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Book Review

Ignition Handbook

by Vytenis Babrauskas, Ph.D.

The foreword of this book describes very well the nature of this work: "the *Ignition Handbook* leaves no stone unturned." This is a comprehensive compilation of ignition data together with selected theoretical descriptions that, in the words of the author, "could lead to conceptual understanding or provide a framework for making useful practical calculations." This book consists of 15 chapters that cover a multiplicity of areas related to ignition. A CD-ROM that contains five Excel® files describing various properties directly related to ignition accompanies the book. The tables provide information for many materials compiled in four different categories: pure chemicals, dusts, commercial natural products, and solids. The CD-ROM might be of practical use to those searching for specific information, but it adds little information not available in the text.

This book can be divided in five sections characterized by a combination of theoretical material, anecdotal information, and an exhaustive compilation of data. An introductory section comprised of Chapters 1 to 5 opens the book. A second section (Chapters 6-10) that addresses in a classical manner all known forms of ignition follows. For organizational purposes, the author divides the material in a classical form – liquids, solids, self-heating – and adds a novel section on explosives, pyrotechnics, and reactive substances generally not treated in fire textbooks. The third section looks into external factors directly related to ignition, such as ignition sources and preventive measures. The chapter on preventive measures focuses on design and lacks information on maintenance-related aspects. Chapter 13 includes a number of important miscellaneous items and can be included within this section. The fourth section is a magnificent compilation of color plates that illustrate many of the issues discussed in all previous three sections. The book has a final section of two chapters, 14 and 15. Chapter 14 corresponds to an encyclopedia where diverse subjects are listed in alphabetical order covering every condition that might lead to ignition. Chapter 15 presents a great amount of data in summary tables. This section is very useful for those readers seeking specific information. A minor criticism is the lack of appropriate references to authors within the figure captions, which makes it difficult to identify the source of the data.

The first two sections deserve more detailed attention, not only because of the large amount of information, but also because they truly represent the conceptual core of this book.

The introductory section provides a detailed presentation of the subject that covers some basic combustion principles as well as very important statistical facts that put the reader in context with the problem to be studied. No detail or derivations are present, emphasizing the physical description of the processes. Throughout this section the author shows a clear preference for simplified models. Practical issues related to piloted ignition of gases such as spark ignition, Auto Ignition Temperature (AIT), Minimum Ignition Energy (MIE) concept, and quenching are explored. Chapter 5 extends the premixed flame approach to the ignition of dust clouds. This section is equivalent to the introductory chapters of any good combustion book but has a practical side that will make it appealing, especially to fire investigators. A detailed definition of terms and acronyms used in the book is also presented. This is very useful because the fire literature is filled with terms that are not defined with precision.

Chapters 4 and 5 analyze standard test methods, including mostly U.S.-based tests, but a brief description of German and British methods is also provided. Similar presentations are made in the second section (Chapters 6-10). This information is very useful not only for the practitioner using this book but also for those who seek to clarify the limitations of the data presented.

Chapter 6 deals with the ignition of solids and 7 with that of liquids. These chapters open with a revision of such concepts as Auto Ignition Temperature, flashpoint, and fire point. Practical relations between the different values coexist with fundamental explanations on the different physics behind each parameter. Historical accounts of the development of assessment methodologies and parameters are presented together with dispelling comments related to common statements on ignition parameters such as the ignition temperature. Consistently, questions are raised on the utility of some correlations and analysis that link fundamental properties to practical parameters. Discussions on limitations of different techniques and standard test methods are done with great thoroughness. A comprehensive treatment of the theories used for interpretation of piloted ignition data allows a clear understanding of the limitations and advantages of each theoretical approach. It would have been nice if the author could have synthesized the theory and converged to a conclusion of what is "good practice" in the interpretation of these results. Chapter 8 represents a brief addition to Chapter 7 that emphasizes the different treatments necessary for metals and carbon particles. Chapter 9 takes a different path and discusses self-heating. The Frank Kamenetskii theory is reviewed again in the context of the FRS test method. This is done thoroughly, and the final example is very useful. Explosives, pyrotechnics, and reactive substances are treated in Chapter 10 in a manner that is consistent with Chapters 8 and 9.

In summary, the author should be commended for being able to compile such a fantastic amount of information into a single text. This book will become a broadly used reference within Fire Safety Engineering and Fire Investigation.

Jose L. Torero, Ph. D.
The University of Edinburgh

FEMA Offers Multihazard Building Design Summer Institute for College and University Faculty

The Department of Homeland Security's Federal Emergency Management Agency (FEMA) has announced four seminars on hazard mitigation in building design to be held during a two-week-long institute in July 2004. The institute covers protective design for earthquakes, fires, flood, and wind.

The seminars, part of the Multihazard Building Design Summer Institute (MBDSI), are designed for active college or university faculty teaching undergraduate or graduate-level architecture and engineering courses in U.S.-based institutions. The seminars were developed by staff at the Emergency Management Institute (EMI) in conjunction with experienced architects and engineers. The sessions, free of charge to qualified applicants, are conducted by EMI, located on the campus of the National Emergency Training Center in Emmitsburg, MD. Qualified applicants are eligible for no-cost housing at the training center and are reimbursed for travel expenses.

During the summer institute, two seminars are offered each week. Flood Protection Design and Wind Engineering are offered the week of July 19, 2004. Earthquake Protective Design and Fire Design are offered during the week of July 26, 2004.

For more information, visit http://training.fema.gov/emiweb/MBDSI/

University of Edinburgh Announces New Degree Programs

The School of Engineering and Electronics at the University of Edinburgh announces new BEng/MEng degree courses in Structural and Fire Safety Engineering, which commenced in October 2003. The programs cover a complete range of Fire Safety Engineering topics including Fire Dynamics, the Design of Fire Safety Systems, Numerical Fire Modeling, Human Evacuation, and emphasizing the understanding of the behavior of structures when exposed to a fire.

Students with undergraduate degrees in any area of engineering from non-UK institutions are welcome to apply for the MEng program. An evaluation of the student's background is made, and a customized course of study is proposed.

In support of this new endeavor, a new state-of-the-art laboratory facility, The Rushbrook Fire Safety Engineering Laboratory, has been developed.

For more information, visit www.see.ed.ac.uk/undergraduate/Courses/struct_fire.shtml.

Fire Safety Council Aims to End Deaths from Residential Fires

Taking a stand during National Fire Prevention Month, the Fire Safety Council announces the first in a series of steps to eliminate deaths from residential fires by 2020. The Council also unveiled its Web site, www.FireSafety.gov, which provides up-to-date information about programs and prevention information, as well as an interactive page for children.

The Council has initiated a pilot program to combine their smoke alarm installation programs to reach the 5 million American homes without smoke alarms. The plan builds on research and programs that demonstrate the effectiveness of installing long-lasting, lithium-powered smoke alarms in homes in high-risk communities.

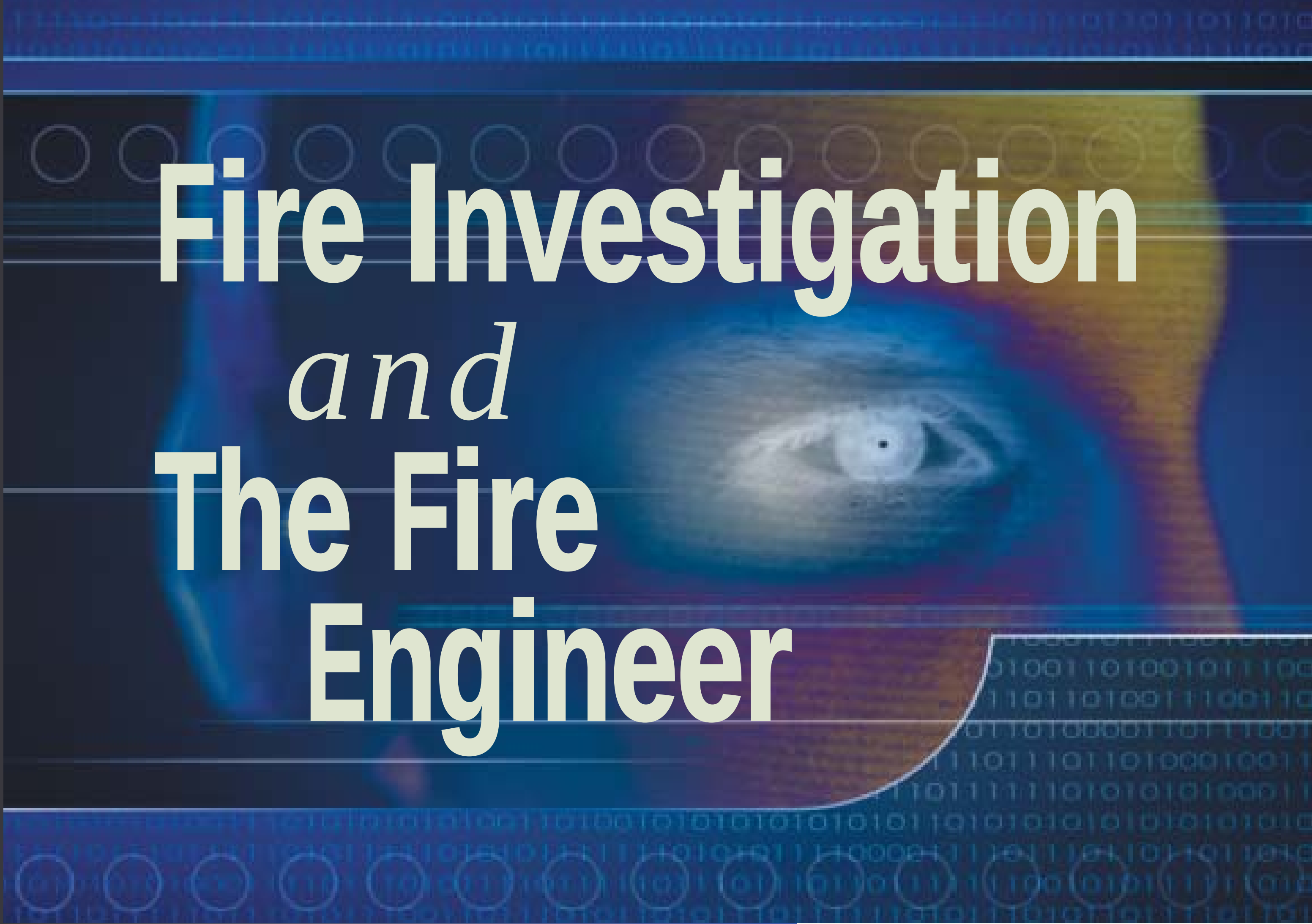
"Each residential fire death is preventable. Our primary injury-prevention goal is ending these unnecessary deaths," says Julie L. Gerberding, MD, director of the Centers for Disease Control and Prevention.

For more information, visit www.FireSafety.gov.

Corrections

On page 23 of the Fall, 2003 issue, article "Balancing Safety and Security in the School Environment," the reference to endnote #11 should have referred to endnote #10.

In the last issue the name of Kevin Biando, P.E. was not included in the table of contents entry for the article entitled "How the GSA Ensures Safety and Security."



Fire Investigation *and* The Fire Engineer

By Robert A. Schroeder, Ph.D.

INTRODUCTION

Fire Protection Engineers (FPEs) are, with increased frequency, included in the initial investigation of fires. The role of the FPE in fire investigation has evolved from an examiner of fire protection-related systems and life safety code analysis to that of principal investigator. With this transformation comes new responsibilities and skills not commonly associated with the discipline. This article reviews the changing role of an FPE in regard to the analysis of a fire scene, fire scene management methods, the needs of all parties participating in the investigation, and the effect of recent court rulings that directly impact the FPE's ability to testify as an expert.

Since the 1960s, FPEs have been called upon to participate in the investigation of large-loss fires, including fires in high-rise structures, fires resulting in the multiple losses of lives, and incidents of failed fire protection systems. Originally, the primary role of an FPE was to support the cause-and-origin investigators, answer the "whys" of fire protection system performance, and assess the adequacy of life safety-related design issues such as exiting capacity. In the 1970s, the number of FPEs conducting cause-and-origin investigations and assessing building and life safety systems was very limited. Often the investigative teams were composed of "specialists," engineers or technicians with specific areas of expertise – alarm systems, sprinkler design, construction, life safety – all employed by the same firm. This practice continues today and has expanded into fire cause and origin, computer modeling, and fire testing.

By the early 1980s, the number of tragic and complex fires revealed the chasm between the analysis (principally cause-and-origin based) of fire scenes and the failure of the current design of buildings. In the United States, the magnitude of litigated cases involving huge losses led to a comprehensive re-examination of fire protection engineering-related issues, such as sprinkler performance, life safety requirements, fire detection and alarm effectiveness, and building construction and its relationship to smoke and fire migration. At the same time, a burgeoning amount of fire research was taking place at the National Bureau of Standards (NBS) and other significant institutions as a result of the fire-loss statistics. The study of fire was being funded. Researchers and professors began to address post-fire analysis in their papers and classrooms. The disturbing rise in life and property loss led people to realize the need for fire scenes to be analyzed for more than merely cause and origin.

Two major steps to increase professionalism in the fire investigation field also took hold in the early 1980s: the establishment of an NFPA Committee to develop a guide to fire investigation[1] and the International Association of Arson Investigators (IAAI) Certified Fire Investigator credential. Both efforts sought to increase the knowledge base of the fire investigator as well as reinforce sound practices and procedures.

The influences of changing attitudes in the 1980s that prompted advanced knowledge in the industry stimulated the transition of fire investigation from a perceived art into an applied science. Fire investigators who once received their primary training and guidance from seasoned investigators, inheriting their habits and practices, are today educated in the scientifically based concepts of combustion, fire dynamics and heat transfer, and the scientific method of analysis. This evolution has been further supported by the creation of formalized college-level coursework that addresses the elements of the fire scene examination, resulting in an increase of practitioners with engineering and scientific backgrounds. The judiciary has also been driving this technical transformation. The U.S. Judicial Courts speak volumes each time expert testimony is excluded from trial due to lack of professional education or comprehensive experience. The unspoken, but strongly influencing, trend that is emerging from the U.S. courts is to exclude expert testimony by those who have not met a level of professional education or experience. The days of qualifying as an expert solely on years of fire investigative work are waning.

The presiding judge determines the acceptable benchmark. An investigator trained in fire scene examination will most likely be allowed to testify as to where the fire originated. As to why the fire started may not be permitted, and most certainly will be challenged.

THE INVESTIGATION

An FPE's job begins when he or she is contacted by an insurance adjuster or an attorney and is hired to undertake or participate in the investigation and analysis of a fire loss. The hiring party may have called an FPE for several reasons: the magnitude of the loss; the presence of sprinkler or fire detection systems; the potential opposition has hired a FPE; or the client recognizes the need for analysis beyond basic cause and origin. Once an FPE determines that a conflict of interest does not exist, the investigation is underway.

CONFLICT OF INTEREST

Although the identities of all the potential parties may not be known when the initial call is received, before accepting the assignment, an FPE will need to know as much as possible about the fire scenario; specifically, who is involved. Employees of multiservice providers must seek as much information as possible regarding the interface of any segment of their company with affected parties, including the potential involvement of company clients in the cause or spread of the fire. Asking questions early and often can ensure an FPE's good faith efforts in exploring conflicts of interest, thereby reducing the likelihood that a problem will arise at a later date.

MANAGING THE SCENE

Responsible fire officials should be contacted before an FPE responds to the scene. Local practices will begin to surface as officials describe their investigative process, conclusions, and means to an FPE and other interested parties seeking access or control of the scene. Policies of releasing reports, statements, photographs, communication tapes, and the interviewing of first-responding emergency workers will vary. Strong interpersonal communication skills are useful. Patience and sensitivity may be advantageous when various interests are vying for attention, and are even more important if lives have been lost, firefighters injured, or other complications have occurred which change the fire scene from a property loss to a tragedy. However, most information will eventually be revealed.

An initial meeting with local fire officials or investigators at the fire scene will normally involve a walk-through and concise briefing of suppression and investigative activities. If the incident is of an incendiary origin (arson), there can be reluctance to release particular information; such release may be dependent on the arson immunity laws of individual states.

THE SCENE

The overriding urge is to get on the scene and start digging it out. This urge must be resisted. Once the local authorities have completed their site investigation and have turned control of the scene back to the property owner, the FPE representing the owner(s) or their insurance carrier must take preliminary steps before the dig begins. Regardless of the condition of the scene, after the Authorities Having Jurisdiction (AHJs) have completed their on-site activities, the scene must be treated as if it were undisturbed and sterile. The condition of the scene at this juncture must be documented. Artifacts examined, opened, and/or removed during the AHJs' site analysis need to be photographed *in situ*, and those who altered or moved them must tell of their location and condition when they were found. A concerted, documented effort must be made to accomplish this. This effort will give insight into how the AHJs' examination was conducted what they focused on, which will provide a defensible record for the FPEs if spoliation arises later on. The scene should be approached as if there will be only one opportunity to process it. The FPE should research the construction features of the building and locations of its contents before the first shovel is turned.

The technical reason for delaying the destructive examination of the scene lies in the understanding of the scene prior to the fire. This knowledge can only be gained from interviews with those persons knowledgeable about the site and the fire area, the last occupants, the first witnesses of the fire, and, if applicable, the job site superintendent. Construction plans and details, pre-fire photographs, and actual fire footage are also valuable sources.

The first phase of a fire investigation directed by an FPE

1. Check for conflicts.
2. Contact public officials (AHJs) responsible for the fire scene and the public investigation.
3. Initiate the gathering of pre-fire information including plans, photographs, etc. Arrange to interview individuals who understand the construction layout, the site's use, as well as the first witnesses of the fire. The Principal Investigator (FPE) should participate in these interviews.
4. Perform a preliminary site survey and walk-through. If the fire's area of origin contains a suspect piece of equipment, if it was recently serviced, or if a construction feature appears to be contributory to the loss, put those parties "on notice."
5. Set a date in the reasonable future to begin the dig-out and disassembly.
6. Resist efforts to short-cut these steps, especially when the identity of the suspect fire cause or contribution is known.
7. Identify special equipment or personal protective equipment (PPE) needs. Arrange for the equipment ahead of time, and convey the PPE needs to all interested parties.

INTERVIEWING WITNESSES – WHAT THEY DIDN'T TEACH YOU IN ENGINEERING SCHOOL

More often than not, witnesses determine the life and death of a fire investigation. The sooner the key witnesses are interviewed, the more likely the information received will be reliable. Those directing the investigation need to be involved in the interviewing process. Once again, patience and self-awareness are necessary. A person who has just lost a business, a home, or – worse yet – a loved one is in no frame of mind to be interviewed. Being overly assertive in trying to get all of this "needed-now" information because an investigation is underway will not be well received. Because of this, there will be delays in getting the plans, meeting with the maintenance personnel, locating pre-fire photographs.

The second reason for waiting before initiating the scene dig-out is "spoliation." In fire-scene vernacular, spoliation means knowingly destroying or changing the scene (or suspect objects) without providing other "interested parties," such as potential defendants or plaintiffs in a legal action borne from the fire, an opportunity to also see it in an unmolested state. For example, the disassembly, modification, or alteration of potential ignition sources, suspected equipment, or switches which are found within the involved area could cause spoliation. Even the appearance of impropriety may cause the opposition to cry "spoliation." This accusation will not be conveyed to the engineer digging out the scene but rather to the judge if the engineer's client decides to litigate. Spoliation, including the digging out of a fire scene without giving the potential interested parties an opportunity to participate in its processing, has resulted in dismissal of subrogation lawsuits. It may also provide an avenue of financial recovery against an FPE's professional liability coverage if the decision to proceed is solely that of the engineer's.

THE GATHERING OF THE CLAN

After written notices to interested parties have been delivered and the managing FPE has performed a site safety assessment, the processing of the scene begins. The site safety assessment includes identification of physical hazards, such as unstable walls and roofs; the distribution of loads and, in particular, loads in the fire-affected areas; biohazards; the potential energy and electrical hazards; the recommended or required PPE; as well as an analysis of the environment.

A number of steps should be taken once the group of interested parties has assembled. After everyone has signed in and identified whom they represent, a briefing and group discussion should be held. Preferably, the briefing will include public information about the fire, witness information (if it helps identify the area of origin), fire alarm data (including report printouts), copies of accurate floor plans, and generally any non-prejudicial information which will assist in the group investigation. The client or counsel must preapprove the distribution of information, including nonprejudicial information, before it is shared. Generally, other investigators are not given open access to the FPE's clients or their employees. The FPE should prearrange for first-in firefighters to provide a group briefing and walk-through, and videotape the meeting, if possible, to memorialize what transpired.

DIRECTION OF THE INVESTIGATION

When multiple "interested parties" have been invited to participate in the scene examination, it can trigger a potentially burdensome avalanche of inquiries for local authorities. Requests to interview the first-arriving firefighters are expected and normally accommodated, but this can become time-consuming. In anticipation of these types of needs, an FPE can prearrange a group briefing or interview. These gatherings may be more productive when conducted in a meeting room as though they were briefings: information is given out, and questions and answers follow. This is also the proper setting to distribute plans, documents, pre-fire photos, and fire photos, if such are available. This efficient and considerate vehicle for distributing information will help expedite the actual scene examination and preserve the group's relationship with the AHJs and witnesses.

This group approach can also be used when important witnesses are employees of an FPE's clients, with a caveat that the responsible attorneys should decide if and how this can be accomplished. The attorneys should also define the constraints on how much information can be shared.

The managing FPE should facilitate an open discussion about the examination protocol including distribution of responsibilities such as shoveling, procuring equipment, and conducting nondestructive measurements. The group should discuss how the scene will be documented (mapped); if this documentation will be "pooled" and made available to all; how the evidence will be identified, removed, tagged, and stored; and, finally, site safety.

The group should also plan to formally meet at a designated time to review what has been accomplished, update any safety concerns, identify which artifacts need to be secured, and assign new responsibilities. The group investigation works well if everyone is allowed to physically participate. Things usually become skewed if people are allowed to remain idle and watch the site-controlling team do the work.

As the scene is being processed (dug out), it is essential to strive for continued consensus among the group. Oftentimes, seemingly small actions can challenge this dynamic, especially if they involve opening up a piece of equipment. The forced opening of a thermally damaged widget can alter a potentially important condition. It is far better to conservatively approach these "let's just open it up" desires. "X-ray before disturbing or distorting" is the mantra of forensic electrical engineers, a conservative position also held by most fire investigators. There are those whose natural curiosity can cloud their under- standing of "destructive examination." Frequently, these individuals have little or no fire scene experience, and thus are not as disciplined in the art of "looking without altering." The usual suspects include manufacturer's field engineers, maintenance employees or owners of the fire-affected business, curious insurance adjusters, or anyone who carries on in a poke-and-prod, look-see manner. Preliminary reminders during the briefing may not be sufficient to prevent the destruction of artifacts by the twist of a knob or the opening of a panel. Sometimes, not-so-subtle reminders are required.

ATTORNEYS AT FIRE SCENES

Attorneys will often be at the scene during the group investigation. Their principal roles are to protect their clients' interests, to become familiar with both the scene and recovered evidence, and to ascertain what the potentially litigated issues may be. They also provide cover for their respective engineers and investigators when control and decision issues arise. Consider, for example, this scenario: At a fire investigation scene, an interested party wants to partially disassemble the battery charger of a forklift to see if it still has a specific component. This action contradicts an earlier consensus of the group to not open equipment at the scene. Those who want to open it, however, have established an alliance with other involved parties. They want to deviate from the agreed-upon examination protocol. Rather than straining the dynamics of the investigating team with a potentially deteriorating posturing discussion, the group can turn to the attorneys. It is the responsibility of legal counsel representing the involved parties to discuss the various positions with each other and to make the decision whether to open it or to wait, thus allowing the *esprit de corps* of the investigating group to continue.

NOT YOUR SCENE

If an FPE represents an equipment manufacturer or service provider, it may be very beneficial to the clients' position to provide some technical information to the group. Consider the manufacturer of an electrical switch panel who is "put on notice" and chooses to send an investigator to participate in the dig-out. The switch panel is opened (nondestructively), and a serial number and cryptic date codes are located. The investigator is then asked to identify when the panel was made. The motivation to reveal this information is clear: Many states have "statutes of repose" – a defined period of time for which a manufacturer may be held liable for design and fabrication defects. If the switch panel in the scenario above is older than the defined period of time, the appeal of the manufacturer as a potential defendant is greatly diminished. If the information as to the date of manufacture is not shared, and the switch maker is sued, the time and economic costs to all parties are greatly increased. If sharing technical information can help extract an FPE's client from potentially lengthy and costly litigation, then the information should be shared – after permission from the client to do so has been obtained.

REPORTS

The premature preparation of reports, which declare or suggest the opinions of an FPE or others in the team, can be detrimental. All documents prepared by an FPE will be disclosed to the opposing parties if the matter is litigated. The FPE will have to answer for each opinion and its basis. If changes are later made, the modified opinion will be a red flag and invite additional scrutiny by the opposition. Lacing opinions with caveats such as "based upon the information as identified in appendix E" or "if additional information is received, I reserve the right to change or alter my opinions" helps, but not much.

The volley of questions from opposing counsel in a deposition or, worse, at trial can be avoided by not prematurely preparing opinionated reports. Clients will often require status reports on the state of the investigation. Simply providing information detailing the process and what was observed, without expressing opinions, may fulfill this requirement. Preparing reports which publish an FPE's opinions prior to the completion of all litigation-driven discovery should be resisted, if not completely avoided.

REPORTS DISCLOSING THE FPE'S OPINIONS

Discovery is the process by which information regarding all aspects of the litigation is developed. This includes the posing of questions, document production, depositions, and expert reports. When discovery is completed and an FPE has been identified as a testifying expert, when all of the fact witnesses have been deposed, when the attorneys have conducted their information-gathering investigation throughout the discovery process, when the recovered artifacts have been examined, and the expert disclosure deadline looms, it can only mean one thing: expert report time. Once again, an FPE should keep close contact with the responsible attorney to determine what, if any, formal report prepared by the FPE will be required and, if one is required, what needs to be included in it. The report requirements span a vast range, which is a function of the jurisdiction in which the litigation is being conducted. Some states simply require that the expert's opinions and the basis for them be included in the "Answers to Interrogatories," which is prepared by the attorneys. For the expert, these disclosures are the least invasive, for the submitting attorney, not the expert, signs the document. If this is the means of opinion disclosure, the FPE should review what the attorney has written and attributed to the FPE before documents are sent to the opposing parties. The way in which the position is presented must be critically scrutinized. The expert should not expect counsel to be familiar with the nuances of the fire safety engineering language, but know that the experts engaged by the opposing side will be.

EXPERT REPORTS AND THE FEDERAL COURTS

Within the last decade, the U.S. Supreme Court has gone to great lengths to clarify and promulgate rules regarding the admissibility of scientific-based expert testimony. Tomes have been written on the cause and effect of the Court's position. According to Rule 702, U.S. Federal Rules of Evidence:

"If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case."[2]

This component of Rule 702 is known as "*Daubert*" and from it came the *Daubert* Tests or Factors. Simply stated, they are as follows:

1. Has the theory or technique been tested?
2. What is the rate of error or reliability of the theory or technique?
3. Has the theory or technique been subjected to peer review and publication?
4. Does the theory or technique enjoy general acceptance within the scientific community?

These factors are applied in U.S. Federal Court and in many state courts as well. Theories or opinions held by an FPE will be subjected to the *Daubert* tests in these courts; in states that have not adapted the *Daubert* standard, the expert disclosure and qualifying requirements may be less stringent. However, expect opposing counsel to use *Daubert* as an examination tool in attempts to discredit witnesses during cross-examination.

The impact of *Daubert* is immense. An FPE may first face *Daubert*'s effect when opposing counsel files a motion to have the expert's opinions and testimony excluded because they did not meet the standard set forth by Rule 702. This pre-emptive motion may be based solely on the expert report provided during discovery. If FPEs fail to adequately present their opinions and the basis for them, they are vulnerable to exclusion. The basis must also formally cite the treatises relied upon by an FPE that support a theory and confirm its general acceptance by the scientific community.

The second wave of challenge becomes personal for the FPE. He or she will be evaluated on knowledge, skill, experience, training, and education. Opposing counsel will conduct an examination and attack on an FPE's background and ability to render the opinions that have been presented. Does this person have formal training with the information used to support the opinions? Does he or she possess the experience to adequately qualify them in this particular area? Is the FPE simply parroting the words of the attorney or client for whom he or she is working? Was this supposed expertise gained through a nontested short course or seminar? Has the FPE ever conducted any research or performed the actions being commented on? This is just a sampling of the scrutiny that the expert should expect. If the inquisitor finds that the FPE has overstated his or her qualifications, experience, or understanding of the supporting basis of their opinions, results can be humiliating or even disastrous.

If an FPE has not received some formal fire investigation training combined with supervised site examination experience, the likelihood of successfully qualifying as a cause-and-origin expert is grim, as it should be. If opposing counsel is successful in disqualifying an FPE in one area such as cause and origin, the remaining opinions and areas of expertise will also be challenged. Attacks on the credibility of an FPE will not come early in the life of the litigation. They are often held back until the eve of trial or, worse yet, when an FPE is on the stand.

It should also be noted that if the opposition is successful in getting the FPE's opinions disqualified or discredited, the discomfort does not end in the courtroom. There is now a public record. Although similar records of each deposition taken of an FPE exist, ill-supported theories or overstated qualifications made by a discredited FPE become part of the public domain. Transcripts of trial testimony and expert depositions are saved, databased, and traded as though they were baseball cards by attorneys. A number of fee-based testimony and deposition repositories also exist. ▲

Robert Schroeder is with Schroeder Fire.

REFERENCES

1 NFPA 921 – *Guide for Fire and explosion Investigations*, 1992 edition; National Fire Protection Association, Boston, MA., 1992.

2 Federal Rules of Evidence, Federal Judicial Center, Washington, 2000.

NFPA 921'S IMPACT ON FIRE SCENE RECONSTRUCTION

By David J. Icove, Ph.D., P.E., and John D. DeHaan, Ph.D.

INTRODUCTION

Courts now prefer science-based methods when describing and providing testimony in fire scene reconstruction. These science-based methods include a reliance on The National Fire Protection Association's *NFPA 921 – Guide for Fire and Explosion Investigations,* as well as on other expert treatises.

Fire scene reconstruction is the process of determining the most likely development of a fire using a scientifically based rationale. Reconstruction follows the fire from ignition to extinguishment, and it explains aspects of the fire and smoke development, the role of fuels, effects of ventilation, the impact of manual and automatic extinguishment, the performance of the building, life safety features, and manner of injuries or death.

Forensic fire scene reconstruction relies upon a comprehensive review of the fire pattern damage, sound fire protection engineering principles, human factors, physical evidence, and an appropriate application of the scientific method. These factors often form the basis for an expert opinion as to the most probable origin and cause of the fire or explosion. The expert opinion may be part of a written report or the basis for oral testimony in depositions or courtrooms.

In order to be effective, these expert opinions must be able to pass the eventual scrutiny of cross-examination during sworn depositions, peer review, and courtroom testimony. Recent court decisions place more weight on expert forensic testimony based upon scientific, rather than merely experience-based, knowledge.[1]

When determining the origin and cause of a fire, a comprehensive reconstruction often involves a fire engineering analysis that tests various scenarios. This analysis may use fire modeling to compare actual events with predicted outcomes by varying causes and growth scenarios. This engineering analysis adds value, understanding, and clarity to an already complex fire scene investigation.

THE NEED FOR SCIENCE IN FIRE SCENE RECONSTRUCTION

A federal conference in November 1997 assessed the current state of the art and identified technical gaps in fire investigation.[2] *The International Conference on Fire Research for Fire Investigation* concluded that many scientific gaps existed in the methodology and principles used to reconstruct fire scenes.

The Scientific Method

The underpinning of forensic fire scene reconstruction is the use and application of relevant scientific principles and research in conjunction with a systematic examination of the scene. This is particularly true in cases that later require expert witness opinions. The scientific method, which embraces sound fire protection engineering principles combined with peer-reviewed research and testing, is the best approach for conducting fire scene analysis and reconstruction. *NFPA 921 – Guide for Fire and Explosion Investigations* defines the scientific method as the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of a hypothesis.[3]

Benefits of the Scientific Method

There are numerous benefits for using the scientific method to examine fire and explosion cases, including:

- Acceptance of the methodology in the scientific community,
- Use of a uniform, peer-reviewed protocol of practice, such as *NFPA 921, and*
- Improved reliability of testimony from opinions formed using the scientific method.

The use of the scientific method is well received in both the technical and research communities. An investigation conducted using this approach is more likely to be embraced by those who would tend to doubt a less vigorously conducted probe. Second, the scientific method is an accepted protocol of practice for *NFPA 921*.

Those persons ignoring or deviating from *NFPA 921* practices would bring closer scrutiny to their reports and opinions. Another guide that repeatedly cites *NFPA 921* is the National Institute of Justice's *Fire and Arson Scene Evidence: A Guide for Public Safety Personnel*.[4] The NIJ guide notes that actions taken at the scene of a fire or arson investigation can play a pivotal role in the resolution of a case.

A thorough investigation is key to ensuring that potential physical evidence is neither tainted nor destroyed, nor potential witnesses overlooked. More importantly, expert testimony in fire and explosion cases will rely more heavily on opinions formed using the scientific method. Recent U.S. Supreme Court decisions underscore these principles, with many state courts following the trend.

Engineering Analysis as a Scientific Method

Fire engineering analysis, which can range from a basic "back-of-the-envelope" first-level calculation to a sophisticated fire model, is an important step in fire scene reconstruction that provides numerous benefits. Historical investigations using fire engineering analysis have accurately assessed fire development, measured the performance of fire protection features and systems, and predicted the survivability and behavior of people during the incident.

Several significant fire engineering analysis studies have been undertaken by the NIST over the years. These detailed reports consist of the Dupont Plaza fire,[5] First Interstate Bank Building fire,[6] Pulaski Building fire,[7] Hillhaven Nursing Home fire,[8] Happyland Social Club Fire,[9] 62 Watts Street fire,[10] and Cherry Road fire.[11] Some form of fire engineering analysis is now considered a necessary step in comprehensive fire scene analysis and reconstruction.

Benefits of Engineering Analysis

Fire engineering analysis, combined with modeling, offers the following benefits:

- Establishes the basis for the collection of data needed to construct event time lines;
- Provides ignition sequences, and failure modes and effects analysis (FMEA);
- Invites application of the scientific method when testing hypotheses and validating fire scene reconstruction;
- Provides a viable alternative to full-scale fire testing and extends full-scale test results to differing ranges of conditions (sensitivity analysis);
- Provides answers to many important questions raised on human factors, ignition sequences, equipment failure, and fire protection systems (detectors, alarms, and sprinklers); and
- Identifies important future research areas in fire investigation.

Historically, the use of engineering analysis and modeling in fire scene reconstruction was conducted on a case-by-case basis, due mainly to the complexity of the process. A vast amount of knowledge and time was required to collect and analyze the information on the development of the fire.

Engineering analysis and modeling are becoming more commonplace. Despite the complexity of the processes, fire engineering analysis and modeling should be applied to cases involving multiple deaths, or cases where code deficiencies contributed to the fire, or in the anticipation of extensive civil or criminal litigation.

A fire engineering analysis often uses fire modeling to compare actual events with predicted outcomes using varying fire causes and growth scenarios. Surface temperatures on the walls can be calculated by the fire model and displayed using a color-coded gradient scale. Results from the surface temperatures can be compared with burn patterns to confirm the sequence of the fire. This analysis often adds value, understanding, and clarity to complex fire scene investigation. Fire modeling can also serve as an alternative to full-scale fire testing to explain burn patterns and the fire dynamics involved.

Fire engineering analysis and modeling may also provide answers to important questions raised during fire investigations. These questions might include the following:

- What was the most probable cause of the fire (i.e., can several possible causes be eliminated)?
- How long did it take to activate fire or smoke detectors and sprinklers?
- What were the smoke and carbon monoxide levels in each room after 10 min?
- Why didn't the occupants of the building survive the fire?
- Was an accelerant used in the fire, and if so, what type?
- How much time elapsed from when the owner of the structure left the building until the fire reached flashover?
- Did a negligent building design or failed fire detection and suppression system contribute to the growth of the fire?
- What changes to policy, building, or fire codes are necessary to ensure that similar fires will not occur in the future?

Discussion and cooperative research between fire investigators and fire protection engineers underscore the need to include fire modeling as an integral and required step in fire scene reconstruction. Fire investigators and engineering professionals need to collaborate further in order to expand their knowledge and validate the methods shared in common by both groups.

THE SCIENTIFIC METHOD AND *NFPA 921*

Listed below is an annotated seven-step systematic process, based upon *NFPA 921*, for applying the scientific method to fire investigation and reconstruction.

1. **Recognize the Need.** First responders must recognize that a scene needs to be protected until a full investigation can be started. This includes not only the origin and cause of the event, but also recognizes the responsibility to determine if future fires, explosions, or loss of life can be prevented through new designs, codes, or enforcement strategies.

2. **Define the Problem.** A tentative investigative plan should be devised to preserve and protect the scene, determine the cause and nature of the loss, conduct a needs assessment, formulate and implement a strategic plan, and prepare a report.

3. **Collect Data.** Facts and information about the incident should be collected through direct observations, measurements, photography, evidence collection, testing, experimentation, historical case histories, and witness interviews. All collected data should be subject to verification of how it was legally obtained, its chain of custody, and notation as to its reliability and authoritative nature.

4. **Analyze the Data.** The investigator relies upon his or her knowledge, training, and experience in evaluating the totality of the data. This subjective approach to the analysis may include knowledge of similar loss histories (observed or obtained from references), training and understanding of fire dynamics, fire testing experience, and experimental data.

5. **Develop a Working Hypothesis.** Based upon the data analysis, a tentative working hypothesis should be developed to explain the fire's origin, cause, and development that is consistent with on-scene observations, physical evidence, and testimony from witnesses.

6. **Test the Working Hypothesis (Deductive Reasoning).** The working hypothesis should be compared with all other known facts, the incidence of prior loss histories, authoritative fire test data, sound published treatises, and experiments. The working hypothesis should be used to eliminate all other reasonable origins and causes for the fire or explosion. The investigator should recommend the collection and analysis of additional data, seek new information from witnesses, and develop or modify the working hypothesis. This may involve reviewing the analysis with other investigators with relevant experience and training. Interactively repeat Steps 4, 5, and 6 until there are no discrepancies between the working hypotheses. By testing various working hypotheses rigorously against the data, those that cannot be conclusively eliminated should still be considered viable.

7. **Select Final Hypothesis (Conclusion or Opinion).** When the working hypothesis is thoroughly consistent with evidence and research, it becomes a final hypothesis and can be authoritatively presented as a conclusion or opinion of the investigation. If a final hypothesis cannot be determined, the cause should be reported as "undetermined."

SCIENCE-BASED EVIDENCE

Recently, the U.S. Supreme Court has ruled on the admissibility of expert scientific and technical opinions, particularly as they relate to fire scene investigations. These decisions impact how expert testimony is accepted and interpreted.

Although much controversy exists over these Court decisions, fire and explosion investigation is emerging more as a "science" and less of an "art." This is particularly true when combining the use of the scientific method with relevant engineering principles and research in providing expert witness testimony.[12, 13]

A judge has the discretion to exclude testimony that is speculative or based upon unreliable information. In the case *Daubert v. Merrell Dow Pharmaceuticals,* 509 U.S. 579 1993,[14] the Court placed the responsibility upon a trial judge to ensure that expert testimony was not only relevant but also reliable. The judge's role is to serve as a "gatekeeper" to determine the reliability of a particular scientific theory or technology. The Court defined four criteria to be used by the "gatekeeper" to determine whether the expert's theory or underlying technology should be admitted.

The four-guideline *Daubert* criteria consist of testing, peer review and publication, error rates and professional standards, and general acceptability. In short, expert testimony must rely on a balance of valid peer-reviewed literature, testing, and acceptable practices if it is to be considered credible by the courts.

In a more recent decision,[15] *Kumho Tire Co. Ltd. v. Carmichael*, the Court applied the four-guideline criteria to expert testimony to determine whether it was based upon science or experience.

Peer Review and Publications

A credible, reliable theory must take into account the body of research that has been compiled, verified, and published by experts in the field. The necessity for credibility underscores advantages of using the scientific method. Recently, there has been a tendency for courts to hold experts to the same standards that scientists use in evaluating each other's work, sometimes referred to as peer review.[16]

Investigators can also participate in peer review when their cases are submitted to supervisors for review. In law enforcement, this is the primary function of supervisory review – to assure that all questions, logical investigative leads, laboratory examinations, and plausible theories are addressed. Some experts develop opinions based solely on the results of tests conducted specifically to support expert testimony.

The *Daubert II* [17] Court places greater weight on testimony based upon pre-existing research that uses the scientific method, as it is considered more reliable.[18] The Eleventh Circuit Court of Appeals applied *Daubert* and excluded the testimony of a fire investigator in the *Benfield* case.[19] The Court held that the investigation of fires is science-based and that the *Daubert* criteria apply.

NFPA 921 specifically cautions that "the elimination of all accidental causes to reach a conclusion that a fire was incendiary is a finding that can rarely be justified scientifically." If pursued vigorously, however, the scientific method can be used to demonstrate successfully that the only mechanism for ignition had to be deliberate by demonstrating that all relevant accidental mechanisms had been specifically evaluated, tested, and eliminated.

Error Rates, Professional Standards, and Acceptability

Under *Daubert*, the Court considers the known or potential rate of error and the existence of acceptable professional standards on the techniques used by the expert. Error rates from repeated tests form the basis for many equations, relationships, and models used to describe fire and explosion dynamics. These error rates are produced during data analysis from fire testing.

A particular practice that has a broad impact on investigators is the *Standard Practice for Examining and Testing Items That Are or May Become Involved in Litigation*.[20] This practice covers evidence (actual items or systems) that may have future potential for testing or disassembly and are involved in litigation.

This practice sets forth the following guidance:

- Documentation of evidence prior to removal and/or disassembly, testing, or alteration,
- Notification of all parties involved, and
- Proper preservation of evidence after testing.

This practice also stresses the importance of safety concerns associated with testing and disassembly of evidence. This is particularly important when dealing with energized equipment or evidence containing potentially hazardous chemicals.

THE IMPACT ON TESTIMONY IN COURT CASES

The importance of *NFPA 921* has also been cited along with *Daubert* as an interlinking element of expert testimony since it establishes guidelines for the reliable and systematic investigation or analysis of fire and explosion incidents.[21]

Several clusters of recent federal court opinions and rules fall into the following areas.

- Use of investigative protocols, guidelines, and peer-reviewed citations,
- Methodological explanations for burn patterns, and
- Qualifications to testify.

Professional education is paramount in any profession. It is incumbent on all professional fire investigators continuously to read and keep abreast of all relevant fire, engineering, and legal publications and critically evaluate their conclusions with this ever-changing knowledge. Today's knowledge may change with new developments, truly affecting an established hypothesis.

Use of Guidelines and Peer-Reviewed Citations

In a case involving a residence fire, a number of independent investigators attempted to determine the exact origin and cause of the fire. One investigator, an electrical engineer, offered the opinion that a television set located in the basement family room caused the fire. The plaintiffs sued the television's manufacturer, claiming product liability, negligence, and breach of warranties.[22]

A federal judge hearing this case held a *Daubert* hearing and concluded that the one investigator's causation testimony was inadmissible. The judge cited that the issue in this case was the second Rule 702 factor, that an expert's opinion should be based upon a reliable methodology. The judge noted that the investigator did not use a fixed set of guidelines in determining the cause of the fire. Notably, the investigator did confirm that, even though he was aware of the existence of established guidelines in *NFPA 921* and *Kirk's Fire Investigation*,[23] he relied upon his own experience and knowledge.

During the hearing, the plaintiffs did not submit any books, articles, or witnesses on proper fire causation techniques other than the one investigator. The judge specifically commented on the fact that the one investigator made reference to his reliance on a burn pattern inside the television set. No citations were made to peer-reviewed sources to support this opinion.

Methodology Needed

A 1996 residential fire started in the corner of a kitchen containing a dishwasher, toaster oven, and microwave oven. The municipal fire marshal concluded that the fire had been caused by the microwave oven, while in a federal civil case, the plaintiff's expert asserted that a defective toaster oven caused the fire.[24]

A senior federal judge held a *Daubert* hearing in which evidentiary and testimonial records were reviewed and ruled that the opinion of the plaintiff's investigator was not admissible under Rule 702. The judge concluded that the plaintiff's investigator did not provide sufficient reliable evidence to support the methodology for investigating the cause of the fire. The judge also noted that the comprehensive nature of *NFPA 921* contained a methodology that could have supported the opinion and tested the hypothesis for the fire's cause.

In a federal civil case, an insurance company sued to recover subrogation paid by the company for fire damage to the property of its subrogors. The judge denied the defendant's motion to exclude the trial testimony of the plaintiff's origin-and-cause expert witness. The judge noted that the expert's testimony is the product of reliable principles based upon the scientific method as outlined in *NFPA 921* and that the expert applied these principles and methods in a reliable and relevant manner to satisfy the admissibility requirements of *Daubert* and the Federal Rules of Evidence 702.[25]

Methodological Explanations for Burn Patterns

In the case of a building fire, a federal U.S. magistrate denied the plaintiff's motion to bar opinion testimony as to the origin and cause of the fire at the time of trial.[26] In this case, both a municipal fire department investigator and a private insurance investigator concluded from their examinations of the scene that the fire was incendiary in origin. No physical evidence was taken for laboratory examination.

The plaintiff argued that these investigators were not reliable and their testimonies were inadmissible under Rule 702, because they did not use the scientific method as outlined in *NFPA 921* and relied upon only physical evidence observed at the scene. The case also contained parallels with the *Benfield* case.[19] In denying the plaintiff's motion, the federal magistrate noted in his decision that the investigators were able to provide an adequate methodological explanation for the analysis of burn patterns that led to how they reached their conclusion as to the fire's incendiary origin.

Methodology and Qualifications

In the case of a residential fire, which resulted in a federal lawsuit for products liability, the judge granted the defendant's motion to exclude the testimony of the electrical engineer citing *Daubert*, Rule 702 and Rule 704.[27] In this case, an insurance company investigator called upon an electrical engineer to remove and examine the charred remains of a bathroom exhaust fan, clock, lamp, timer, compact disc player, computer with printer and monitor, ceiling fan, power receptacle, and power strip. The engineer came to an opinion that a defect in the compact disc player caused the fire. His observations were based on burn patterns in the room, on appliance remains, and on his experience, education, and training.

In his ruling, the judge noted that the training and experience of the engineer did not qualify him to offer an analysis of burn patterns and theory of fire origin. Furthermore, the judge noted that the engineer did not use the scientific methodology recommended by *NFPA 921* to form a hypothesis from the analysis of the data, nor did he satisfy the requirements for expert testimony under *Daubert*. ▲

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FROM THE LAWYER'S PERSPECTIVE:

The Role of a Fire Protection Engineer

By Paul R. Bartolacci, Esq., and
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in the Investigation of Fire-Related Losses and Subsequent Litigation

Any discussion surrounding the role of an expert witness, e.g., a qualified fire protection engineer, in loss site investigations and litigation must begin by defining the purposes for which the fire protection engineer is retained. From the lawyer's perspective, the purpose of an expert in a fire investigation is two-fold: he or she is an investigator of the loss and an advocate for his client during litigation. Too often, experts consider themselves only as investigators and disregard or minimize the importance of being an advocate for their client during later litigation. Both roles are equally important, and an expert should be mindful of these dual roles throughout the assignment as they go hand in hand.

Not only do clients and attorneys rely on experts to investigate losses and formulate opinions as to their causes, but they rely on experts to convincingly testify as to their opinions during litigation or trial. The best, most accurate opinion as to the cause of a loss can be severely undermined if not testified to or presented with confidence and conviction. A way in which to develop confidence in one's opinions is to conduct a thorough investigation to ensure that properly supported conclusions are reached. This, in turn, will foster conviction in one's opinions and assist in communicating that conviction to an opposing party, judge, or jury.

In order to provide effective testimony and advocate strongly on behalf of a client, the fire protection engineer must be comfortable with the facts that support his or her opinions and be able to strongly present his or her opinions and conclusions. Opinions and conclusions that are not supported by the facts, or the standards of care applicable to the industry, will surely come across to a fact-finder as weak and not believable. Finding the facts to support one's opinions begins at the investigation stage.

CONDUCTING A PROPER INVESTIGATION

The first and most critical step in any investigation is to have the right expert. From an attorney's prospective, selecting and retaining the proper expert is essential to a successful resolution of a claim or defense. The use of expert witnesses in litigation has blossomed, in part, because of the specialization and concentration of practices that all professions are currently experiencing. The attorney's task, on behalf of his or her client, is to initially identify the need for a particular forensic analysis and then ask the proper questions of particular consultants to make sure that the consultant has the appropriate expertise for the situation. Fire protection engineers should not feel offended if an attorney vigorously "cross-examines" him or her during the engagement process. It is the attorney's job to know the law and the standards for admissibility of testimony and opinions. Background questioning and interviewing of expert witnesses is designed to allow the attorney to make an assessment as to whether the particular witness possesses the background, experience, and knowledge to be able to meet the standards for admissibility. Some points are obvious, but warrant repeating. As with any witness, honesty is always the best quality. Fire protection engineers should never stretch their qualifications or experience in order to "get the project."

After confirming that the right expert has been retained, the next step is to define the tasks and duties of the fire protection engineer. Almost universally, the earlier that an expert can become involved in a conflict, the more useful and beneficial the role of that expert will be. Personally inspecting a fire scene and the related equipment, material, burn patterns, and building construction, as well as interviewing eyewitnesses, will prove ultimately to be invaluable when testimony is offered. The fire protection engineer should not only address the specific issues he or she has been asked to review, but also guide counsel in spotting additional issues and educate counsel along the way. The exchange of information, facts, and ideas will typically push an investigation into areas and directions not immediately evident when the project originates.

Perhaps the most obvious situations calling for the expertise of a fire protection engineer arise when there are issues surrounding the design, installation, and operation of automatic sprinkler systems and smoke/fire detection devices. In order to provide value for a client, a fire protection engineer must understand the design criteria that existed at the time that devices were designed, installed, modified, or upgraded. Similarly, a fire protection engineer should be retained in situations involving compliance with building codes or standards, such as fire separations, fire areas, seals around openings and conduits for utilities, and flammability standards for particular materials, all of which are extremely important in any fire investigation. Typically, fire cases involve two critical areas of analysis. The first is why the fire started, and the second is whether there is some particular event or design or construction defect that permitted the fire to spread into areas that it should not have otherwise spread under the circumstances. Usually, the fire protection engineer's role is more critical in the second stage of the analysis.

Simply because a property, building, job, or project was designed, built, or installed does not necessarily mean that all aspects of the work were performed in compliance with applicable codes and standards. All too often, fire or other catastrophic events occur in municipalities where code officials or building inspectors have simply relied upon certifications of others, such as sprinkler inspection companies, design professionals, or contractors, rather than inspecting the items themselves. This is not to suggest that there is anything unusual or inappropriate about this situation; in fact, this is probably the norm in most jurisdictions. Many jurisdictions simply do not have the manpower, time, or resources to determine compliance with every code, standard, or design practice. Rather, they rely on the certifications of other professionals who are especially retained to conduct such detailed and in-depth inspections. However, many times, these companies fail to properly perform their duties. Fire protection engineers can be particularly useful in identifying design and construction errors that are overlooked by parties merely because the work has received prior "approval" or certification.

In addition to determining factors and circumstances that promote fire, smoke, and water spread, nonoperation of fire-suppression and fire-detection devices, and design and installation issues, fire protection engineers are necessary to establish the "standard of care" with which a particular party is alleged to have failed to comply. A fire protection engineer can expect to research the appropriate standard of care for design issues, such as hydraulic analysis, proper sizing of pipes, sprinkler ratings, and the protection of sprinkler devices from environmental effects. Fire protection engineers should be able to establish the standard of care with respect to construction and installation errors involving automatic sprinkler systems and comment upon practices relating to inspection, testing, and maintenance of sprinkler systems. The bottom line is that without a fire protection engineer, or a similarly qualified witness, a party to a lawsuit will likely face a difficult task establishing what should have been done in a particular set of circumstances and why the act or failure to act fell below the standard of care within the governing industry.

The overall task of the fire protection engineering forensic project should be to show that a different design, construction, technique, product, or material would have made a difference in the outcome of the event. There must be a nexus or causal connection between the event and the issue being reviewed. Code violations or installation errors are factually irrelevant if they play no role in leading to the "bad" result or if the same result would have nevertheless occurred, even if the design, installation, testing, and maintenance of a particular system or building component was originally performed correctly. Of course, identifying a series of code violations and other deficiencies in conjunction with a particular violation that caused a fire or fire spread might be extremely beneficial in showing a pattern of sloppy work on the part of a particular party.

PROVING YOUR CASE

After the fire protection engineer has inspected the fire scene, reviewed all of the appropriate codes and standards, reviewed all of the documents exchanged during the course of litigation, and prepared his or her report, the next step is proving the case. This is where the advocacy role of the expert comes in. Before addressing how to best go about proving one's case, it is important to have an understanding of the potential pitfalls that attorneys and experts face in having an expert disqualified or having expert opinions excluded because they are not properly supported.

In today's courtrooms, there is a harsh legal climate restricting the ability of parties in lawsuits to present "opinion" evidence that supports their respective positions. Obviously, the goal in any lawsuit brought by a plaintiff, or resisted by a defendant, is to develop facts that will convince a fact-finder (typically a jury, but sometimes a judge) that a particular theory, scenario, or position is correct. But equally important, and sometimes overlooked, is the need to build the proper foundation that enables those parties to present that evidence, i.e., the story, the documents, the physical evidence, through appropriate witnesses whom the court will permit to provide expert testimony at the time of trial.

Now, more than ever, this potential stumbling block dominates trial and evidentiary rulings as they relate to expert or opinion testimony. The strict standard for admissibility has its genesis in the 1993 United States Supreme Court landmark decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc.* There, the Court directed trial judges to be "gatekeepers" of evidence and responsible for evaluating and guarding against improper evidence making its way to a jury for consideration. The Court implored trial judges to keep "junk science" out of the courtroom. To identify "junk science," the courts generally look at the overall "reliability" of an expert's opinions as the cornerstone of admissibility. Courts consider factors such as the background and experience of the proposed expert witness; the existence of standards against which the acts in question can be judged; whether there have been peer review processes involving the expert's opinions on the same issue; whether the opinions, theories; and scenarios have been tested; and whether the expert has utilized the appropriate methodology in reaching his or her conclusions.

How then does this preliminary evaluation by a judge impact the role of a fire protection engineer? First, it potentially translates into more business opportunities for the expert. Because of the heightened standard of admissibility for expert testimony, more and more fire protection engineers will need to be involved in forensic matters in order to overcome the *Daubert* challenges. For example, today, in a fire spread case, it is risky for a claimant to rely solely on a basic cause-and-origin fire investigator, with no fire protection engineering background, to give opinions on issues involving fire spread, automatic sprinkler operation, fire detection devices, or system designs. Retaining the proper fire protection engineer is essential to complement the other members of the forensic investigative team. The fire protection engineer can assist counsel in a manner that will allow for the presentation of facts and opinions that will prove a client's case.

Second, *Daubert* means that the fire protection engineer must ensure that his or her opinions are factually and scientifically supported. An expert should be especially mindful of this requirement when preparing his report and testifying during deposition, as these two things generally define the scope of the opinions and conclusions that an expert can offer at the time of trial. Although an expert will prepare a report in preparation of litigation, the report itself is not admissible at trial. Rather, the expert must testify as to his or her opinions at trial. However, this does not mean that an expert's reports, letters, and other communications are not discoverable by the other side. To the contrary, experts should be mindful of what documents they place in their files as everything that an expert reviews and relies upon will most likely be discoverable by the opposing party and can be used to impeach an expert's opinions and credibility during a deposition or at trial.

Experiments and tests that a fire protection engineer under-takes also become part of his or her work product. While it is certainly encouraged that the expert and the attorney exchange ideas and discuss particular issues in the case, an expert witness, whether a fire protection engineer or not, should never undertake testing or significant work on a particular project without discussing it in detail with counsel and having the project approved.

The final question then is what is the best way to communicate the expert's opinions convincingly so as to prove the client's case? As with most things, preparation is the key and cannot be undervalued. Experts should insist upon meetings with counsel in order to have sufficient time to prepare for anticipated cross-examination questions during depositions and at trial. In addition to being well-prepared for one's testimony, there are other things that an expert can do to convincingly set forth his or her opinions. It is now well known that jurors like to see examples of what they are listening to. We live in a visual society, one in which attention spans are very limited. Thus, there is an increasing use of computer-generated fire modeling and animations that should be within the capabilities of a fire protection engineer. These types of endeavors are particularly helpful when there are issues involving storage practices of combustible materials, allegations that a fire was intentionally set and with multiple points of origin, and theories including deficiencies with regard to system design and building construction.

Most importantly, in order for these types of computer programs to be admissible in court, they must be properly supported by the facts of the situation. The proponent of the visual aids and models must be able to establish the reliability of the program. This requires working closely with counsel on a regular basis and an ongoing exchange of information and facts that are incorporated into the finished product. These projects are effective in terms of establishing what a sprinkler system would have done had it operated properly, whether a sprinkler system would or would not have been overwhelmed by an intentional fire, whether an alarm system should have alerted a central station or fire department at an earlier point in time, or whether particular building materials should have restricted or contained a fire in particular areas. Here again, the ultimate admissibility of the work is the primary concern. The greatest computer-generated program does an attorney or his or her client no good if a court ultimately rules that a jury cannot see the fruits of the fire protection engineer's work. Generally, if the work is presented as a "depiction" of the ultimate opinions and conclusions of the fire protection engineer who will testify to the content of the program and modeling, it will be admissible. On the other hand, if the work is intended to be a "re-creation" of an actual event, courts have typically frowned upon that type of potential evidence. ▲

Paul R. Bartolacci and Georgia S. Foerstner are with Cozen O'Connor.

Failure of a Sprinkler System: A CASE STUDY

By Daniel Arnold, P.E.

INTRODUCTION

Fire sprinkler systems have a deserved reputation of reliability and effectiveness. When properly designed, installed, inspected, and maintained, they are expected to lie dormant for decades, poised ready to respond to a potentially damaging fire. As a result, fire protection engineers have confidence that sprinkler systems will reliably function when called upon to do so. However, on rare occasions, sprinkler systems may fail to perform as intended or expected. When this occurs, fire protection engineers may be called upon to determine the cause of the system failure. This article summarizes a portion of an investigation and analysis of one such failure: the unexpected separation of a mechanical coupling that had been installed for nearly three years.

INCIDENT SUMMARY

At approximately 11:00 p.m., a 2-inch (50 mm) diameter wet pipe sprinkler line installed in a large metropolitan hospital suddenly separated and began to immediately discharge water. The separated pipe was above the suspended ceiling of the high-rise hospital's eighth floor. The hospital building housed in-patient sleeping areas, diagnostic and treatment suites, operating rooms, support, and related patient care areas.

It was estimated that water discharged from the separated pipes at a flow rate in excess of 1,000 gallons per minute (0.63 m^3/s). In total, more than 10,000 gallons (40 m^3) of water flowed directly into the hospital from the separated pipes. On-duty hospital personnel responded immediately, investigated the separation, and shut down the flow of water. In the meantime, the water rapidly flooded the upper floor of the hospital and cascaded to all floors below, causing extensive damage to the building, equipment, and contents.

In response to the massive flow of water, the hospital instituted their formal Internal Disaster Procedures to assure patient care and safety, and to mitigate the impact of the water. Off-duty personnel were called in. Patients were relocated, and efforts were made to stem the flow of water. There were no injuries reported.

SEPARATED COUPLING

After the water was shut off, it was observed that the pipe separation had occurred at a mechanical coupling used to join a piece of feed main to a fitting on a wet pipe sprinkler system.

A mechanical coupling connects pipe ends and fittings together using a specially designed clamping collar and gasket. The coupling used two bolts that, when tightened, clamp the pipe ends and fittings together. Hospital staff took photographs of the coupling still in place on the pipe end as it was found after the water to the sprinkler system was shut off.

The separated coupling was a flexible, rubber-gasketed fitting, which was listed and approved for fire protection service. The joining pipe was manufactured of thin-wall steel with rolled-groove treated ends with the coupling still attached on one end to a rolled-groove coupling. The coupling was compatible with and listed for use with the installed fittings and pipe.

A material and dimensional analysis of the connecting pipe and fitting determined that their wall thicknesses and groove dimensions were within tolerances specified by the manufacturer. No material defects were observed in either component. However, upon inspection, striations were evident on the separated end of the pipe section. (See Figure 1.)

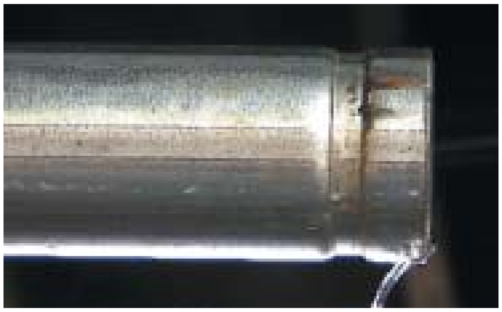


Figure 1. Separated pipe section

AUTOMATIC SPRINKLER SYSTEM

When originally constructed in the early 1970s, the hospital was not provided with automatic sprinklers throughout the upper floors. As a result, many sprinkler systems were retrofitted into areas of the hospital after the original construction. A review of available records showed that the system that experienced the coupling separation had only been installed for approximately three years at the time of the separation.

The automatic fire pump supplying the sprinkler system and other areas of the hospital campus was rated for 1,000 gpm (0.63 m^3/s) at 165 psi (1.13 MPa). The pump developed a maximum churn discharge pressure of more than 230 psi (1.6 MPa). The fire pump was pre-existing when the subject sprinkler system was designed and installed.

INITIAL INVESTIGATION

Due to the extensive damage and disruption caused to the hospital and to guard against a possible reoccurrence, it was critically important to hospital representatives that the cause of the coupling separation be determined. As a result, an engineering investigation was undertaken to determine the underlying cause.

The initial phase of the investigation included gathering and documenting all available factual data surrounding the circumstances of the coupling separation. Data was collected through a detailed review and documentation of the existing sprinkler system installation, study of available construction records, nondestructive examination and testing of system components, and eyewitness interviews.

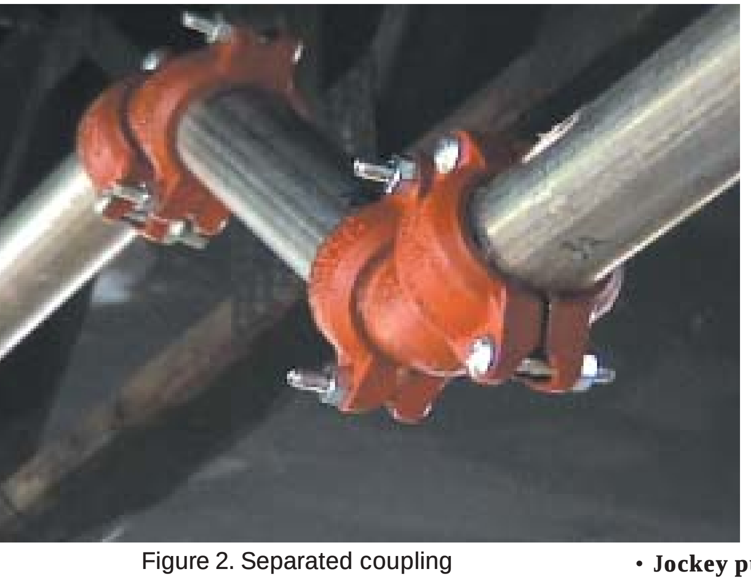


Figure 2. Separated coupling

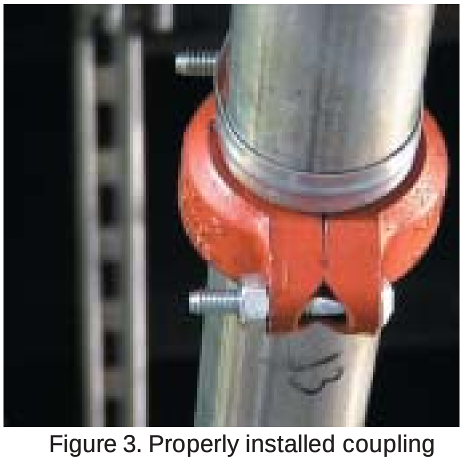


Figure 3. Properly installed coupling

From an initial inductive analysis of the collected data, the following factors were identified as potential contributing factors to the coupling separation.

- **Improperly installed coupling** – Photographs of the separated coupling showed a gap between the mating surfaces of the coupling's bolt shoulders. (See Figure 2.) A coupling installed per the manufacturer's installation instructions for the coupling exhibited no such gap. (See Figure 3.)
- **Lack of pressure reducing valve (PRV)** – Hydraulic calculation errors were made during the design of the subject sprinkler system that resulted in the omission of a PRV for the subject sprinkler system. A PRV was required by applicable standards based on the operating pressures of the existing fire pump serving the hospital campus, the sprinkler system's relative location to the fire pump, and the rating of sprinkler system components.
- **Improper hangers** – Certain pipe hangers and supports that were required by applicable standards were omitted near the location of the coupling separation.
- **Improper pump start pressures** – An hydraulic calculation error resulted in the fire pump start pressure being established well below the setting recommended by relevant standards (NFPA 20).
- **Jockey pump cycling** – On the afternoon of the separation, the hospital's jockey pump was noted by hospital staff to be cycling on and off very frequently.
- **Air in the piping system** – The subject sprinkler system piping that separated served the uppermost level of the hospital, providing a greater opportunity for the accumulation of trapped air.

COLLEGE PARK TESTING

To assess the contribution of the above potential factors, tests were conducted at the Maryland Fire and Rescue Institute (MFRI) in College Park, Maryland, under the direction of Dr. Fred Mowrer, Associate Professor of Fire Protection Engineering at the University of Maryland. A substantially similar replica of the fire sprinkler system was constructed using exemplar fittings, couplings, and piping. The layout of the system mirrored detailed measurements and technical data from the failed system. The replicated system addressed factors such as downstream piping volume, specific hanger configuration, and fire/jockey pump arrangement and settings.

A series of initial tests was conducted to validate the testing concept for the replica system and to investigate the general relationship between the identified potential factors and their tendency to cause or contribute to a coupling separation. Factors including coupling bolt torque, the presence of a pressure reducing valve, jockey pump cycling, fire pump pressure surges and air entrainment in the piping system were varied to determine which, if any, may have led to the coupling separation (alone or in combination with other potential factors).

JOCKEY PUMP CYCLING TESTS

One of the initial test series focused on the potential impact of jockey pump cycling on the integrity of the installed coupling. The purpose of the testing was to investigate if the cycling of the jockey pump observed by the hospital staff on the afternoon of the separation would generate enough pressure, pipe movement, etc., to loosen an installed coupling and/or contribute in any way to the coupling separation.

Jockey pump cycling tests were run on both a properly installed coupling (tightened to the manufacturer's specified bolt torque) as well as on exemplar couplings with loosened and finger-tightened bolts. Conservative pump pressure ranges and cycle frequencies (i.e., start/stop duration) were used. The cycling tests were conducted for durations as long as 15 hours. In each test, the sprinkler system piping simply swayed gently with each start/stop cycle. No separations occurred, and no leaks were observed anywhere in the system including during tests with loosened and finger-tight couplings.

Further jockey pump cycling tests were conducted using the actual jockey pump that was removed from the hospital. The regenerative turbine jockey pump was physically replaced and reinstalled in a test set up to evaluate a theory developed that the repetitive jockey pump cycling observed by the hospital staff would result in a cumulative increase in downstream system pressure due to the specific configuration of the hospital system's check valves and backflow preventer. Reportedly, an independent surge analysis/computer model predicted that extraordinary pressures well in excess of the rated system pressure could develop due to the cumulative effects of jockey pump cycling. While the model was not reviewed, it was theorized that excessive forces from these predicted excessive pressures could be related to the separation.

The additional testing clearly demonstrated that excessive pressures predicted by the computer model would not develop from the observed jockey pump cycling. As expected, the maximum pressure achieved by the hospital's jockey pump system was equivalent to the jockey pump shut-off pressure plus the maximum available static pressure from the pump source of supply. The maximum potential pressure from the hospital's jockey pump system was well within the working pressure of the sprinkler system and coupling.

HYDROSTATIC PRESSURE TESTS

Another important portion of the investigation was to conduct hydrostatic tests on the replica system to the requirements of *NFPA 13, Standard for Installation of Sprinkler Systems*. The testing was performed to assess the hydrostatic performance of the separated coupling under varying bolt tightness conditions to the acceptance testing criteria contained in *NFPA 13*. To accomplish this, the replicated sprinkler system was hydrostatically tested several times under two configurations:

- Each coupling on the system was installed in strict accordance with the manufacturer's installation instructions. Specifically, all coupling bolts were tightened to the required torque.
- The exemplar coupling at the location of the separation was installed with its bolts loosened and only "finger-tight." That is, the final tightening step specified by the manufacturer's instructions was not accomplished. The "finger-tight" and loosened bolts resulted in a gap between the mating surfaces of the bolt shoulders similar to that observed in the photographs taken of the actual separated coupling.

In each hydrostatic test, the replicated system successfully passed the acceptance requirements of *NFPA 13*. No leaks developed or occurred during any hydrostatic test. Surprisingly, the hydrostatic tests required by *NFPA 13* did not uncover the improperly installed couplings, including those with their bolts installed only "finger-tight."

SURGE TESTING

Following the initial exploratory testing, a series of preliminary surge tests was conducted on the replicated system. For each preliminary surge test, water was introduced into the piping system by rapidly opening a valve installed in the sprinkler system's supply. The character and magnitude of the induced surge was established from a study of the flow and pressure potential of the hospital's fire pump and the pump "start pressure" settings. and recorded using pressure transducers and data recording equipment. A similar capacity mobile pump was used to simulate the hospital's fire pump.

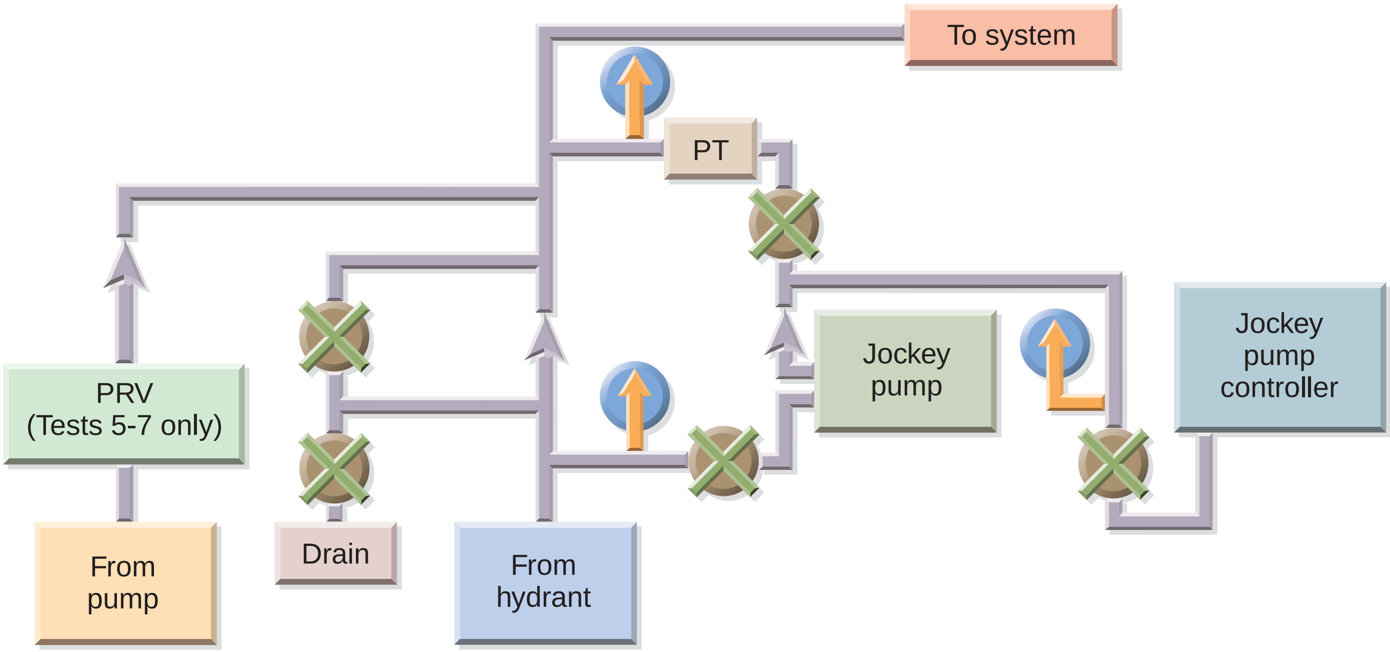
The following identified potential factors were considered in the preliminary surge testing. Each potential factor was tested independently and in combination.

- Coupling installation (i.e., varied bolt tightness)
- Installation of pressure reducing valve (set per *NFPA 13* requirements)
- Air in the piping system

During each of the preliminary surge tests, the piping system moved dramatically in response to the rapid introduction of water flow and increase in pressure. However, as expected, the magnitude of the piping system's response to the induced surge was clearly dampened for tests that included a pressure reducing valve and those when the piping system was "water solid" (i.e., with no introduced air).

For all but one of the preliminary surge test sequences, the piping system (including with loosened couplings) maintained the system pressure boundary and did not separate or even leak. However, during one of the surge tests, the test coupling catastrophically separated. (See Figure 4.) It was noted that striations similar to those observed on the actual separated pipe were also created on the pipe from the test.

Figure 4. Separated coupling



CATASTROPHIC PIPE SEPARATION

The factors present at the time of the coupling separation during the preliminary surge testing included:

1. "finger-tight" coupling bolts,
2. no pressure reducing valve, and
3. air introduced into the piping system.

When only one or two of these factors were present, the coupling did not separate.

Based on the results of the preliminary surge test series, subsequent surge testing was performed varying coupling bolt torque, installing a compliant pressure reducing valve, and introducing air in the sprinkler system piping. Again, the coupling separated only when all of the above three conditions were present.

GENERAL OBSERVATIONS

Sprinkler systems have a deserved history of reliable and durable performance. This investigation supports this reputation. However, when failures do occur, the lessons learned from related investigations can provide useful knowledge to fire protection professionals.

The fundamental cause of this coupling separation was the improper installation of a mechanical coupling. Specifically, the bolts of the coupling were left finger tight when originally installed. While the lack of a PRV and accumulated air in the system also contributed to this particular occurrence, these factors would have been inconsequential but for the loose coupling bolts.

The use of a torque wrench by sprinkler system installers is unusual, and traditional rolled-groove couplings do not have a visual tell-tale, such as break-away bolt heads, to assure minimum torque is reached. Fire protection engineers should recognize that the absence of a gap between mating coupling surfaces is not a reliable indicator that the specified bolt tightness has been achieved. (For example, the gap on this coupling tested completely closed when less than 10 percent of the required bolt torque was applied.) Further, while counterintuitive, the hydrostatic testing requirements of *NFPA 13* may not reveal improperly installed couplings, including those that are only "finger-tight."

Notwithstanding the above, rolled-groove mechanical couplings are well accepted and reliably used in the fire protection industry. Overall, the testing conducted in this investigation supports this comfortable reliance. Even when the coupling bolts were installed with significantly less torque than specified, the couplings performed well and did not separate or leak when subjected to this surge test protocol.

The sole purpose of this investigation was to review a discrete and specific set of potential factors on a particular coupling configuration and separation, and the related information should not be considered a general review of coupling performance. However, it is somewhat instructive on a practical level that there were more than 350 opportunities for a coupling to separate during the surge testing, yet the only separations or leaks that occurred were with couplings that were "finger-tight." This outstanding performance, as well as the rarity of coupling separations generally in fire protection systems, is clearly due to the robust design of the coupling and diligent installers. Nevertheless, installation oversights can occur. Fire protection engineers in conjunction with the installing contractor should give appropriate consideration to specific methods to assure the tightness of coupling bolts in accordance with manufacturer's requirements.

ACKNOWLEDGEMENTS

Mr. Duane Johnson, Fire Protection Engineering student at the University of Maryland, is specially acknowledged for his assistance in constructing the replicated system and conducting of the testing. Also, thanks are extended to the Maryland Fire & Rescue Institute and College Park Volunteer Fire Department for use of equipment and facilities. ▲

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Strategies for Reducing the "CRY WOLF" SYNDROME

Part 2

ALTERNATIVE TESTING STRATEGIES

In some occupancies, such as office buildings, it is easy to separate the occupants from fire alarm testing. Background noise measurements can be taken during occupied times, and the audible system tests can be conducted at unoccupied times. Similarly, strobes can be inspected during occupied times and tested during unoccupied times. Unfortunately, this is not possible in many occupancies, such as apartment buildings, multiple-shift factories, and hospitals.

Can the number of tests and the total testing time be reduced? For audible testing, some authorities, owners, engineers, and service companies use an engineered, statistical approach and target specific locations where the system is most likely to produce the lowest SPLs. They then check all other areas subjectively and verify that all appliances are at least operating. This is not a simple statistical sampling that has, by definition, some probability of missing areas likely to fail. A careful engineering analysis and a thorough site inspection are needed to develop a successful testing plan. An engineered statistical test plan reduces the probability of missing areas that would fail. Because this method does not meet the intent of the code, it should only be used where specifically permitted by the AHJ and approved by the owner and engineer.

Testing time can be further decreased by the use of more meters and more personnel. It takes very little training to use a sound level meter – particularly one with a peak-hold function. One problem is that very few contractors, distributors, AHJs, and even manufacturers of fire alarm systems show up for a test with a certified and calibrated ANSI Type 2 meter. Most use a nonrated meter available at many electronic stores for about $50.

An informal test of five nonrated meters against a calibrated Type 2 meter showed that the nonrated meters had an error range of approximately +/- 6 dB.[1] Two of the analog-type meters were consistently within 2 dB of the ANSI Type 2 meter. A digital version ranged from -4 dB to +6 dB. A third analog-type ranged from -6 dB to 0 dB difference from the rated meter. The largest range for any single test was from -2 dB to +6 dB.

Because many system designs are trying to meet a +5 dB signal-to-noise ratio (S/N), these nonrated meters would clearly not be suitable for accurate testing. However, they may be useful in parts of the building where the signals are not expected to be marginally close to the required minimum or maximum. For example, for this batch of meters, one might use an error bar of +/- 10 dB based on +/- 6 dB in the tests and a factor of safety of 4 dB. If a measurement indicates a level of 100 dBA in a space where the goals is 85 dBA, it can be concluded that the system meets the minimum and does not exceed the maximum: 100 - 10 = 90 > 85 dBA minimum and 100 + 10 = 110 < 120 dBA maximum.

A good testing strategy is to designate short, exact times when the system will be tested. The test plan should be communicated to the occupants one week and again one day prior to the test using mail, e-mail, bulletin boards, posters, etc. On the day of testing, traffic cones can be placed with signs at all entrances before occupants arrive. If the building has an intercom, public address system, or if the fire alarm system has voice capability, it should be used (in addition to the other means of communication) on the day of testing to inform the building occupants.

The test should be planned on the hour, say 10:00 a.m., for exactly three minutes. One or two more test times can be scheduled with at least one or two hours between. If a test time has been designated, the test team should test at the designated time, even if testing is completed in the first or second time slot. Expectations should be set, and the occupants should be trained that management, the test team, and the fire alarm system are reliable.

A good test plan includes provisions for what to do if a real fire occurs during the testing. This includes how occupants should report emergencies and how a real alarm will be communicated to the occupants and to the fire service. The comic piece “One Morning at the Office” is a story of an alarm technician’s attempt to come up with such a plan after testing has already been announced.[2] To be effective, the plan needs to be thought out in advance and communicated in writing to the occupants. In offices, hospitals, and other buildings where many of the occupants are employees, the emergency procedures should be a part of employee training.

The regular occupants of the space can be solicited to assist in subjectively evaluating the fire alarm signal in their spaces. In facilities such as hospitals, offices, and factories, designated employees can be charged with walking through specific areas to subjectively evaluate the loudness and effectiveness of the system. Occupants can be given forms to record the room numbers or locations and their perceptions of the system. Properly done, the subjective part of an engineered statistical approach serves several functions. Using the regular occupants of the building, including residents in apartment buildings, makes them a part of the test, not an outside observer that is annoyed by the testing. They take on some ownership and develop some pride in being part of a safety team. They can be trained to remind others several minutes before a test starts. This sets up the expectation that any other time the system sounds, it must be real since they were not notified in advance and asked to participate. This helps to condition their response. Immediately after each test, occupants that assist the test team should be asked to relay their recorded perceptions to a central location – either by hand, fax, phone, or e-mail. Although they are subjective evaluations, they may uncover areas that should be investigated by the professional testing team. Sufficient time should be allotted before the second scheduled test time of the day to do a visual inspection of the “problem” areas and determine if measurements are warranted.

Often, occupants report many areas where they feel the system is too loud and some areas where they feel it is not loud enough. The test team can be “calibrated” with a little bit of informal training and education. The test team should be shown the code requirements and allowed to take a few readings with a meter using a test horn in an area where it won’t disturb others. Systems that are too loud and too soft should be demonstrated, although they should not be exposed to noise levels that could damage their hearing. Instead, the system’s design maximum should be used. Occupants should be invited to approach the sounder from a distance and allowed to stop when they feel uncomfortable. Occupants can be given hearing protection to approach closer and make measurements.

Newsletters, posters, mail, and e-mail should be used to inform occupants when testing has been completed. Occupants should be told that they will be given notice before the next scheduled test of the system, and reminded that any alarms they hear should be assumed to be real and that it is critical that they respond and evacuate quickly. Occupants should also be told that the next test won’t be for X months, or better, for one year.

Although statistically it’s better to test some part of the occupant notification system at each regular test, it causes failure in the occupant response part of the protection scheme by increasing the “Cry Wolf” syndrome. The wires of the system are monitored for integrity so that faults will be known. Between tests, the failure most likely to be undetected is a failure of the appliances themselves since they are not monitored. For example, the flash tube and lens of a strobe light can be broken without generating a trouble signal. Similarly a pillow or duct tape can be placed over audible and visible appliances, causing failure of their mission. These types of failures are not discoverable by the electrical supervision of the circuits. However, these failures can often be uncovered as part of the required visual inspection mandated by the fire alarm code. By testing the occupant notification portion of a system only once per year, the “Cry Wolf” ratio is reduced.

Several formats or methods should be used to provide information to staff and occupants, and use different sources.[3] For example, the owner may send a newsletter, management may send e-mails or place notices on video bulletin boards, the alarm contractor may provide posters and signs, and the fire department may post notices at entrances.

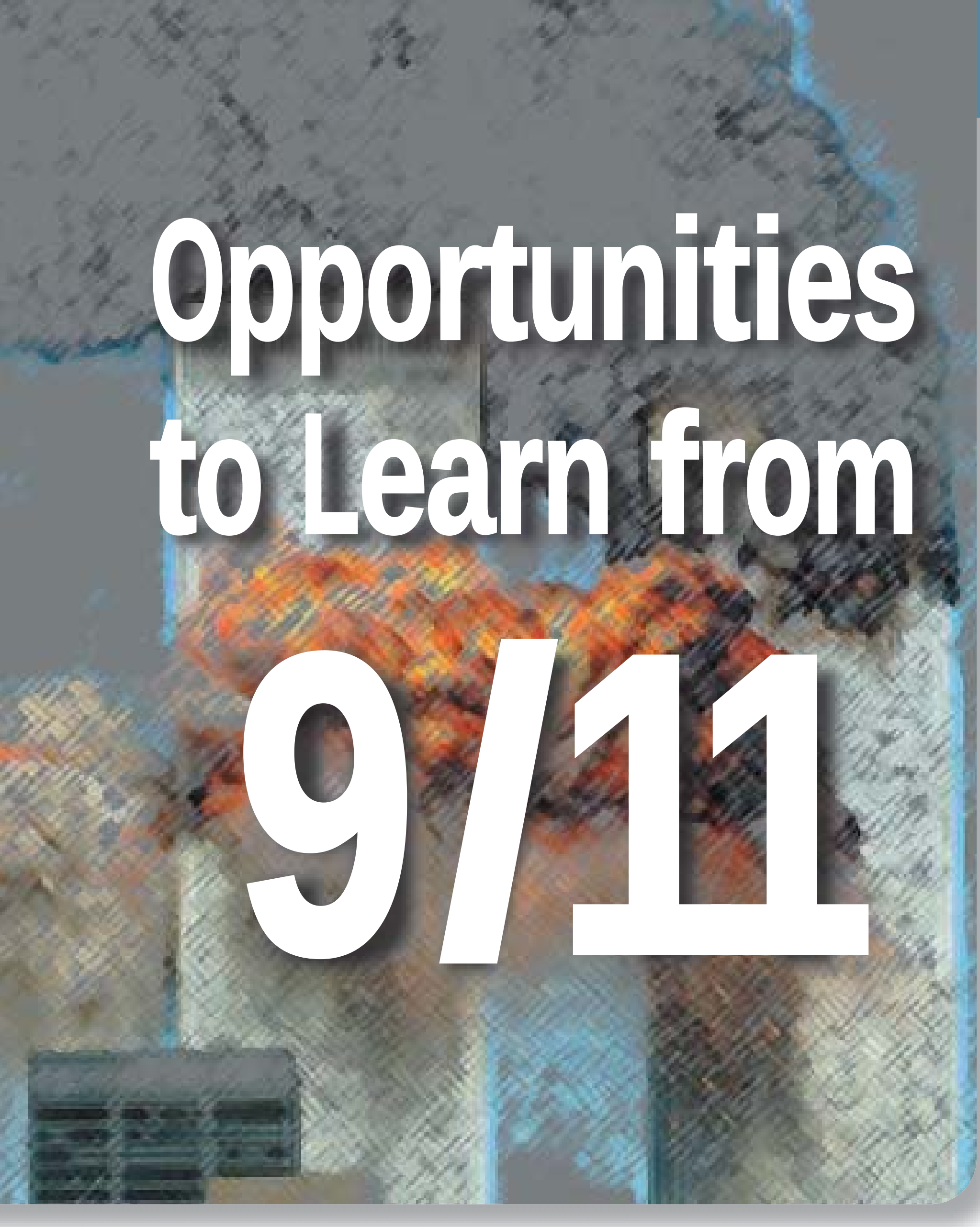
Professionals need to be cognizant that fire safety is a system that includes the occupants. It is necessary to weigh the effects of one part of the system – testing – on the other parts, such as occupant response and behavior. By using carefully planned testing strategies, the success of the system as a whole is increased. ▲

REFERENCES

1 These tests were not exhaustive scientific tests: The meters were not arranged to provide data logging; analog meters were read by eye; the meters being compared varied in age from 2 years to 10 years old; new meters were not included; and tests were done using only two different noise samples, one broadband and one dominant at approximately 3 kHz.

2 Shay, K., “One Morning at the Office,” Timothy McSweeney’s Ultimate Makeover, http://www.mcsweeneys.net/2001/08/20morning.html, August 2001.

3 Sorensen, J., “Risk Communication And Disaster Warning: Lessons For Counter-Terrorism,” Oak Ridge National Laboratory, National Academy of Sciences Forum, February 28, 2002, http://www7.nationalacademies.org/ndr/1Sorenson_Presentation.pdf



Opportunities to Learn from 9/11

By James G. Quintiere, Ph.D.

INTRODUCTION

On September 11, 2001, terrorists crashed 767s into the World Trade Center twin towers, ultimately causing their collapse. The Pentagon was similarly attacked. The investigation of these catastrophes has been varied. This article examines some of the opportunities to learn from these tragic events, so that improvements can be made in the future through fire protection engineering.

Initial statements following 9/11 offered a variety of explanations as to the reason for the collapses of the World Trade Center buildings: the jet fuel fires were significant and therefore precipitated the collapse; the steel melted or softened; the collision by the aircraft was too much for the 110-story twin towers despite the fact that the buildings had been designed to withstand a Boeing 707 (traveling at 180 mph [290 km/h] with a weight of 230,000 pounds [100,000 kg]) compared to the actual impact of the 767 (traveling at approximately 530 mph [850 km/h] weighing about 274,000 pounds [124,000 kg]).[1] The building weight was about 750,000 tons (680 Gg)[2] or about 5,500 times that of the 767. The energy expended in bringing these aircrafts to rest is mass x $velocity^2/2$, or about .4 GJ. The 59 14-inch (350 mm) square box columns could have absorbed this, in part or entirely, with a plate thickness of about 1/4 inch (6 mm) on the face of each tower.[1] The columns could have been sheared away, but the ultimate question is what damage was rendered inside. Some said the steel columns in the core were damaged, some said the insulation was blown away, some said the floor truss systems were severely damaged. Statements on each of these issues require more than opinions; they require scientific analysis. Even simple analyses can be sufficient, and such are necessary before anything more complex is even considered.

The Federal Emergency Management Agency (FEMA) report[1] did not find any substandard features in the design of the World Trade Center buildings, "in fact, many structural and fire protection features... were found to be superior to the minimum code requirements." The FEMA report further pointed out that prior to 9/11, high-rise buildings have not fallen in fire. However, the collapse of the high-rise buildings at the World Trade Center complex should be analyzed to determine if the fire resistance requirements that are presently used are adequate. Indeed, the process presently used is not based on engineering at all in the U.S., but rather a prescription of good intentions. A Russian text[3] recommends a resistance rating for structures based on the fire duration multiplied by a factor of safety, which is a function of the building type. What is the correct approach? These are some of the fire protection issues stemming from 9/11.

THE EVENT

WTC 1, the first hit, fell in about 104 minutes, and the South tower (WTC 2) fell in 56 minutes.[1] It is noteworthy to consider that the FEMA report[1] states that the impact zone (floors 94-98) of WTC 1 had an upgraded 1-1/2 inch (38 mm) thickness of insulation on the floor truss members, while the South tower had only 3/4 inches (19 mm). The insulation thickness specification for the truss system was upgraded to 1-1/2 inches (38 mm) in 1996. Only about a third of the trusses received this upgrade by September 11, 2001.[4]

Initially, the collapse of WTC 1 & 2 was attributed to the airplanes and the huge amounts of jet fuel. Some simple analyses can illuminate these claims. Each plane was estimated to have had 10,000 gallons (37 m^3) of jet fuel on board at impact.[1] Based on the asymp-

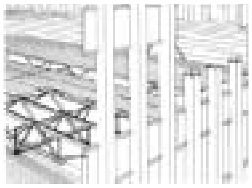


Figure 1. WTC 1 & 2 floor and exterior construction

Figure 2. Hit of WTC 2

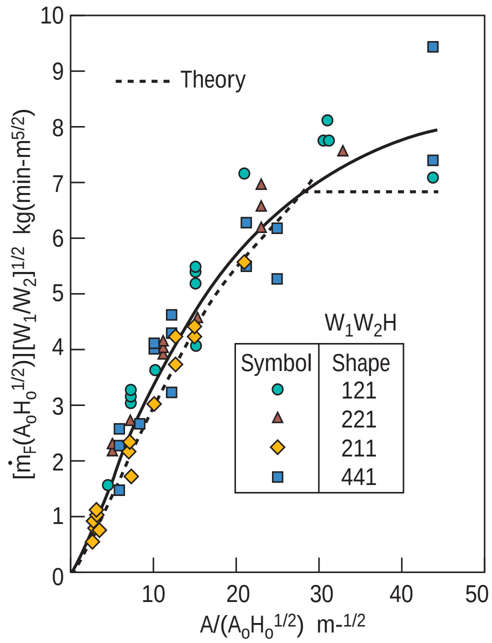


Figure 4. CIB correlation for the burning rate of wood[7]

totic burning rate for jet fuel (JP-4) of 60 g/m²-s,[5] a total burning rate of 242 g/s would result if the fuel burns homogeneously over the entire floor of 63 x 63 m. 10,000 gallons (37 m³) of jet fuel has a mass of approximately 28,500 kg. About four fireballs of roughly 60 m in diameter (D) resulted from a jet impact. The mass (M) burned by these fireballs can be estimated as:[5]

$$M = \left(\frac{D}{5.25}\right)^{\left(1/0.314\right)}$$

or about 9,400 kg per impact. The burning duration of the remaining fuel over one floor is

$$M = \left(\frac{D}{5.25}\right)^{\left(1/0.314\right)} = 79 \text{ s.}$$

Hence, the jet fuel fire was short-lived. The jet fuel acted merely as the arsonist torch in igniting large quantities of the building contents. Indeed, all of the jet fuel did not burn on the floor since accounts have described spillage into the elevator shafts, burning people in the lobby.

Therefore, the majority of the heat produced in the fires in the buildings was due to the burning of the contents – the same contents that the fire resistance design is based upon. This raises a question that must be answered: Should buildings be protected from fires similar to those which occurred in the World Trade Center buildings? An appropriate fire protection design should consider the duration of the fire that is likely under the plausible fire scenarios for the building.

The temperatures that occurred in WTC 1 & 2 can be estimated. The area of openings, A_o, has been estimated as ranging from 124 and 267 m² for WTC 1[1] with an opening height, H_o, equal to 3 m and a floor area, A, based on a floor of 63.5 m by 63.5 m and a utility core of 26.5 m by 41.8 m that is about 4100 m².

With these values, the quantity $AA_0^{-1}H^{-1/2}$ can be estimated as between 15 and 33 $m^{-1/2}$. For wood crib-like fires, the results of a CIB study[6] shown in Figures 3 and 4 correspond to temperatures of 800°C-1000 °C and burning rates of 14.5-18.7 kg/s. For typical floor loadings of 30 to 40 kg/m², the fire duration per floor would be in the range of approximately two to three hours.

It is interesting to contrast these results with the Standard Time-Temperature Curve[8] (Figure 5). The burning of fuel types other than wood can increase the temperatures and the burning rate as the heat of combustion to heat of gasification ratio increases. Thus, for fuel controlled burning, lighter-weight furnishings that are more volatile can give shorter fire durations with higher temperatures than shown here.

THE OFFICIAL RESPONSE

Following the attacks on the morning of 9/11, the Bureau of Alcohol, Tobacco and Firearms (ATF) convened one of their National Response teams to investigate the Pentagon fire. They subsequently spent several days at the Pentagon site and left when the Federal Bureau of Investigation no longer needed them. They were also told that no team was needed in New York since the cause was clearly arson. ATF has the authority to investigate federal arson and would have done more had they become involved. The National Transportation Safety Board was relegated to searching for aircraft debris, and the WTC and Pentagon events were investigated as terrorist actions, not fire events. A report was written by The National Institute of Standards and Technology (NIST) on the Pentagon, but that is classified. FEMA did render an investigative

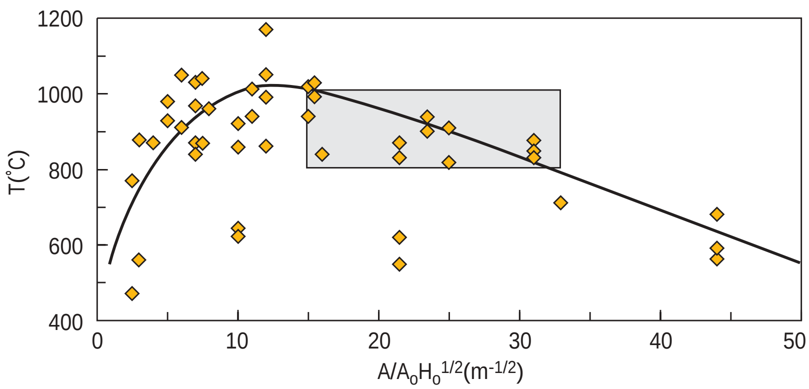


Figure 3. Compartment temperatures from the CIB study[6]

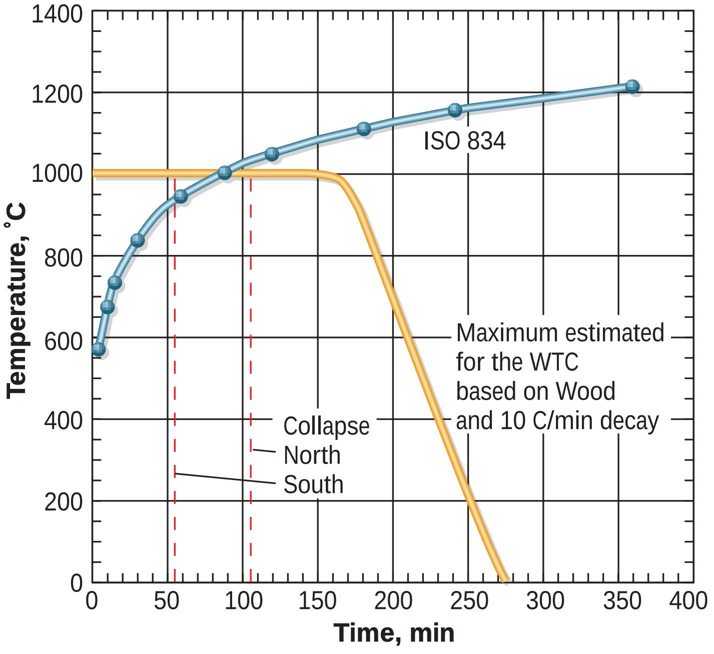


Figure 5. An illustration of the WTC fires with the Standard Time-Temperature Curve[9]

effort by contracting to the American Society of Civil Engineers (ASCE).

The response to the WTC event fell mainly to NYC. The clean-up was conducted by the Department of Design and Construction.[10] They decided to remove the steelwork and sell it. Metallurgical analysis of the steel could have detected changes in the phases of the steel from temperature and therefore an estimate of its temperature, e.g., 1000°C from an analysis by Barnett, et al.[11] Moreover, each piece of steel used in the WTC buildings was stamp-labeled to indicate its location in the building. A limited amount of the steel was, however, recovered by ASCE from the dumpsites.

FEMA assumed the federal government role to provide an investigation and enlisted the support of ASCE, which had previously established a voluntary team. The resulting investigation was intended to collect data, make initial observations and recommendations, including areas of further research. Its report was presented in May 2002.[1] While this study is packed with much information, it does not go into the detail that an investigation of an incident as significant as this warrants. In August 2002, an official federal investigation was begun by NIST, funded at a level of $16 million of $60 million that had been requested. The NIST investigation is planned to take two years.

THE INVESTIGATION

Meanwhile investigative efforts from litigation claims have been underway and can shed light on the events, but are always fraught with special interests and restrictions. The Silverstein Group (the lease holder on the WTC) commissioned a study to estimate the damage wrought by the aircraft to the buildings. Their results, reported by *The New York Times*,[12, 13] suggest that the severe damage to the columns, including the major load-bearing columns of the core, were responsible for the collapse. The fire played a role a weakening the columns according to the study. The *The New York Times* further reports that these investigators felt “there was no need to invoke a failure of the floors to produce collapse.”

Alternatively, the floor trusses have been considered as the weak links. A conduction analysis of the truss rods, 1.09 inch (27.7 mm) diameter A36 steel, with properties for the steel and the insulation obtained from the literature, gave results for the rod temperatures as shown in Figure 6. These results shown here are slightly different from the results presented by Quintiere, diMarzo and Becker.[14] The results in Figure 6 were developed by taking the variation of thermal conductivity and specific heat with temperature into account. While these were rendered by numerical computations, approximate hand-calculations gave similar results. The critical temperatures, for buckling of the truss diagonal rod, can range from 630 to 770 °C. Since the rate of change of temperature with respect to time is low in this range, the buckling times can vary. A 700°C mean critical temperature gives failure times of 60 and 100 minutes for the south and north towers, respectively. These times are consistent with the actual building failure times of 56 and 104 minutes.

The correct answer to the cause of the collapse can have a profound impact on the future design and construction of buildings, and must be determined. Other buildings of the WTC

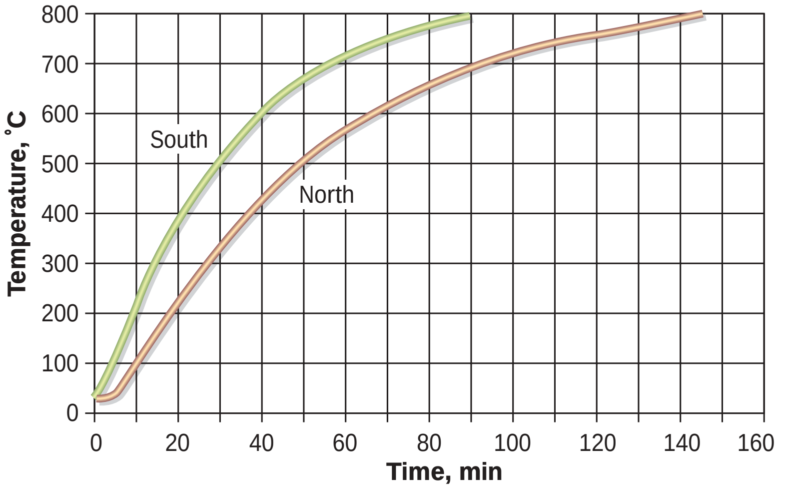


Figure 6. Steel truss rod temperatures due to a fire of 900°C[14]

also fell, but were not hit by aircraft, and similarly require a thorough analysis. WTC 7, a 47-story building, fell after fires were initiated by falling debris.

THE NEEDS

While the collapse of the buildings at the World Trade Center complex was initiated by aircraft collisions into buildings 1 & 2, fires of similar scale could have occurred without the aircraft collisions (the First Interstate Bank and 1 Meridian Plaza fires offer cases in point). The codes and standards governing structural fire protection design presently have little science and engineering supporting them. This lack of science makes it impossible to determine exactly the level of safety compliance provided by the codes and standards. While such safety regulations can be viewed as a drag on the economy, their ineffective application can produce high cost effects and may even be deficient in the safety they portend. It is highly likely that the root cause of the collapse of the WTC buildings can help illustrate the cost and consequences these deficiencies cause in the current state of the art.

The total cost of fire can approach 1% of the GDP.[15] The investment of research and education for the development of the science and technology for fire safety is about $20 million in the USA. Based on a total cost of fire of $100 billion, only 0.02 % of this is devoted to research and education. This is too little to assure cost-effective and engineered fire safety. Help is needed from the federal government to make a change in the infrastructure that addresses fire safety and, now, the vulnerability to terrorism. The federal government is the only entity that has the resources and objectivity to develop the needed research for standards and the education and training for the field. The private sector needs to administer the process of developing regulations appropriate for society, but grounded in science and engineering.

EPILOGUE

Since this article was submitted in November 2002, new information has emerged. But conclusions on the cause of the WTC collapses remain to be determined. NIST is nearing the end of its investigation. James Glanz and Eric Lipton of *The New York Times* have written a book, *The City in the Sky, the Rise and Fall of the WTC,* which sheds some light on the construction process and decisions. The SFPE held a conference in September 2003, "Designing Structures for Fire," that brought together an international perspective on theories of the collapse. Most believe the fire was key. Hopefully, these studies will address the role of fire protection, the process of assigning ratings, and the relevance of the standard furnace test method. In a step toward performance-based design, the SFPE will soon publish a new guide: "Engineering Guide to Fire Exposures to Structural Elements." ▲

James Quintiere is with the University of Maryland.

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2004 SFPE Professional Development Calendar

Spring Professional Development Week

March 22-25

Tuscany All Suites Hotel

Las Vegas, Nevada

By popular demand, SFPE returns to the west with four days of seminars of interest to practicing engineers and allied professionals. This event will feature 7 seminars including SFPE's newest in-depth seminar for the AHJ – An Enforcer's Guide to Performance-Based Design Review.

Monday March 22	Tuesday March 23	Wednesday March 24	Thursday March 25
An Enforcer's Guide to Performance-Based Design Review			
Sprinkler Design for Engineers			
Principles of Fire Protection Engineering			
	Introduction to Fire Dynamics Simulator and Smokeview		
Fire Alarm Systems Design			Tenability Systems for Smoke Management
Welcome Reception	Southern Nevada Chapter Dinner	How to Study for the FPE/P.E. Exam	

2nd Annual Meeting and Professional Development Conference

September 20-24

Palmer House Hilton, Chicago, Illinois

Our fall meeting moves to Chicago! Following in the path of 2003's successful event, the 2004 Annual Meeting format will include a one-day professional program addressing issues of concern for the practicing FPE, as well as the familiar ice cream social. This will be followed by the traditional Awards and Honors Banquet, and by four days of education events, including 10 seminars, a Symposium on Flammable and Combustible Liquids, and an expanded Engineering Technology Showcase.

Seminars being held are: Principles of Fire Protection Engineering; An Enforcer's Guide to Performance-Based Design Review; Sprinkler Design for Engineers; How to Study for the FPE/P.E. Exam; Human Behavior in Fire; Tenability Systems for Smoke Management; Dust Explosion – Hazard Recognition, Assessment, and Management; and much more.

5th International Conference on Performance-Based Codes and Fire Safety Design Methods

October 6-8

European Commission Facilities, Luxembourg

Performance-based codes, regulations, and design methods are gaining formal and widespread acceptance in many countries. For example, in the European Union, the recently completed Benefeu study by the European Commission found "... it is clear that a majority of Member States intend to implement an alternative fire safety engineering approach into national building fire safety legislation in the future."

This conference promises to continue the tradition established by SFPE to present the state of the art in performance-based code approaches and design methods.

Co-sponsored by: Institution of Fire Engineers, International Council for Research and Innovation in Building and Construction (CIB), and Inter-jurisdictional Regulatory Collaboration Committee.

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❒ Spring Professional Development Week

❒ 2nd Annual Meeting and Professional Development Conference

❒ 5th International Conference on Performance-Based Codes and Fire Safety Design Methods

❒ Contract Seminar

❒ Interested in Being an Instructor

UPCOMING EVENTS

March 2-4, 2004

Use of Elevators in Fires and Other Emergencies
Atlanta, Georgia
Info: www.asme.org/cns/elevators/cfp.shtml

March 17-19, 2004

Fire & Safety at Sea
Melbourne, Australia
Info: conference@rocarm.com

March 17-20, 2004

6th Asia-Oceania Symposium on Fire Science and Technology
Paegu, Korea
Info: 203.232.135.200/english/index.htm

March 22-24 2004

International Fire Safety Engineering Conference
Sydney, Australia
Info: www.sfs.au.com

May 2-7, 2004

CIB World Building Congress 2004
Toronto, Ontario, Canada
Info: www.cibworld.nl

May 9-14, 2004

5th International Scientific Conference – Wood & Fire Safety
Slovak Republic
The High Tatras
Info: uvt.tuzvo.sk/wfs/english/info/g_info.htm

May 23-26, 2004

NFPA World Safety Conference and Expo
Salt lake City, Utah
Info: www.nfpa.org

July 5-7, 2004

Interflam, 2004
Edinburgh, UK
Info: www.intercomm.dial.pipex.com

September 1-3, 2004

Public Fire Safety – Professionals in Partnership
3rd International Symposium
Belfast, United Kingdom
Info: www.intercomm.dial.pipex.com/html/events/hbif.htm

October 6-8, 2004

5th International Conference on Performance-Based Codes and Fire Safety Design Methods
Info: www.sfpe.org

Products/Literature

Heat and Smoke Detector

The F220 Series Smoke Detectors are the perfect smoke detectors for an imperfect world. The series of detectors combines revolutionary new detector strategies including photoelectric only, photoelectric with heat detection, photoelectric with carbon monoxide detection, and heat only versions. All the detectors in the F220 Series feature an easy-to-clean chamber that does not require the units to be disassembled, a valuable time-saver. These detectors also automatically compensate sensitivity to contamination in the chamber, extending the time between cleanings and reducing false alarms.

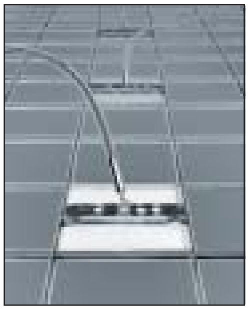
www.boschsecurity.com
—Bosch Security Systems

Code Comparison Book

Rolf Jensen & Associates, Inc., has released *Designing & Building with the IBC, Second Edition*. This reference on the latest building codes allows architects, engineers, building officials, and contractors to easily compare the new International Building Code® (IBC) 2003 to the three model building codes and the 2000 edition of the IBC.

www.rjagroup.com
—Rolf Jensen & Associates, Inc.

Flexible Fire Sprinkler Connections



FlexHead now offers flexible fire sprinkler connections to the commercial marketplace. These connections are designed for use in suspended ceilings and are fast and simple to install. Flexible connections enable engineers to specify a product that provides simplified project management, faster occupancy, and cost-effective code compliance.

www.flexhead.com
—FlexHead

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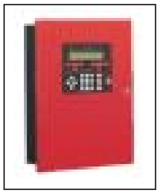
Thermafiber® Smoke Seal™ Compound is an elastomeric acrylic water-based caulking material that is applied over a fire-resistant forming material. Fire/smokestop systems with this product are available for through-penetrations in walls and floor-ceilings and for perimeter fire-containment systems. The compound is flexible, yet effectively bonds to keep the firestop in place.

www.usg.com
—United States Gypsum Co.

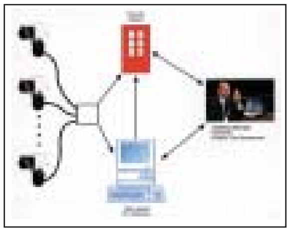
Fire Alarm Control Panel



The IdentiFlex™ (IF) 602 analog-addressable fire alarm control panel is ideally suited for small- to medium-sized installations of commercial, institutional, and industrial life safety applications. The IF602 uses SmartLink™ peer-to-peer protocol to connect up to 250 network nodes for added flexibility for challenging design applications. It features SmartStart® advanced self-programming and XP95 fully digital communications protocols, which allow for easy set-up and compatibility with any type of new or existing wiring.

www.gamewell.com
—The Gamewell Co.

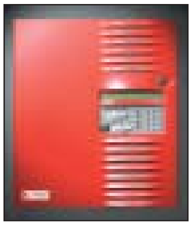
Video-Based Fire Detection



Video-based fire detection systems can cover a large area and do not require the smoke to reach any specific point location. The use of a video-based system does not add additional costs for the testing or maintenance of hardware than would already exist for the video surveillance system. The systems may be designed to provide digital snapshots associated with other events, such as pre-alarms or trouble conditions.

www.firesentry.com
—Fire Sentry Corp.

Upgraded Software



Fire Control Instruments has released version 6.1 of its Windows®-based Field Configuration Program (FCP-7100) and System Operating Software (SOS) for the 7100 Series fire alarm control panel. The 7100 Series is a microprocessor-based, analog addressable fire control panel system. The basic 7100 Series control panel provides two analog-addressable signaling line circuits, each supporting up to 99 analog-addressable sensors and up to 98 addressable monitor modules and/or control points.

www.firecontrolinstruments.com
—Fire Control Instruments

Fire Sprinkler Evaluation Software

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When it counts

New software allows Atlantic Mutual loss-control professionals to more quickly evaluate a customer's fire sprinkler system and water supply, resulting in a more accurate loss-control assessment and better protection of a customer's property and business assets. Named SAVE (Sprinkler Analysis Verification Evaluation), the software calculates sprinkler design adequacy, including density and area adjustments; pipe schedule capabilities; water supply adequacy for sprinklers and hose demand; two-inch drain test flow estimates; and in-rack demands.

www.atlanticmutual.com
—Atlantic Mutual Insurance Co.

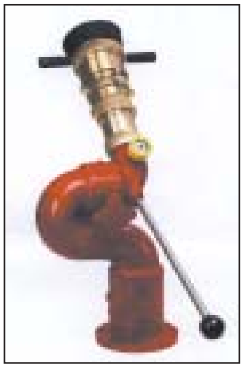
Products/Literature

Combo Exit Sign/Emergency Lamp

The new mcPhilben® CCHX Series of compact thermoplastic combos combines an exit sign with two internally designed lamp heads into a small unit. With contemporary round corners, the units blend into any decor where emergency lighting is needed. The CCHX Series uses red or green LED lamps for energy efficiency and low cost. Engineered for easy installation, units feature a snap-together quick-mount design for wall or ceiling mounting, and have Xtest™ self-diagnostics.

www.daybritelighting.com
—Day-Brite Lighting

Fixed Monitor



The Copperhead™ Fixed Monitor is ideal for small or restricted spaces. Just 16 inches high, it has an all-brass configuration which delivers efficient flows up to 1,250 gpm with minimal friction loss. Vertical movement of 90 degrees above to 45 degrees below horizontal, and full and continuous 360-degree rotation combine for safe, easy operation.

www.elkhartbrass.com
—Elkhart Brass Mfg. Co.

Website Offers Spec Info

SureSpec.info allows users to review and compare multiple fire alarm data and specification sheets from one site on the Web. In partnership with many leading fire alarm manufacturers in the U.S., the SureSpec site was developed to help users prepare fire alarm specifications with information that is updated continuously. Additional site features include instant e-mail updates, blueprint review service, links, and more.

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—SureSpec

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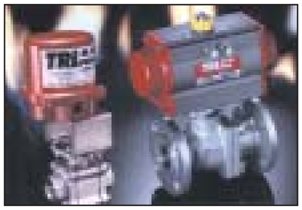
Durable, portable detectors from Crowcon are available in several versions including the Gasman II single-gas version for applications where only one hazard is to be monitored. Several sensor types are available for different applications including combustible gas, carbon monoxide, and hydrogen sulfide. For applications involving multiple gas risks, Triple Plus four-channel instruments are available, which may also be used for sampling gas from vessels and pipework.

www.crowcon.com
—Crowcon Detection Instruments

Firesafe Ball Valves



Firesafe-tested and -certified to API-607 4th edition specifications, Triac ball valves combine operating confidence with wide specification choices, direct-mount compactness, and complete pre-assembled valve/actuator packaging convenience. Two model lines – 3-piece F88 and flanged full-port FD9 – enable application versatility. The valves come in 316 stainless steel or carbon body steel.

www.a-tcontrols.com
—A-T Controls, Inc.

Pressure Relief Valve CD Catalog

Oklahoma Safety Equipment Co., Inc., now offers its product catalog on a free CD, which contains detailed information on the company's custom-engineered rupture disks, rupture panels, and other pressure relief products. The CD catalog contains links from the table of contents, PDFs containing in-depth information, illustrations, and specifications.

www.oseco.com
—Oklahoma Safety Equipment Co., Inc.

Micro Thermal Imaging Camera

The Fire-Warrior, a new micro thermal imaging camera, enables firefighters to concurrently use both hands, both eyes, and the camera during fire attack, search-and-rescue, and related operations. It is light enough, small enough, and advanced enough to be helmet-mounted without obstructing normal vision.

www.totalfiregroup.com
—Morning Pride

Smoke Control Panels

Using the latest technologies, H.R. Kirkland manufactures smoke control panels with full color electronically printed graphic displays, printed on the rear of UL listed lexan, and laminated to .125” CNC punched aluminum. The full color feature is beneficial as the air handling functions are color coded. The panels offer the flexibility of being hardwired or wired for interface with FA or HVAC software.

www.hrkirkland.com
—H.R. Kirkland Company, Inc.

B R A I N T E A S E R

Four people of different ages told each other how old they were. One of them said "If I multiply my age by any of your ages, the product is a permutation of the digits of the two ages." How old is everyone?

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

Solution to last issue's brainteaser

A car is driven 20,000 km per year. The car averages 12 km per liter of fuel. Assuming perfect combustion (i.e., no carbon monoxide or unburned hydrocarbons are created) and that the chemical formula for gasoline is C_8H_{18}, how much carbon dioxide is emitted by the car annually?

Since the car averages 12 km per liter of fuel, driving 20,000 km in a year requires 1,670 liters of fuel. From Table B.3 in the *SFPE Handbook of Fire Protection Engineering*, the specific gravity of gasoline is 0.68, which corresponds to a density of 680 kg/m^3. Therefore, 1,670 liters of gasoline weighs 1,140 kg. Since the reaction for burning C_8H_{18} is

$$C_8H_{18} + {}^{25}\!/_{2}\, O_2 \rightarrow 8CO_2 + 9H_2O$$

for each 114 grams of gasoline that are burned, 352 grams of carbon dioxide are produced. Therefore, burning 1,140 kg of gasoline would create 3,500 kg of carbon dioxide.

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Structural Fire Resistance Design – We Can Do Better

Morgan J. Hurley, P.E.
Technical Director
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Fire resistance is ubiquitous in commercial buildings as a means to protect people, property, and mission from damage resulting from fire-induced collapse. In most cases, fire resistance is designed based on single-element tests that are conducted in accordance with standard tests such as ASTM E119[1] or ISO 834.[2] In these standard tests, exemplar elements or assemblies, such as beams or columns, are subjected to a standardized fire exposure. The pass/fail criteria of these standard tests generally relate to the ability of the tested element to maintain a load (in the case of beams) or stay below specified temperature criteria (in the case of columns). The rating that is given to structural elements is expressed in units of hours, which is a measure of the time before the element reaches the endpoint criteria in the standard test. This hourly rating is intended for comparative purposes only and is not intended to represent the length of time that a structure would withstand any given fire without failure.

When designing fire resistance for a specific building, the required rating is determined by referring to the applicable building code. Any needed protection for the structure is determined by considering the type of structure that is desired, the rating that is required by the building code, and the results of fire resistance tests on specific assemblies. If an assembly proposed for a structure differs from a tested assembly, simple engineering calculations are used to vary the size of members, protection or cover thickness, etc.[3]

Designing structural fire resistance in this manner has a number of shortcomings. These include:

- The fire exposure used in the standard test does not consider factors that would influence the temperature and duration of a fire, such as ventilation, fuel load, and thermal properties of materials of construction.
- Single elements are tested in isolation, and true performance of structural systems and frames is not considered.

Moreover, structural fire resistance design is typically performed by design professionals other than fire protection engineers. In most cases, an architect determines the required fire resistance rating and applies the results of fire resistance testing for a structural assembly that is similar to the one that will be used in the building. While these design professionals do a fine job of specifying fire resistance in this manner, they do not necessarily have a background that enables them to understand how structures will perform in a fire, and hence, they may not be able to determine how unique building characteristics could affect structural fire performance.

While structures that are designed in this manner have an excellent record of performance in fire, the result is that the actual performance that will result if these structures are exposed to fire conditions is unknown. Fortunately, the engineering infrastructure exists today to design structures based on the expected fire loads and the structural fire resistance needed to accomplish the desired performance in fire.

Designing structures on an engineering basis requires the following steps:

- Determination of the fire conditions to which a structure or portion thereof could be exposed. These conditions are a function of the amount and distribution of combustible items, the available ventilation, and the thermal properties of an enclosure.
- Based on the fire conditions, estimation of the thermal response of the structure or portion thereof.
- Based on the thermal response of the structure or portion thereof, determination of the response of the structure.

Methods exist to perform each of these tasks. Internationally, structural design standards for the fire condition have been developed and are presently in use.[4] Additionally, the National Institute of Standards and Technology has embarked on a major program to benchmark and further develop the state of the art in structural fire safety design.

The Society of Fire Protection Engineers is working in collaboration with the American Society of Civil Engineers and representatives from the steel, masonry, concrete, and timber industries to more formally implement this design infrastructure in a series of standards and guides. Once completed, these standards and guides will allow the design of buildings in which the structural fire resistance is designed such that the building performance in the event of fire is known.

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