (CO) protection using four wires and one footprint. Like all System Sensor CO detectors, the CO sensor of the AMCF/CO detector can be field tested using RealTest, the first functional CO test fully compliant with NFPA 720: 2009. The AMCF/CO works with the System Sensor B200S intelligent sounder base to provide both Temp 3 and Temp 4 signals for fire and CO. The B200S can be synchronized with System Sensor AV devices and used as part of the evacuation signal.

www.systemsensor.com
—System Sensor

**Amber Lens Strobes**

Cooper Notification has added amber lens strobes to its Wheelock Exceder LED Series, a line of notification appliances, to utilize high-efficiency light emitting diodes (LEDs) as the light source. The new colored lens is ideal for mass notification and emergency communications environments, and delivers a low current draw to allow for energy savings. Other features include four field-selectable candela settings (15, 30, 75, 110 cd), a single-gang design, four mounting options, and the ability to change settings without tools.

www.coopernotification.com
—Cooper Notification

**Fire Alarm Communications Panel**

Honeywell Power’s IPGSM-4G fire alarm communications panel allows installers to select IP, GSM (cellular), or both for fire alarm reporting to a central station. It is compatible with virtually any brand of fire alarm control panel and simply connects to both ports on the panel’s digital alarm communications transmitter. This upgraded version is able to operate over a 2G, 3G, or 4G network, automatically choosing the best available cellular signal in the area.

www.honeywellpower.com
—Honeywell Power

**Touch-Screen Fire Alarm Panel**

The S3 Series fire alarm control panel is a small, addressable system that features an intuitive, touch-screen display to simplify use. It can be used as a standalone system or part of an extensive network serving multi-buildings. The interface centers on system status, events details, and service mode. Five additional press buttons can be customized for each facility.

www.gamewell-fci.com
—Gamewell-FCI

**Insulating Firebricks**

Insulating firebricks are ideal for the ceramics market, including kilns, furnace linings, and cyclical furnaces. Ten different grades are available, from 2,300°F to 3,300°F. Engineering support is available for custom configurations.

www.morganadvancedmaterials.com
—Morgan Advanced Materials
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www.notifier.com/faast
Sprinkler Monitoring Panel

The PFC-6006 Sprinkler Monitoring Panel is a small, affordable, yet highly robust fire alarm panel created specifically to handle flow, pressure, and tamper switch notifications. The first zone is selectable as a Class A or Class B water flow input and the other five zones are selectable from a menu of options including two-wire smoke detection. The panel has a 1.0 amp power supply that powers the panel, charges the batteries, and supplies 0.5 amps to a notification appliance circuit and 0.5 amps of auxiliary power.

www.pottersignal.com
—Potter Electric Signal Co., LLC

Storage Sprinkler

Viking’s new Early Suppression Fast Response (ESFR) pendent sprinkler, with a K factor of 22.4 (320), is suitable for use in warehouses and other storage applications. The new VK506 uses a fast response fusible element and is approved to protect most common storage materials, including encapsulated and unencapsulated class I-IV commodities as well as expanded and unexpanded plastics.

www.vikinggroupinc.com
—Viking Corp.

Fire & Carbon Monoxide Detector

The Farenhyt IDP-FIRE-CO detector senses both fire and carbon monoxide (CO) using four different sensing elements. Its sounder base delivers customized tones to differentiate between a fire and a CO event. The marriage of fire and CO detection into one device, combined with the sounder base, eliminates the traditional installation of separate fire and CO detectors, notification devices, a monitor module, and all the necessary junction boxes. This reduction in materials leads to reductions in labor and overall cost, in addition to providing a cleaner, less cluttered appearance.

www.silentknight.com
—Silent Knight

Early Suppression Sprinkler

The N25 ESFR Sprinkler uses a fast-response levered fusible alloy solder link, available in either a 165°F or a 212°F rating. FM Global considers this a “Quick Response” storage sprinkler for use in Data Sheets 2-0 and 8-9. With a nominal K-Factor of 25.2, the N25 ESFR will deliver approximately 98 GPM of water at 15 psi. The smaller deflector and frame provides a broad pattern capable of suppressing fires between sprinklers in high storage-height areas, while core water is available to penetrate and suppress fires occurring directly beneath the sprinkler.

www.reliablesprinkler.com
—Reliable Automatic Sprinkler

Fire Panel Enhancements

Siemens has made product enhancements to its FireFinder XLS fire panel. The responsive intelligent fire detection system, which can be networked and configured with or without optional voice evacuation and integrated smoke control functionality, now features a faster processor that fuels a full-color user interface with events color-coded by type and touch-sensitive keys. The new system also exceeds mass notification specifications, with digital capacity for up to 300 custom messages and the capability to play multiple messages simultaneously.

www.usa.siemens.com/firefinder-xls

Gas Detector Module

The VESDA ECO Ex, a gas detector module for use with VESDA smoke detection systems in Class I Division 2 classified hazardous locations, reduces the number of detectors required to cover an area, and provides easy access for routine maintenance. Each VESDA ECO Ex gas detector can house up to two gas sensors, and additional detectors can be added to the VESDA pipe network to monitor more gases if required. Seventeen different gas sensors are available, and re-calibrated sensor cartridges are easily replaced in the field.

www.xtralis.com
—Xtralis
About the Mircom Group of Companies (MGC™)

The Mircom Group of Companies (MGC) was founded in 1991 by Mr. Tony Falbo. Today, MGC stands as one of the fastest growing companies in the building solutions sector and the largest independent fire alarm manufacturer in North America.

Our product line spans Fire Alarm and Emergency Audio, Communications and Security and our brands include Mircom™, Secutron™, and United Export Corporation (U.E.C.™). With a well-earned reputation for excellence, innovation and quality, we’ve consistently achieved double-digit annual growth.

We support the sale and installation of MGC solutions in more than 50 countries, with international offices located in New York, California, Illinois, North Carolina and Florida U.S.A.; Mexico City, Mexico; Buenos Aires, Argentina; Bangalore, India; Dubai, UAE; Saudi Arabia and Singapore. Under our U.E.C. division, we also distribute a broad range of exceptional fire protection equipment to more than 70 international markets.

Our network of dedicated Sales and Service Offices, known as Mircom Engineered Systems allow us to be a full solution provider, tackling projects of various scopes and sizes. Additionally, we offer assistance to Fire Protection Engineers, making the selection and application of our solutions seamless. Our advanced systems are scalable to satisfy diverse user demands, from small buildings to large complexes, using a common firmware platform and distributed processing architecture.

North American Manufacturing

We operate an 85,000 sq.ft. head office and manufacturing facility, in Vaughan (Toronto), Canada. Our unwavering commitment to North American manufacturing enables us to offer the highest quality and best competitive value across our vast range of fire alarm, mass notification, communications, building automation and access control products.

Complete In-House Product Design Capabilities

From electronic hardware and metalwork to firmware and applications software, MGC utilizes world-class product engineering, development and testing facilities. In fact, more than 10% of our staff resides in R&D. This allows us to maintain complete command of the product development process, from concept to finished deliverable.

Award Winning Products

Our Open Graphic Navigator™ (Open GN) solution was awarded the Gold Medal at the 2013 Chicago Edison Awards™ in the Smart Systems category. Find out more on our website!

The Mircom Family

MGC is led by Tony Falbo and his sons – Mark, Rick, and Jason. We credit our success and growth to the fact that we are a privately owned and family-run company. This allows our focus to be on the needs of our customers and their requirements, rather than motivators such as quarterly financial results. As a family run business, it’s not only our company’s reputation on the line with every product and solution delivered – it’s our family name as well.
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