FIRE PROTECTION
Engineering
4TH QUARTER 2012
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Fire Research
A Roundtable Discussion

Lithium-Ion Battery Hazards

Bridging Installation Standards and Fire Protection Engineering

Fire Safety Engineering Education – Part of a Certification Framework

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FIRE PROTECTION Engineering

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From the TECHNICAL DIRECTOR

"Changing the Conversation"

During the last few years, the engineering field has been working to change how it is perceived by people who are not engineers. The purpose of this effort was to reverse stereotypes about the engineering profession and better emphasize the positive contributions that engineers have on people and society. Pre-existing stereotypes resulted from the engineering community's focus on the skills needed to become an engineer as opposed to the work that engineers do.

In 2008, the National Academy of Engineering (NAE) published a report titled, "Changing the Conversation: Messages for Improving Public Understanding of Engineering."[1] The report was a result of 18 months of study into messaging strategies that would be effective at improving the understanding of the engineering profession among non-engineers. The messages published in the report include:

- Engineers make a world of difference.
- Engineers are creative problem-solvers.
- Engineers help shape the future.
- Engineering is essential to our health, happiness and safety.

The University of Colorado in Boulder adopted the NAE messages in the University's outreach efforts. The University has also changed the visual imagery that it used to show what engineers do — moving away from abstract images of things like gears to pictures of people working together.

Initial anecdotal data indicate that this messaging strategy has been successful. In the fall of 2010, the University of Colorado in Boulder reported an increase of 24% in the number of women enrolled in engineering and an increase of 67% in the number of minorities.

Similarly, the University of Hartford has emphasized engineering projects and good communications skills in introductory engineering courses.[2] The result has been a 100% retention rate for freshman engineering students — whereas a large number of engineering students were previously lost to other fields like business, law or medicine.

Fire protection engineering suffers from less recognition among the general public than the broader engineering profession receives. While many people would recognize some of the types of work that engineers do, they would be less likely to recognize the work that is performed by fire protection engineers.

SFPE developed a set of messages that can be used to better explain what fire protection engineers do and the positive impact that this work has on society. These messages, which are similar to the NAE messages, include the following:

- Fire is a big problem.
- Fire protection engineers design ways to protect people from fire.
- 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 bridge industries.
- Fire protection engineers allow innovation.
- Fire protection engineers reduce risk.

These messages and lessons learned from the successes at the University of Colorado in Boulder and the University of Hartford can be used to help recruit people into fire protection engineering. First, the messages are useful when speaking with students who are considering their future career paths. Second, while images of fire can be more exciting than pictures of gears, visual images should focus on people working together. If there's anything that fire protection engineers do in abundance, it's work with others — whether coworkers, other engineers, architects, clients, or enforcement officials.

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

References:

1 *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, National Academies Press, Washington: 2008.

2 McLaughlin, M. "Conversation Starter," *PE: The Magazine for Professional Engineers*, August/September 2012, pp. 24-27.

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Global COE Program and Graduate School at Tokyo University of Science

By Yoshifumi Ohmiya, Ph.D.

In 2008, Tokyo University of Science (TUS) launched the "Center for Education and Research on Advanced Fire Safety Science and Technology in East Asia," which was accepted as the "Global COE (Centers of Excellence) Program," a five-year project funded by Japan's Ministry of Education, Culture, Sports, Science and Technology. This succeeds the "Center of Advanced Fire Safety Science and Technology for Building," which was also known as the "21st Century COE Program" and was launched in 2003. Based on results, both in theory and practice, from the 21st Century COE Program, the Global COE Program promotes further research and seeks deeper understanding on potential fire risk not only in Japan but also in East Asia.

In recent years, cities in East Asia have experienced drastic transformation at a rapid speed. Along with rapid urbanization, fire risk is also increasing because of the construction of new high-rise buildings, new underground structures, and the use of new materials, such as aluminum, plastics, and so on. Fires and explosions frequently occurred in urban structures, causing deaths and property damage.

As an educational and research institution engaged in fire safety engineering, our primary mission is to respond to the urgent risk in urbanized cities by collaborating with researchers from each region. For this purpose, the Global COE set up four tasks:

- Develop and diffuse effective education and study in order to reduce fire risk
- Promote collaborative research in efforts to foster human resources through developing theory and conducting large-scale fire tests in laboratory settings
- Establish a graduate school for fire science and technology
- Further promote the use of the unique fire research and test laboratory at TUS

The most significant result of the Global COE Program so far is the establishment of the graduate school. The Graduate School of Global Fire Science and Technology launched a master's course in April 2010, and then the doctoral course started in April 2012. The graduate school aims to train professionals who have advanced and specialized knowledge of fire safety engineering through lectures and practical experiments using the full-scale test laboratory at TUS.

Currently in the Graduate School of Global Fire Science, 37 master's students and five doctoral students are working on individual research topics under the supervision of eight faculty members. The Graduate School of Global Fire Science is the first and only graduate course specializing in fire science and technology in Japan that offers an integrated and trans-disciplinary academic program of fire safety engineering. It specifically aims at training professionals who are qualified to:

- Understand and determine burning properties of various materials and fuels in order to identify the cause of fire and to invent new materials (e.g., flame-retardant or noncombustible materials)
- Develop prediction models for fire behavior and evacuation behavior
- Evaluate and design systems for fire protection of buildings

The graduate school is open not only to students but also to firefighters and other specialists who seek career enhancement. In addition, we accept a number of international students, mainly from East Asia, and this helps Japanese students acquire and improve their international communication ability and leadership at the global forefront.

The curriculum of the graduate school consists of three areas: (1) basic theory and practice of fire science, (2) fire protection engineering for practical building design, and (3) fire protection engineering for policy-making and planning. Basic theory and practice of fire science covers basic knowledge such as physics, chemistry, human behavior, and fire testing and experimentation. Fire protection engineering for practical building design deals with fire phenomenon and architectural aspects, while fire protection engineering for policy-making and planning offers lectures on laws and regulations concerning fire safety. The well-balanced curriculum is designed to develop problem-solving ability from a social perspective.

Another significant achievement of the Global COE Program is research collaboration. The Global COE Program actively promotes human resource development and enhances research activities through personnel exchange programs. TUS has concluded collaborative research agreements with 13 universities and two research institutions, both within Japan and worldwide. Especially, collaboration with the Building Research Institute (BRI) in Japan and other Japanese research institutions that conduct a wide variety of multi-disciplinary research of building and urban design intensified our research ability.

TUS expects further results from the Global COE Program that will contribute to fire safety in Japan and East Asia.

For details of the Global COE Program and the Graduate School of Global Fire Science and Technology, see *http://gcoe.moritalab.com/eng/.*

Yoshifumi Ohmiya is with the Tokyo University of Science.

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UL/ULC Changes to Certification Programs

UL has recently conducted research on a wide array of current products and systems originally certified under UL 2196, *Tests for Fire Resistive Cables* and ULC-S139, *Standard Method of Fire Test for Evaluation of Integrity of Electrical Cables* and determined that they no longer consistently achieve a two-hour fire-resistive rating when subjected to the standard Fire Endurance Test of UL2196 or ULC-S139. Consequently, UL and ULC will not be able to offer certification to the currently existing program related to these standards.

As a result, manufacturers are no longer authorized to place the UL mark or ULC mark on UL Classified Fire Resistive Cable (FHJR); ULC Listed Fire Resistant Cable (FHJRC); and UL Listed cable with "-CI" suffix (Circuit Integrity).

Furthermore, UL has removed from its certification directory all Electrical Circuit Protective Systems (FHIT) constructed with Fire Resistive Cable.

To date, UL is not aware of any field failures with currently installed systems. For guidance on buildings under construction, visit UL's website.

UL will provide research findings to the relevant technical committees and work with those bodies to determine appropriate next steps. Stakeholders who want to participate in the standard development activities should contact the relevant standard committees. Until the technical committees' recommendations are complete, UL has made available *an interim certification program for subscribers* who wish to certify the above referenced products/systems.

For more information, contact Neil.Lakomiak@ul.com or go to *http://bit.ly/UmiNnZ*

USFA Releases Smoking-Related Fires in Residential Buildings Report

The Federal Emergency Management Agency's (FEMA) U.S. Fire Administration (USFA) has issued a report examining the characteristics of smoking-related fires in residential buildings. The report, *Smoking-Related Fires in Residential Buildings* (2008-2010), was developed by USFA's National Fire Data Center. The report is part of the Topical Fire Report Series and is based on 2008 to 2010 data from the National Fire Incident Reporting System (NFIRS).

According to the report:

- An estimated 7,600 smoking-related fires in residential buildings occur annually in the United States, resulting in an estimated average of 365 deaths, 925 injuries, and $326 million in property loss.
- While smoking-related fires account for only 2 percent of all residential building fires, they are a leading cause of fire deaths, accounting for 14 percent of fire deaths in residential buildings.
- Cigarettes are, by far, the leading type of smoking material involved in residential smoking fires and account for 86 percent of these fires.
- Residential building smoking-related fires occur most often in the afternoon and evening hours, peaking from 2 to 3 p.m. Forty-two percent of smoking-related fires in residential buildings occur from noon to 8 p.m.; however, the smoking-related fires that occur in the late evening and early morning tend to be the most deadly.

For information regarding other topical reports or any programs and training available at USFA, visit *www.usfa.fema.gov.*

SFPE 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 ROUNDTABLE DISCUSSION

ON FIRE RESEARCH

By William E. Koffel, P.E., FSFPE

On October 21 and 22, 1999, the Society of Fire Protection Engineers (SFPE) hosted a workshop to develop a research agenda for the fire protection engineering profession.[1] On November 17 and 18, 2008, the Fire Protection Research Foundation sponsored a conference that has been referred to as the "Next 25 Years Conference."[2]

SFPE convened a group of researchers from various types of research organizations in mid-2012 to revisit some of the recommendations/comments from these two reports and to identify how fire protection engineers can benefit from and provide benefit to fire protection research efforts.

The panelists were:
William E. Koffel, P.E., FSFPE – *Session Moderator*
Greg Baker – *Branz, New Zealand*
Louis Gritzo, Ph.D. – *Factory Mutual, USA*
Andre Marshall, Ph.D. – *University of Maryland, USA*
Russ Thomas, Ph.D. – *NRC, Canada*
Ulf Wickström, Ph.D. – *SP Fire Technology, Sweden*

QUESTION: Does your organization focus on any specific areas of fire research and if so, what are they?

Gritzo: FM Global performs fire research (*www.fmglobal.com/research*) on all aspects of commercial and industrial property loss prevention in a balanced portfolio of commercial/industrial client-focused problem solving projects and long-term strategic research programs. Research is performed using a blend of integrated computational and experimental/testing activities, including large-scale experiments and testing at the 6.4 km^2 FM Global Research Campus, and small-scale experiments and testing as well as 10+ teraflop scientific computing at our Center for Property Risk Solutions. Major areas of focus include all aspects of fire protection, flammability, and system reliability for both existing and emerging applications.

Thomas: If we have a focus, it is on experimental studies of fire behavior and also over the years on human performance in emergencies.

Marshall: The University of Maryland is involved in many different areas of fundamental and applied fire research. Our faculty has a range of research interests from developing technology for firefighter safety to exploring fire safety in outer space.

Baker: The main areas of research are risk analysis, modeling, structures in fire, design fires, and post-earthquake fires.

I do not think the results from commercial testing will ever be openly available. The legal conditions for commercial testing, not only fire testing, would need to change completely.

—Wickström

Wickström: SP carries out fire research in many areas, like fire performance of materials and composites, risk analyses, temperature analyses, fire dynamics, structural performance, etc. About 50% of our fire activities are research and the other half are standardized testing.

The following questions are related to the SFPE document, *A Research Agenda for Fire Protection Engineering* from February 2000.

QUESTION: In the summary of the report, a comment is made that "A significant amount of fire testing is conducted; however, the results from these tests are not readily available." Is this still the case?

Gritzo: There continues to be the potential for improvement by making data from fire research- related testing (i.e., tests outside those proprietary for product development, certification, etc.) available and in a form suitable for use and collaboration.

Wickström: I do not think the results from commercial testing will ever be openly available. The legal conditions for commercial testing, not only fire testing, would need to change completely. To use test results for theoretical analyses is difficult as they are generally not intended for that. For most test methods (with the exception of fire resistance tests controlled by plate thermometers), the thermal exposure is not very well known. We do not even have reliable theories for specifying the thermal exposure in the cone calorimeter for predicting times to ignition!

Marshall: Although there is a shortage of available test data, there is also a corresponding deficit in the available analytical options for putting this fire data to use. In other words, if we had all the data we wanted, how creative could we be with it to engineer effective fire protection solutions? It is my hope that the available test data would be used to not only support current engineering practices, but also to inspire the development of new engineering

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tools for fire protection engineering as well.

QUESTION: What is your organization doing to make the results from fire tests more available to the practicing fire protection engineer?

Marshall: Consistent with our pedagogical mission at the University of Maryland, we communicate test results through a number of channels. In the classroom, we have expanded the sophistication of our teaching laboratories providing students within and even outside of fire protection engineering valuable firsthand experience with fire. Our Fire Testing and Evaluation Center (FireTEC) has expanded its web communications to include important information regarding proper use and analysis of standard test data. At FireTEC, we are also deliberate about publishing our results when appropriate in applied fire safety channels. FireTEC is also conducting public service announcements (PSAs) and participating in other media communications to the general public. Finally, the faculty at the University of Maryland is very active in communication of our fire research findings in scientific journals, while pushing our discoveries towards engineering applications through applied research collaborations with industry and fire protection engineering firms.

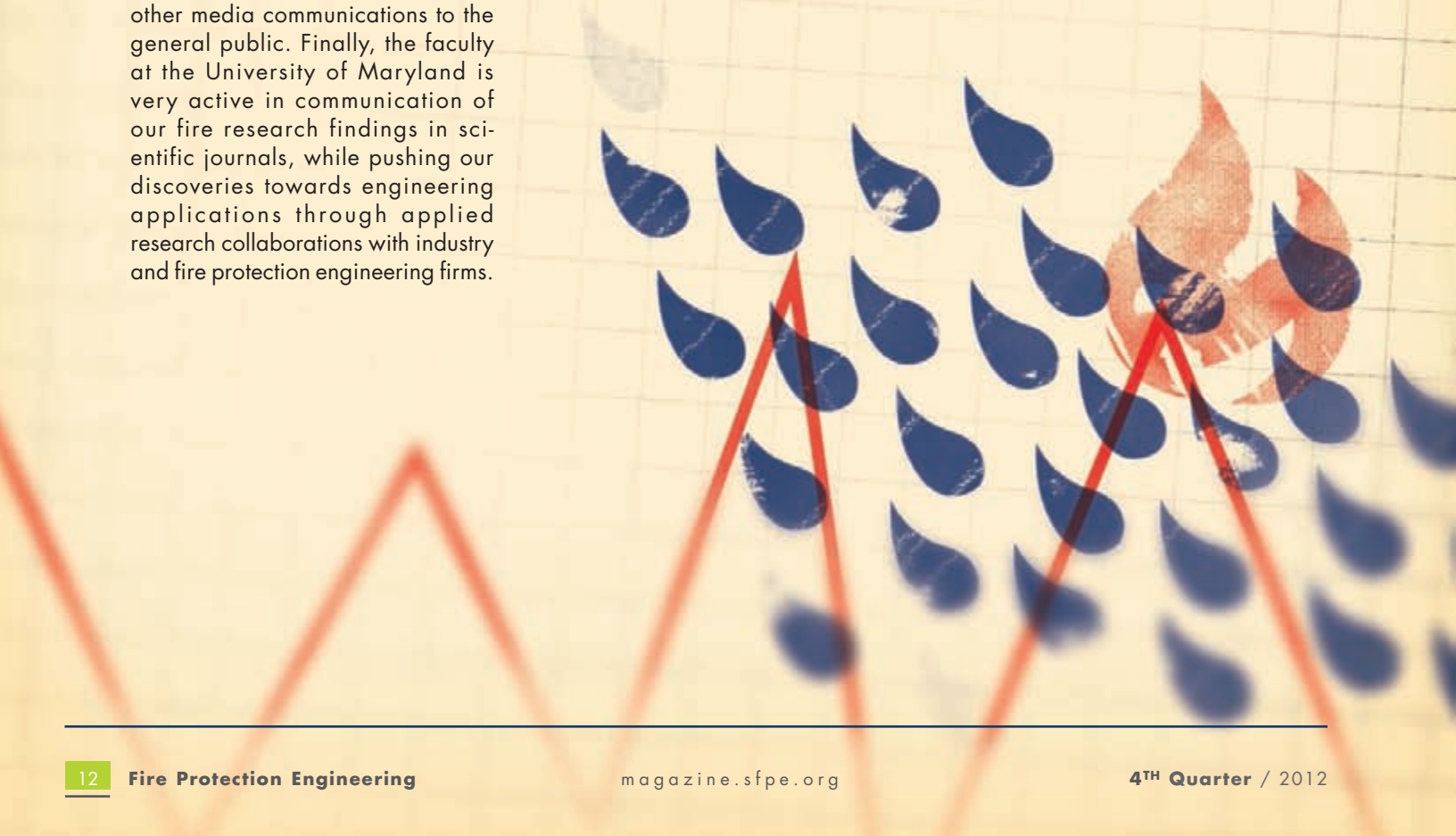
Gritzo: FM Global has proactively made fire protection engineering guidance, as well as the research on which it is based, openly available to the public. We have continued to build upon a long tradition of publishing research studies by increasingly contributing data, as well as the necessary information to understand and apply the results, in conferences and technical journals. In 2009, we began making key technical reports available to the public at *www.fmglobal.com/researchreports* as well as video from selected tests available on *www.youtube.com*. The results of FM Global research in the form of *FM Global Property Loss Prevention Data Sheets* are now openly available for use by the fire protection community at *www.fmglobal.com/datasheets* as are the FM Approvals Standards for loss prevention products testing certification at *www.fmapprovals.com*. Advances in technology developed at FM Global are non-exclusively, royalty free licensed to the private sector to encourage widespread use.

Baker: The most common way that fire test results are made available is through the publication of research study reports.

Thomas: For some of our projects, we are looking at making the "data" files available, but doing so is not without its risks as it is often difficult to provide full insight into the context in which the data was collected.

QUESTION: A question that often arises concerns the reliability of fire protection systems and features. Has your organization performed any work regarding reliability of fire protection systems and features?

Baker: We were involved in a project with the Fire Protection Association of New Zealand in 2007/08 that inspected the standard of passive fire protection in buildings.[3] We are currently in the middle of a project that investigated the performance of fire protection systems in the recent Canterbury earthquakes.[4] We are



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The Fire Protection Research Foundation within the NFPA has contributed to the development of this agenda and the International FORUM of Fire Research Directors continues to provide global coordination within fire research labs.

—Gritzo

also involved in a joint research project with the University of Canterbury, which includes a component on system reliability.

Gritzo: FM Global has performed extensive internal studies on reliability of fire protection systems from the 1990s to the present. The reliability of water supplies in sprinkler systems, water-mist systems, and foam-water systems has been analyzed. In addition, FM Global is currently completing a study that compiles and provides a review of the past several decades of the reported studies on reliability of sprinkler systems. The results of this study will be in a report on the FM Global website, and will be submitted for publication in the refereed archival literature.

Wickström: One of the things that could be done to improve reliability of fire protection systems is to improve the test methods and the understanding of them.

QUESTION: The SFPE Report (2000) indicates the need for a collaborative effort to develop and implement a research agenda. Do you see any organization addressing this need within your own country? Do you see any organization addressing this need globally? Is there an organization that may be best suited to serve in this capacity from a global perspective?

Baker: In NZ, we have recently published a Fire Research Roadmap. Internationally, the International FORUM of Fire Research Directors is well placed to do this.

Gritzo: The development and, more importantly, the implementation of a cohesive research agenda remains a challenge. The Fire Protection Research Foundation within the NFPA has contributed to the development of this agenda and the International FORUM of Fire Research Directors continues to provide global coordination within fire research labs. The successful implementation of a cohesive agenda becomes more achievable with additional focus. To these ends, FM Global is leading the development of an Open Source Fire Model (*www.fmglobal.com/modeling*) that serves as a means of integrating research into an open computational framework with an evolving agenda developed as a global collaboration of members from universities, laboratories, and companies.

Wickström: I think the spread of basic fire engineering science and education of fire safety engineers needs to be improved. That could possibly be done by better cooperation between universities offering courses in fire safety engineering.

Thomas: The FORUM of International Fire Research Directors has attempted to undertake this role over the years. There have though been many changes taking place amongst the various labs around the world, some moving from government agencies to commercial ventures or even into university groups. The issue of funding to undertake collaborative research has proven to be difficult, and although there have been proposals for a unified research agenda over the years, the ability to bring them to fruition has generally failed other than situations where a few labs have collaborated on a common priority topic.

Marshall: The National Institute of Standards and Technology (NIST) has been very deliberate about developing a fire research agenda. At the same time, the National Science Foundation's (NSF) Combustion, Fire and Plasma Systems program has demonstrated national leadership in funding Fire Research. FM Global and United Technologies Research Center (UTRC) have also demonstrated leadership over the last several years through their fire modeling workshops. The International Association of Fire Safety Science (IAFSS) has

provided a forum for communicating fire research advances and helped to establish direction for the fire research community on the international stage.

THE FOLLOWING QUESTIONS ARE RELATED TO THE FPRF REPORT, *THE NEXT 25 YEARS* FROM NOVEMBER 2008.[2]

QUESTION: The participants indicated a concern regarding the changes in furnishings and contents. In general, what research has your organization performed regarding changes in furnishings and contents?

Wickström: We have worked quite a bit developing large and small scale test methods and prediction models.

Marshall: We focus on developing new test methods for evaluating the fire performance of furnishing and contents of the future. The ability of tests to effectively screen these new materials is crucial because there is no historical fire performance data available for guidance.

Thomas: We have been undertaking a four-year "Design Fires" project that has, amongst other things, characterized both the furnishings and contents of a range of different occupancy types.

Baker: BRANZ conducted a research project for the NZ Fire Service that looked at the cost-benefit of mandating fire retardant treatment for upholstered furniture.[5] This was followed up later with a report that also included sustainability in the analysis.[6]

QUESTION: Environmental sustainability is an issue that was addressed in the FPRF conference, and there has been much written recently about the environmental aspects of certain chemicals used to enhance fire performance. In general, what research has your organization been conducting in this area?

Gritzo: FM Global has led major efforts to advance the understanding of loss prevention as an integral part of environmental sustainability, including several publically available studies (*www.fmglobal.com/researchreports*). In collaboration with our commercial and industrial client owners, we continue to perform research on practical means to maintain or further reduce losses while concurrently

reducing environmental impact. For example, FM Approved products that are beneficial in environmental certification programs now include measurements of key parameters and carry the "GREEN" symbol as part of their FM Approvals listing (*www.fmapprovals.com*).

Marshall: We are performing research to support the development of new additives for enhanced fire performance. New screening methodologies are being developed to evaluative additives and identify viable candidates.

Wickström: We have done a life cycle analysis on fire retardant chemicals.

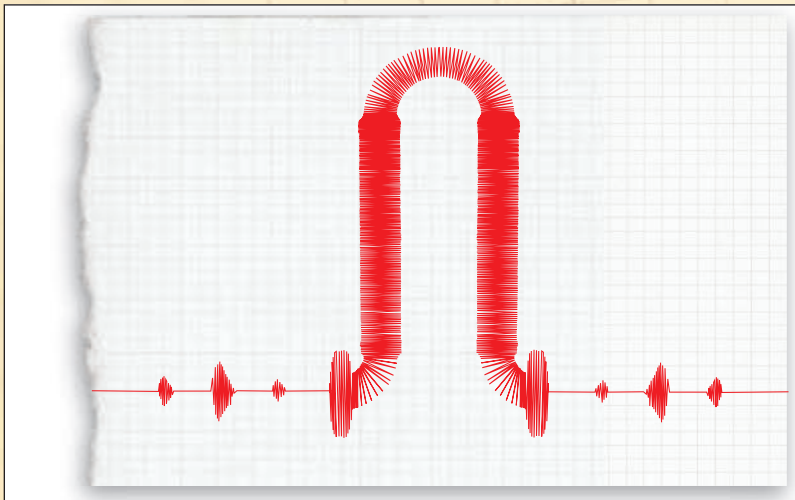
Baker: We have just published a report that reviews this area.

OTHER QUESTIONS:

QUESTION: How are the research projects undertaken by your organization determined?

Marshall: The research projects are largely undertaken based upon faculty interest. There is a growing interest in more applied research projects. At the same time, the faculty is embarking on large-scale collaborative fundamental research efforts, partnering with a variety of stakeholders that would push their activities toward more ambitious and far-reaching projects.

Wickström: We apply for funding from national and European organizations. Some research money is coming from industry, often as complements to funding from other sources.



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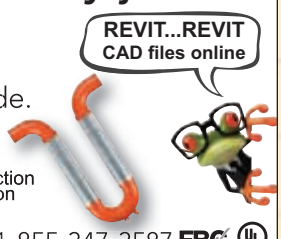

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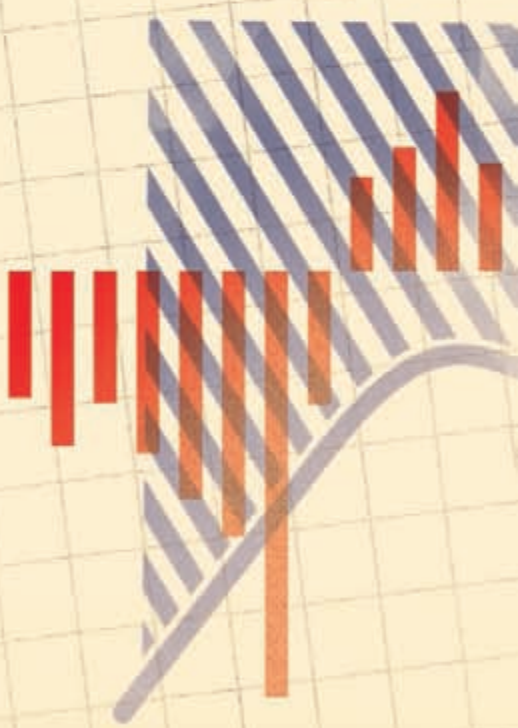

Gritzo: Research at FM Global is driven by the existing and emerging needs of our commercial and industrial client owners. Problem-solving research projects are defined based on input from more than 1,300 field engineers that perform more than 100,000 risk assessments annually. Joint research projects in key areas are also conducted in collaboration with clients, partners, and industry groups. Strategic research programs are developed based on capabilities needed to meet emerging trends in industry (i.e., nanotechnology, aging systems, new building technology, etc.) as well as improve the efficiency and effectiveness of problem solving in the future (i.e., fire modeling, improved test techniques, etc.).

Thomas: Usually by industries' needs and often in support of codes development.

Baker: We have an annual internal bidding round where projects across all disciplines are considered for funding on a competitive basis and with input from end-users and stakeholders.

QUESTION: How are you seeing that the research performed is being shared with the practicing fire protection engineer?

Gritzo: The results of FM Global's research form the basis for FM Global *Property Loss Prevention Data Sheets*, and FM Approvals Standards for certification of products for property loss prevention, both of which are openly available. In addition, FM Global personnel serve on over 340 technical committees worldwide and consistently present work at technical and scientific conferences and publish research in refereed journals. In specific areas of interest (such as sustainability, next generation protection standards, etc.), FM Global research and engineering staff are available to support specific requests from the fire protection engineering community.

Wickström: The most important and efficient way of sharing the results of testing is probably for the practicing fire protection engineers and representatives from industry to participate in all phases of a research project.

Marshall: We are collaborating more with fire protection engineers to conduct applied fire research and testing. It is hoped that these collaborations will lead to the development of new understanding and also better engineering practices.

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QUESTION: What can the practicing fire protection engineer do to assist your organization in achieving your fire research goals?

Wickström: By pointing out areas where there is a lack of knowledge.

Baker: They contribute to the identification of research needs.

Thomas: Keep us informed of the issues that they are seeing in their practices and the needs that are becoming apparent to them.

Marshall: I believe that the research at University of Maryland would be enhanced in relevancy and focus if the fire protection engineering faculty could be engaged as expert resources on some of the fire protection challenges presented to practicing fire protection engineers. I have found that working on real-world problems has inspired my research and helped me to identify pathways for making it immediately useful.

Gritzo: FM Global encourages increased communication and collaboration with fire protection engineers, including any activities that help identify research needs or communicate and implement research results. To help define research objectives, we encourage fire protection engineers working with or for our insurance clients to collaborate with FM Global engineers to best apply current practices and define potential needs or improvements. As we complete research objectives, we request increased opportunities from the organizers of fire protection engineering conferences to present the results of our work in a form tailored to engineering implementation and gaining meaningful feedback on how we can better work together toward our shared goals of improved fire protection.

QUESTION: Is there anything else you would like to share with the practicing fire protection engineer as it relates to research?

Thomas: That they should fully understand the context and uncertainties associated with the experimental outcomes that are reported in the literature before trying to apply them in their own practices. With limited resources, experimentation is rarely replicated, and it is often difficult to fully understand the robustness of a set of research findings in the real world.

Gritzo: Fire research has a long history of being reactive to severe events. In some cases, existing, sound solutions were not employed, often due to their cost. In other cases, there was a lack of knowledge within the fire protection community that resulted in engineering shortcomings. Knowledge continues to grow, and the available tools to practice the profession are improving. In this evolving landscape, we all need to remain wary of applying solutions that have not been proven. Instead, we encourage strongly advocating, and seeking to make increasingly feasible, the sound implementation of proven solutions while identifying and defining increasingly effective research methods to provide new, proven alternatives.

Wickström: It may not be the most important item, but I think that the education and the spreading the theoretical basics of fire dynamics would help to make it easier to gain acceptance of sound test and evaluation techniques, thereby improving the efficiency of fire protection measures.

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LITHIUM-ION BATTERY **HAZARDS**

By R. Thomas Long, P.E., Michael Kahn, Ph.D., and Celina Mikolajczak, P.E.

Lithium-ion (Li-ion) has become the dominant rechargeable battery chemistry for consumer electronics devices (e.g., smartphones and notebook computers) and is poised to become commonplace for industrial, transportation, and power-storage applications. Li-ion battery chemistry is different from previously popular rechargeable battery chemistries (e.g., nickel metal hydride [NiMH], nickel cadmium [NiCad], and lead acid) in a number of ways. From a technological standpoint, because of high energy density, Li-ion technology has enabled entire families of portable devices, such as smartphones. From a safety and fire protection standpoint, a high energy density coupled with a flammable organic, rather than traditional aqueous electrolyte, has created a number of new fire protection challenges. Specific challenges include the design of batteries containing Li-ion cells, the storage and handling of these batteries, and challenges in determining the best response to suppress and control fires involving Li-ion batteries.

The Fire Protection Research Foundation (FPRF) completed an assessment of the hazards associated with Li-ion batteries related to storage of Li-ion batteries and fire protection; this article provides a brief overview of this work to-date.[1] Before the global fire safety challenges associated with Li-ion batteries can be addressed, an understanding of Li-ion technology is useful and follows.

LI-ION CELLS AND BATTERIES

The term Li-ion battery refers to an entire family of battery chemistries. It is beyond the scope of this article to describe all of the chemistries used in commercial Li-ion batteries. Li-ion battery chemistry is an active area of research, and new materials are constantly being developed. Li-ion cells are distinct from lithium (or lithium primary cells). The term "lithium cell" most accurately refers to non-rechargeable battery chemistry, where lithium metal is used as one of the cell electrodes. Lithium metal is not used as an anode in Li-ion cells. However, the similarity in these two names has routinely led to confusion with regards to appropriate fire protection techniques. The following is an overview of rechargeable Li-ion technology and focuses on the characteristics of Li-ion batteries common to the majority of available batteries.

There is no free lithium metal within a Li-ion cell; thus, if a cell ignites due to external flame impingement or an internal fault, metal fire suppression techniques are not appropriate for controlling a Li-ion battery fire.

In the most basic sense, the term Li-ion battery refers to a battery where the negative electrode (anode) and positive electrode (cathode) materials serve as a host for the lithium ion (Li+). Lithium ions move from the anode to the cathode during discharge and are intercalated into (inserted into voids in the crystallographic structure of) the cathode. The ions reverse direction during charging (see Figure 1). Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a Li-ion cell; thus, if a cell ignites due to external flame impingement or an internal fault, metal fire suppression techniques are not appropriate for controlling a Li-ion battery fire. Under certain abuse conditions, lithium metal in very small quantities can plate onto anode surfaces. However, this should not have any appreciable effect on the fire behavior of the cell.

Cells can be constructed by stacking alternating layers of electrodes (such as in prismatic cells or by winding long strips of electrodes into a "jelly roll" configuration typical for cylindrical cells. Generally, cell form factors are classified as prismatic, cylindrical, and pouch cells (also known as polymer, soft-pack polymer, or lithium polymer).

In a Li-ion cell, alternating layers of anode and cathode are separated by a porous film (separator). An electrolyte composed of an organic solvent and dissolved lithium salt provides the media for lithium ion transport. A variety of safety mechanisms might also be included in a cell mechanical design, such as current interrupt devices (CID) and positive temperature coefficient switches.

An individual Li-ion cell will have a safe voltage range over which it can be cycled that will be determined by the specific cell chemistry. A safe voltage range will be a range in which the cell electrodes will not rapidly degrade due to lithium plating, copper dissolution, or other undesirable reactions. For most cells, charging significantly above 100% state of charge (SOC) can lead to rapid, exothermic degradation of the electrodes. Charging above the manufacturer's high voltage specification is referred to as overcharge. Since overcharging can lead to violent thermal runaway reactions,[2] a number of overcharge protection devices are either designed into the cells or included in the electronics protection packages for Li-ion battery packs.

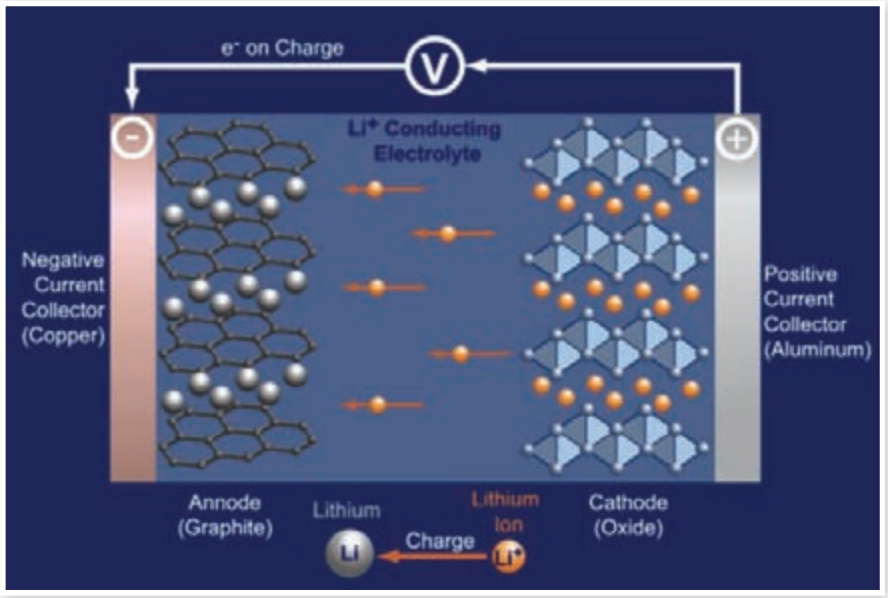

Figure 1. Li-ion cell operation: during charging, Lithium ions intercalate into the anode; the reverse occurs during discharge.

A Li-ion battery (or battery pack) is made from one or more individual cells packaged together with their associated protection electronics. By connecting cells in parallel, designers increase pack capacity. By connecting cells in series, pack voltage is increased.

For large format battery packs, cells may be connected together (in series or in parallel) into modules. The modules may then be connected in series or in parallel to form full battery packs. Thus, large format battery pack architecture can be significantly more complex than small consumer electronics battery packs, which typically contain series connected elements consisting of two or more parallel-connected cells.

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The four primary functional components of a practical Li-ion cell are the anode, cathode, separator, and electrolyte. Additional components of Li-ion cells, such as the current collectors, case or pouch, internal insulators, headers, and vent ports also affect cell reliability, safety, and behavior in a fire.

The chemistry and design of these components can vary widely across multiple parameters. Cell components, chemistry, electrode materials, particle sizes, particle size distributions, coatings on individual particles, binder materials, cell construction styles, etc., generally will be selected by a cell designer to optimize a family of cell properties and performance criteria. As a result, no "standard" Li-ion cell exists, and even cells that nominally appear to be the same (e.g., lithium cobalt oxide/graphite electrodes) can exhibit significantly different performance and safety behavior. In addition, since

Li-ion cell chemistry is an area of active research, one can expect cell manufacturers to continue to change cell designs for the foreseeable future.

LI-ION TECHNOLOGY APPLICATIONS

Li-ion cells have gained a dominant position in the rechargeable battery market for consumer electronic devices. The primary reason for Li-ion battery dominance is the chemistry's high specific energy (Wh/kg) and volumetric energy density (Wh/L), or more simply, the fact that a Li-ion cell of a specific size and weight will provide substantially more energy than competing technologies of the same size or weight. Li-ion cells have enabled smaller, more slender, and more feature-rich portable electronics. The smallest Li-ion cells are found in devices such as hearing aids and Bluetooth headsets. Larger, single cell applications include batteries for digital cameras, MP3 players, and e-readers. The most common single-cell Li-ion battery applications are cell phones and smartphones.

For larger electronic devices, such as notebook computers, power tools, portable DVD players, and portable test instruments, multi-cell battery packs are used. Multi-cell devices, such as notebook computer battery packs, utilize complex protection electronics.

Notebook computers represent the largest population of relatively complex Li-ion batteries in the commercial market. Many of these packs contain between six and 12 cylindrical, 18,650-size cells connected in series and parallel, though smaller cylindrical cells and flat soft pouch Li-ion polymer cells are becoming more common (see Figure 2).

The demand for Hybrid Electric Vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and purely electric vehicles (EVs) is expected to increase. At present, many hybrid vehicles implement NiMH batteries. A few vehicles that implement Li-ion battery technology have recently entered the U.S. market.

Figure 2. Examples of 18,650 cylindrical cells (these are the most common consumer electronics Li-ion cell form factor).

With penetration of electric vehicles comes the addition of charging stations in public areas, as well as in private residences. Automotive battery packs will also be serviced and thus, stored at service and battery switching locations. This new type of infrastructure will pose high voltage and fire safety challenges in addition to those associated with Li-ion batteries themselves.

Considerable interest has been generated in the last two to three years for applying Li-ion batteries for a variety of energy storage and grid stabilization (stationary) applications.[3] Prototype systems have been installed.[4] Megawatt-scale systems typically include thousands of cells housed in shipping container-sized structures that can be situated on power utility locations. These systems usually include integrated fire suppression in their installations. Smaller systems have also been planned and are being delivered for evaluation purposes, particularly for use with renewable energy sources.

LI-ION BATTERY FAILURES

The fact that batteries can fail in an uncontrolled manner on rare occasions has brought an increased public awareness for battery safety, in particular as a result of some very large product recalls of portable notebook computer and cell phone batteries. Both energetic and non-energetic failures of Li-ion cells and batteries can occur for a number of reasons, including poor cell design (electrochemical or mechanical), cell manufacturing flaws, external abuse of cells (thermal, mechanical, or electrical), poor battery pack design or manufacture, poor protection electronics design or manufacture, and poor charger or system design or manufacture. Thus, Li-ion battery reliability and safety is generally considered a function of the entirety of the cell, pack, system design, and manufacture.[5,6]

Performance standards are designed to test cell and battery pack designs. Failures that occur in the field are seldom related to cell design; rather, they are predominantly the result of manufacturing defects or subtle abuse scenarios that result in the development of latent cell internal faults.

CELL AND BATTERY FAILURE MODES

Li-ion batteries can fail in both non-energetic and energetic modes. Typical non-energetic failure modes (usually considered benign failures) include loss of capacity, internal impedance increase (loss of rate capability), activation of a permanent disabling mechanism such as a CID, shutdown separator, fuse, or battery pack permanent disable, electrolyte leakage with subsequent cell dry-out, and cell swelling.

Often, energetic failures lead to thermal runaway. Cell thermal runaway refers to rapid self-heating of a cell derived from the exothermic chemical reaction of the highly oxidizing positive electrode and the highly reducing negative

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electrode; it can occur with batteries of almost any chemistry.

In a thermal runaway reaction, a cell rapidly releases its stored energy. The more energy a cell has stored, the more energetic a thermal runaway reaction will be. One of the reasons Li-ion cell thermal runaway reactions can be very energetic is these cells have very high-energy densities compared to other cell chemistries. The other reason that Li-ion cell thermal runaway reactions can be very energetic is because these cells contain flammable electrolyte. As a result, not only do they store electrical energy in the form of electrochemical potential energy, they store appreciable chemical energy (especially compared to cells with water-based electrolytes) in the form of combustible materials.

The severity of a cell thermal runaway event will depend upon a number of factors, including the SOC of a cell (how much electrical energy is stored in the form of chemical potential energy), the ambient environmental temperature, the electrochemical design of the cell (cell chemistry), and the mechanical design of the cell (cell size, electrolyte volume, etc.).

For any given cell, the most severe thermal runaway reaction will be achieved when that cell is at 100% (or greater, if overcharged) SOC, because the cell will contain maximum electrical energy. If a typical fully charged (or overcharged) Li-ion cell undergoes a thermal runaway reaction, a number of things occur, including:

- Cell internal temperature increases;
- Cell internal pressure increases;
- Cell undergoes venting;
- Cell vent gases may ignite;
- Cell contents may be ejected; and
- Cell thermal runaway may propagate to adjacent cells.

ROOT CAUSES OF ENERGETIC CELL AND BATTERY FAILURES

There are a number of ways to exceed the thermal stability limits of a Li-ion cell and cause an energetic failure. Energetic Li-ion battery failures may be induced by external forces, such as exposure to fire or mechanical damage, or they may be the result of problems involving charge, discharge, and/or battery protection

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circuitry design and implementation, or they may be caused by internal cell faults that result from rare or subtle manufacturing problems. Generally, the root causes of energetic cell and battery failures can be classified as:

- Thermal abuse (e.g., external heating);
- Mechanical abuse (e.g., denting, dropping);
- Electrical abuse (e.g., overcharge, external short circuit, over discharge);
- Poor cell electrochemical design (e.g., imbalance between positive and negative electrodes); and
- Internal cell faults associated with cell manufacturing defects (e.g., foreign metallic particles, poor electrode alignment).

FACTORS THAT INFLUENCE THE EFFECT OF FAILURE

The severity of a Li-ion cell failure will be strongly affected by the total energy stored in that cell: a combination of chemical energy and electrical energy. Thus, the severity of a potential thermal runaway event can be mitigated by reducing stored chemical energy (i.e., by reducing the volume of electrolyte within a cell), or by changing the electrolyte to a noncombustible material (i.e., the cell chemistry).

The most flammable component of a Li-ion cell is the hydrocarbon-based electrolyte. The hydrocarbon-based electrolyte in Li-ion cells means that under fire conditions, these cells will behave in a fundamentally different way than lead acid, NiMH or NiCad cells, which contain water-based electrolytes.

Although all charged cells contain stored electrical energy, even fully discharged Li-ion cells contain appreciable chemical energy that can be released through combustion of the electrolyte. Water-based battery chemistries, under some charging conditions, can produce hydrogen gas through electrolysis of the water; however, this hazard is seldom a concern during storage where no charging occurs.

Although all charged cells contain stored electrical energy, even fully discharged Li-ion cells contain appreciable chemical energy that can be released through combustion of the electrolyte.

If cells with water-based electrolyte are punctured or damaged, leakage of the electrolyte can pose a corrosive hazard; however, it does not pose a flammability hazard. In comparison, leakage or venting of Li-ion cells will release flammable vapors. Fire impingement on Li-ion cells will cause release of flammable electrolyte, increasing the total heat release of the fire (assuming there are well-ventilated conditions).

Other combustible components in a Li-ion cell include a polymeric separator, various binders used in the electrodes, and the graphite of the anode.

When a cell vents, the released gases mix with the surrounding atmosphere. Depending upon a number of factors, including fuel concentration, oxygen concentration, and temperature, the resulting mixture may or may not be flammable.

FIRE BEHAVIOR OF CELLS AND BATTERY PACKS

Currently, there is no publicly available data from large-scale Li-ion cell or battery pack fire tests. There are a number of reasons for the lack of large-scale test data. The Li-ion cell industry has been evolving rapidly, so there has been an inherent difficulty in defining an "average" cell, battery pack, or device. Thus, if testing were to be conducted and considered reasonably comprehensive, it would require testing of multiple models of cells, packs, or devices from multiple suppliers, and even so might quickly become obsolete, as cell chemistries and mechanical designs evolve.

In 2010, testing was conducted involving a consumer electronic device package that contained a Li-ion battery pack, and a cell within a consumer electronics device package undergoing a thermal runaway reaction (no external heating).[7] The observations from this testing may have significant implications on firefighting procedures, specifically fire protection and fighting strategies, fire scene overhaul procedures, and fire scene monitoring for rekindles. Specifically, if a fire occurs adjacent to stored Li-ion cells and battery packs, those cells and battery packs must be protected from relatively modest (compared to flashover)

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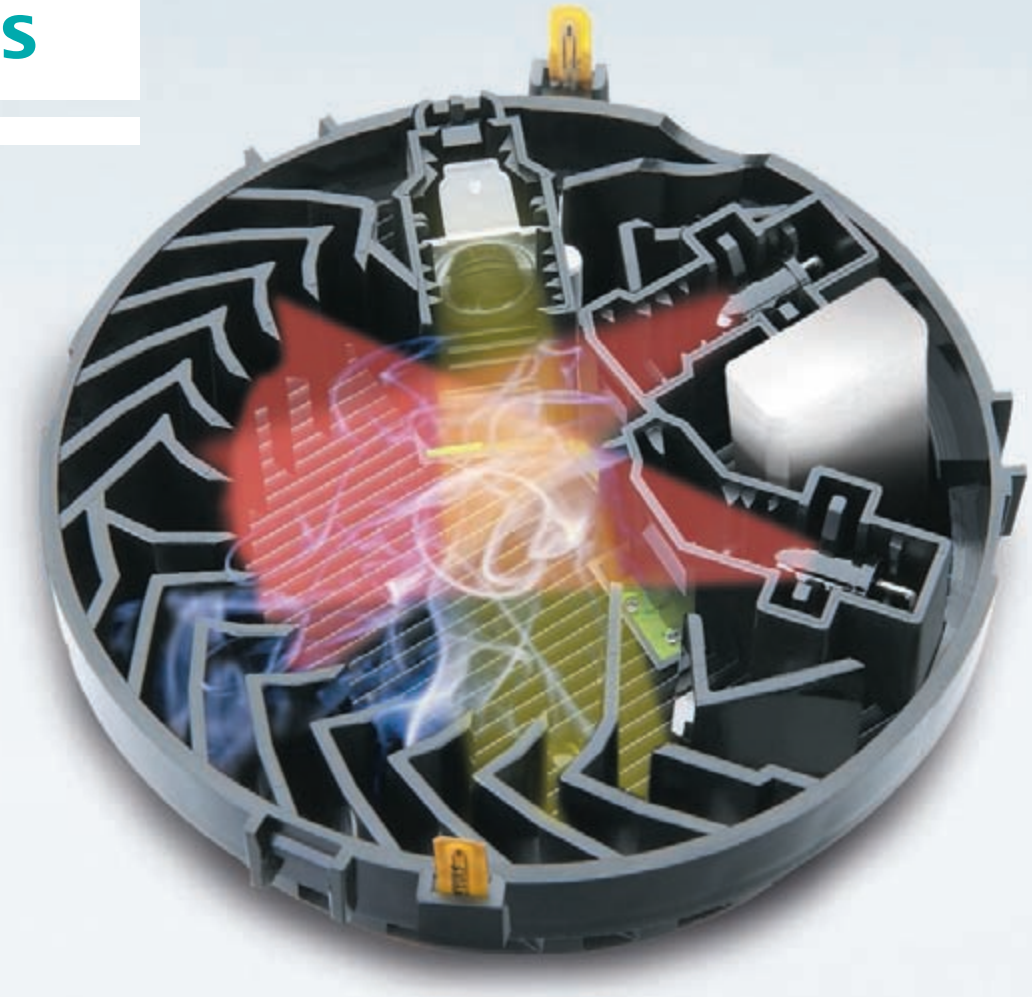

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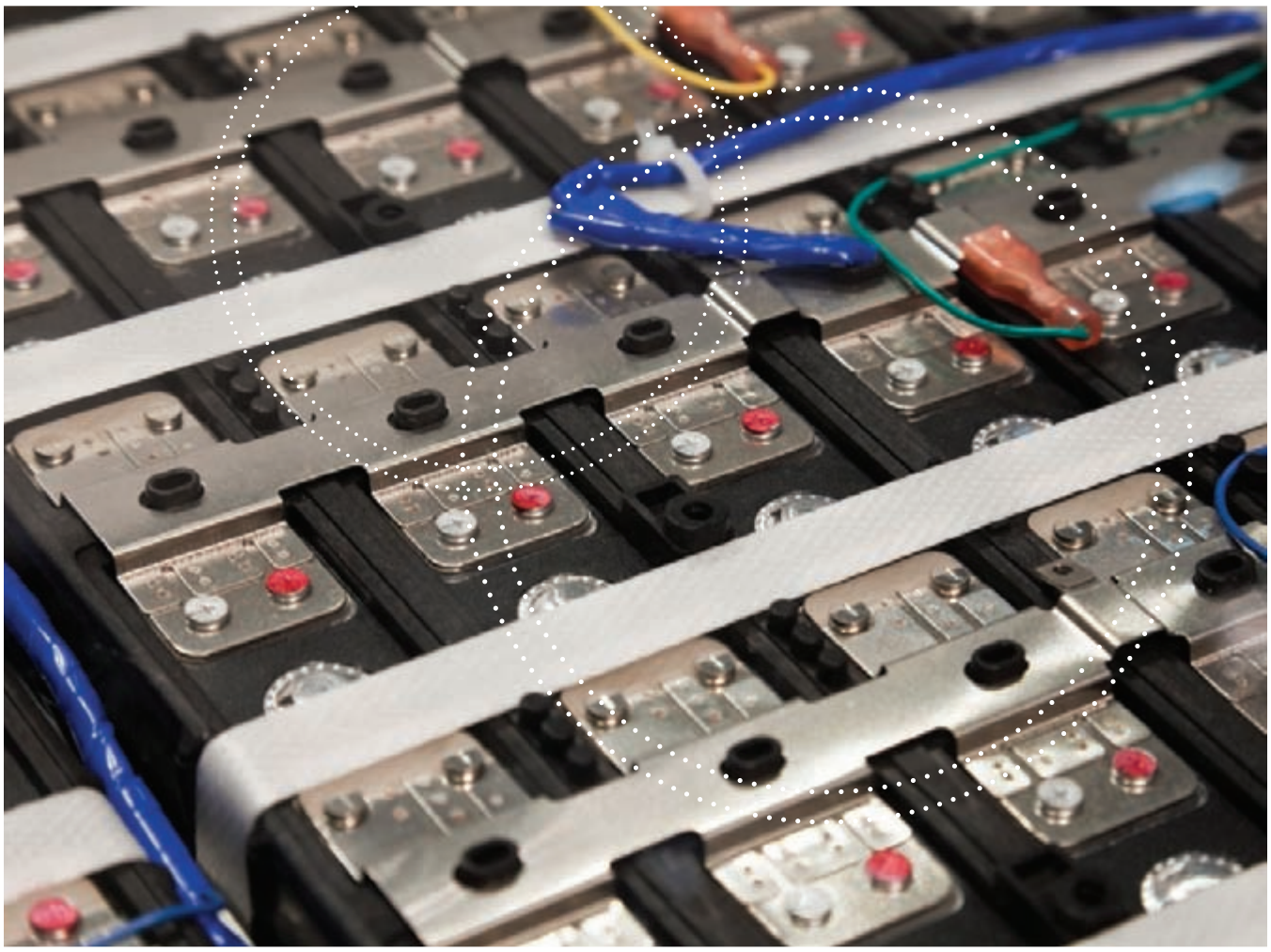

overheating, or cells may begin to vent and ignite, spreading the fire more rapidly than would be expected for normal combustibles.

On fire scenes where large quantities of Li-ion cells have been involved, decisions regarding overhaul procedures must be made with an understanding that as cells are uncovered, moved, or damaged by overhaul procedures, they may undergo thermal runaway reactions and vent, they may ignite, and they may generate (or may themselves become) hot projectiles. Similarly, the potential for rekindles will be high at such fire scenes, and these scenes will require extended monitoring.

As these products saturate the marketplace, distribution, storage, warehousing and retail locations will store Li-ion batteries, as well as the products that contain them. With new battery technologies come new hazards and new challenges for determining the best way to suppress and control fires, including determination of the most effective suppression agents.

FIRE PROTECTION STANDARDS

Li-ion batteries and battery packs have a higher energy density than other, more common battery types, which is appealing to the end user, but provides distinct fire protection challenges given the current body of knowledge available regarding Li-ion battery fires.

At present, the authors are not aware of any fire protection standards specific to Li-ion cells. None of the widely accepted standards applicable to Li-ion battery packs

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includes water application tests. The publicly available information from testing conducted to date does not allow a comprehensive assessment of whether traditional water-based automatic sprinkler systems, water mist systems, or some other water-based suppression system would be most effective in the protection of stored Li-ion cells or batteries.

Water-based automatic sprinklers are the most widely used fire suppression system and have proven their efficiency and reliability over the years. Many locations are currently provided with the infrastructure necessary to facilitate suppression strategies using water-based suppression systems. Therefore, based on current knowledge and infrastructure, a water-based fire suppression system is the strongest candidate for the protection of stored Li-ion cells and batteries. As warehouse and retail spaces see an increase in the volume of these products, the current codes and standards do not provide adequate guidance on how to best protect Li-ion batteries or classification of their commodity type.

Commodity classifications for water-based suppression strategies are described in NFPA 13,[8] which addresses sprinkler system applications and proposes requirements for storage protection. Commodity classifications relate directly to the fire protection system design requirements.

Classification of actual commodities is primarily based on comparing the commodity to be protected to the definitions for the various commodity classes. NFPA 13

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provides a list of commodity classes for various commodities.[8] Once the commodity classification is known along with the geometry and configuration of the stored product, sprinkler design densities can be selected. Different types of batteries and the recommended commodity classification for those batteries are mentioned:

- Dry cells (non-lithium or similar exotic metals) packaged in cartons: Class I (i.e., alkaline cells);
- Dry cells (non-lithium or similar exotic metals) blister packed in cartons: Class II (i.e., alkaline cells);
- Automobile batteries – filled: Class I (i.e., lead acid batteries with water-based electrolyte); and
- Truck or larger batteries, empty or filled Group A Plastics (i.e., lead acid batteries with water-based electrolyte).

Currently, NFPA 13 does not provide a specific recommendation of a commodity classification for Li-ion cells or complete batteries containing several cells. A number of features specific to Li-ion batteries could make any of the existing battery classifications inaccurate and the recommended fire suppression strategy may not be appropriate:

- Flammable versus aqueous electrolyte;
- The potential to eject electrodes / case material (projectiles) upon thermal runaway;
- Latency of thermal runaway reactions (cell venting can occur sequentially and after a significant delay resulting in re-ignition of materials);
- Large format battery packs may exhibit voltages much higher than typical truck batteries; and
- Individual cells generally have metal versus plastic outer shells.

The venting and projectile potential of Li-ion cells has some similarities with aerosol products, which typically utilize a flammable propellant, such as propane, butane, dimethyl ether, and methyl ethyl ether. However, these products generally have no associated electrical energy and are not as susceptible to re-ignition events. As they contain flammable electrolyte, Li-ion cells might also be compared to commodities such as ammunition or butane lighters in blister packed cartons (high-energy density).

Currently, NFPA 13 does not provide a specific recommendation of a commodity classification for Li-ion cells or complete batteries containing several cells.

For commodities not specifically covered by NFPA 13, full-scale fire suppression tests are typically used to determine the commodity classification. Most current sprinkler system design criteria are based on classifications of occupancies or commodities that have been developed from the results of full-scale fire suppression test data and the application of experimental results that have been shown to provide a minimum level of protection. According to the *Automatic Sprinkler System Handbook:*[9]

> *Where commodities are not currently defined, commodity classification testing can provide an accurate comparison between the proposed commodity and known commodity classifications. This testing is essential when determining acceptable sprinkler design criteria for new or unknown commodities where a meaningful comparison cannot be made between the given commodity and other known commodity classifications. Bench-scale testing is not useful for making precise commodity classifications.*

One of the main reasons that specific test data are required when determining the commodity classification of a new or unknown commodity is that the current ability of an engineering analysis is insufficient to define sprinkler suppression characteristics.[9] At present, there is no publicly available large-scale fire test data for Li-ion cells that can be used to fully assess the storage hazards of Li-ion cells or batteries or to determine an appropriate commodity classification that could be used to provide an overall fire protection suppression strategy.

The FPRF is currently preparing for Phase II of the Li-ion Hazard and Use Assessment, which will likely involve fire tests aimed at determining the fire behavior characteristics of bulk

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packaged Li-ion batteries with the end goal of determining commodity classifications, as appropriate, for various Li-ion battery products. This data will likely prove useful to the NFPA 13 technical committees responsible for the development of provisions related to the suppression of Li-ion battery fires in various occupancies.

R. Thomas Long, P.E., and Michael Kahn, Ph.D., are with Exponent Failure Analysis Associates*; Celina Mikolajczak, P.E., is a battery consultant.*

ACKNOWLEDGEMENTS

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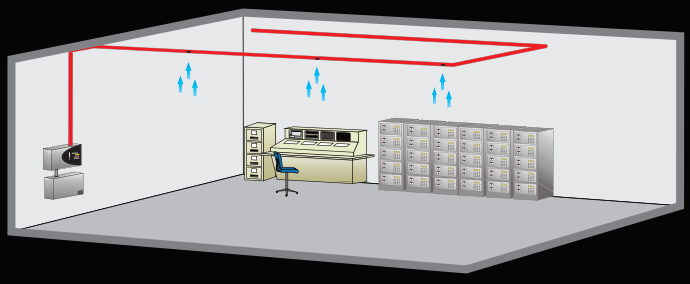

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RECENT RESEARCH AT THE FIRE PROTECTION RESEARCH FOUNDATION

By Kathleen Almand, P.E., FSFPE

In June of 2011 the University of Edinburgh's Center for Fire Safety Engineering convened a seminar on the topic of fire safety engineering education. One of the agenda items for that seminar was the role of codes and standards in the future education of a fire safety (or fire protection) engineer. How does a legacy of fire safety principles inherent in prescriptive codes and standards enable and complement an increasingly capable fire safety engineering profession?

In considering a response to that question, it is useful to review the research carried out at the Fire Protection Research Foundation, the National Fire Protection Association's (NFPA's) independent research affiliate. Each year, NFPA technical committees come to the Foundation seeking technical information on fire safety issues. In the research conducted at the Foundation over the past several years, many of the questions asked and answers provided contribute to the emergence of engineering in its various forms in code development. The most frequently asked question by far is:

"What is the basis for that number?"

NFPA standards are full of numbers! This legacy of prescriptive codes and standards requirements embodies the basic fire safety principles embedded in the modern codes and standards framework. So, when the Foundation is asked to determine the technical basis for these numbers, it is in effect being asked to articulate the engineering design principles embodied in them. Here are some examples of the "numbers": a spacing requirement for fire protection equipment; a required minimum distance from a hazard; the minimum performance criteria for a fire protection technology; a hazard classification; and many others.

The Foundation has answered this question for various technical committees on various fire protection topics. Although all Foundation work relies on engineering and scientific principles, from the perspective of further enabling the use of engineering methods, projects may be labeled "ok," "better," and "best." The examples below illustrate each of these categories.

"OK"

The Foundation has conducted a number of projects to provide a better technical basis for performance criteria for equipment specified in NFPA codes and standards. This is a particularly common type of project in support of the *National Fire Alarm Code®*, NFPA 72,[1] where new detection and signaling technologies are rapidly entering the marketplace and code provisions must adapt from a prescriptive basis that relates to older forms of the technology.

A current example is a project to develop performance criteria for emerging light sources for emergency notification appliances.[2] The goal of this project is to adapt requirements based on traditional strobe light characteristics to the different visual qualities of other sources such as Light Emitting Diodes (LEDs). With a quantified understanding of performance, engineers can more easily integrate these systems into fire safety design for egress. This project, and others like it, uses engineering analysis to develop new prescriptive code provisions; this will more easily enable further changes once the technical basis for requirements is clearly understood. This is the most common of Foundation research projects.

A second example involves friction loss characteristics for modern fire hose.[3] The calculation of friction loss in fire hose is a common task for firefighters responsible for operating fire apparatus pumps. This is required to deliver water at the proper flow rate and pressure to firefighters controlling the fire hose nozzle. Pressures and flow rates too low will be insufficient for fire control, while pressures and flow rates too high will create dangerous conditions with handling the nozzle, burst hose and other hazards.

Baseline friction loss coefficients used by today's firefighters for calculating fire hose pressure loss were

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derived using hose design technology from upwards of 50 years ago. A need exists to update these coefficients for use with today's fire hose. The focus of this study has been to develop baseline friction loss coefficients for the types of fire hose commonly used by today's fire service, and identify any additional performance characteristics that should be considered for friction loss calculations. The methodology developed in this study can be used to evaluate future updates to this technology.

Another example of an "OK" project investigated combustion air require-ments for power burner appliances.[4]

The National Fuel Gas Code® [5] combustion air requirements in section 9.3 were developed primarily for residential-sized non-power burner appliances. The code contains no separate requirements for power-burner type appliances often having large volume inputs. Therefore, when the code's current combustion air requirements are applied to these high-volume input power burner appliances, they usually result in excessively-sized outdoor combustion air openings. The objective of this project was to provide the technical justification to establish new combustion air provisions for high-volume input power burner appliances.

From the fire protection engineering perspective, perhaps the ultimate installation standard would simply refer the user to engineering analysis and design methods, removing "prescribed numbers" altogether from the standard.

"BETTER"

A second typical project type is hazard assessment: the Foundation has conducted several projects to understand the storage hazard associated with emerging hazards. This type of project conducts a thorough engineering hazard assessment to identify storage configurations, ignition scenarios, and often includes laboratory research to characterize fire hazard parameters.

A recent example of a Foundation project in this category is the assessment of the hazards associated with the storage of lithium ion batteries[6] so that engineers can develop appropriate protection strategies for the growing proliferation of this hazard in storage warehouses. By quantifying the hazard scenarios upon which protection criteria in the code are based, fire protection engineers can design alternative strategies in real facility scenarios.

Another example is in the area of detection in warehouses.[7] Recent large-loss warehouse fires have caused the community to explore the application of fire detection for early fire warning, fire location identification and monitoring with perceived benefits of quicker response of suppression systems, reducing water supply requirements, and minimizing the involvement of fire departments. However, currently there is little research available or guidance on the utilization of fire detection technologies of various types in warehouse environments. In the recently-completed first phase of this project, a hazard assessment of warehouse fires, based on incident data and potential fire scenarios, was conducted to form the basis for developing performance criteria for detection systems in this environment.

A third example of a "better" project analyzed the hazards involved with fire safety in consumer fireworks storage and retail facilities.[8]

This study reviewed the fire incident literature and fundamentals of the hazards associated with this commodity in order to identify research gaps for the basis of facility fire protection criteria.

"BEST"

From the fire protection engineering perspective, perhaps the ultimate installation standard would simply refer the user to engineering analysis and design methods, removing "prescribed numbers" altogether from the standard.

The Foundation is currently embarking on a project to develop a reliability-based engineering template to determine required inspection and testing frequencies for fire protection equipment. These types of requirements have a long history in many NFPA standards and are often the subject of frequent technical committee debate, as they have strong implications for the maintenance costs.

The proposed template will identify the required reliability-based calculation methods, review the data needs, and address means to accommodate limitations in those data. Individual technical committees (and engineers tasked with developing specific maintenance plans for fire protection equipment) can then adapt this template using the data resources available to them.

A second project in the category of "best" evaluated health care operating rooms as wet/dry locations.[9]

This study defines and analyzes the hazards associated with hospital operating rooms to clarify the classification type (i.e., wet location versus dry location) of their electrical environment.

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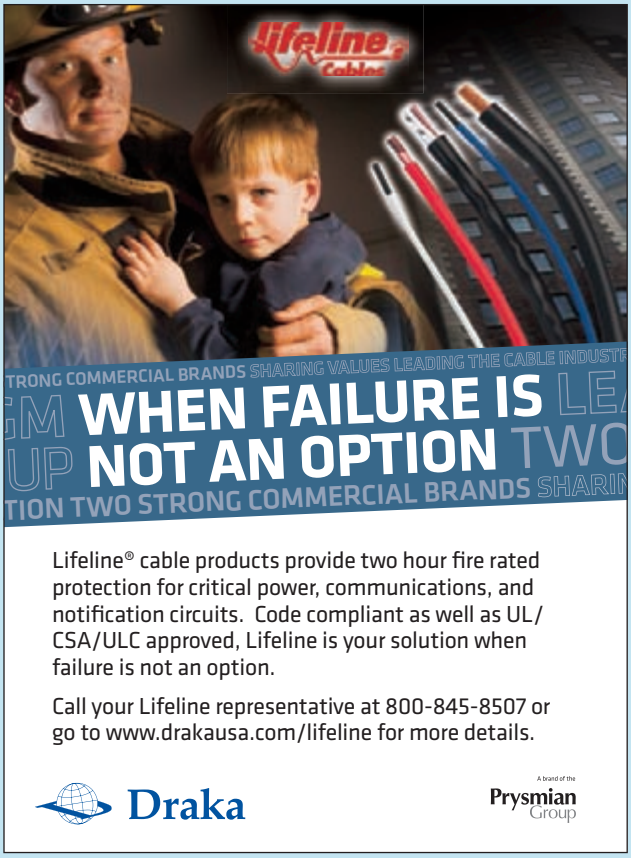

This included a review of the existing literature on fluid spills and electrical hazards in the operating room, a gap analysis for missing information, and a proposed risk assessment method for hospitals to use to evaluate the proper classification of an operating room.

A third project in this category evaluated entrainment fractions for dust layers.[10]

NFPA 654[11] includes long-standing prescriptive criteria that have been used for determining whether an explosion hazard exists in a building compartment. The objective of this project was to establish the technical basis for quantitative criteria for determining that a compartment is a "dust explosion hazard" that can be incorporated into NFPA 654 and other relevant safety codes and standards. This report presents the results of the Phase I portion of the study, which is the development of a strawman method to assess the dust hazard.

Another type of Foundation project that falls in the "best" category from the perspective of integrating engineering methods into codes and standards are projects that evaluate computer modeling applications. Here, the goal is to build confidence in models that predict performance in a given application, enabling the most flexible tool for the profession. Two projects of this type are underway at the moment: a project focused on validating models to predict smoke detector actuation in high air flow environments (for NFPA standards 75[12] and 76[13] on Protection of Information Technology Equipment and Telecommunications Facilities) and a project on evacuation modeling as applied to mixed evacuation from high-rise structures.

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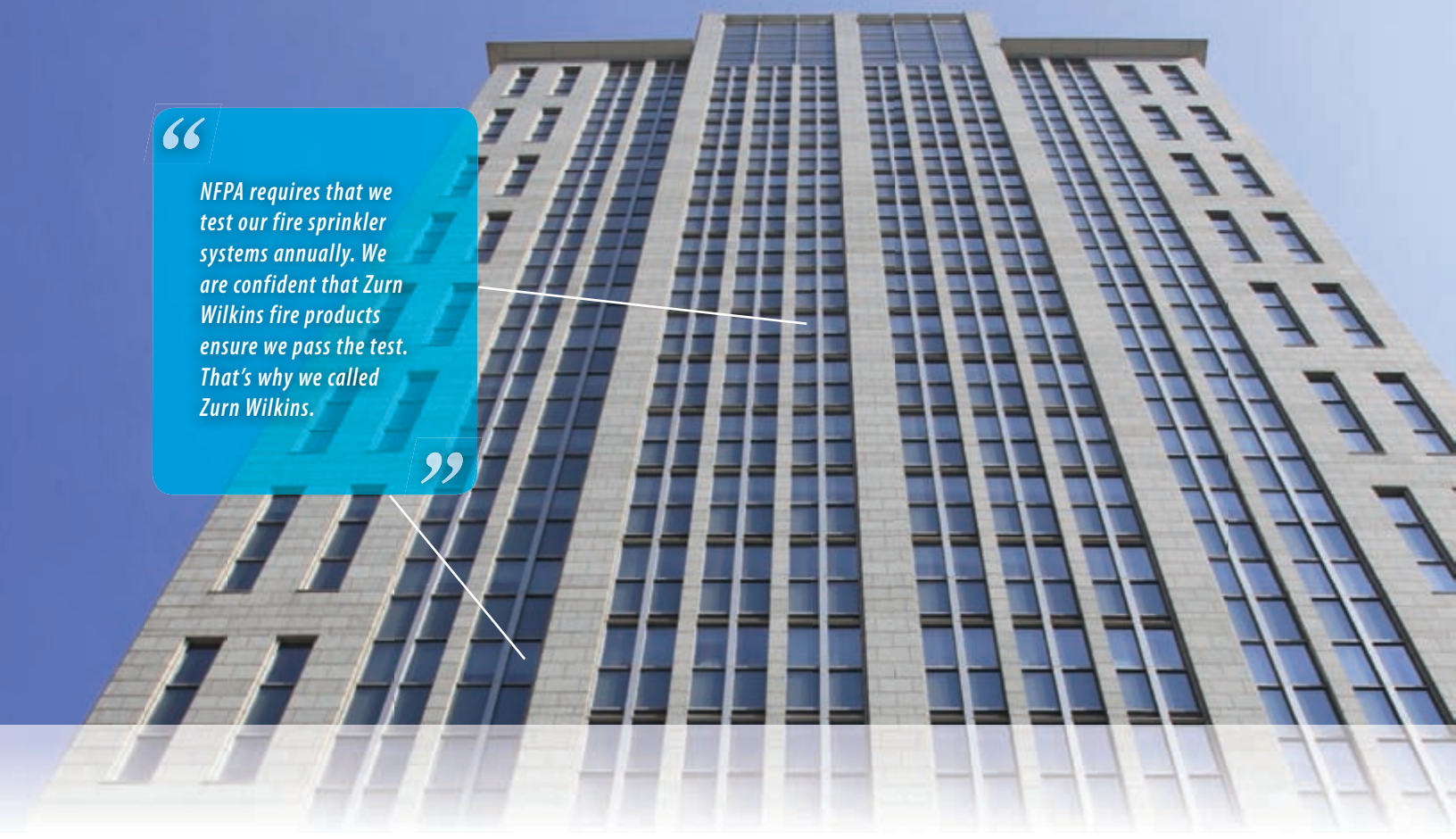

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THE DATA CHALLENGE

Each of these projects at various stages has faced the same challenge that every fire protection engineer faces in every project: access to quality, relevant data to inform engineering methods. Each Foundation project that involves the collection of data contributes to the larger body of information upon which the tools of our profession are based. As codes and standards move towards further enabling engineering design, the profession needs to work together to strengthen this database.

For more information on Foundation projects, visit *http://www.nfpa.org/foundation*.

Kathleen Almand is with the Fire Protection Research Foundation.

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FIRE SAFETY ENGINEERING EDUCATION–

By Peter Johnson, C.P. Eng.

INTRODUCTION

The Fire Protection Association, Australia (FPA Australia) has a new policy that highlights the need for practitioner competency and insurance in all areas of fire safety design and the fire protection industry.

Individuals have been able to practice as fire safety engineers, fire sprinkler designers or passive fire protection practitioners in some states of Australia with little if any control over professional competency or reasonable Professional Indemnity (PI) or Public Liability (PL) insurance.

There is a need, therefore, for a national approach to accreditation and to establishing certification of fire safety engineers and all practitioners in the industry, based on established levels of competency appropriate to their roles, as well as compulsory requirements to carry adequate PI and PL insurance and comply with ethical standards

In a sense, the process starts with sound overall fire safety engineering design. If this is unsatisfactory, it cannot be easily remedied by fire protection systems design, construction or maintenance provisions. However, the situation can be made worse if these subsequent activities are equally not undertaken at a satisfactory standard.

Within this broad FPA Australia framework and policy, this article

looks primarily at competency requirements for fire safety engineers developing performance-based fire safety solutions, i.e., the front end of the design and construction process. Some examples of the risks associated with a lack of competency and insurance in Australia are provided, which could affect building and infrastructure owners, designers and the industry as a whole, if this FPA Australia policy is not adopted nationally.

CURRENT SITUATION – FIRE SAFETY ENGINEERING

Australia has a performance-based building code,[1] which is based on the Nordic hierarchy, with objectives and functional statements that sit above the performance requirements. The latter of which are the legal requirements, which are referenced in state acts and regulations. The performance requirements can be satisfied by meeting the prescriptive, or so-called "deemed-to-satisfy" requirements of the code, or by developing alternative solutions, or by some combination thereof. The building code covers all requirements for buildings, including health, safety and amenity. There is no separate fire safety code. Any alternative solutions related to fire safety require supporting fire safety (protection) engineering analysis or risk assessment.

When the performance-based *Building Code of Australia* was introduced in 1996, most states introduced

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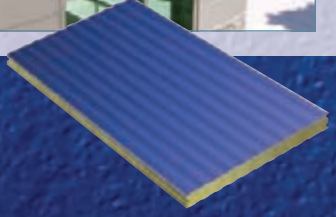

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elements of a model building act, with reform of liability to include proportionate liability arrangements and avoid the "deep pocket" syndrome. That is, people who share responsibility for mistakes only pay in proportion for their contribution to the liability. In Australia, this sits with an English-style common law system. Another requirement of the model legislation introduced only in some states was to require some professional practitioners, but often not all types of engineers and often not trades people, to hold minimum levels of insurance. The principle was to ensure that where engineers or others failed in their duty, those affected by their decisions could at least recover some funds through insurance, even if the engineering firm or their engineers were made bankrupt.

Whilst a limited number of building failures, large fires and litigation may highlight some of the weaknesses

A number of Australian states have no registered practitioner scheme for fire safety engineers.

in the performance-based building code system and in some aspects of fire safety design, it must be said that there are many sound fire safety engineers operating in Australia who:

- demonstrate competence
- have professional registration
- maintain their continuing professional development
- understand and operate within their code of ethics
- carry the requisite PI and PL insurance, and
- produce fire safety designs for some great buildings around Australia and internationally

This does not mean that there are no problems or issues with Australian buildings being constructed and operated. For a start, there are only a limited number of fire safety engineers who carry the National Professional Engineers Registration (NPER) or IFE Engineering Council registration or certification. A number of Australian states have no registered practitioner scheme for fire safety engineers. Even where these schemes are in place, the level of professional scrutiny and auditing is not rigorous. Equally, some fire safety engineers may be operating at times beyond their level of competence, and may not even realize this fact.

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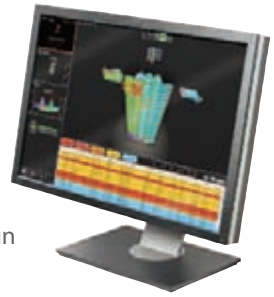

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The problem issues that are sometimes seen in fire safety engineering designs include:

- Discharge of exit stairs internally within buildings without protected routes, instead of direct to open space
- "Performance-based" or "fire engineering" changes to sprinkler system design when no acceptable engineering method is available for this analysis.
- Alternative solutions involving unprotected steel or reduced FRL elements with no input or review by competent structural/ fire engineers
- Designs based on no or limited hazard analysis, and simple use of one scenario design fires.
- Poor use of fire models with no proper understanding of heat transfer, fluid mechanics, or thermodynamics

OTHER ISSUES

If the fundamental fire safety strategy and fire engineering analysis is satisfactory, there are still a number of areas in which the overall fire safety outcomes for the building or infrastructure can go wrong. These include:

- Poor design of fire protection systems, such as sprinklers, fire detection and smoke control, resulting in non-compliance with Australia Standards
- Inadequate inspection of fire-rated construction and fire protection systems during construction
- Structural designers deviating from prescriptive standards without proper fire engineering investigation
- Inadequate system commissioning, particularly of systems integration, and poor Operations and Maintenance Manuals
- Inadequate maintenance, and lack of audit by owners or third parties of maintenance contractors
- Inadequate fire safety management, in terms of site induction training, hot work permits, evacuation drills, etc.

In part, faults in these areas can be attributed to:

- A lack of proper professional or trade training at many levels of the fire industry
- No accreditation or individual certification requirements for many design and installation practitioners in some states

> Another risk or opportunity lost can be if facilities are grossly over designed because the fire safety engineer or services designer has not understood their task.

- Over-reliance by principal certifiers (building approval officials) issuing occupancy permits based on certification by others purporting to show adequate inspections of construction and fire protection systems were undertaken
- Poor checking and quality assurance of design and installation work
- Poor project management practice putting pressure on designers to lower their standards or over reliance on dubious practices such as "it was done on another job somewhere"
- Consultants willing to operate outside their area of expertise because of market competition
- Building owners looking to minimize expenditure on maintenance and fire safety management

Some issues relate to the certification process as exemplified by a recent discussion paper entitled "Improving Building Certification in Queensland."[2] This focused particularly on the role of private (non-government) certifiers. Issues raised include:

- Handling conflicts of interest
- How to manage the public interest role and maintain an "independent" approval view of the design
- Avoidance of participation in design
- Handling designs involving performance-based solutions
- Making decisions on "minor" alternative solutions without a fire safety engineer being involved

Many practitioners fail to carry sufficient PL and PI insurance, unless forced by law, which means if things do go wrong with a design or within a completed project, they have insufficient protection. Equally, building owners and managers find they have little or no recourse to legal means of recovering their losses from the practitioners involved.

RISKS

The fire statistics in Australia do not show at this stage any major market failure that could be attributed to performance-based design, fire safety engineering or other aspects of fire protection in the construction industry. However, there are a number of risks.

The first is that failures of design could result in fire deaths or injuries, asset damage, business interruption or other losses when key measures of fire protection do not function as intended. The risks could include endangering

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the lives of firefighters, even if the facility occupants are able to escape.

Another risk or opportunity lost can be if facilities are grossly over designed because the fire safety engineer or services designer did not understand their task. For example, the fire resistance of structural elements could be chosen to be significantly in excess of the fire severity requirements if this analysis process is not well understood, thus resulting in wasted construction funds. At least this design ends up "on the safe side." However, the community is not served adequately because resources are wasted.

An increasing risk is that of litigation where a facility owner or manager finds that they have building elements that are poorly designed or fail to perform their function. A number of the legal cases for residential buildings in Australia have first been detected as acoustic problems between tenancies, but with further investigation have shown to also be a failure to build separating walls and floors to the required fire resistance level (FRL), including penetrations.

A greater risk than all of these is that the fire engineering profession becomes marginalized because of the conflict of interest that private certifiers operate under. Possible examples include:

- Certifiers, whether government or private, have a critical role with approvals to look after community interest above their duty to their client. However, where they have involvement in the design process, the private certifier may then not judge the design impartially in issuing approvals.
- The private certifier wants to help his or her client and make more fees, and so he or she might recommend alternative solutions that he or she has approved before. Poor design may result from this situation through higher safety risk or missed opportunities.
- The profession of fire engineering becomes diminished and de-valued because the design process is short cut or avoided, and the fire engineer is either 1) not involved in the process or 2) reduced to simply justifying a design solution developed by the private certifier and which may not be appropriate.
- The fire services tend to see certifiers as part of the client team, and not independent. The result is that the fire services consider it is their duty to do much of the certifier's job of assessment of an alternative solution on behalf of the "public interest" and some may not have the skills for the task.

THE WAY FORWARD

If these issues are to be resolved satisfactorily, and future major industry

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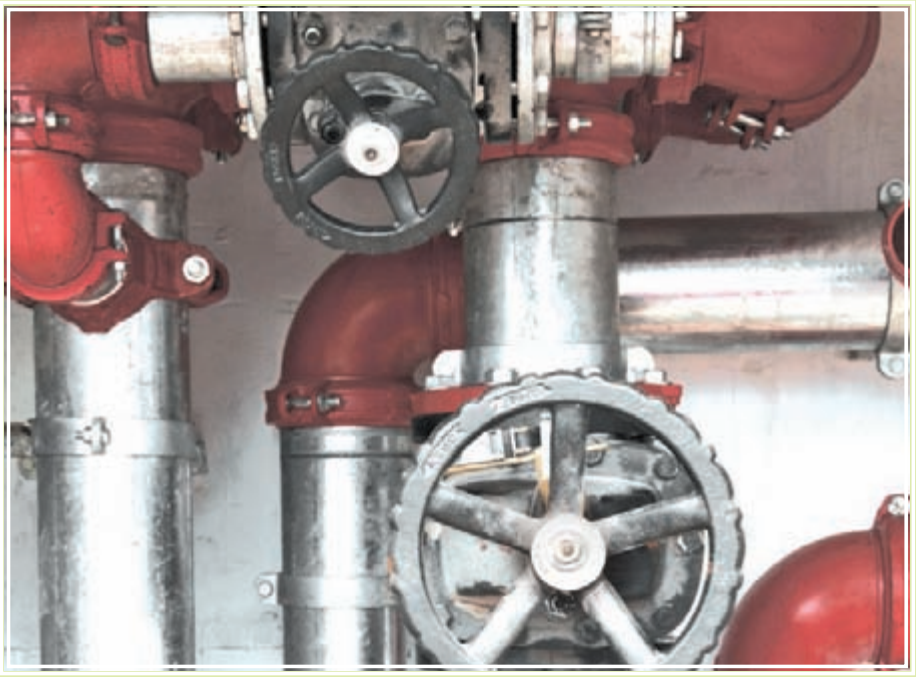

and individual problems prevented, then action needs to be taken.

FPA Australia has taken action at the broad industry level by setting policy on competency and insurance. To that end, FPA Australia is ramping up its learning and development activities and practitioner certification schemes. These need to be complemented by consistent actions by all state governments to require certification of all practitioners and set requirements for mandatory insurance.

The second step is to get the certification/approval and inspection of fire safety measures in buildings improved, as is being proposed in Queensland, and have it rigorously enforced. Conflicts of interest and no involvement in design by certifiers must be enforced, especially in relation to fire safety. Equally, inspections need to be more thorough.

The third step is to reexamine what constitutes fire safety engineering and what sort of background, qualifications and training practitioners should have to ensure fire safety strategies are robust.

EDINBURGH UNIVERSITY

The University of Edinburgh held a global technology leadership seminar on fire safety engineering education in May/June 2011. This week-long seminar on the future of fire safety education was the start of a major program sponsored by the Lloyd's Register Educational Trust (LRET).

The objective of the seminar was to review the current position of the profession of fire safety engineering, and the present approaches to fire safety engineering education. The aim was identification of areas for improvement and future needs.

Some key conclusions from the seminar were:

- The profession of fire safety engineering is still in adolescence.
- Courses need to have a rigorous approach to fire fundamentals, including fire dynamics, that is built upon a good foundation of fluid mechanics, thermodynamics, and heat transfer.
- Fire safety engineers need a good understanding of structural behavior and human behavior.
- Courses could benefit from more experience of real world problem solving, design studies and practice oriented projects.
- Most courses need to pay more attention to hazard analysis, risk assessment, uncertainty/variance, sensitivity analysis, etc.
- Real fire training is essential to complement theoretical studies.
- Many practicing fire safety engineers lack the rigorous knowledge of fire safety engineering as a result of inadequate education or insufficient professional experience.

There was a good deal of discussion around a set of five criteria that were agreed as measures of successful fire safety education programs. These measures were:

- Good quality students entering the course
- Sound curriculum (rigor, fundamentals)
- Good teaching faculty
- Strong research programs
- Demand for graduates

The Lund University program in Sweden for fire engineering and risk management was highlighted as the exemplar of a successful program.

A number of attendees at this LRET-sponsored seminar could point to programs and courses internationally where graduates were not targeted by the top firms because those programs accepted students who were not technically strong and the university curriculum lacked rigor in the fundamentals, and often was not supported by world class research.

Peter Johnson is with Arup.

A longer version of this paper was first presented at the Fire Australia 2011 conference held in Adelaide, Australia, in November 2011 under the theme, "The Essentials of the Future – Education and Maintenance."

References:

1 *Building Code of Australia*, Australian Building Codes Board, Canberra, 2012.

2 "Improving Building Certification in Queensland," Department of Local Government and Planning, Queensland, Australia, 2011.

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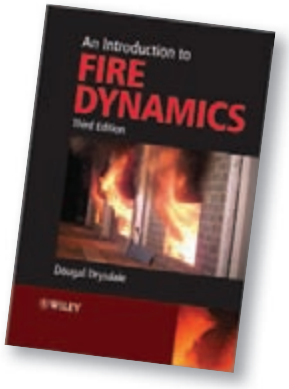

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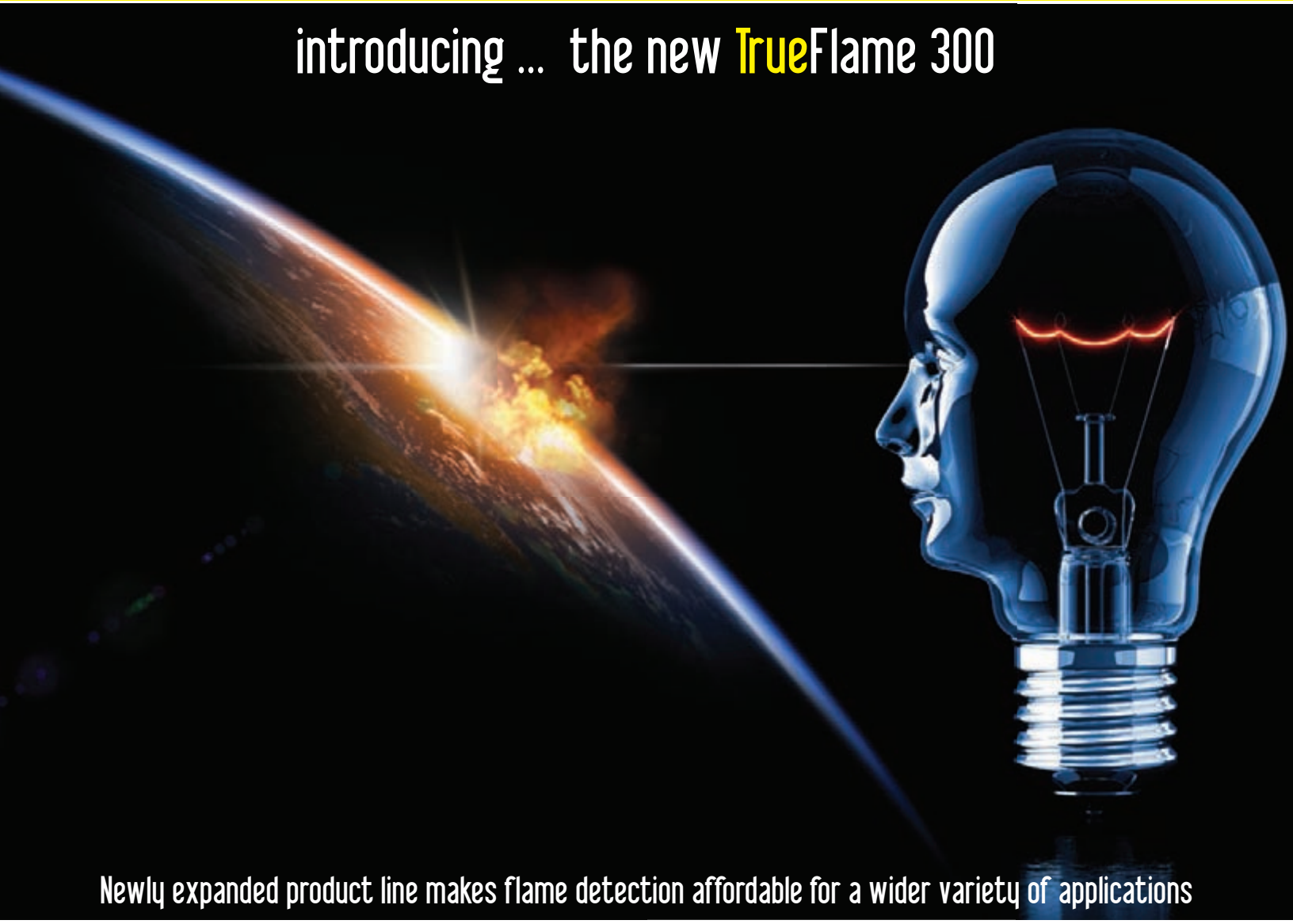

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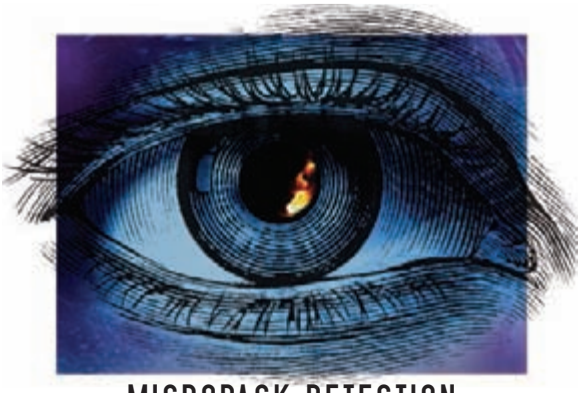

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Savannah, GA, USA
Info: www.sfpe.org/SharpenYourExpertise/Education.aspx

October 18–19, 2012
Fireforum Congress – Fire & Sustainability
Brussels, Belgium
Info: www.ifireforum.be

November 7–8, 2012
Fire Safety Design and Sustainable Buildings: Challenges and Opportunities
Chicago, IL, USA
Info: http://tinyurl.com/FPRFSustainable

November 10–14, 2012
SFPE-SAC 4th Conference and Exhibition
Dammam, Saudi Arabia
Info: www.sfpe-saudi.org/2012Conference/index.html

June 10–13, 2013
NFPA Conference and Expo
Chicago, IL, USA
Info: www.nfpa.org

June 24–26, 2013
Interflam 2013
London, England
Info: www.intersciencecomms.co.uk

October 27–November 1, 2013
SFPE 2013 Annual Meeting: Professional Development Conference and Exposition
Austin, TX, USA
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BRAINTEASER [Problem / Solution]

Problem

Two cars travelling in the same direction leave from the same location at the same time. One car travels at a speed of 100 km/h, while the other car travels at a speed of 120 km/h. How long will it be before the faster car is 15 minutes ahead of the slower car?

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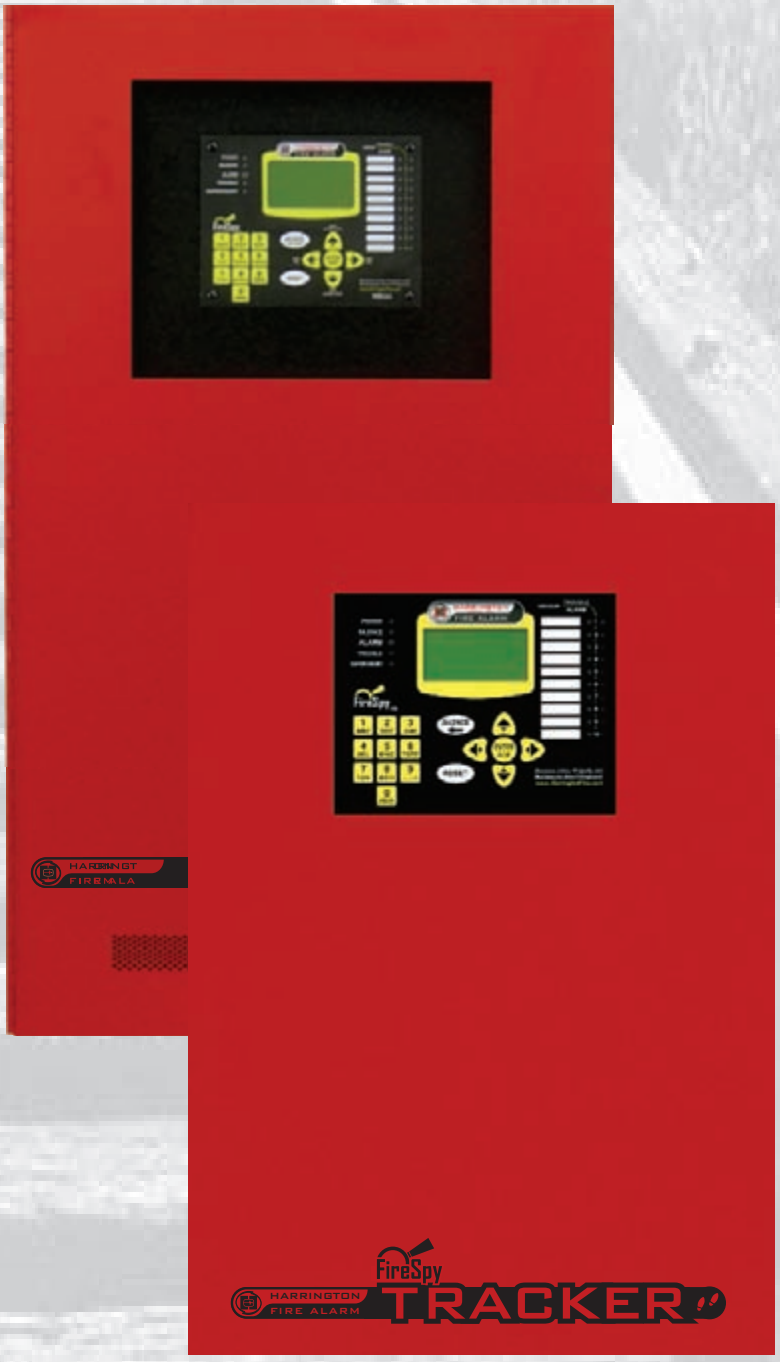

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