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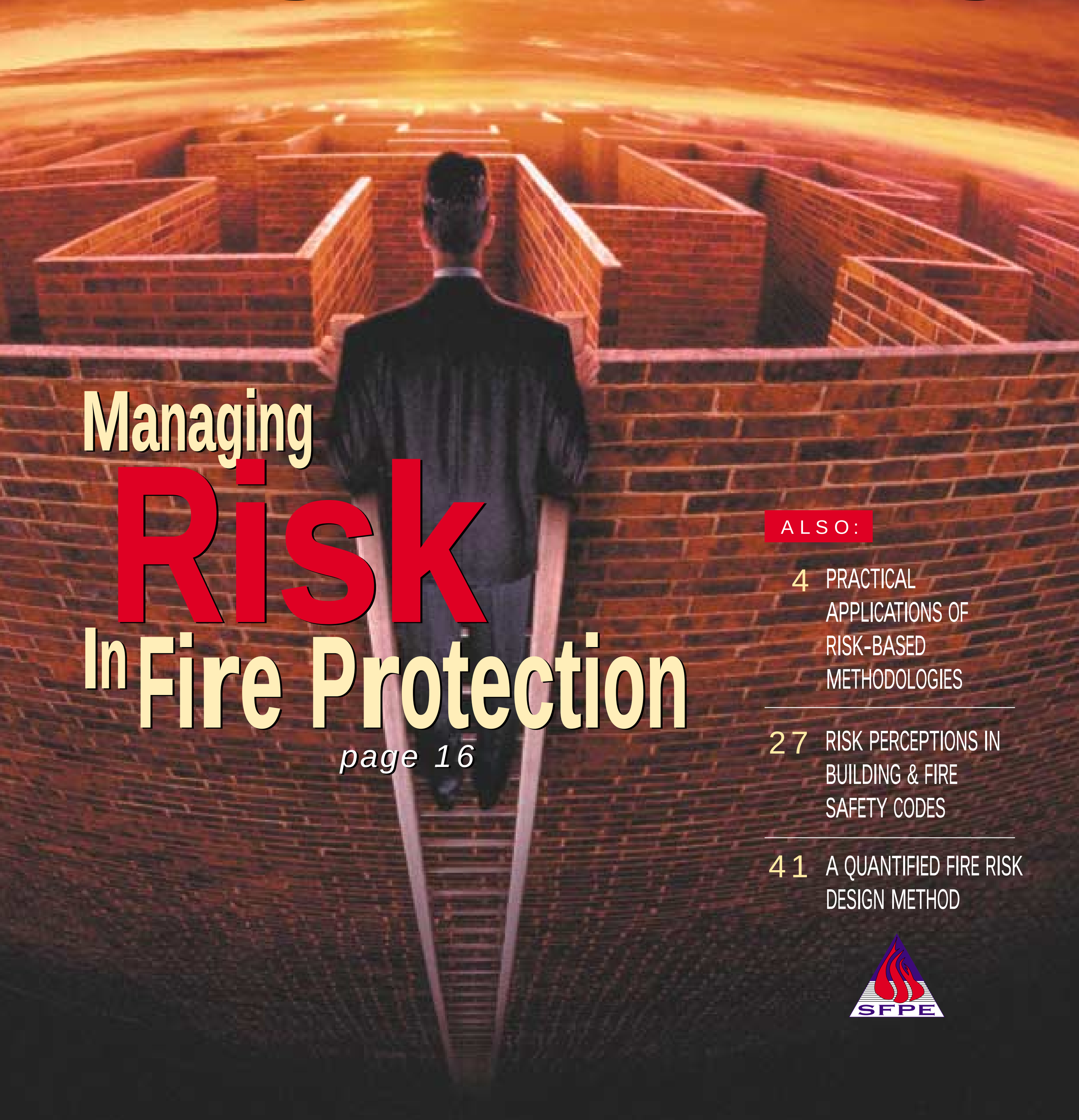
FIRE PROTECTION Engineering

SPRING 2001

Issue No. 10



Managing Risk In Fire Protection

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Fire Risk Analysis in the SFPE Handbook of Fire Protection Engineering

By John M. Watts, Jr., Ph.D., and John R. Hall, Jr,. Ph.D.

As the field of fire protection engineering evolves, we are using measures of effectiveness that go beyond the response of materials, products, and assemblies, to the predicted response of buildings in terms of their ability to perform in a fire. Fire risk analysis offers approaches to such measures and Section 5 of the *SFPE Handbook of Fire Protection Engineering* is evolving along with this aspect of the profession.

The second edition of the *SFPE Handbook* contains 12 chapters in Section 5 on Fire Risk Analysis. The third edition will have 15 chapters on risk, including 5 entirely new chapters, and major revisions, including some new authors for many of the chapters from the previous edition.

Section 5 of the third edition of the *Handbook* is being organized into three broad areas that progress from the general to the specific. There are some basic tools that most approaches to fire risk analysis should consider, if not incorporate. There are some examples of generic models applied to fire safety problems, and there are detailed descriptions of fire risk analysis procedures that have been adopted in several areas of application.

Chapters 5-2 through 5-7 cover generic tools used in many other disciplines and inherent to fire risk analysis, but not typically included in more traditional approaches to fire protection.

The most common use of fire risk analysis is as a basis to make choices. The choice may be between two alternative designs for a building or two alternative formulations for a model code or standard. The choice may be whether to tighten requirements on product type A or product type B. Chapter 5-2 describes *decision analysis*, a generic field on forms of analysis that support this kind of decision-making. *Cost-benefit analysis* is a specific type of decision analysis in which a fire risk analysis would provide estimates for some of the benefits and other analysis would quantify corresponding costs.

Chapter 5-3 addresses *reliability*. Fire risk analysis depends upon many types of probabilities. One is fire scenario probability, the estimation of likelihood for the initial conditions and ensuing major events in fire development. Another group of probabilities might be transitory conditions related to people, such as the locations and capabilities of occupants when fire begins. Critically important sets of probabilities have to do with status and capabilities of fire protection equipment, features, and arrangements.

Chapter 5-4 addresses the uncertainty of the engineer or decision-maker regarding estimates of the magnitude of fire risk. Uncertainty may be caused by imprecision or bias in our techniques of observation or calculation, a lack of clarity in our goals, uncontrollable technological variation, or variations of natural phenomena, to name only the major components. Unwanted combustion is perhaps the least predictable common physical phenomenon. Uncertainty analysis is the scientific calculation procedure that should underpin choices of *safety factors* and *safety margins*. It is central to the valid use of fire risk analysis – or any other form of engineering analysis – for code equivalency, design approval, or any other important decision in the real world.

Chapter 5-5 addresses *data sources* for engineering analysis, particularly data useful for calculating scenario probabilities, reliability probabilities, or any other probabilities needed for fire risk analysis.

Chapter 5-6 addresses the *measurement of consequences in economic terms*. This includes indirect losses, economic measures of the value of a lost life or of an injury, the use of utility measures to capture people's desire to avoid uncertainty about loss as well as loss itself, the implications for people's risk aversion for the basic mathematics of insurance, and so on. The common theme is treating consequences comprehensively and in a form that captures people's real preferences and can be readily compared to the costs of alternative choices. Chapter 5-7 addresses *other economic topics* that arise in the practice of engineering analysis, with particular emphasis on monetary valuations over time (e.g., rate of return, interest, discounting).

Chapters 5-8 through 5-10 describe the use of some examples of generic models of risk analysis and decision-making that have been widely adapted and used for fire safety applications. Chapter 5-8 addresses special topics in the calculation of low probabilities, under the heading of *extreme value theory*. Chapter 5-9 describes techniques and available models using *computer simulation*, with special emphasis on those having a fire risk analysis basis, such as state-transition models. Chapter 5-10 describes less-quantified methods of fire risk analysis, involving *fire risk indexing*.

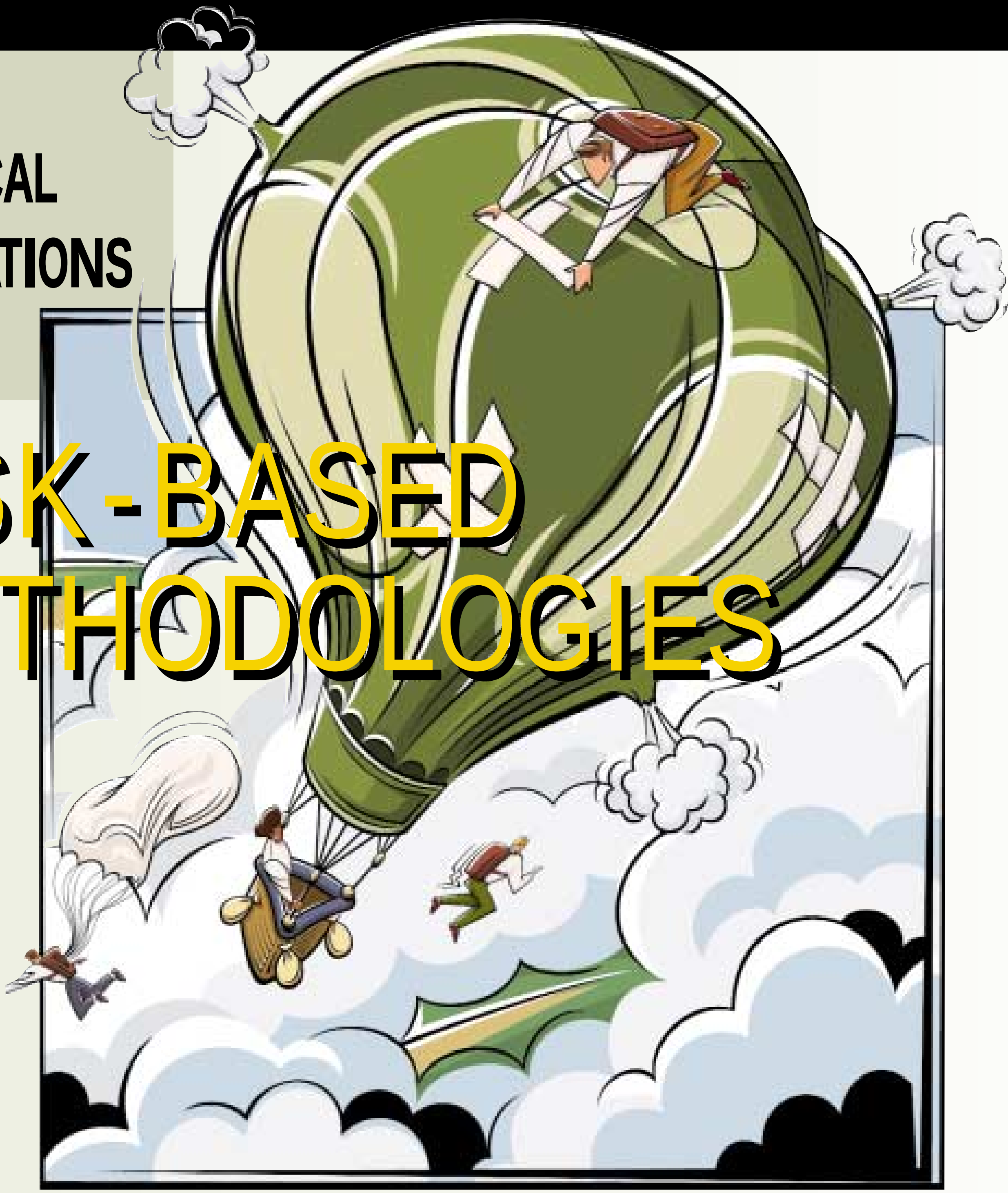
Chapters 5-11 through 5-15 deal with specific applications of fire risk analysis that have been implemented in the areas of consumer products, buildings, chemical processes, nuclear facilities, and vehicles. Much of the information in these chapters can be extracted and adapted for other areas of application. Of particular note is how the tools in Chapters 5-2 through 5-10 have been incorporated into the applications in these areas.

Chapters 5-11 and 5-12, respectively, describe general techniques and available methods for *fire risk analysis of products or buildings*. Chapters 5-13 and 5-14 describe the much more specific methods tailored to applications in two industries where the use of fire risk analysis is far more common than in others, namely, *chemical process industries* and *nuclear power plants*. Finally, Chapter 5-15 describes new methods addressing consequence measurement for *transportation vehicles*, which now exists in a form ready for use in fire risk analysis.

John M. Watts is with the Fire Safety Institute. John R. Hall is with the National Fire Protection Assocation.

PRACTICAL APPLICATIONS OF

RISK-BASED METHODOLOGIES



By Kenneth W. Dungan, P.E.

Everyone makes decisions based on risk, or at least his or her perception of risk. Some sky dive with or without understanding that the annual risk of fatal accident is 1 in 1,000.[1] Most of us drive accepting an annual risk of 1 in 5,000 of dying in an auto accident. Still, some people are afraid to fly even though the annual risk of fatal accident is 1 in 250,000. These decisions are made with a perception of risk, which is usually qualitative. The above risks are reported as annual risks of a fatal accident for the "average American." The likelihood varies, but the consequence is consistently fatal. Would our perception of risk change if we knew the number?

When the weather forecast is for a 40% chance of showers for the day, do you plan a picnic? Do you cancel an outside wedding? Do you carry an umbrella? In this case, the likelihood is the same, 1 in 2.5, but the consequences vary significantly. The public grasp consequences more fully than likelihood and, therefore, may choose to carry an umbrella, but not cancel a wedding. However, weather reports, which quantify a chance of showers, may be an indicator of a broader trend to quantify risk in a way acceptable to the public.

Each type of risk being measured uses specific units, understood by those familiar with that risk. These units may by in frequency terms (so many events per year) or demand terms (so many failures per demand). To make effective use of a published number, the units are essential.

In fire safety, code requirements have evolved largely by trial and error, or more accurately, error then trial remedy. In response to consequences which society deems unacceptable, something must be done. So our codes are peppered with anecdotal driven requirements. All usually agree on the consequences to be prevented or mitigated, but far fewer agree on the likelihood of our success, which provides the basis for cost-benefit. These comments are not intended to criticize current codes and standards, but rather to emphasize that using risk (likelihood x consequence) as opposed to hazard (consequence) is necessary for the success of performance-based fire safety.

ABSOLUTE VERSUS RELATIVE RISK

One of the difficulties in applying risk methodologies is clearly defining acceptable risk. An absolute risk, such as “fire deaths per year” or “dollars per year,” is more difficult to declare as acceptable because it requires the

Figure 1. Risk-Informed Methodology Process[2]

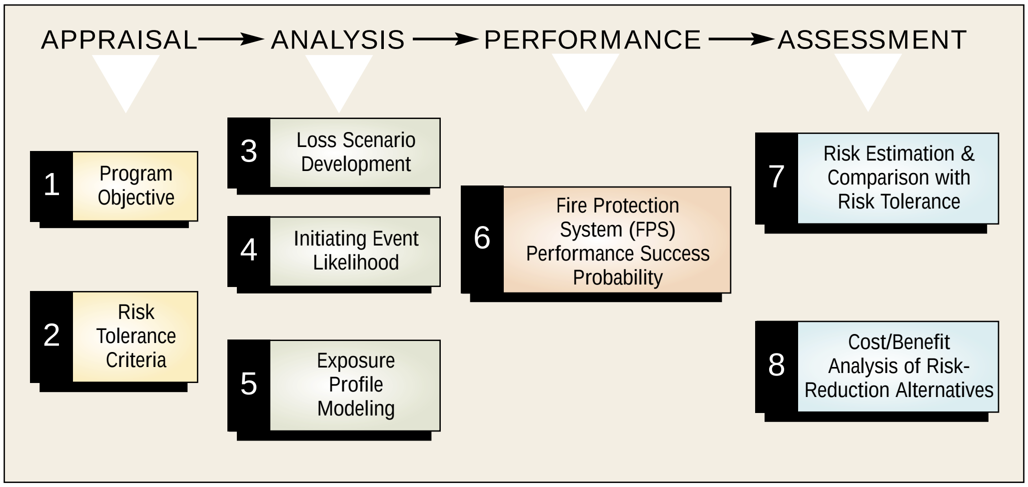
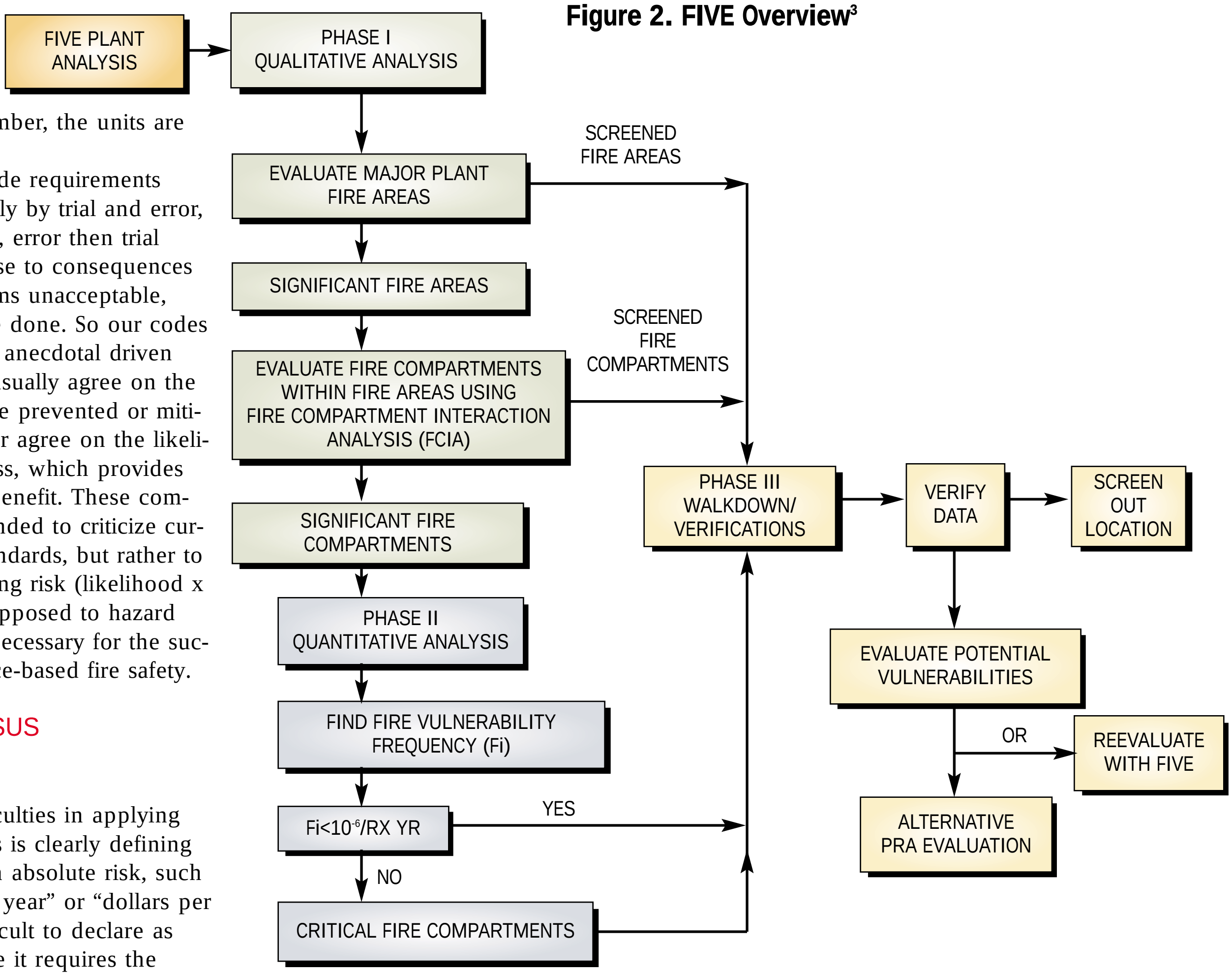


Figure 2. FIVE Overview[3]



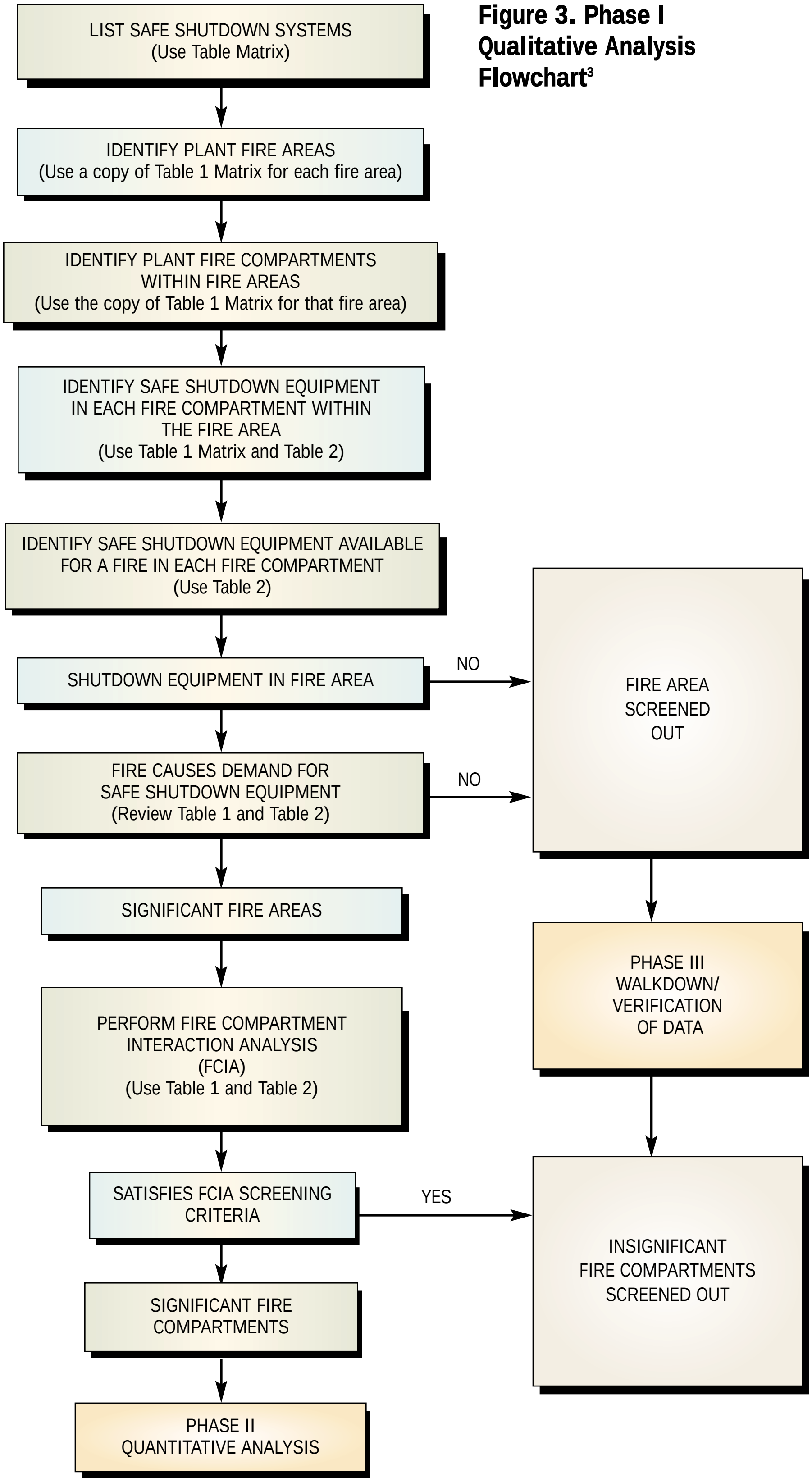


Figure 3. Phase I Qualitative Analysis Flowchart[3]

acceptance of a known risk. If such a hard number can be agreed upon, however, it allows a more quantitative measure of acceptability and equivalency.

One of the problems with these "hard number" approaches is the general mistrust of statistical data and their cause-effect relationships. This does not mean fire protection engineers should shy away from risk-based tools. Quite the contrary, these tools should be understood, then embraced. Below are some practical examples of how risk methodologies have been used in fire safety.

Applying risk measures as a relative ranking to establish priorities or to compare cost-benefit of different approaches makes effective use of the methods without becoming mired down in the acceptability of any one risk. These rankings can be qualitative or quantitative in nature, as the examples below will illustrate. Such relative risk ranking can be a powerful decision tool.

FRAMEWORK FOR APPLICATION OF RISK METHODS

T.F. Barry, in his book, *Risk-Informed Performance-Based Fire Protection*,[2] outlines an eight-step process for using risk methods to address fire safety problems. These steps, shown in Figure 1, provide a useful framework for applying risk-based approaches and help the users of individual elements of the process see how the pieces fit together.

PRACTICAL EXAMPLES

The three examples outlined below illustrate the range of application of risk methods to fire safety problems.

FIRE-INDUCED VULNERABILITY EVALUATION

The first example is a screening tool developed for the nuclear power industry, under an Electric Power Research Institute contract.[3] This tool is a two-phase evaluation to assess the likelihood of a fire causing reactor core damage. The "risk tolerance" was established as a fire contribution to core damage frequency of 1×10^{-6}.

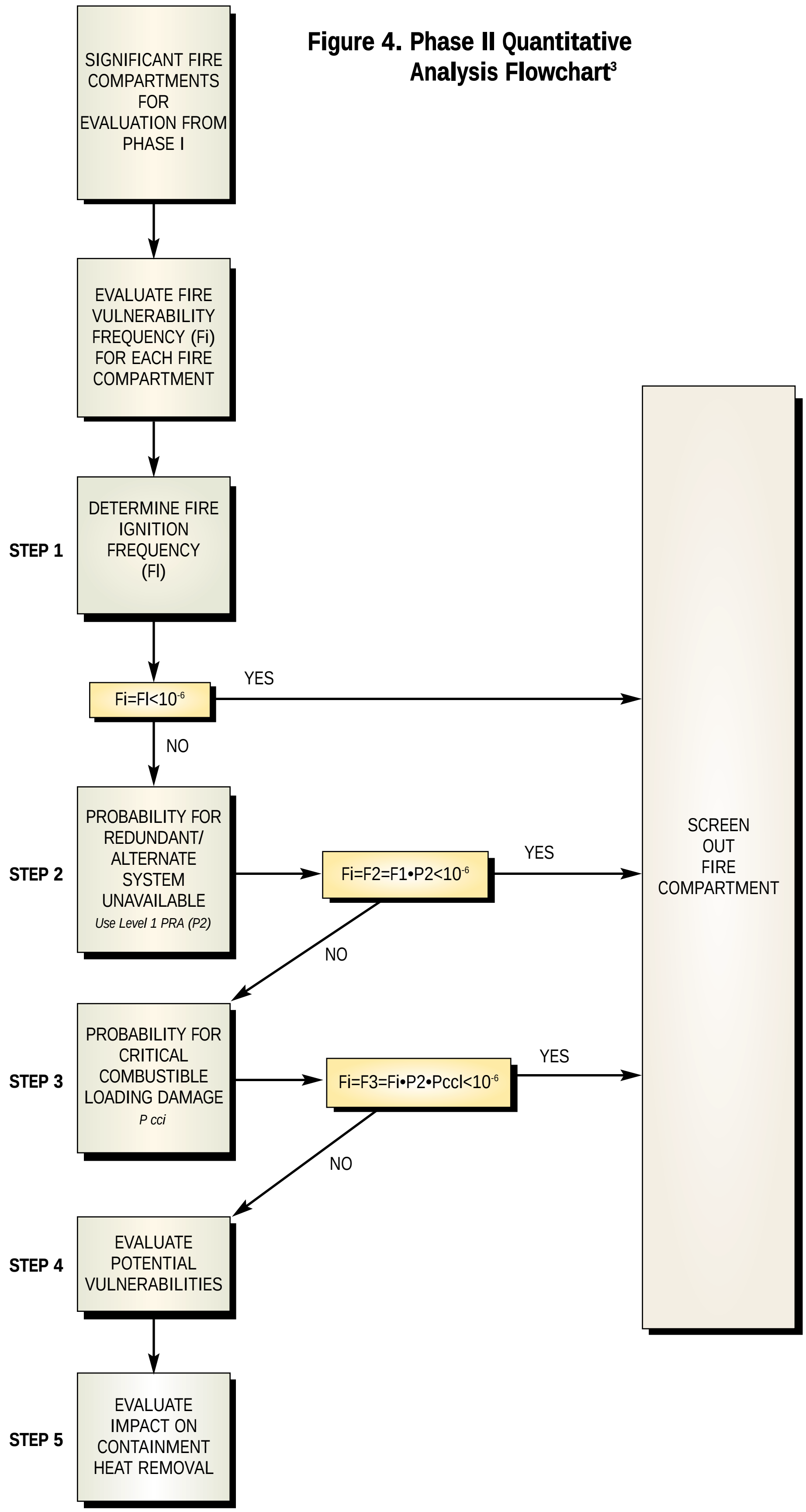
Figure 2 provides an overview of the steps. Phase I, as shown in Figure 3 flow diagrams, identifies safety significant fire areas by qualitatively identifying if any safe shutdown equipment is in the area or if a fire could cause a demand for safe shutdown equipment. This approach is similar to identifying those fire scenarios that are significant to a performance-based design. Fires in these screened-out areas are not significant to the performance objective of reactor safety.

The second phase for those fire areas not screened out is more quantitative. As shown in Figure 4, these steps include an assessment of fire frequency, availability and reliability of redundant safe shutdown equipment, and the performance of the fire protection features. Step 3 addresses the potential consequences of fires as well as the reliability of fire protection systems. This step also includes assessment of fire growth and spread, to evaluate damage to systems and components exposed to a fire. Again, the screening criteria eliminate scenarios with a core damage frequency less than 1 x 10.$^{-6}$ This simplified methodology is a good example of how probabilistic and deterministic tools can be effectively applied, if the acceptability criteria can be agreed upon.

RISK-BASED INSPECTION PROGRAMS

The second example addresses Steps 3 and 4 of Barry's process, relating to initiating events. This example demonstrates the application of risk-based methods in preventing releases of flammable or toxic materials. Since some consequences cannot be successfully mitigated, they must be prevented. The question remains, "what are the most cost-effective means of prevention?" The mechanical integrity provision of the OSHA Process Safety Management Rule[4] emphasizes inspection of containment (vessels, piping) of hazardous materials. Since not all containers represent the same likelihood of failure or consequence of failure, a risk-based approach to optimizing inspection activities seems appropriate. One methodology of risk-based inspection was initiated by the American Petroleum Institute.[5] This Risk-Based Inspection

Figure 4. Phase II Quantitative Analysis Flowchart[3]



(RBI) methodology defines the risk of operating equipment by combining both a consequence of failure term and a likelihood of failure term. The method applies both qualitative and quantitative approaches to prioritizing first analysis efforts and then inspection activities.

The chemical and petrochemical industries are not alone in recognizing the advantages of RBI. The utilities industries, both gas and electric, apply risk-based methods to determine what, when, and how to inspect and maintain systems. The natural gas industry, through the Gas Research Institute (GRI), has developed risk management tools to optimize inspection and maintenance activities relating to pipeline safety.[6,7] The nuclear power industry and its regulators are moving toward risk-informed decision-making for inspection and maintenance activities.[8,9,10]

RELIABILITY-CENTERED MAINTENANCE

The third example addresses Barry's Step 6, Fire Protection System Performance, and applies Reliability-Centered Maintenance (RCM) to Inspection, Testing, and Maintenance (ITM) for these systems. This example will be discussed in more detail.

The basis for optimizing what to do and when to do it should be risk. The following example is based on a study done by Risk Technologies and JBF Associates for the U.S. Air Force, which resulted in MIL-HDBK 1117.[11] For this project, failure modes and effects analysis (FMEA) was applied to identify failure modes, their causes, and their effects on fire protection system performance. The FMEA was performed to systematically identify component failures resulting in functional failures of interest. The key elements of the FMEA are defined by the following terms:

- Failure modes – conceivable malfunctions that prevent the component from performing its intended function
- System effects – anticipated effects (i.e., functional failures) that a specific component failure mode will have on the operation of the system
- Causes – credible reasons why failure modes might occur

The failure modes for a component were derived from standard listings of failure modes by component type (e.g., pump, valve, transmitter). Failure modes were modified or added as necessary, to ensure all conceivable malfunctions for a component were included in the analysis. During the FMEA, it was first decided whether each failure mode resulted in a system effect that caused a functional failure of interest and then determined whether a credible cause existed for failure modes of interest (i.e., those that resulted in functional failures of interest).

Table 1. Correlation of Qualitative PFOD* Rankings to PFOD Estimates

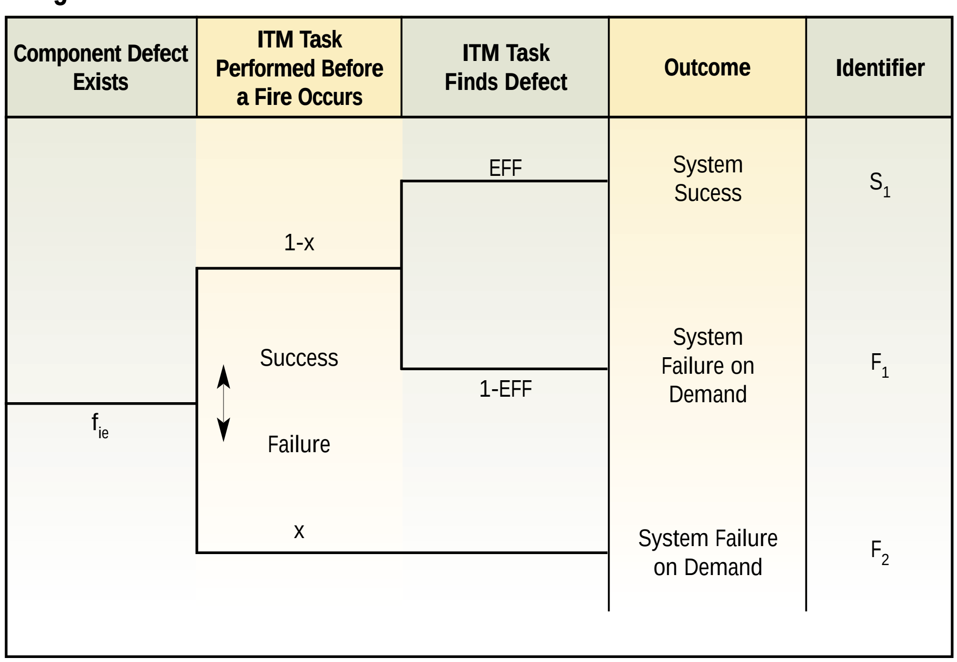
PFOD Ranking	PFOD Estimate
High	$> 10^{-2}$
Medium	$> 10^{-3}$ to 10^{-2}
Low	$> 10^{-4}$ to 10^{-3}
Very Low	$> 10^{-4}$

* Probability of Failure on Demand

Table 2. General Range of Effects for System Degradation Levels

System Degradation Level	Range of Effects
Total	Complete loss of primary system functions
Partial	Impairment of a primary system function, loss of a redundant component critical to the operation of a primary system function, or total loss of a secondary system function
Minimal	Impairment of a secondary system function, loss of a redundant component critical to the operation of a secondary system function, delayed response of primary or secondary system function, or false trip of the system

Figure 5. Event Tree Model[11]



Next, the risk for each failure mode was characterized by qualitatively ranking the probability of failure on demand (PFOD) for the component failure mode and the resultant system degradation level (total, partial, or minimal). These risk characterizations are used to assess the significance of each failure mode of interest. The PFOD ranking is the estimate of the likelihood of the component's failing in that particular mode. The qualitative PFOD rankings for component failure modes were high, medium, low, and very low. Table 1 provides the qualitative PFOD rankings and the corresponding PFOD estimates used. Fire data from the Air Force manual AFM 91-73, *Maintenance of Fire Protection Systems*, generic equipment failure data, and fire protection engineering experience were used to estimate the PFOD ranking for each component failure mode (that resulted in a functional failure).

The system degradation levels are the estimates of the severity level of the functional failure that results from a component failure mode (i.e., a measure of the functional failure's consequence). The qualitative system degradation levels were total, partial, and minimal. The range of effects for each system degradation level was defined for each functional failure during the FMEA. Table 2 describes the general range of effects for the three levels of system degradation.

The system degradation and PFOD rankings were used in the task selection and frequency assessment step to identify component failure modes that require ITM tasks and to determine the appropriate frequency for ITM tasks.

The ITM task selection process involved identifying all the applicable tasks in the various National Fire Protection Association (NFPA) codes for each component failure mode of interest. The applicability of a task was determined by assessing if the task would be an effective means of preventing or detecting the failure mode and its associated causes.

The frequency assessment was performed using a mathematical model. This model uses estimated failure rate for a component failure mode. The model also incorporates the frequency of fire occurring, an estimate of the ITM task effectiveness in correcting the failure mode, and overall system (and ultimately the component) performance requirements.

DOD set the reliability goals of 0.99 or no more than one failure in 100 demands. Reliability goals for partial and minimal system degradation were allowed to be lower, 0.9 and 0.5, respectively. Rather than use site-specific or system-specific demand frequencies, a fire frequency of 1/50 years was applied to all.

The model was developed to allow the determination of the frequency with which ITM tasks need to be performed to achieve system and component reliability targets.

The development of this model involved four steps:

Step 1 – Development of an event tree model

Step 2 – Derivation of the mathematical expression for the event tree

Step 3 – Prediction of failure rates for component failure modes

Step 4 – Calculation of system reliability

An event tree model was developed to represent the different scenarios that result in a fire protection system not operating correctly because of a component failure. The event tree is shown in Figure 5. The mathematical symbols used in the event tree are provided in Table 3.

The event tree was used to develop a mathematical model that represents the frequency with which a system (i.e., fire protection system) will fail for specific failure mode when there is a demand (i.e., fire). The frequency with which the system will fail when there is demand is obtained by adding F_1 and F_2 (as defined in Figure 5). This results in the following equation:

$$F_{system} = F_1 + F_2 = f_{ie}(1-x)(1-EFF) + f_{ie}(x) \quad (1)$$

The probability of a fire's occurring before an ITM task is performed was modeled assuming constant frequency of fires. The following equation was used to model this probability.

$$x = 1 - e^{-f_{Fire}\left(\frac{T}{2}\right)} \quad (2)$$

where,

f_{Fire} = frequency of fires

T = interval of system testing

Substituting equation 2 into equation 1 gives the following equation:

$$F_{system} = F_1 + F_2 = f_{ie}\left[1 - EFF \times e^{-f_{Fire}\left(\frac{T}{2}\right)}\right] \quad (3)$$

This frequency of the system's failing when there is a demand was used to determine the frequency for ITM tasks required to achieve a targeted performance for fire protection systems. The targeted performances are defined in terms of availability.

It was then assumed that a component unavailability (1-availability) can be approximated by the unreliability equation to calculate the ITM task frequency. This assumption is valid since the ITM tasks are condition-monitoring tasks rather than rebuilding or refurbishing-type tasks. Given this assump-

Table 3. Mathematical Symbols in the Event Tree

Event Tree Branch	Mathematical System Description	
Component Defect Exists	f_{ie}	Failure rate for component failure mode
ITM Task Performed Before a Fire Occurs	1-x	Probability that a fire does not occur before an ITM task (that should detect the defect) is performed
ITM Task Finds Defect	EFF	Probability that the ITM task will indeed detect and correct the defect, given that the ITM task is performed
Outcome – System Success	S_1	Frequency of the system operating successfully
Outcome – System Failure on Demand	F_1 and F_2	Frequency of the system failing on demand

Table 4. Estimated Failure Rate for Component Failure Modes					
PFOD Ranking	NFPA Recommended Interval				
	Weekly	Monthly	Quarterly	Semi-annually	Annually
High	10.4 failures/year	2.4 failures/year	0.8 failures/year	0.4 failures/year	0.2 failures/year
Medium	0.52 failures/year	0.12 failures/year	0.04 failures/year	0.02 failures/year	0.01 failures/year
Low	0.052 failures/year	0.012 failures/year	0.004 failures/year	0.002 failures/year	0.001 failures/year
Very Low	0.0052 failures/year	0.0012 failures/year	0.0004 failures/year	0.0002 failures/year	0.0001 failures/year

Scoring Model

Equation 4 can be rearranged and simplified to provide the following: $y = f_{ie} \times z$,

Where $y = -\ln(1-R)$

$f_{ie} \times z = F_{system} \times T$

This yields the order of magnitude scoring model: $Y=F-Z$,

Where Y = score for target reliability (99% = 2, 90% = 3, 50% = 4)
F = score for component failure rate, and
Z = reduction attributed to ITM tasks

The table to the right shows the scores for F.

Score for F	Value for f_{ie}
1	0.00001 to 0.0001
2	0.0001 to 0.001
3	0.001 to 0.01
4	0.01 to 0.1
5	0.1 to 1

tion to be valid, then the following equation is valid:

$$\text{(1-availability)} \approx \bar{R} = 1 - e^{-F_{system}T} \quad (4)$$

where, $\bar{R}$ = unreliability of the component

Comparing NFPA ITM frequencies with the range of PFODs, yields implied failure rates. Using the PFOD rankings, an estimated failure rate for each NFPA recommended test interval was calculated using the following equation:

$$\text{PFOD} = f_{ie} \times \left(\frac{T}{2}\right) \quad (5)$$

Table 4 shows these implied failure rates.

A scoring model was developed for specific application to the DOD study to determine ITM task frequency to meet the established reliability goals, based on the expected failure rate of the system or component, given the fire (demand) frequency, and the ITM task

Table 5. Recommended Frequencies for Components Failure Modes Resulting in Total System Degradation					
PFOD Ranking	NFPA Recommended Test Interval				
	Weekly	Monthly	Quarterly	Semi-annually	Annually
High	<1 week	1 week	1 month	1 month	1 month
Medium	1 month	1 month	6 months	6 months	6 months
Low	6 months	6 months	1 to 2 years	1 to 2 years	1 to 2 years
Very Low	1 to 2 years	1 to 2 years	Inspection and testing not required	Inspection and testing not required	Inspection and testing not required

effectiveness. This model provided an order of magnitude measure of the reliability improvement attributed to ITM activities. (See box on opposite page)

Using order of magnitude scores for failure rates, targeted reliability, and inspection frequency, frequency tables were developed allowing the adjustment of NFPA recommended frequencies based on the PFOD ranking. The results for Total System Degradation are shown in Table 5.

Equations 3 and 4 can also be applied to evaluate ITM requirements for site-specific or industry-specific programs as well. If component failure data is available and fire-demand frequency is known, the effects of inspection frequency and task effectiveness on reliability can be calculated. The model has been applied to large office complexes and industrial occupancies to optimize ITM activities. The model provides a good insight into performing the right ITM tasks with properly trained people (EFF), as well as task frequency.

Kenneth W. Dungan is with Risk Technologies.

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Addressing Risk and Uncertainty in Performance-Based

By Brian J. Meacham, Ph.D., P.E.

Performance-based fire protection engineering is gaining momentum in the United States and throughout the world. Reasons for this include the slow but steady maturation of the fire protection engineering discipline, the ongoing global transition from prescriptive- to performance-based building regulations, and the development of fire protection engineering guidelines for use by practicing engineers.[1] As this momentum grows, so do opportunities to apply engineering principles to a wide range of fire safety concerns, from estimating the time at which a structural member may fail, to estimating the time available for safe egress.

Along with such opportunities, however, come associated responsibilities to ensure that the scope of the fire safety problems being addressed are well understood, that the tools and methods being used are applied properly, and that the resulting designs and levels of safety afforded are tolerable to society. The best way to address these responsibilities is by understanding and integrating risk concepts into performance-based fire protection engineering.

DEFINING RISK, FIRE RISK, AND FIRE RISK ANALYSIS

Risk is a complex construct that means different things to different people. For some it is an indication of impending doom (smokers have an increased risk of heart disease), whereas for others it reflects the possibility for significant gains (risking a small investment in the stock market for the possibility of a large return). Likewise, some see risk as readily quantifiable given objective data (e.g., frequency times consequence), whereas others tend to view risk more qualitatively due to their concerns over the quantification of frequencies and consequences.

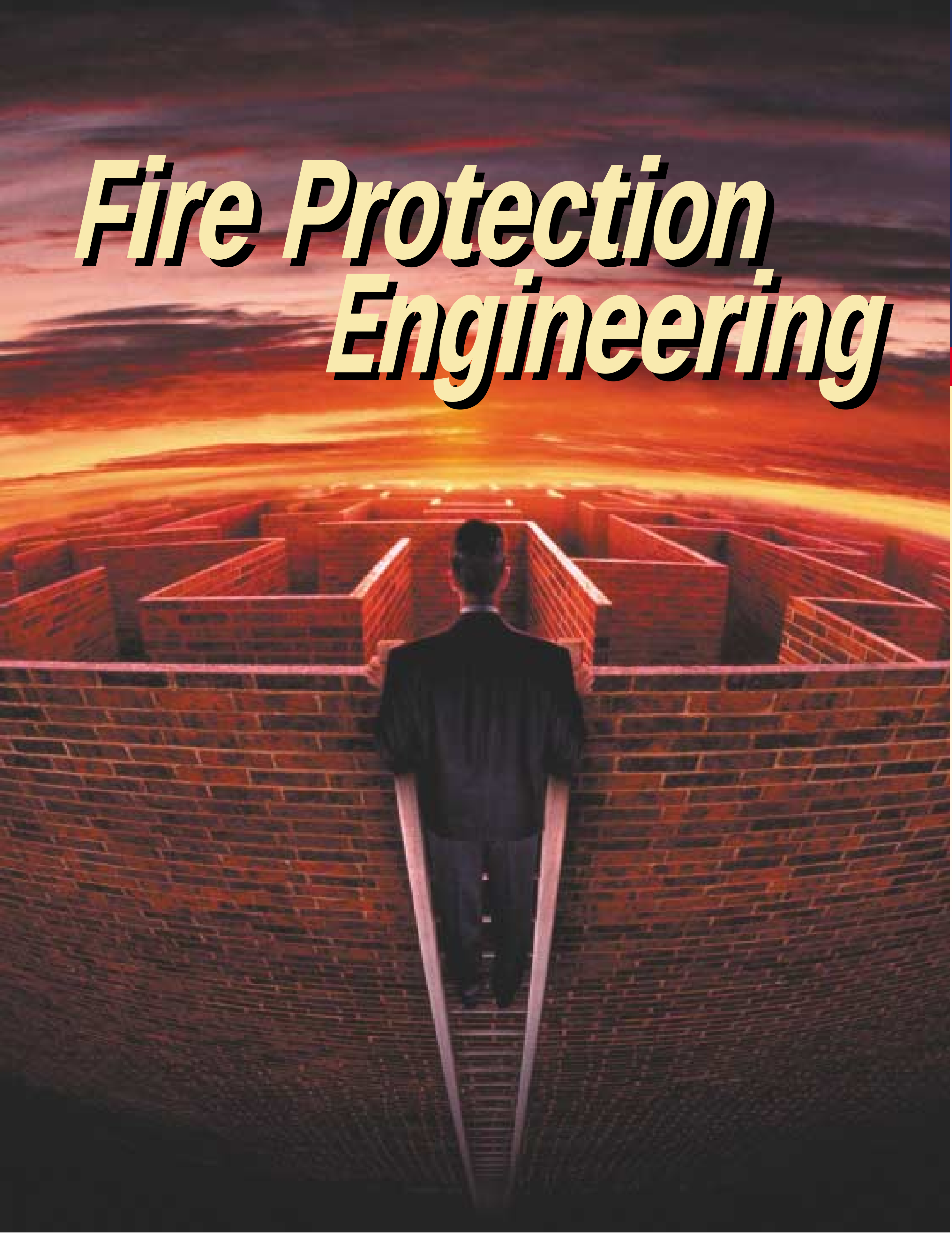
Although people can view risk so differently, the negative connotation is often the most prevalent. Further to this view, many agree in concept that risk can be defined as the possibility of an unwanted outcome in an uncertain situation, where the possibility of the unwanted outcome is a function of three factors: loss of or harm to something that is valued, the event or hazard that may occasion the loss or harm, and a judgment about the likelihood that the loss or harm will occur.[2] Differences in viewing risk often surface during discussions of unwanted outcomes, uncertainty, valuation, and likelihood of occurrence.

When considering risks from fire, the focus is typically on the negative aspect of risk (e.g., risk of injury or death). As such, using the above definition, fire risk can be viewed as the possibility of an unwanted outcome in an uncertain situation, where fire is the hazard that may induce the loss or harm to that which is valued (which is typically life, property, business continuity, heritage, and/or environment). As with the general definition above, key areas of concern in fire risk discussions include unwanted outcomes (consequences), uncertainty, valuation, and likelihood of occurrence. Fire risk analysis can address these concerns.

In general, fire risk analysis can be considered the process of understanding and characterizing the fire hazard(s) in a building, the unwanted outcomes that may result from a fire, and the likelihood of fire and unwanted outcomes occurring, taking into due consideration the issues of uncertainty and valuation. Fire risk analysis must consider several factors, some of which are familiar to fire protection engineers and some of which might not be.

- What are the fire hazards and how might fires occur?
- What are the unwanted outcomes (consequences), how are they valued, and by whom are they valued?
- What differences in risk perceptions, expectations, and valuation exist and how they should they be treated (e.g., should high-consequence events be disregarded if the probability of occurrence is very low)?
- Are any social or cultural issues involved, and if so, how are they addressed?
- Do stakeholder views differ on the likelihood of fire occurrence and of the resulting consequences?
- Have uncertainty, variability, and unknowns been adequately identified and appropriately addressed?

Fire risk analysis can play a significant role in performance-based fire protection engineering, from assessment of the current situation, to establishing stakeholder objectives, to identifying fire scenarios, and, ultimately, to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selecting a final design. (See *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*[3] for definitions of these terms and for an overview of the performance-based fire protection engineering process.) The following highlights some key areas where fire risk analysis can be helpful.

FIRE HAZARD ASSESSMENT

The purpose of a fire hazard assessment is to identify possible sources of fire ignition and various conditions that may result from the fire without consideration of the likelihood of occurrence. Fire hazard assessments typically involve surveys of facilities or processes to obtain such information as potential ignition sources, potential fuel sources, arrangement of fuel packages, building and compartment configurations, and presence of fire safety features.

Armed with this information, one assumes either ignition or established burning, then estimates or predicts the fire growth, spread, and impact under a variety of fuel, compartment, and fire protection systems configurations. Identification of ignition sources requires knowledge of how ignition can occur and often involves simply a visual survey. However, visual inspections may be supplemented by general or facility-specific loss data, material safety data sheets, and other sources of information as appropriate. This latter point is important, as a review of historical loss data can help minimize the chance of focusing too closely on unique hazards, while overlooking more common, but equally important, hazards.

Evaluation of fire hazards is something that fire protection engineers do well and for which numerous tools and methods exist (e.g., see *The SFPE Handbook of Fire Protection Engineering*). Survey assessment and hazard identification tools range from checklists and "what-if" analyses to fault tree and event tree analyses. Analytic tools, such as simplified equations or computer fire effects models, are often used to assess time-dependent hazard conditions. A critical component of any hazard assessment is research into loss history for similar facilities or processes. Fire hazard assessment is important to understanding the current conditions in a building. The tools of fire hazard assessment can be very helpful in identifying the current situation and in developing pertinent fire scenarios and design fire scenarios.[3]

CONSEQUENCE IDENTIFICATION AND VALUATION

A typical outcome of a hazard assessment is the identification of consequences. Such outcomes may be described in qualitative terms, such as "failure of valve leads to pooling of oil and subsequent pool fire," or in quantitative terms, such as "smoke layer descends to a height of 2 m above floor level in 5 minutes." Again, this is an activity that fire protection engineers are quite familiar and comfortable with.

The valuation of consequences, however, may not be so familiar to engineers and is typically quite challenging, as it should consider physical, economic, health, environmental, social, cultural, and psychological factors. In valuing life safety consequences, for example, many engineers consider only injury and loss of life to an individual. However, there may be times when they should also consider such factors as reduced quality of life, the inability to continue to work, and the impact on family relationships. In valuing property damage, factors such as smoke and water damage should be considered, in addition to thermal damage. In valuing business interruption, long-term issues such as loss of image and market share should be considered, in addition to the short-term monetary losses associated with downtime.

A key to valuing consequences is to adequately identify and elicit feedback from interested and affected parties (stakeholders). This may seem trivial to some that might say, "the only stakeholder of concern is the client who is paying my fee." However, this is a dangerous attitude, as the local authorities may not agree with the client, the public may not agree with the client, and perhaps others in the client's company may not agree (e.g., a Chief Financial Officer may value things differently than a facilities engineer).

Valuing consequences is a key issue in the development of stakeholder goals and objectives,[3] and warrants serious attention. To avoid subsequent problems, as wide a range of input as possible should be obtained from stakeholders. The process of risk characterization can be helpful at this stage.

RISK CHARACTERIZATION

Risk characterization requires a well-defined problem agreed to by those involved, a sound scientific base, the proper use of analytical techniques with due consideration of uncertainties and unknowns, and sufficient discussion and deliberation so that everyone understands all the issues.[2, 4]

The fire risk characterization process will likely require several iterations, as new information and data become available and as participants gain better understanding and raise more issues. It needs to be an interactive process and not a process where one group dominates the deliberations and/or analysis and forces a solution. To help characterize fire risk, a number of questions need to be asked: [2, 4, 5]

1. Who or what is exposed?
2. If it is people, what groups are exposed?
3. What is posing the risk?
4. What is the nature of the harm or loss?
5. What qualities of the hazard might affect judgments about the risk?
6. Where is the hazard experience?
7. Where and how do hazards overlap?
8. How adequate are the databases on the risks?
9. How much scientific consensus exists about how to analyze the risks?
10. How much scientific consensus is there likely to be about risk estimates? How much consensus is there among the affected parties about the nature of the risk?
11. Are there omissions from the analysis that are important for decisions?

Various tools and methods can help obtain needed information for building fire risk characterization, such as those discussed for fire hazard assessment. Others are outlined in the following sections. Detailed discussion and application examples can be found in the references.

FORMING JUDGMENTS ON THE LIKELIHOOD OF OCCURRENCE

Much like the difficulties in valuing consequences, the issue of determining the likelihood of fire occurrence is unfamiliar to many fire protection engineers and is not without its challenges. One issue concerns the differing views on the concept of probability (likelihood): the frequentist view versus the subjectivist view.[2, 6]

In brief, the frequentist view is held by classical statisticians, who consider probability to be a property of a process that can be determined from an infinite population of data. They believe probability to be a precise value and that information needed to estimate it can come only from observing the process. (For example, one can only determine the probability of a coin landing with "heads" up or "tails" up by flipping the coin an "infinite" number of times.) The subjectivist view, however, holds that probability has a value at any time that represents the total available knowledge about the process at that particular time. (For example, one can look at a coin having a "head" and a "tail," assess whether it is well-balanced, observe a single coin toss, and estimate the probability of getting a "head" or a "tail" if one flips the coin again.)

Whether one holds the frequentist or subjectivist viewpoint, the availability of information to determine probabilities is critical, as is the applicability of the probability information to the problem at hand. For example, what data are available – e.g., how many fire ignitions have there been in office buildings in the past ten years that did not result in significant fire damage? How applicable are historical data as an indicator of future events – e.g., were fire loss data from cellulosic materials prior to 1960 an appropriate indicator of fire losses involving synthetic materials after 1960? How might changes to the building or its contents in the future impact the likelihood of fire occurrence and/or magnitude and type of consequences? These issues are critical in the development of fire scenarios and design fire scenarios.[3]

Because fire data are sparse (e.g., limited data are available from "successful" fire events where the fire safety systems worked as designed) and conditions are likely to change over the life of a building, quantifying risk can be difficult; uncertainty, variability, and indeterminacy will play a significant role. These issues are also important when considering fire protection system reliability (will operate when needed) and effectiveness (will perform as intended). Again, data are sparse, but realistically addressing system reliability and effectiveness is critical to performance-based fire protection engineering.[3]

UNCERTAINTY, VARIABILITY, AND INDETERMINACY

As noted at the outset, uncertainty, variability and indeterminacy are inherent in any fire risk problem. How these factors are identified and addressed is critical to the fire risk analysis, especially with respect to the stakeholders involved in passing judgment on the "acceptability" of the risk. In this regard, it is important to understand the distinction that is made between uncertainty, variability, and indeterminacy.

The concepts of uncertainty, variability, and indeterminacy all relate to incomplete knowledge or information, as does the overall concept of risk (if one has complete information, there is no uncertainty and no risk). A distinction is often made between the concepts for purposes of identification and treatment.

The term uncertainty is often used to reflect incomplete knowledge that can be reduced by obtaining more information (e.g., through observation, test, measurement, etc.). For example, there may be uncertainty about the peak heat release rate of a particular upholstered chair. Measuring the peak heat release rate of the chair in a furniture calorimeter can reduce this uncertainty.

The term variability is often used to reflect incomplete knowledge that is due to differences in the real world that result from randomness or chance, which cannot be reduced by obtaining more information, but can simply be better understood and addressed. In other words, the uncertainty about the variability can be reduced, but not the variability itself. For example, the population in any given movie theater may range from infants to elderly, or from completely independent to completely dependent persons. If an engineer walks into the theater and conducts a survey, he or she can better understand the differences (variability) in the population, thus reducing uncertainty about who is there. However, unless the engineer asks certain people to leave, he or she cannot reduce that variability, but is better poised to address it. (Simply obtaining information does not reduce the variability – some other action is required.)

The term indeterminacy is used when there are significant difficulties in identifying and quantifying unknowns – either due to the time scale involved or to some aspect of object of concern. For example, it is difficult to estimate what changes in building technology and contents may occur over the next fifty years. Likewise, it has been argued that one cannot predict the future actions of people.[7, 8] In cases such as these, where information is difficult or impossible to obtain, solutions may need to be more social/cultural/institutional than technological.

Lastly, ignorance is uncertainty that goes unrecognized. This is perhaps the biggest concern, as it can result in serious implications for proposed solutions that claim to address uncertainty and variability.

To help people better understand the complex issues surrounding uncertainty, variability, and indeterminacy, various taxonomies and treatments have been suggested.[9, 10, 11, 12, 13] Regardless of specific differences, much of the literature identifies the following areas as requiring consideration: scientific uncertainty; human factors; risk perceptions, attitudes, and values; and decision-making uncertainty.

Scientific Uncertainty

Scientific uncertainties result from lack of knowledge (either obtainable through further study or due to random chance and variations) and from necessary approximations. They are among the most readily recognizable and quantifiable uncertainties, and can be grouped into four subcategories: theory and model uncertainties; data and input uncertainties; calculation limitations; and representativeness.[9, 10, 14, 15]

- Theory and model uncertainties may arise when physical processes are not modeled due to a lack of knowledge about them or about how to include them (e.g., flame spread in a zone model), when processes are modeled based on empirically derived correlation (e.g., plume correlation models), and/or when simplifying assumptions are made (e.g., assuming a heat release rate).
- Data and input uncertainties arise from inaccuracies in data collection and reporting (e.g., relative accuracy of measuring instruments and reporting with error bars), incomplete knowledge of specific input values and variations in those values as a function of confounding factors (e.g., walking speed of population in building in the event of a power failure), and input errors made by the modeler (e.g., shifting a decimal place).
- Calculation limitations encompass such factors as the control volume selected for modeling (e.g., cell, compartment, or building), the level of detail of the model (e.g., zone or CFD model), and the model-domain parameters specified (i.e., what parameters are included in the model).
- Representativeness relates to how well the modeled situation reflects reality (e.g., is a heat release rate selected because data exist or because heat release represents what can be expected in the compartment).

Scientific uncertainty issues are important to address, for example, when selecting and using fire effects models. Unfortunately, there is no single uncertainty treatment that is applicable to all of the above issues. However, a variety of tools exist to identify (e.g., sensitivity analysis and switchover analysis), to quantify (e.g., statistical methods), and to treat (e.g., parametric or probabilistic treatment) those sources of uncertainty that are significant to the problem.[3]

Human Factors Issues

In considering human factors, uncertainty, variability, and indeterminacy are present in several modes. For example:

- Uncertainty regarding who might be affected and how. That is, it is not always known who will be impacted (uncertainty or indeterminacy), and within the population affected, there will be physiological differences (variability).
- Uncertainty, variability, and indeterminacy related to how people will react in different situations, especially under stress.

Risk Perceptions, Attitudes, and Values

People perceive and value risk in significantly different ways, and they have different attitudes about risk. This gives rise to uncertainty, variability, and indeterminacy with respect to problem identification, risk characterization, and acceptability of solutions. For example:

- Factors such as dread, level of control, observable, known/unknown, voluntary/involuntary, level of impact (consequences), and immediacy of effects will impact perceptions of risk and attitudes toward the tolerability (acceptability) of risk.[2, 4] For example, some people may view the risks associated with fire in a healthcare facility as being higher than in a single-family dwelling due to lack of individual control over the circumstances (e.g., dependency on others), whereas others may view the situation from the opposite perspective (e.g., there is staff available to help). If the approval authority has the former perspective and the client, the latter, effort will likely be required to come to a common view or at least to a solution that addresses each perspective.
- Social, economic, philosophical, religious, or cultural differences affect people's values systems. People who struggle to make ends meet, for example, may perceive fire risk as much less important than the benefit gained by cooking on an "unsafe" appliance. Likewise, the developer of a speculative office building may view the property-related fire risks as less important than an owner/occupier of a building.
- Some people are risk-tolerant, while others are risk-averse.

Recognizing such differences is especially important when setting fire safety goals and objectives for a project. Understanding where various stakeholders are "coming from" can go a long way to making the fire engineering design process a smooth one. Many times, needed information can be obtained by simply asking questions, which goes a long way in reducing associated uncertainty.

Decision-Making

The decision-making process can encompass considerable uncertainty, including uncertainty about how to:

- Define the decision problem;
- Assess the facts of the matter;
- Quantify relevant risk values;
- Incorporate the human element in the decision-making process;
- Assess the quality of the decisions that are produced.[2, 16]

These factors are important to remember when developing stakeholder goals and objectives, because if the fire risk problem is not clearly understood, sufficiently well defined, or agreed upon by all, obtaining agreement on proposed solutions will be difficult. Any uncertainty in the problem definition – the first step in the process – will be propagated throughout the risk characterization process. If this uncertainty is large (e.g., if the stakeholders do not agree on key issues or parameters of the problem), the uncertainty in any proposed solution will be some factor greater.

KEY ISSUES IN IDENTIFYING AND ADDRESSING UNCERTAINTY, VARIABILITY, AND UNKNOWNS IN FIRE RISK ANALYSIS

As discussed above, when identifying and addressing uncertainty and unknowns, various factors come into play. Following are a few key points that may help avoid problems:[2, 9, 10, 14, 15, 17]

- *Do not avoid the issues of uncertainty, variability, and unknowns* – they will not magically go away simply by not addressing them.
- *Seek the data and information necessary to inform the decision.* Although fire data are sparse, they do exist. Sources of fire data include private organizations, such as the National Fire Protection Association; government agencies, such as the Federal Emergency Management Agency; textbooks; handbooks; journals; and reports. If the risk problem warrants, consider undertaking research or testing.
- *Beware of sources of uncertainty that may not be immediately recognized.* This includes uncertainty in variables that are built into analytical tools and methods, uncertainty associated with criteria selected for assessing acceptability, and uncertainty and variability in human behavior, attitudes, and values.
- *Avoid treating variability as uncertainty.* If the risk problem relates to the human population, for example, recognize that both uncertainty and variability exist, and that they must be addressed differently. As discussed previously, the number of people in an exposed population may not be known (uncertainty), and individuals in a potentially exposed population will differ (variability). This becomes important when discussing issues such as using the entire population or some subset of sensitive or vulnerable persons, and if the latter is selected, what defines the subset.
- *Avoid treating "unknowns" (indeterminate events) as uncertainty,* as this could lead to an inappropriate treatment being selected. As discussed earlier, it is impossible to accurately predict some event that far into the future (e.g., types of building materials that will be in use in 100 years) or to control the circumstances upon which certain assumptions are based (e.g., arrangement of building contents). In some cases, the risk problem may be better addressed by a social solution (e.g., a regulatory solution) rather than by a technological one.
- *Obtain stakeholder agreement on how to treat the various types of uncertainty in the project.* Not only are there different types of uncertainty, as discussed above, but different treatment options as well. For example, Morgan and Henrion[11] argue that the only type of quantities whose uncertainty may be appropriately represented in probabilistic terms are empirical quantities. However, there are other types of quantities, such as model domain parameters, decision variables, and value parameters. For these, parametric or switchover analysis (or other) may be needed. The references provided offer far more insight into this difficult area than is possible in this article (e.g, References 9, 10, 11, 14, and 15).
- *When used, obtain agreement on quantitative methodology (or set of quantitative methodologies)* to be used for treating uncertainty. Even if stakeholders agree to perform a probabilistic analysis on an empirical quantity, they may disagree on the appropriate approach to apply. For example, probabilistic approaches range from classical, statistical-based analyses to subjective, Bayesian analyses, with other types of quantitative or qualitative analyses scattered in between. To complicate the issue, frequentists often reject the Bayesian approach, and subjectivists often reject the statistical approach. This philosophical difference alone can sometimes be a "show-stopper." Furthermore, concern over lack of the data, mathematical rigor, and expertise needed to conduct a quantitative uncertainty analysis might render such an analysis infeasible, and as a result, the analysis would not be undertaken or would be performed incorrectly.[18] Although this concern can be real, simple methods, such as sensitivity analysis and switchover analysis, can give a quick indication of which parameters require detailed consideration.

SUMMARY

Performance-based fire protection engineering requires judgments on issues ranging from the scope of the fire safety problem, to valuing consequences, to identifying design fire scenarios. Because each of these judgments requires decisions about treating uncertainty, applying risk concepts can help ensure that the problems being addressed are well understood, that the tools and methods used are applied properly, and that the resulting designs and levels of safety afforded are tolerable to society.

This article has helped identify issues of concern and has offered broad approaches for treatment of these complex yet important issues. But it has barely scratched the surface. Areas not addressed include:

- Quantification of risk, including whether, when, and how to do so;
- Pros and cons of using point values, thresholds, or distributions;
- Lack of frequency data and the options for filling gaps in incomplete data; and
- Guidance on the availability and use of specific risk-assessment methods and approaches for treating uncertainty.

Organizations such as the NFPA and the SFPE have formed committees to help develop methods of addressing risk and uncertainty in fire protection engineering. Recent academic work has also been helpful, yet much more work is needed.

Brian Meacham is with Arup.

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The Importance of

Risk Perceptions in Building and Fire Safety Codes

By Armin Wolski, P.E.

Every year, the National Fire Protection Association publishes fire statistics.[1,2] From these statistics, it is not hard to determine that the risk of dying in a high-rise office building fire is much less than the risk of dying in a single-family home fire. So why have the building fire safety codes maintained such stringent requirements for high-rise offices, yet have done little about increasing safety in single-family homes?

In a democratic society, regulations are intended to address and satisfy the public mandate for managing risks and benefits of a technology. The public mandate is based on values and how the risks and benefits of various options are perceived. Choosing one risky option over another is an exercise in resolving a problem, known as a "risk problem."[3] Risk problems are filtered through human perceptions.[4] When in a given year, 10 occupants die in a single fire, such as a high-rise fire, the event is perceived as "catastrophic." Public reaction is strong. When 10 independent fires cause the death of one individual at each occurrence, such as in single-family home fires, the public reaction is muted. People react differently to different types of risk problems.[5, 6] Catastrophic risk problems are perceived differently than noncatastrophic "ordinary" risk problems. Voluntary risk problems differ from non voluntary risk-problems. Risk problems in which control is perceived differ from risk problems where no control is perceived. In addition, risk problems with a clear perception of benefit differ from those with hidden benefits. Numerous psychological human factors come into play. At least 40 different risk factors that describe the spectrum of risk perception have been identified.[7] Nine of the most important of those 40 risk perception factors are highlighted in Table 1.[8] These factors influence society and the public mandate for regulation. These preferences filter their way through to the regulations including building fire safety codes.[9]

Table 1. Risk Factors

Nine risk perception factors that can be used to describe the public attitude towards differently perceived risk problems.

Risk Perception Factors	Scale
Volition	Voluntary – Involuntary
Severity	Ordinary – Catastrophic
Effect Manifestation	Immediate – Delayed
Familiarity	Common (Old) – Dread (New)
Controlability	Controlable – Uncontrolable
Benefit	Clear – Unclear
Necessity	Necessary – Luxury
Exposure Pattern	Continuous – Occasional
Origin	Natural – Manmade

RISK PERCEPTION IN PRESCRIPTIVE BUILDING FIRE SAFETY CODES

In the United States, the "representative" prescriptive code system has inherently, perhaps unwittingly, accommodated perceptions of risk. Evidence is found in the comparison of single-family home requirements to high-rise office building requirements.[10] For example, high-rise office buildings over 75 feet (23 m) in height require many protection features including fire-resistive building materials, a fire alarm and occupant notification system, a sprinkler system, smoke control equipment, a special elevator control system, and emergency power. In comparison, for new single-family homes the code requires few fire protection measures. The code permits (from a fire safety viewpoint) almost any building material to be used, minimal levels of "local" smoke detection, and only in some cases, a second exit from an upper floor. Although much attention is given to the high-rise office building fire protection, over 70% of civilian fire deaths occur in homes and garages.[2] Why are there so many more safety systems in high-rise buildings when there is so much more risk in single-family homes? The discrepancy of the level of protection is due to perceptions of risk. Since risk perceptions influence the public mandate, the public demands greater risk reduction from the high-rise catastrophic risk.

More evidence of how perceptions of risk have influenced the building code is reflected in the difference between the requirements in single-family homes versus apartments. People are willing to accept higher risks when they perceive control.[11] This is analogous to transportation. People are willing to accept a higher risk traveling (driving) in an automobile than being a passenger in an airplane. In a car, the driver perceives a higher level of control, while an airplane, the passenger perceives no control. In our building fire safety example, owner/occupants in single-family homes have control of the amount and type of smoke detection they install, and are in control of common ignition sources such as heating systems and cigarette smoking.[2] On the other hand, in rental properties such as apartments, occupants perceive less control. A renter cannot easily change the fire protection system in his/her building, nor do they have control of the fire safety "practices" of a neighbor. Prescriptive regulations accommodate this lack of control through more rigorous fire protection provisions. A quick review of any one of the three regional codes, the *Uniform Building Code*, the *BOCA National Building Code*, and the *Standard Building Code*, would reveal that apartment houses require significantly more protection (fire-resistive construction, smoke detection and fire alarm systems, fire sprinklers) than do single-family homes.[13]

Another example regarding the issue of perceived control is reflected in the sprinkler retrofit ordinances in many major U.S. cities. In the 1970s and 1980s, many major jurisdictions (e.g., Los Angeles, Boston) required the retrofit of automatic fire sprinkler systems in high-rise occupancies such as offices and hotels.[13] High-rise condominiums were exempted. Occupants in high-rise office buildings and hotels have no control of their building's design. Occupants in condominiums own their units and, as an association, have collective control of the fire safety systems installed in their building. This issue of control may help explain why society did not see a "need" to regulate and increase safety in condominiums.

A third example involves the risk perception factor "perceived benefit." As the perceived benefit increases, so does the acceptance of risk. Many recreational sports, such as snow skiing,[11] are examples of this factor. It seems that people are concerned more with the risk of climbing a mountain on a chair lift, but think nothing of the risks associated with skiing down the hill. Although other risk perception factors come into play (control, severity, volition), people accept the risk of skiing because they like to ski – they perceive a benefit from skiing. Fire safety in historic buildings is approached differently than fire safety in new buildings. Many jurisdictions have special building code requirements for the renovation of historic buildings. These codes usually include less-stringent fire protection requirements for historic structures so that damage to the historic fabric may be avoided. Less-stringent requirements generally mean a higher level of risk is accepted. More risk is accepted because of a perceived aesthetic architectural benefit that the building provides the community.

RISK PERCEPTIONS IN PERFORMANCE-BASED BUILDING FIRE SAFETY CODES

Most performance-based building fire safety designs are based on deterministic approaches: using fire models and egress models to develop a design.[14] Using a deterministic approach, the design should be such that, in a fire scenario, adequate time is provided for occupants to reach a safe place before the interior environment becomes untenable. The approach is based on providing enough protection such that occupants can exit the building before the fire adversely affects them. This solution is independent of whether one is analyzing a high-rise office or a single-family home. Will this lead to fire protection engineers designing high-rise buildings such that they are as "safe" as single-family homes? Based on what we know from the prescriptive code and concepts of risk perception, such an approach does not likely reflect the current social mandate.

It is the building code's responsibility, not the engineer's, to provide a framework that determines whether the appropriate level of safety is met given a particular risk problem. Depending on the facility, the building fire safety risk problem is perceived differently. It is therefore the building code's responsibility to provide a framework that accommodates risk perceptions. Because the performance-based approach is based on quantification methods, accommodating risk perceptions can be much more difficult.[15] How have the two current U.S. performance-based building fire safety codes addressed the issue?

THE INTERNATIONAL CODE COUNCIL PERFORMANCE-BASED BUILDING CODE

The *ICC International Performance Code*[16] provides the designer some guidance such that risk perception is considered. The *Code* requires that the designer consider at least two or three of the nine identified risk perception factors listed in Table 1. In Chapter 3 of the *Code*, the designer is required to establish a performance level for the facility under consideration. In order to do so, the *Code* directs the designer to Appendix A for guidance on how to characterize the facility. In Appendix A, a variety of occupancies similar to those found in traditional prescriptive codes are discussed. Some risk perception factors are included in the discussion. The designer is encouraged to consider risk perception factors such as severity and volition. With that knowledge, the user is guided to a worksheet in Appendix B that helps her/him establish the "importance" of a building. This Appendix is also intended as a tool to assist in choosing the appropriate design performance levels when a unique set of circumstances exists. For example, a town with one primary centralized employer, such as an automobile factory, will probably perceive the severity of the factory loss as catastrophic, whereas that same facility in a larger city with a diversified economy will perceive the severity of the factory loss as ordinary. Therefore, a higher performance level may be chosen in the first scenario than in the second. With these additional considerations, a performance level is established for the facility. Once the performance level is established, the designer turns to a matrix to find the proper level of safety required for the facility under design. (See Figure 1.)

Application of the matrix results in the designer choosing the appropriate level of safety for the facility. This process results in forcing the designer to provide a higher level of safety for facilities that are perceived as more hazardous (high-rises) than others (single-family homes).

The concepts of reliability and durability are also addressed within the *Code* through rigorous administrative requirements and a chapter relating specifically to the subject. The administrative provisions contain information on qualifications, maintenance, documentation, etc. As discussed in the next section, addressing reliability can be a key factor in addressing risk.

CHAPTER 5, PERFORMANCE-BASED OPTION, NFPA 101 *LIFE SAFETY CODE*

The performance-based option in NFPA 101[17] may indirectly accommodate perceptions of risk. The *Code* does not discuss risk perception factors explicitly. However, the *Code* contains language that may result in designs that, to some extent, accommodate perceptions.

Notably, the *Code* and the guidance provided in the appendix to the *Code* emphasize the issue of reliability. The standard regards reliability as crucial to both the design process and in the design solution.

Design Process related:

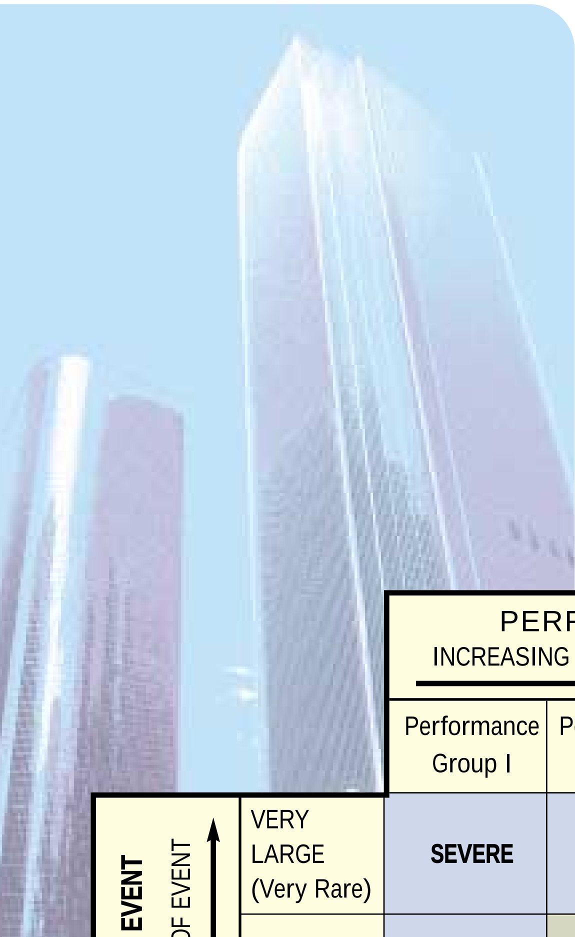
Section 5.1.3. Approved Qualifications. The performance-based design shall be prepared by a person with qualifications acceptable to the Authority Having Jurisdiction.

Section 5.1.5 Independent Review. The Authority Having Jurisdiction shall be permitted to require an approved, independent third party to review the proposed design...

Design Solution related:

Section 5.4.7. Post-construction Conditions. Design characteristics... that affect the building to meet the stated goals and objectives shall be specified, (and) characterized sufficiently for evaluation of the design.[17]

The issues of risk, uncertainty, and reliability are intertwined.[18] The greater the emphasis on reliability, the greater the potential of resolving the risk problem successfully. In addressing uncertainty and reliability issues, the *Code* allows for judgment by the design pro-



MAGNITUDE OF DESIGN EVENT (INCREASING MAGNITUDE OF EVENT ↑)	PERFORMANCE GROUPS — INCREASING LEVEL OF BUILDING PERFORMANCE → Performance Group I	Performance Group II	Performance Group III	Performance Group IV
VERY LARGE (Very Rare)	**SEVERE**	**SEVERE**	**HIGH**	**MODERATE**
LARGE (Rare)	**SEVERE**	**HIGH**	**MODERATE**	**MILD**
MEDIUM (Less Frequent)	**HIGH**	**MODERATE**	**MILD**	**MILD**
SMALL (Frequent)	**MODERATE**	**MILD**	**MILD**	**MILD**

Figure 1. *ICC International Performance Code* Performance Matrix.[16] Each facility or occupancy is characterized and assigned to a Performance Group. The higher the Performance Group, the greater amount of safety is required for a given fire event.

fessional and the Authority Having Jurisdiction (AHJ). Keeping in mind the judgment is affected by perception:

5.1.6 Final Determination. The Authority Having Jurisdiction shall make the final determination as to whether the performance objectives have been met.

5.6.3.3. Uncertainty and Conservatism of Data. Uncertainty in ...data shall be... as determined appropriately by the Authority Having Jurisdiction, addressed through the use of conservative values.

5.7 SAFETY FACTORS

5.7.1 General. Approved safety factors shall be included in the design methods and calculations to reflect uncertainty...

And finally in the commentary in Annex A:

A.5.5.3.8... The Authority Having Jurisdiction will determine which level of performance... is acceptable, given the very low probability (that is, the system's unreliability probability) that the system will not be available.[17]

These sections place the AHJ in a distinct role. Not only does the AHJ act as a representative of society, the AHJ wields significant power. In the performance design process, the AHJ is offered more influence on the design than in the prescriptive design process. And because the AHJ is subject to biases similar to those in the general population, risk perceptions will affect their judgment. This is the area where risk perceptions will affect a performance-based design.

For example, the AHJ will likely be concerned more with the reliability of a performance-based design of a high-rise hotel than a two-story office building. The high-rise hotel presents a potentially catastrophic risk, and the nature of the hotel risk is one where occupants have less control and/or familiarity. (Granted, the high-rise hotel may require specialized fire protection features because of fire fighting concerns.) Even so, biases stemming from these risk perception factors may reflect itself in the AHJ having a predisposition to require more reliability (more safety) in the high-rise hotel. For example, assume that in either facility, the design is highly dependent on the successful operation of the fire sprinkler system. The AHJ may not accept that a single fire pump system is reliable enough for the hotel high-rise, but may be reliable enough for the two-story office building. Because of these biases, the AHJ may require additional safeguards to increase the reliability in the hotel's sprinkler system. The high-rise hotel may be required to have a redundant fire pump system and/or redundant water supply for the sprinkler system, whereas the two-story office building may be required to have only one fire pump. This effectively results in a safer facility for the one that is perceived as potentially catastrophic, less controllable, and less familiar.

Building fire safety regulations, both performance-based and prescriptive-based, establish a standard for design that is intended to provide an acceptable level of risk from fire. In order to provide an acceptable level of risk that meets the public mandate, a building fire safety code should accommodate social perceptions of risk. It seems as if the representative, evolutionary nature of the prescriptive code indirectly addresses the issue of risk perception. The prescriptive code has had the benefit of addressing risk perceptions without the need to quantify safety. A performance-based building fire safety code is a step in the direction of quantifying safety in a way that the prescriptive code never has. The two current performance-based building fire safety codes in the United States appear to have mechanisms that will, to a certain extent, address risk perception. Only with time will we discover which, if any, adequately addresses the issue. Those responsible for the development of the performance codes are advised not to lose sight of the importance that risk perception has in society.

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Fire Protection Design in STADIA

Photo by John H. Reid III.

By Gene Boecker, R.A.

INTRODUCTION

Throughout history, public gathering places have existed in every civilization. They have also evolved over the years. While the Coliseum in Rome bears a striking resemblance in many ways to current sporting venues, the intricacies of today's stadia are vastly different. Even within the last decade, these facilities have undergone a metamorphosis that challenges our understanding of these facilities.

A stadium can include anything from the bleachers surrounding a high school football game to the mammoth structures built to entertain us at soccer, baseball, football, and Olympic track and field events. These modern facilities do not fit neatly into the categories for which the various building and life safety codes ascribe to them. For a successful project, the cooperation of the design team, is required in order to provide a satisfactory result.

The concept of a modern-day stadium is a combination of indoor and outdoor spaces. Unfortunately, the model codes consider most stadia to be various sizes of the high school football stadium concept.

While each stadium is unique, the challenges of the modern-day stadium are somewhat consistent. The grandstand portion of the facility is commonly referred to as the seating bowl. In most of these facilities, this is treated as a smoke-protected assembly seating area. Smoke-protected assembly seating is treated differently than traditional facilities in that in the presence of a smoke-protected means of egress allows use of factors representative of the size of the facility and allows travel distances based on the type of construction and its outdoor nature. For example, while the typical building calculates egress capacity at 0.3 inches (8 mm) per person for stairs, smoke-protected facilities with greater than 25,000 seats allow for 0.06 inches (1.5 mm) per person for stairs.

The occupants of outdoor seats exit to an outdoor concourse and traverse exterior stairs and ramps to reach an outdoor plaza. This outdoor setting has intrinsic characteristics for consideration as a smoke-protected assembly seating facility. The challenge lies in the fact that many interior spaces are also included within the facility that are not considered smoke-protected, such as locker rooms and offices. Additionally, in a number of facilities, occupants of outdoor seating areas must egress through interior portions of the building. Where this is done, the means of egress must be maintained in a smoke-protected condition. This necessitates, in most cases, the use of a mechanical smoke control system. This situation is a common occurrence where club seating exists.

The fire protection engineer must also address the specific activities of the facility owner/operator. In many of these facilities, it is not uncommon to have maintenance shops that involve painting, welding, carpentry, and solvent use. Each of these must be addressed and an appropriate level of protection determined. Concessions with commercial cooking hoods and suppression systems are usually provided. Some of these include cooking inside concession stands while some have cooking outside, on open-air concourses. Combinations of compartmentation, suppression, and/or special storage systems are viable options for addressing each potential hazard.

FIRE SPREAD AND EXPOSURE

Since the codes recognize one type of construction for outdoor stadia and another construction for traditional buildings with interior spaces, the type of construction for most modern-day stadia is mixed. That is, most of the interior spaces are protected with fire-resistant construction consistent with that for large buildings, while outdoor spaces are constructed consistent with those for outdoor stadia. This in and of itself is a significant challenge, since the demarcation between interior and exterior spaces frequently causes the greatest concern to potential fire exposure and smoke involvement.

In some cases, it may be necessary to evaluate the potential fire exposure to exterior, unprotected grandstand structural elements from a fire either within an interior space or one of those exterior areas originating from a portable concession stand. It therefore becomes critical to identify those areas which are and which areas are not being protected with fire-proofing, as well as how the interaction between these two spaces is addressed. This may involve exterior sprinklers, fire shutters, limited fire-proofing, engineering analysis of a fire exposure, or a combination of the above.

A performance-based design approach may be necessary in evaluation of the exposed structure. Questions that must be addressed include: What is the appropriate design fire for this particular location? What effect will sprinkler activation have? What is the exposure and anticipated heat transfer to the structure? Can the heat be dissipated through the structure before it has the potential for detrimental effects? What is the total egress time for the area of concern? If the heat transfer is such that structural failure is possible, what effect will the loss of the element cause?

FIRE ALARM AND EMERGENCY NOTIFICATION

Another area that requires discussion is that of a fire alarm and emergency notification. While not all the model codes require it, it is typical for a voice alarm system to be provided for areas that are located outside the seating bowl. These voice alarm systems should be zoned on a floor-by-floor basis consistent with the provisions of NFPA 72. Additionally, each level within the stadium may need to be separately zoned to identify end zone, outfield, sideline, and other conditions that distinctly segregate areas within the same floor level. Visual alarms in addition to voice alarm systems are necessary. In some cases, it may be beneficial to include multiple alarm zone levels within a single notification zone. Such an example would be an open club lounge and the private suite levels open into it.

Within the seating bowl, the concept of emergency notification becomes more complex. It is, quite literally, impossible to provide fire alarm speakers spaced at intervals in accordance with NFPA 72. In order to acknowledge the need for emergency notification for spectators in the seating bowl, the public address (PA) system is typically used to accomplish this purpose. For reliability, the public address system is tied into the emergency power system. It is impractical to provide electrical supervision for the public address system, as would be required for a fire alarm system. However, the interconnection between the public address system and the voice alarm should be monitored and supervised.

AUTOMATIC SPRINKLER PROTECTION

Simply due to the size of the facility, most model codes would require such a building to be protected by an automatic sprinkler system. The model codes and sprinkler standards require sprinkler protection for all interior/enclosed spaces. Outdoor concourses, as mentioned above, can contain portable concession areas that must be properly evaluated for the fire exposure potential. In many cases, it may be necessary to require sprinklers in these outdoor areas to protect the structure from the fire potential.

STANDPIPES

Similarly, standpipes, while required in buildings of this size by modern building codes for interior buildings, are not typically required for outdoor stadia. This apparent contradiction necessitates a performance-based evaluation of the manual fire fighting capabilities. Standpipe outlets are typically provided at exit stairs and ramps for firefighter accessibility. Supplemental outlets are not typically spaced for 200 feet (61 m) coverage around the concourses. This is in recognition of the relatively low fuel load and fire potential. Supplemental outlets are provided where the distance between stairs may be considered too great to reach potential fire hazards on the concourses.

However, a requirement for hose outlets within 100 feet (30 m) of the outdoor spectator seating area is a misappropriation of fire-fighting resources.

MEANS OF EGRESS

Numerous means of egress issues are unique to this type of assembly seating area. One of the major issues of concern is the dead-end aisle condition within the seating bowl. Most codes recognize the condition whereby a dead-end aisle may exceed the 21 rows where the row width within the adjoining seating sections is increased. This allows occupants to flow through adjoining seating sections in case of emergency where the aisle may be obstructed and travel must be in one direction due to the dead-end condition.

A similar provision exists within the codes, which limits the common path travel distance to 50 feet (15 m) before an occupant has a choice of paths. This same provision, which allows for the increased row width in adjoining seating sections, can be equally applied to address the issue of a common path of travel. In situations where the common path of travel may exceed 50 feet (15 m), the increased row width can be used as an effective means of providing an alternate route to reach a second aisle. This is particularly appropriate where seating is outdoors, the facility is smoke-protected by the natural ventilation to the atmosphere, and the construction is of noncombustible materials.

Means of egress concerns also conflict with the typical perimeter security systems. Typically, fences and gates are provided around the perimeter of stadia. While the codes typically limit the maximum width of doors to 48 inches (1.2 m), the use of wide gates at the perimeter and exit discharge points of stadia is commonplace. While it is possible to provide multiple gates with leafs no greater than 48 inches (1.2 m), the use of much wider single leafs allows for a more even flow through the gate area. In this case, widths greater than 48 inches (1.2 m) are preferred.

Additionally, panic devices are typically required where the occupant load exceeds 100. Hence, these exterior gates would require panic devices due to the fact that the building will be occupied at any given time by more than 100 people in an assembly setting. It must also be recognized that panic devices on an exterior gate provide virtually no security whatsoever since locking can be easily overcome at an exterior gate if a panic device is present. This is one of the critical areas where close coordination and cooperation between the Authority Having Jurisdiction and the operator of the facility are necessary. Only with closely coordinated and approved operation procedures can these perimeter gates be locked effectively for security and yet allow ease of egress during times when the building is occupied for spectator events.

The lowest level of the stadium, the one that provides direct access to the field, is often one of the most complicated to address. Much of the level contains spaces such as locker rooms, storage areas, and administrative offices, which are not treated as assembly seating. However, many times the field level is used for spectator seating, such as in concerts. In this case, the field area must be reviewed very carefully to determine how egress will be provided. If egress is provided up through the seating bowl, the smoke-protected assembly seating status can be maintained. If the egress is provided through tunnels on the service level, these tunnels must be evaluated to determine how best to maintain the smoke-protected assembly seating status for those spectators on the stadium field.

Whereas arenas are indoor spaces, stadia exist conjunctively with both indoor and outdoor spaces, each requiring the appropriate level of protection for the specific function. The fire protection engineer must also be aware of the fact that this function can change. The club lounge area, which is used by the club level spectators during a football game, could also be used for a wedding reception. In this case, the smoke-protected assembly seating status cannot be considered, nor can the staff control of perimeter gates be assumed. Each use and each scenario must be separately evaluated and considered for these special facilities.

LOSS PREVENTION

Of primary concern, after life safety, is the ability of the fire protection concept to limit fire loss to the structure and its contents. Fortunately, the two major stadium fires, Atlanta's Fulton County (baseball) Stadium and Irving's Texas (American football) Stadium, both in 1993, demonstrate that the noncombustible nature of the structure and its unique design have an intrinsic ability to withstand attack by fire. Both fires originated in suites and spread unhindered to other areas close to the fire origin. In both cases it was the combustible contents that contributed to the rapid fire spread, compounded by the fact that neither area was protected by automatic sprinklers. Sprinkler protection was provided only on the lower levels in service areas.

Extensive damage to the structure and loss of contents could have been limited had there been automatic sprinkler protection in place. Of note is that in both cases, a response plan was in place so that coordination with the arriving fire fighting forces could be effective. The fire protection designer must be aware that in order to protect the contents of the stadium, the contents themselves must be considered, as well as interior finishes, fixed furnishings, the geometry of the spaces, and the fire-fighting forces ability to respond.

Questions need to be answered for loss prevention as: Where is the fire department response location?; What is the role of the on-site security forces?; What is the reliability of the suppression system or is compartmentation necessary as a redundant protection system?; and, What are the operational characteristics of the facility that could allow a fire to either start or grow undetected? In the two fire examples noted above, the fire spread to adjoining areas through the corridors and field windows, although rated partitions were provided between suites. In at least one of the cases, losses could have been avoided if the catering group would not have left unattended open-flame warming devices.

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A Quantified Fire Risk DESIGN METHOD

By Fredrik Nystedt

The term fire risk analysis incorporates a variety of different methods. These methods are not unique for fire safety and could therefore be divided into the following well-established categories of risk analysis methods, namely qualitative, semiquantitative, and quantitative methods.[1]

OVERVIEW OF RISK ANALYSIS METHODS

Qualitative methods are often used in an informal way when a well-defined trade-off is evaluated and the effect on the fire safety strategy is limited. Designer experience and engineering judgment are often sufficient to make minor alternations to existing accepted solutions or to rank performance of different safety measures qualitatively. The performance criterion used in the verification is relative and can be expressed as "as safe as" or "not worse than." The use of semiquantitative methods have only recently begun in the design process of buildings. In industrial risk management, methods like the balanced scorecard and index methods have been widely used to rank and prioritize different preventive safety measures. In Sweden, similar methods are developed for healthcare facilities as a tool to use for fire service inspection.[2] In the context of fire safety design, risk analysis is used to verify that threshold levels of risk are not exceeded for a design solution. The method of verification is based on a comparison of derived risk with some form of design criterion.

THE FIRE SAFETY DESIGN PROCESS

In Sweden, there are two code compliance methods available: the prescriptive, or "deemed-to-satisfy," method and a performance-based design method. The performance-based design method uses an engineering methodology to approach the design problem. An engineering solution is developed and analyzed to determine whether it achieves the fire safety objectives. The keyword is to "verify" that a satisfactory level of safety is achieved. Risk-based methods may be used for this analysis. Figure 1 outlines the design process.

CASE STUDY IN QUANTIFYING FIRE RISKS

A case study was performed on a fictive hospital building in Sweden in 1998.[4] The aim of the case study was to quantify fire risks for a number of trial design solutions when building new hospitals. The analysis applied the QRA-methodology presented in this article. The approach presented in this section has been developed by the Department of Fire Safety Engineering at Lund University and is internationally presented in a number of journals and conferences.[5, 6, 7]

THE QUALITATIVE DESIGN REVIEW

The building consists of three stories and a basement. There is a daytime medical reception, a pharmacy, waiting hall, and a cafeteria on the entrance floor. The first and second floors consist of two hospital wards each. The two wards are separate fire compartments, and there is a protected lobby. The number of staff varies with the time of day. During the daytime, there are seven nurses available on each ward, and at night, there are only three. The

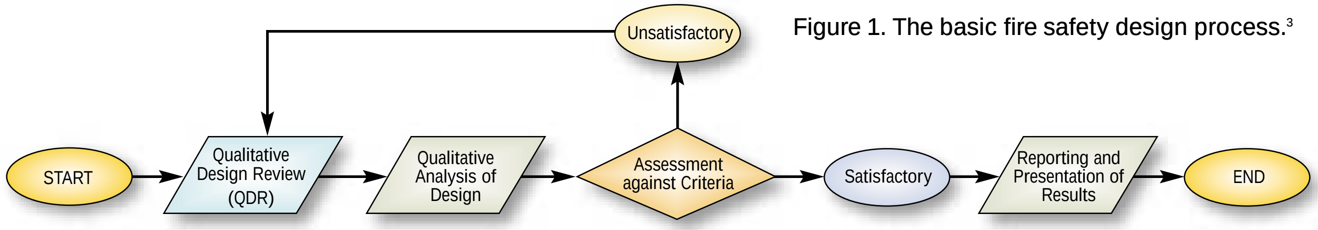

Figure 1. The basic fire safety design process.[3]

staff is trained in fire safety practices. There is a maximum of 36 patients on each ward which would need assistance to evacuate. Patients are assumed to be sleeping at night and to be awake during the day. The patients are not familiar with the building.

The objectives of the fire safety design are to limit the likelihood of fire, ensure safe evacuation of occupants, prevent large property losses, and protect the environment. In this study, only the first two objectives have been analyzed. Organizational fire safety is the key factor in fire prevention. Regular fire safety inspections and the staff training are two other elements in fulfilling this objective. Fire safety design solutions must ensure that the total escape time is shorter than the available safe egress time. A risk-based fire engineering method will be used to analyze this objective.

The evacuation strategy proposed is to move people from the ward where the fire is located to safe places, e.g., another ward or the protected lobby. Horizontal evacuation is the key tactic. However, if the escape route to the protected lobby is blocked, patients would be evacuated via the stairwell located at the end of each corridor. Evacuation to safe places must be carried out without the assistance of the fire service. If it is necessary, people can continue to perform total evacuation to the outside. For the design to be considered acceptable, occupants must, in the worst case, complete total evacuation approximately thirty minutes after the fire breaks out.

According to the Swedish regulations,[8] satisfactory escape shall be affected in the event of fire. The regulation gives some general recommendations on which design criteria are to be used in the analysis. These criteria provide limit states for visibility, temperature, and thermal radiation.

The fire hazards in hospitals include arson, technical malfunction, and forgotten stove. Fire by arson may occur in storerooms, nursing rooms, stairwells, etc. Technical malfunction includes fire in medical devices, televisions, etc. Kitchen devices, such as a hot plate or a forgotten stove, coffee machine, etc., may also result in a fire. Malfunctioning fluorescent tubes are also potential sources of ignition. Based on data from previous hospital fires, most fires start in the wards. The fire scenarios considered are:

- Arson in a nursing room involving a wastebasket, linens, or curtains
- Ignition in medical equipment in a nursing room
- Ignition caused by malfunctioning fluorescent tubes in a storeroom
- Fire in a coffee machine or the electric stove in the staff room
- Fire in the television set in the day room
- Unauthorized smoking in nursing rooms
- Fire in the cafeteria kitchen
- Arson in stairwells, basement, or garbage rooms
- Electrical failure, causing a fire in a shaft

Naturally, other scenarios beyond those listed above could occur. Expert judgment was used to determine which scenarios would be analyzed quantitatively: the nursing room fire caused by smoking in bed, the staff room fire caused by electrical failure in a coffee machine, and the cafeteria fire caused by fire in the deep-fryer.

Three trial design solutions were evaluated in the analysis:

- The first fire safety design solution (FSD1) is the reference solution in the comparative analysis and consists of smoke detectors placed throughout the ward and an alarm bell to notify occupants of fire.
- The second fire safety design solution (FSD2) consists of sprinklers and smoke detectors placed throughout the ward.
- The third fire safety design solution (FSD3) uses smoke and fire separating doors in the corridors, smoke detectors placed throughout the ward, and an alarm system that also notifies staff on adjacent wards so that they can assist in evacuation.

THE QUANTITATIVE RISK ANALYSIS

The event tree consists of a number of events (questions) where two answers are possible, "Yes" or "No". The questions are put so that the answer "Yes" results in a better outcome, that is, lessening the consequences. A positive answer thus leads to longer available safe egress time or shorter evacuation time. A large number of scenarios are derived from the event trees.

The following events were included in the event trees:

Initial fire?
Daytime fire?
Nonflaming fire?
Fire suppressed by staff?
Automatic detection?
Door to room closed?
Staff response correct?
All escape routes accessible?
Door closed after fire?
Fire separation sufficient?
Sprinkler successful?
Staff back up available?
Fire & smoke separation successful?

The computerized two-zone model FAST[9] has been used to calculate the time elapsed before critical conditions are reached. The use of FAST does, however, require some precaution. The model is not valid after sprinkler activation. This problem is addressed by assuming that when the sprinkler activates before untenable conditions have been reached, the environment will not become life threatening.[10] In the hospital, the environment is considered to become untenable when the interface reaches a height of 1.9 m above the floor.

The evacuation phase consists of three steps that are assumed to be independent. These are detection, reaction, and travel. Detection time is calculated by using the computerized model Detact-T2.[11] The reaction time is estimated by using reference literature and depends on time of day and fire location. The travel time is calculated by a simple formula where the ratio between patients and members of staff is a key parameter.

RESULTS AND DISCUSSION

The risk due to fire is calculated for each fire safety design solution. The risk is quantified by calculating the safety margin, i.e., time to reach untenable conditions minus the total evacuation time for each of the scenarios in the event tree, and comparing it to the frequency at which the scenario could be expected. In order to create the risk profiles illustrated in Figure 2, the probability and consequence pairs for each

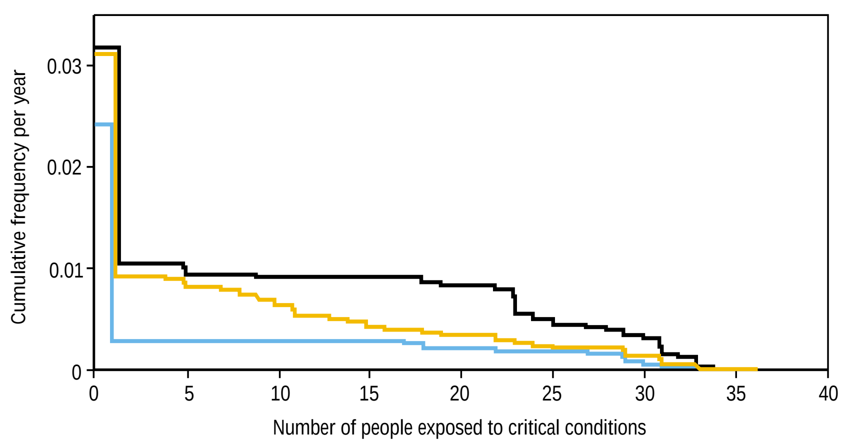

Figure 2. Risk profiles for the three fire safety designs. The upper (black) line represents FSD1, the middle (orange) line is for FSD3, and the lower (blue) line is for FSD2.

Table 1. Risk Measures for the Three Fire Safety Design Solutions

Design solution	Individual risk	Mean risk	Maximal consequence
FSD1	0.033	0.27	36
FSD2	0.024	0.09	36
FSD3	0.032	0.18	36

scenario must be graphed. When the pairs are graphed, it is possible to calculate the cumulative probability for a certain consequence and plot the result as a step function.

The risk profile provides the analyst with at least four important measures of the actual safety level. The first measure is the individual risk, i.e., the sum of the probabilities for all scenarios where the consequence is one or more deaths. This measure is the point on the Y-axis where the curve starts. The second measure is the mean risk. The mean risk is a measure of the risk to the society, stating what expected consequence a fire should have on average. The third measure is the slope of the curve. The higher slope the more risk averse is the design. A high slope is a fundamental risk evaluation criterion. The fourth measure is the maximal consequence, i.e., the value on the X-axis when the cumulative frequency is zero. The maximal consequence provides information on the worst possible outcome of a fire. The risk measures for the three fire safety designs are outlined in Table 1.

The risk profile for FSD1 illustrates that there is a relatively high risk for serious consequences, i.e., more than 20 people exposed to critical conditions. The evacuation of patients is highly dependent on the ratio between the number of patients and staff available to assist in evacuation.

The installation of sprinklers provides effective protection against untenable smoke and fire spread. The mean risk is lowered by 67% in FSD2 compared with the standard design. However, even when sprinklers are installed, there is a high-consequence, low-probability tail which cannot be reduced without decreasing the patient-to-staff ratio.

Using smoke-separating doors to limit smoke spread combined with a backup alarm system lowers the risk by about 33%. For between one and ten people, the profile corresponds well with the profile for the standard design (FSD1), but for ten or more exposed people, the profile agrees with the sprinkler risk profile.

The most cost-efficient way to reduce the risk of people being exposed to fire is therefore to install an alarm system that alerts members of staff on adjacent wards so that they can assist in the evacuation process in combination with the installation of smoke-separating doors in the ward.

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Technical Literature

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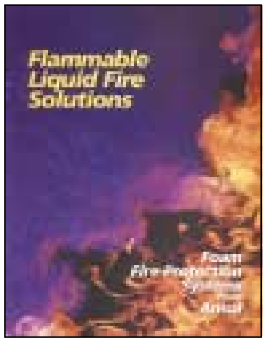
Foam Fire Protection Systems



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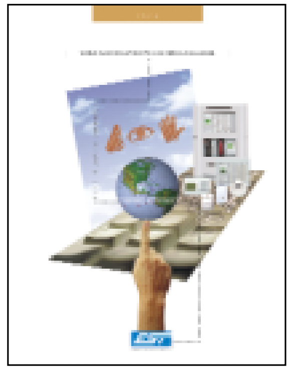
Life Safety Equipment



EST is proud to offer the industry's most complete line of life safety equipment on the market today. Audible and visual devices, multiple element detectors, control panels from 1 zone to the largest network systems round out our offering. Keep costs down and quality up with innovative products from EST.

—Edwards Systems Technology

Circle 5 on reader service card.

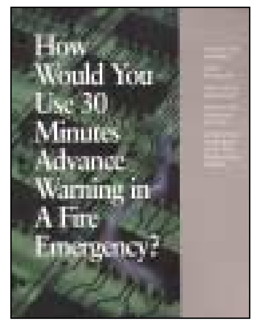
BlazeMaster®

Visit www.blazemaster.com for the latest developments in fire protection and design solutions for fire sprinkler systems. The Web site also features the "BlazeMaster® Blaster" newsletter, case studies, and the BlazeMaster® Fire Sprinkler Systems Design and Specification Resource Library, a downloadable CD-ROM collection of detail drawing blocks, sample drawings and clear-cut technical information.

—BlazeMaster

Circle 2 on reader service card

Fenwal® AnaLASER® II H-S-S-D System



Designed for mission-critical facilities like telecommunications facilities, data processing centers, and process control rooms, the Fenwal AnaLASER II High-Sensitivity-Smoke-Detection-System is thousands of times more sensitive than conventional smoke detectors. It provides up to thirty minutes of advanced warning in a fire emergency and virtually eliminates nuisance alarms.

—Fenwal Protection Systems

Circle 6 on reader service card.

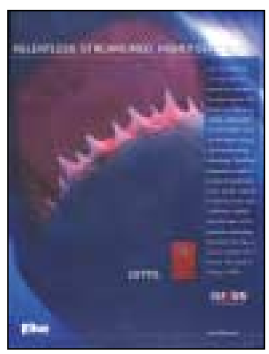
ESFR Pendent Sprinkler

Central Sprinkler Company introduces a better and less expensive way to protect inventory assets – the K17 ESFR Pendent Sprinkler. The K17 ESFR utilizes the same flows as traditional 14 K-factor ESFR sprinklers, but at much lower pressures. The results are significant installation cost savings due to reduced branch lines and the potential elimination of fire pumps.

—Central Sprinkler Company

Circle 3 on reader service card.

Fire Alarm Control Panel



Fike Corporation introduces the Shark analog, addressable fire alarm control panel. The Shark carries Fike's reputation and experience of building high-quality suppression panels into the fire alarm market. The Shark system is feature-rich, cost-effective, and backed up with the same reliability we build into all Fike control panels.

—Fike Corporation

Circle 7 on reader service card.

LIFELINE™ RHH

LIFELINE™ RHH, UL-listed type RHH – Power Cable, is a cost-effective means for providing two-hour fire protection as required for your most critical circuits. It replaces Mineral Insulated (MI) cable, concrete encasement, or construction of unnecessary fire barriers as the optimum way to protect critical circuits against attack by fire and water.

—Draka USA

Circle 4 on reader service card.

FCI Product Sales CD

For over 25 years, Fire Control Instruments (FCI) has designed and engineered life safety systems for commercial, industrial, and institutional applications worldwide. Our FCI Product Sales CD offers information on our complete line of conventional and analog fire alarm control panels. This CD comes complete with all Product Data Sheets and Architect/Engineering Specifications.

—Fire Control Instruments

Circle 8 on reader service card.

Technical Literature

Big Box Sprinklers

Gem Sprinkler Company's new K-25 EC Upright Big Box Sprinklers are the perfect solution to area-density fire protection needs. Designed specifically to meet the fire protection needs of big box retailing, extra hazard, and high piled storage occupancies (including exposed plastics). Effectively expands the maximum coverage area to 14' x 14'.

—Gem Sprinkler Company

Circle 9 on reader service card.

Fire Alarm and Detection

Grinnell Fire Protection offers companies of all sizes innovative and technologically advanced fire alarm and detection products, systems, and services. The brochure covers system communication protocols, networking, graphical user interface capabilities, voice communications, and more.

—Grinnell Fire Protection

Circle 10 on reader service card.

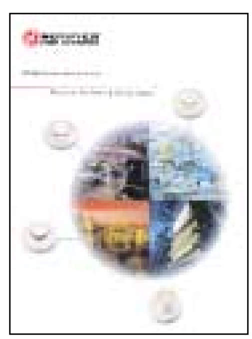
Metraloop® Fireloop™

The new, UL-listed Metraloop® Fireloop™ expansion joint is capable of movement in all directions and should be installed anywhere building or pipe movement is expected, especially crossing seismic joints. More compact than grooved pipe loop arrangements, it simplifies fire sprinkler system design.

—The Metraflex Company

Circle 11 on reader service card.

Advanced Detection Systems

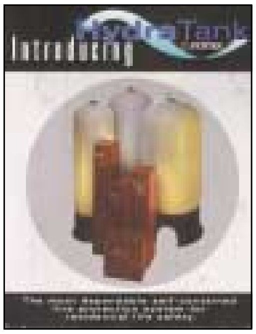


An intelligent fire alarm system is only as good as the devices connected to it. Different hazards and environmental conditions require different detectors, and NOTIFIER's product family is armed and ready with devices designed to meet these various applications. When special conditions exist, look to our "Advanced Detection" systems to meet the challenge.

—NOTIFIER Fire Systems

Circle 12 on reader service card.

Introducing HydraTank

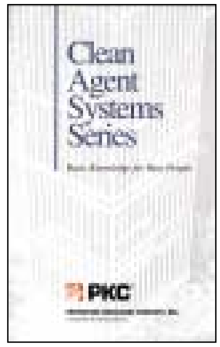


When fire strikes, HydraTank will provide the most dependable protection for 13D applications. HydraTank is a pressurized water supply that doesn't rely on a traditional water pump. Therefore, it does not depend on electricity, moving parts, or frequent maintenance. HydraTank utilizes a corrosion-free, lightweight composite tank.

—Potter Electric Signal Company

Circle 13 on reader service card.

Clean Agent Systems Training Series



Learn the basics of clean agent fire protection in this four-video series developed by the engineers at Rolf Jensen & Associates. Here's the economical, learn-anywhere training that covers the halon controversy, the SNAP list, EPA usage restrictions, halon alternative agents, and clean agent applications. It's perfect for busy people who must specify, recommend, or buy these vital systems.

—Protection Knowledge Concepts, Inc.

Circle 14 on reader service card.

New Products from Reliable

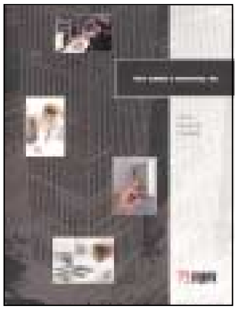
Request Reliable's New Product Brochure to get the latest and greatest information about Reliable's products, including the industry's only quick-response, extended-coverage, concealed horizontal sidewall. PrePaK preaction systems in 1 1/2", 2", 4", and 6". Full line of 300 psi sprinklers. The 1", 1 1/2", and 2" Reliable Riser; and more.

—Reliable Automatic Sprinkler Co., Inc.

Circle 15 on reader service card.

Technical Literature

RJA Security Engineering Services



Rolf Jensen & Associates now offers a full range of security services for clients who want seamless integration of their fire and security programs. Services range from business risk analysis and master planning to systems design, drawings review, and project management. Put the experience and leadership of RJA to work on your next project.

—Rolf Jensen & Associates, Inc.

Circle 16 on reader service card.

Preaction and Firecycle Systems

When you're protecting colocation sites, carrier hotels, data warehouses, and telecommunication sites from fire, keep in mind that not all water-based systems are created equal. Learn how Viking Preaction and Viking Firecycle systems can set your mind at ease with their fail-safe designs. And remember, Firecycle is the only UL-listed, FM-approved cycling system available.

—The Viking Corporation

Circle 18 on reader service card.

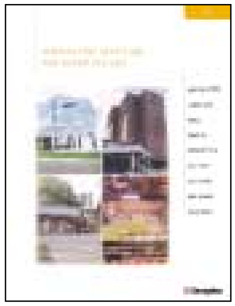
SPEC1FIRE™

Wheelock has introduced the new SPEC1FIRE™ Multi-Candela Notification Appliances. These revolutionary products have field-selectable candela settings of 15, 30, 75, or 110 candela and satisfy virtually all requirements for indoor, wall-mount appliances. The Multi-Candela strobes are available on the Series RSS-MC Remote Strobes, Series RSSP-MC Retrofit Plates, Series E-MC and ET-MC Speaker Strobes and the Series CH-MC Chime Strobes, the Series AS-MC Audible Strobes, and the Series NS-MC Horn Strobes.

—Wheelock, Inc.

Circle 19 on reader service card.

SimplexGrinnell Fire Systems



Simplex, the market leader in fire detection and alarm systems, has a full range of products; broad experience in systems integration, project management, and installation; regulatory expertise; and a commitment to quality service. Simplex is being combined with Grinnell Fire Protection, the leader in fire suppression, to form an even stronger company, SimplexGrinnell.

—SimplexGrinnell

Circle 17 on reader service card.

Careers/Classifieds

Fire protection engineering is a growing profession with many challenging career opportunities. Contact the Society of Fire Protection Engineers at www.sfpe.org or the organizations below for more information.

BRAINTEASER

Each letter below stands for only one other letter. Can you crack the code and figure out what all these fire protection words are?

PRIH
MXEXIA
ROFRYRLF
HWGLUTIH
AHFURYS
HWYRFOTRUMHI
AHZXFA
UGIRFVCHI
FLEECH
GILYHJYRLF

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

Solution to last issue's brainteaser

What is the smallest positive number N that leaves remainders of 3, 4, 5, and 6 when divided by 8, 9, 11, and 13, respectively?

The number N is of the form $8r + 3$, $9s + 4$, $11t + 5$, and $13u + 6$, where *r, s, t,* and *u* are integers. Setting the first two expressions equal to each other gives $r = (9s + 1)/8$. Numbers solving this equation are of the form r = 8 + 9n, and s = 7 + 8n. Setting the first and third expressions equal to each other gives $t = (8r - 2)/11 = (62 + 72n)/11$. Numbers solving this equation are of the form $n = 8 + 11m$. Trying $m = 0$ gives $r = 80$, $s = 71$, $t = 58$, and $u = 49$. Any of these gives $N = 643$.

Correction to solution of issue #9 brainteaser

A wire loop is constructed with enough wire so that the loop just touches the top of Mt. Everest when the loop's center coincides with that of the earth's center (i.e., it wraps all the way around the earth). You are placed at the top of Everest and asked to cut the wire and insert a 10 meter section.

Assuming that the radius of the loop is 20,000 km, how far above the top of the mountain will this large wire loop rise?

With a radius of 20,000 km, the circumference of the loop is:

$$C = 2\pi r = 2 \times \pi \times 20{,}000 \text{ km} = 125{,}663.706 \text{ km}$$

With the addition of the 10-meter section, the circumference would become 125,663.716 km, which would correspond to a radius of 20,000.0016 km. Therefore, the loop would rise 1.6 m above the top of the mountain.

CORPORATE 100

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

ADT, Inc.
Arup Fire
Automatic Fire Alarm Association
BFPE International
Bourgeois & Associates, Inc.
Central Sprinkler Corp.
The Code Consortium, Inc.
Code Consultants, Inc.
Copper Development Association
Demers Associates, Inc.
Draka USA
Duke Engineering and Services
Edwards Systems Technology
Factory Mutual Research Corp.
Fike Corporation
Fire Consulting Associates, Inc.
Fire Suppression Systems Association
Gage-Babcock & Associates, Inc.
Grinnell Incorporated
Harrington Group, Inc.
HSB Professional Loss Control
Hubbell Industrial Controls
Hughes Associates, Inc.
Industrial Risk Insurers
James W. Nolan Company (emeritus)
Joslyn Clark Controls, Inc.
Koffel Associates, Inc.
Marsh Risk Consulting
MountainStar Enterprises
National Electrical Manufacturers Association
National Fire Protection Association
National Fire Sprinkler Association
Nuclear Energy Institute
Poole Fire Protection Engineering, Inc.
The Protectowire Co., Inc.
The Reliable Automatic Sprinkler Co., Inc.
Reliable Fire Equipment Company
Risk Technologies, LLC
Rolf Jensen & Associates
Safeway, Inc.
Schirmer Engineering Corporation
Siemens, Cerberus Division
Simplex Time Recorder Company
S.S. Dannaway Associates, Inc.
Starwood Hotels and Resorts
TVA Fire and Life Safety, Inc.
Tyco Laboratories Asia Pacific Pty., Ltd.
Underwriters Laboratories, Inc.
Vanderweil Engineers
Van Rickley & Associates
Vision Systems, Inc.
Wheelock, Inc.
W.R. Grace Company

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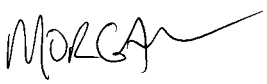
International P.E. Registry Could Facilitate International Practice



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

International practice of engineering can be hampered by the differing licensing structures that exist around the world. Comity of engineering licensure between different countries frequently is not possible, which requires engineers who wish to practice internationally to go through the licensing process in each country in which they wish to practice. However, the Asia Pacific Economic Corporation has developed an international register of licensed engineers, which is intended to facilitate the international practice of engineering.[1]

The Asia Pacific Economic Corporation is an international organization that promotes open trade and economic cooperation among 21 countries. For each participating country, the register would provide the country's standards for engineering licensure (education and experience) and a listing of the engineers licensed in the country.

Each APEC member country would maintain their portion of the registry. For each engineer listed, the registry would list their engineering education, professional experience, record of responsible charge, and a commitment to continuing education.

Being included in the APEC registry would not automatically entitle an engineer to practice in other APEC countries. The engineer would still be required to apply to and meet the requirements of the countries in which they wish to practice. Additional testing might be required, for example, to demonstrate knowledge of the country's codes and standards. However, the register would be a recognized credential, and APEC member countries would agree to provide a copy of an engineer's complete record to other member countries when requested by the engineer.

Of the 21 countries that belong to APEC, Australia, Canada, Hong Kong, Japan, Korea, Malaysia, and New Zealand have committed to participating in the register. The United States, which is represented by the United States Council for International Engineering Practice, has not agreed to participate because the standards of professional practice developed by APEC were not acceptable to USCIEP.

The United States Council for International Engineering Practice is a partnership between the National Council of Examiners for Engineering and Surveying, the Accreditation Board for Engineering and Technology, and the American Consulting Engineers Council. NCEES is the organization in the United States that administers the testing and grading of engineering examinations in the United States, and ABET is the organization that accredits engineering and engineering technology schools in the United States.

However, USCIEP and APEC have worked to address USCIEP's concerns, and the United States is expected to begin participating in the register this year. Indonesia, Thailand, Vietnam, and the Philippines are also expected to begin participating this year.

The development of the APEC register, and future participation by the USCIEP will be a first step toward facilitating international engineering practice and international mobility of engineers. Additionally, USCIEP and APEC are continuing to work towards further removing barriers to international engineering practice.

1 This article is based on information contained in Ganz, J. "Engineer Registry Could Aid International Practice," *Engineering Times*, January, 2001.